Czech Bioclimatological Society
Mendel Museum of Masaryk University Brno
Slovak Bioclimatological Society
Mendel University in Brno
Czech Hydrometeorological Institute, Brno branch
Crop Research Institute

organize

International Conference

MENDEL AND BIOCLIMATOLOGY

3rd – 5th September 2014

Mendel Museum, Brno, Czech Republic

MENDEL AND BIOCLIMATOLOGY

CONFERENCE PROCEEDINGS

Conference Reviewers:

RNDr. Ing. Jaroslav Rožnovský, CSc.
Mgr. Ondřej Dostál, Ph.D.
RNDr. Mojmír Kohut, Ph.D.
RNDr. Tomáš Litschmann, Ph.D.
Prof. Ing. František Toman, CSc.
Ing. Bc. Hana Středová, Ph.D.
Ing. Jan Haberle, CSc.
Prof. RNDr. Bernard Šiška, Ph.D.
Prof. Ing. Jaroslav Škvarenina, CSc

3rd – 5th September 2014

Brno, Czech Republic

MENDEL AND BIOCLIMATOLOGY

CONFERENCE PROCEEDINGS

Conference proceedings from the Mendel and Bioclimatology International Conference, held between 3rd and 5th September 2014 in Brno.

Jaroslav Rožnovský, Tomáš Litschmann (eds)

Editors of the proceedings: Tomáš Litschmann, Jáchym Brzezina

Published by: Masaryk University, 2014

1st edition, 649 pages

Number of copies: 300

The authors are responsible for the content and the publication was not proofread.

ISBN 978-80-210-6983-1

TABLE OF CONTENTS

MICROCLIMATIC CONDITIONS OF HOUSING ESTATE CHRENOVA 1 IN NITRA CITY

KATARÍNA BAHNOVÁ[1], ZDENKA RÓZOVÁ[2]

1) *Department of Ecology and Environmental Sciences, Faculty of Natural Sciences, Constantine The Philosopher University in Nitra,*
2) *Department of Ecology and Environmental Sciences, Faculty of Natural Sciences, Constantine The Philosopher University in Nitra*

ABSTRACT

Observation of microclimate in urban environment is nowadays current topic which links up several fields of science. Measurements, analysis and proposals are the tools for effective solutions of negative impact of climate changes. The aim of this study was to evaluate the interaction between vegetation structure and microclimatic conditions of Housing estate Chrenová 1 in Nitra city. Housing complexes A, B, C are part of the first construction on Chrenová 1. There are housing complexes with meander structure and 4 floors. This layout allowed the allocation of block areas with vegetation area near the building (Jarabica, 2011). The legwork was accomplished during the spring season, in months (April, May). Vegetation areas in urban environment pursue several functions. Significant impact on the wind direction has vegetation with structure and type of canopy. Vegetation areas in urban environment work as a thermal stabilizer. Crowns of trees in dense canopy keep the air temperature in the spring period. Significant microclimatic function of vegetation is to provide partially obscuration.

Key words: vegetation area, hard surface, measurment, function

INTRODUCTION

According to Wardoyo (2011); (Wardoyo, 2011) is urban environment specific to hard surface, typical urban geometry, vegetation areas and variability of surface materials. These factors form and influence microclimate. For every active surface is typical, that there is a transformation of the energy of the short wave radiation to the thermal energy. The part of this energy goes to sub base of active surface and vice versa. The active surface is the main climatic factor (Středová, et. al., 2011). Vegetation plays the significant role in the forming of microclimate and thermal comfort. Surface temperature of vegetation influence the thermal balance through the blazing change (Scudo et. al., 2002). Tree vegetation uses 2% of solar energy on photosynthesis, 60-80% absorbs by leafs and 5-15 % reflects back to space. The rest of solar energy goes trough leaves. The certain amount of radiation is being used for warming up the particular parts of the tree. Trees with thin crowns can receive 60-80% of solar radiation. Through the trees with compact crowns penetrates 2-3% of solar radiation (Pauditšová, Reháčková 2006). Vegetation areas dont accumulate heat. After the opening of stomata and during the assimilation the temperature of stomata matches with the air temperature or drops down under this temperature (Slováková, Mistrík, 2007). According to Small and Miller (2010); (Small, Miller, 2010) vegetation influences the city conditions of the environment. Vegetation areas have the impact on energetic demand and on formation of thermal heats Island. In certain conditions plants are on direct sun overheating too, but this is just short-term overheating, Leaves close the stomata to prevent excessive evaporation which cause seven more overheating of leaves. It is important to mention that overheated dry soil, asphalt, concrete, walls of the buildings, tin roofs, or body shells of cars radiate the heat even though sun is not shining (Čaboun, 2008).Vegetation decreases UHI effect, the air temperature on areas with vegetation can be lower by 2,5°C (comparing to maximum temperature in the city) (Gomez, Gaja&Reig, 1998). Vegetation improves environmental variables such as solar radiation, surface temperature, air temperature, relative air humidity, velocity of air. These variables are important for thermal comfort (Akbari, Pomerantz&Taha, 2001). Mode of surface temperatures in urban and suburban land can be defined with surface thermal monitoring.

The aim of this study was to evaluate the interaction between vegetation structure and microclimatic conditions of Housing estate Chrenová 1 in Nitra city.

MATERIALS AND METHODS

In Housing estate Chrenová 1 have been selected research areas A1, A2, B1, B2, C1, C2 (Fig. 1), depending on vegetation structure.

We accomplished the analysis of characteristic of selected model of vegetation according to Rózová, Mikulová (2011), (Rózová, Mikulová, 2011).

Fig. 1: Research areas A1, A2, B1, B2, C1, C2 in Housing estate Chrenova 1

Foliation

Three-foliation – trees-shrubs-herbs

Bilayer-foliation – trees-shrubs, trees-herbs, shrubs-herbs

Single-foliation – trees, shrubs, herbs

Species diversity - the number of species in the area

Involvement - overlapping of vegetation parts

We accomplished analysis of relations with surrounding (Rózová, Mikulová, 2011). It is relations on surrounding, connection of vegetation in site and in surrounding landscape.

Measurements on research areas were implemented during the spring season (in months April, May) in the noon (12:30). Using the method of surface thermal monitoring – with Anemometer

TSI VelociCalc and Surface temperature Probe, following microclimatic factors were observed : air flow, air temperature, relative air humidity and surface temperature in two type of active surface – vegetation area and hard surface. In three second's interval for measurement points were accomplished 20 samples.

Places of measuring:

1. In vegetation area
2. On hard surface

Measurement points were chosen on the basis of assumed differences of measured values depending on type of surface.

Vegetation area- in summer time vegetation carries function of heat stabilizer. Vegetation areas also do not accumulate heat and during assimilation their temperature equalizes with air-temperature, or more precisely decreases under this temperature. As a result is reduction of maximum of day temperature in vegetation comparing to surrounding landscape.

Hard surface – (road communication separating vegetation area from the housing area). Overheating of asphalt area and radiate heat exchange plays significant role in summer times. During the day, hard surface absorbs much more of thermal energy as plants (for example asphalt absorbs 75-90% of solar radiation).

Statistically evaluation

Measurement of microclimatic factors we evaluated by using the softwer Statistica 7. For comparing of microclimatic factors depending on specific areas we used the Tukey HSD test. Microclimatic factor of surface temperature between two type of active surface we evaluated using by Mann- Whitney test.

RESULTS

Analysis of vegetation structure on research areas

Locality A1*:* Vegetation in the locality A1 is bilayer with 50 trees. Monitoring point is located in dense and relative closed canopy of 26 trees with continuity on the open lawn. The highest part has the type *Acer pseudoplatanus* – 16%.

Locality A2*:* Vegetation in the locality A2 is three-layer with 33 trees, it is structured into 5 formations with central lawn. Vegetation area is opened to the inside of residential area. Monitoring point is located in sparse vegetation with 7 trees. The highest percentage has *Pinus sylvestris* – 38%.

Locality B1: Vegetation in the locality B1 is three-layer with 46 trees. Trees are organized into 3 small clusters on the left side. In the middle of the vegetation area is the lawn with solitaire tree. Monitoring point is located in vegetation with dense canopy of crowns with 9 trees. The highest percentage has *Tilia cordata* – 34,9%.

Locality B2: The vegetation in the vegetation area B2 is three-layer, it is organized into 2 cluster with dense canopy of crowns. Number of trees in vegetation area is 11. Monitoring point is located in central lawn near the children's playground. The highest percentage has *Pseudotsuga menziesi*– 35,8%.

Locality C1: Vegetation in the locality C1 is three-layer with 68 trees. Tree vegetation is organized into 5 clusters. The lawn is open near the river Nitra. Monitoring point is located in the cluster of 3 trees with sparse canopy of crowns. The highest percentage has *Juglas regia* – 42,8% .

Locality C2*:* The vegetation area in locality C2 is typical bounded area by inside of residential area. In vegetation area are 22 trees organized into 5 clusters with sparse canopy of crowns. Monitoring point is located in central lawn. The highest percentage has *Taxus baccata, Pseudotsuga menziesii, Tilia cordata* – 25%.

Results of measurements in research areas

We compared all microclimatic factors (air flow [l/s], air temperature [°C], relative air humidity [%], surface temperature [°C]) of vegetation areas depending on vegetation structure by using the softwer Statistica 7.

In the (Fig. 2) we compared the microclimatic factor of air flow [l/s] for all vegetation areas of localities A1, A2, B1, B2, C1, C2. The lowest value of median of factor air flow we recorded in the vegetation area A2 (4.05l/s). Vegetation in this locality is structured into 5 formations with central lawn. This vegetation area is opened to the inside of residential area. Intensity of air flow influences urban geometry, density and type of buildings change the wind direction and in this case have an effect on barriers in urban environment. The highest value of median of air flow we recorded in the vegetation area B2 (5.56 l/s). Vegetation in this locality is organized into 2 cluster with dense canopy of crowns. This vegetation area has the heterogeneous organisation, number of trees is 11. Monitoring point is located in central lawn. In this vegetation area, we dont recorded an effect on barriers of build-up areas or trees vegetation, as a result is the big range between minimum and maximum of measurment values of air flow.

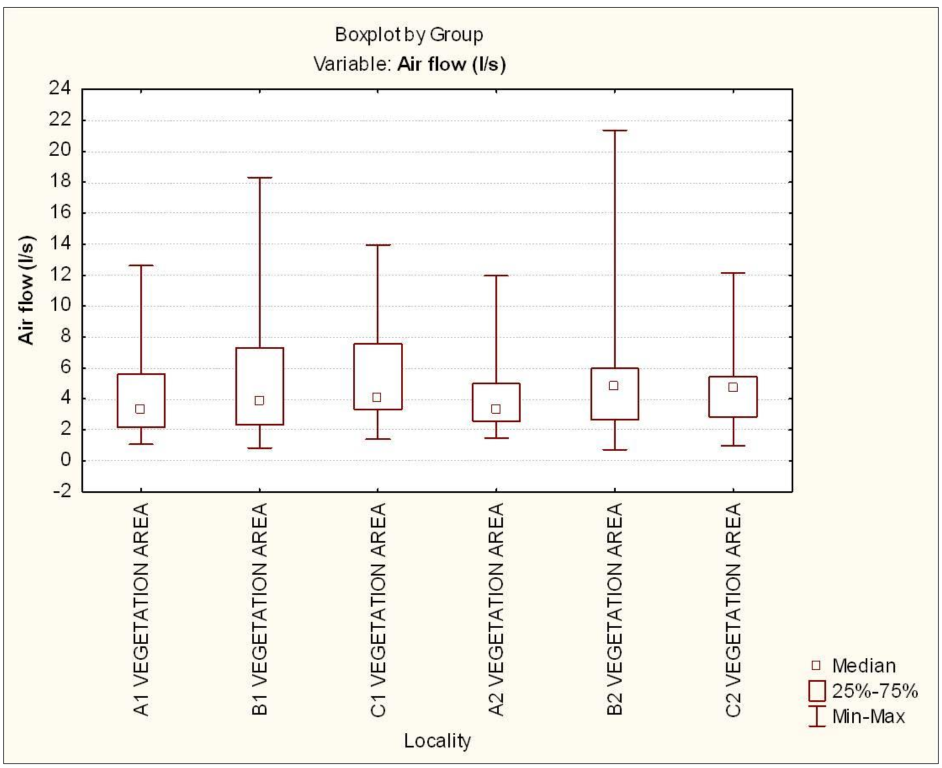


Fig. 2: Comparing of microclimatic factor of air flow depending on vegetation area

In the (Fig. 3) we compared the microclimatic factor of air temperature (°C) for all vegetation areas of localities A1, A2, B1, B2, C1, C2. The lowest value of median of air temperature we recorded in the vegetation area A2 (18.9°C). Monitoring point is located in the sparse canopy of 7 trees. In the vegetation area A1 we recorded the highest value of median of air temperature during the spring period (20.06°C). Monitoring point is located in dense and relative closed canopy of 26 trees with continuity on the open lawn. Closed canopy of vegetation in this area is the factor, which influences the values of air temperature. Crowns of trees in dense canopy keep the air temperature in the spring period.

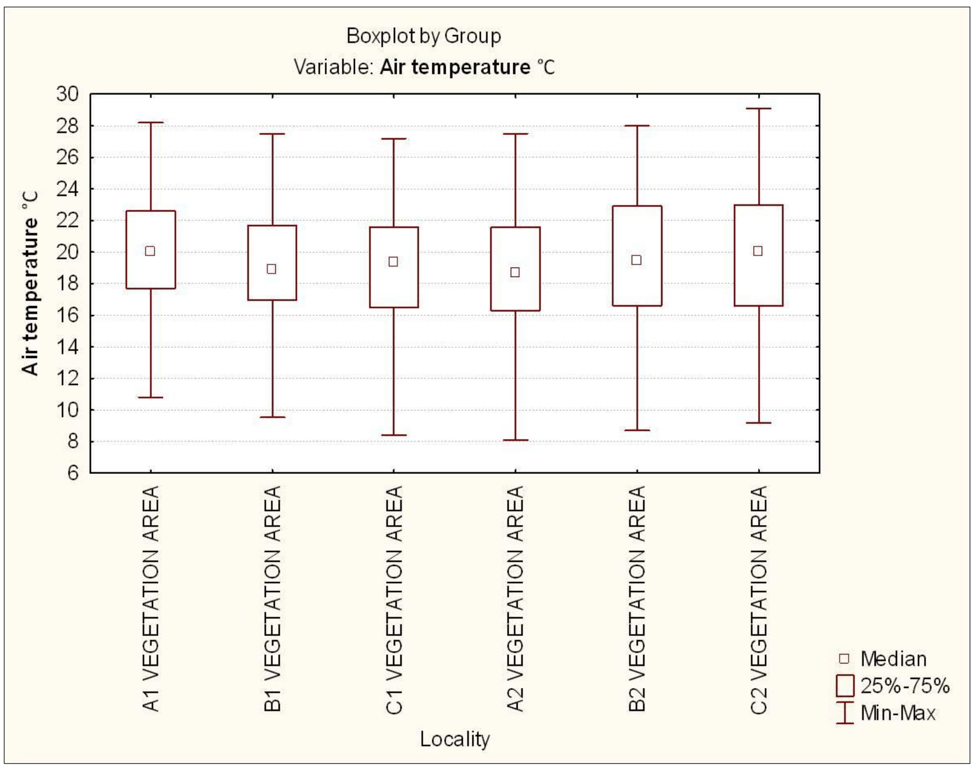


Fig.3: Comparing of factor of air temperature depending on vegetation area

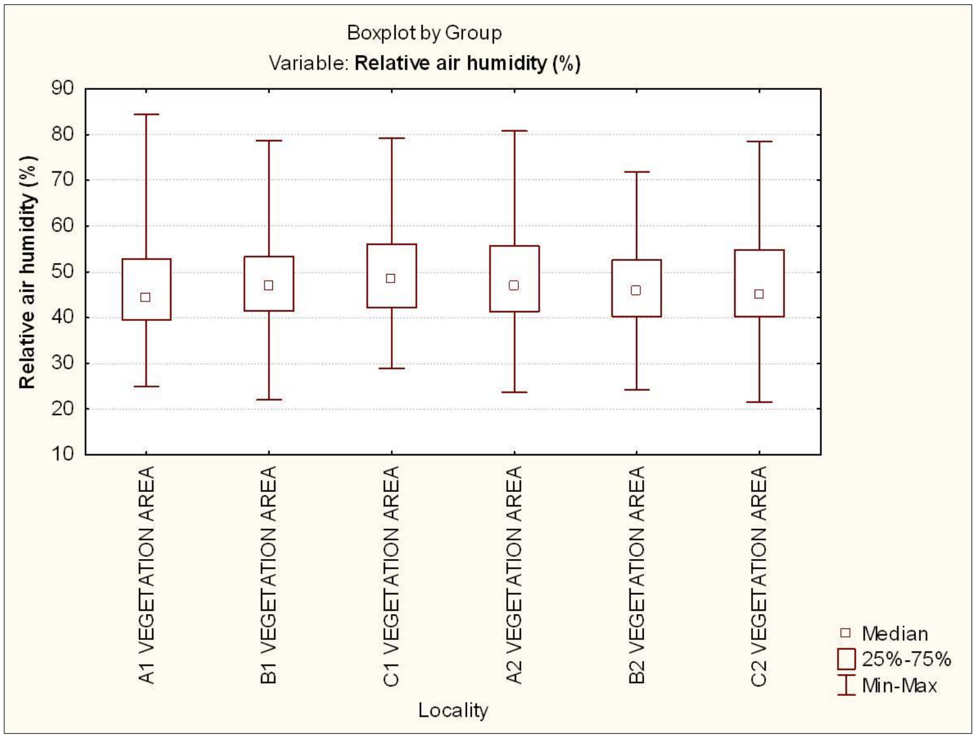


Fig. 4: Comparing of factor of relative air humidity depending on vegetation area

In the (Fig. 4) we recorded the highest value of median of relative air humidity in the vegetation area C1 (49.57 %). Vegetation in the locality C1 is three-layer with 68 trees. According to Čaboun, (2008), (Čaboun, 2008) vegetation increases the relative air humidity on average 18%. Monitoring point is located in the cluster of 3 trees with sparse canopy of crowns, which continue on open lawn. The significant role in factor of relative air humidity plays too vicinity of river Nitra. 50% of values of relative air humidity were in range – minimum-maximum (28-79%) during the spring season.

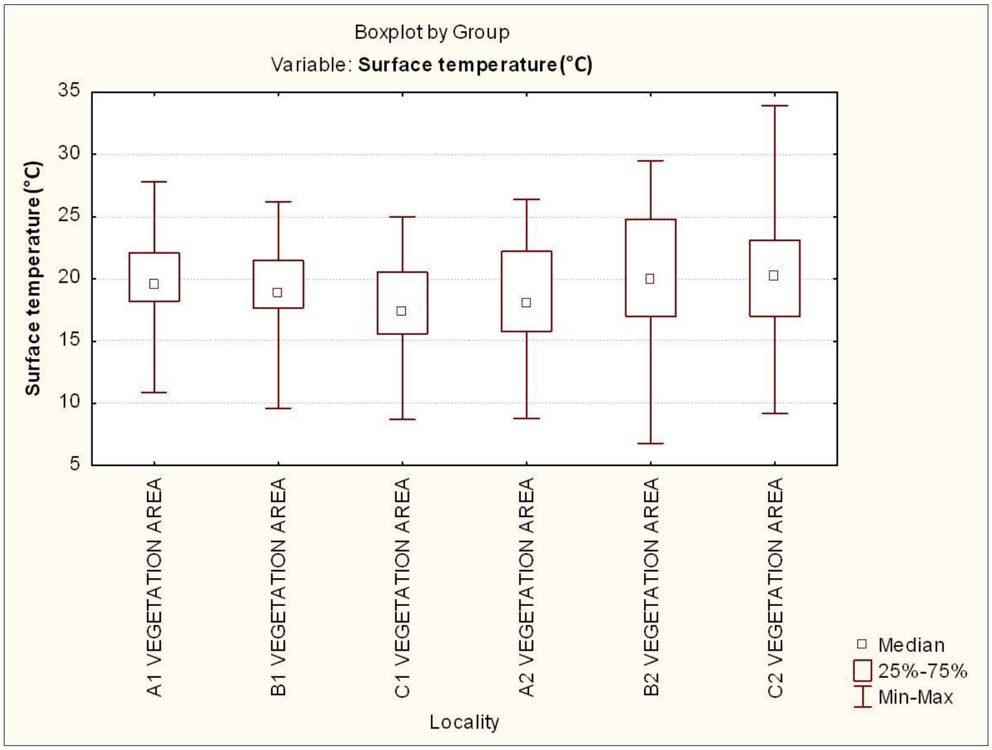


Fig. 5: Comparing of factor of surface temperature depending on vegetation area

In the (Fig. 5) we compared the values of median of surface temperature for all vegetation areas depending on vegetation structure. Geometry of active surfaces and its structure in urban environment influences intensity of falling on and reflecting solar radiation. The highest value of median of surface temperature we recorded in the vegetation area C2 (19.98°C). Here is monitoring point located in central lawn with sparse cover without trees. The lowest value of median of surface temperature we registered in vegetation area C1 (17.74 °C). In this vegetation area was the highest value of relative air humidity between localities. Between measuring microclimatic factors of relative air humidity and surface temperature we recorded the negative corelation (Fig. 6) during the spring season (R= -0.105772, in p level=0.042013).

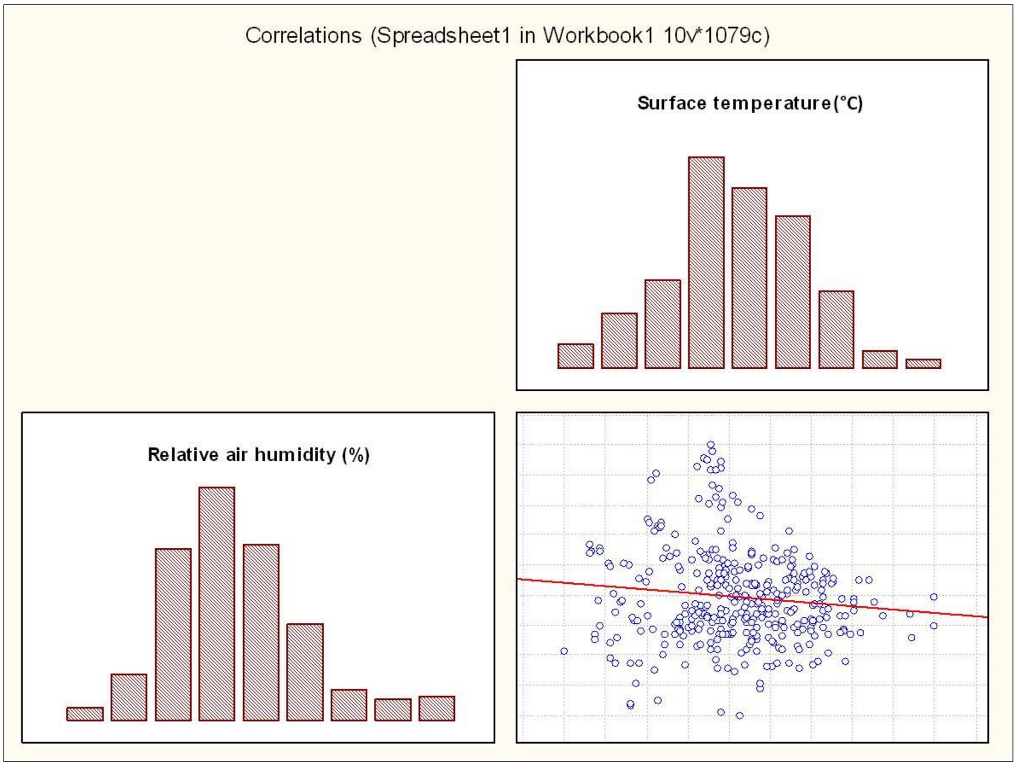


Fig. 6 : Negative correlations between microclimatic factors – surface temperature and relative air humidity in research areas during the spring period

Vegetation carries the function of thermal heat stabilizer. Active surfaces limit the area with direct light from source of radiation. This effect we recorded in the (Fig. 7) in microclimatic factor of surface temperature between measuring points vegetation area and hard surface in locality A1. Trees in dense canopy provide partial shading on hard surface in time of positive energy balance (12:30). As a result is minimal difference in factor of surface temperature between hard surface and vegetation area.

The highest statistically significant difference in microclimatic factor of surface temperature between active surfaces – hard surface and vegetation area we recorded in the locality B2 (Mann-Whitney test, p=0.000932, p<0,001) (Fig. 8). Value of median of surface temperature in measuring point hard surface during spring season was (24.82°C). In measuring point vegetation area was the median of value of surface temperature (19.91°C). In vegetation area B2 is monitoring point located in central lawn. Variance of surface temperature between two types of active surfaces – lawn and asphalt presented (4,91°C).

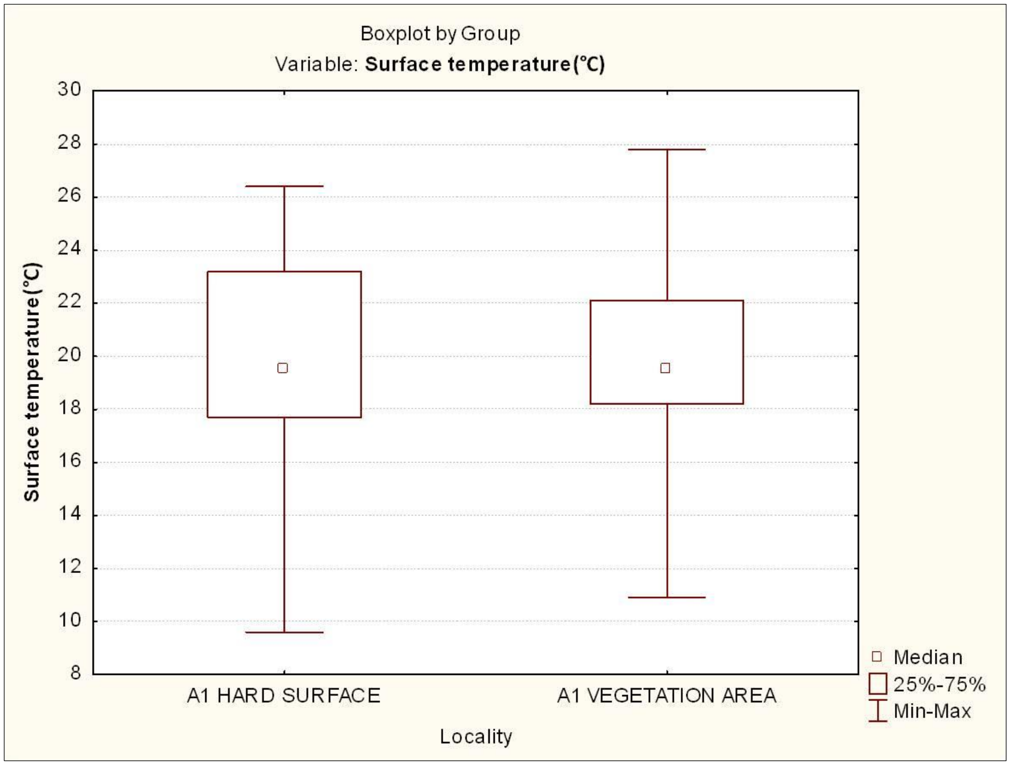


Fig. 7: Minimal difference in the surface temperature between two measuring points – hard surface and vegetation area in the locality A1

Discussion

In this study we dedicated evaluation of the interaction between vegetation structure and microclimatic conditions of Housing estate Chrenova 1 in Nitra. The legwork was accomplished during the spring season, in months (April, May) after the beginning of phenology phase. Measurements by method of surface thermal monitoring were accomplished in two types of active surfaces – vegetation area and hard surface. According to Voogt, Oke, (2003), (Voogt, Oke, 2013) during the day, hard surface absorbs much more of thermal energy as plants. On the other side vegetation areas do not accumulate heat and during assimilation their temperature equalizes with air-temperature. According to Wardoyo, (2011), (Wardoyo, 2011) intensity of air flow influences urban geometry; density and type of buildings change the wind direction and have an effect on barriers in urban environment (Fig. 2). Significant impact on the wind direction has vegetation with structure and type of canopy. The big range between minimum and maximum value in factor of air flow was recorded in locality B2. Vegetation in this area has heterogeneous structure, trees in sparse canopy have not the windbreak function. Vegetation areas in urban environment work as a thermal stabilizer. In the vegetation area A1 crowns of trees in dense canopy keep the air temperature in the spring period. This function influences the highest value of median of air temperature. According to Čaboun, (2008), (Čaboun, 2008) vegetation increases the relative air humidity on average 18%. The highest value of median of relative air humidity was recorded in the vegetation area C1. Structure of vegetation area and vicinity of river Nitra influence the microclimatic factor of relative air humidity. Significant microclimatic function of vegetation is to provide partially obscuration. This effect was recorded in the (Fig. 7), where the value of median of surface temperature between measuring points vegetation area and hard surface in locality A1 was the lowest. These points represent the different type of active surface in urban environment.

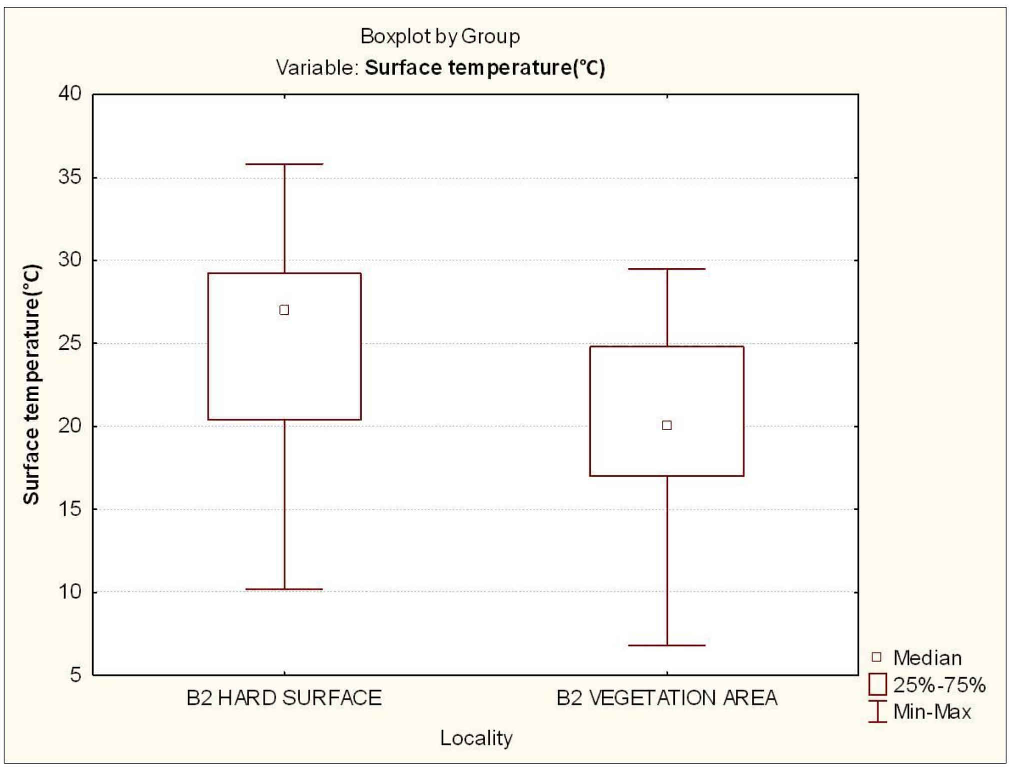


Fig. 8: The highest statisticaly difference in factor of surface temperature between two measuring points- hard surface and vegetation area in the locality B2

CONCLUSION

The increasing of variability of active surfaces in the cities is very typical nowadays. It leads to rising of air temperature and surface temperature in urban zones. The extreme conditions of weather are more often. Superheat of hard surfaces in time of positive energy balance lead to change of atmosphere and to change of temperature conditions. The tool for regulation of negative changes is the vegetation care and effective new planting. Up-to-date urban proposals and solutions should be based on functionality of vegetation areas and their positive impact on urban climate. Research in this field of science confirms that vegetation areas in urban environment are effective tool of how to eliminate negative impact of urban climate.

REFERENCES

Akbari, H., Pomerantz, M., Taha, H., 2001: *Cool surfaces and shadet rees to reduce energy use and improve air quality in urban areas.* Elsevier Science Ltd., *Solar Energy* Vol. 70, No. 3, pp. 295 – 310

Čaboun, V., 2008: *Vplyv vegetácie na znižovanie teploty povrchov a ovzdušia pri extrémnych horúcavách*. In: Rožnovský, J., Litschmann, T. (ed): „Bioklimatologické aspekty hodnocení procesu v krajine", Mikulov 9. – 11.9.2008, ISBN 978-80-86690-55-1

Gomez, F., Gaja, E., Reig, A., 1998: *Vegetation and climatic changes in a city*. *Ecological Engineering* 10, pp. 355-360

Jarabica, V., 2011. *Chrenová I v Nitre*. Dostupné na http://www.urbion.sk/chrenovai-v-nitre/

Pauditšová, E., Reháčková, T., 2006. *Praktické skúsenosti s hodnotením mikroklimatickej funkcie vegetácie v urbánnom prostredí*. In: Sídlo - Park – Krajina IV.

KULTÚRNA VEGETÁCIA V SÍDLACH A V KRAJINE. 2006, Zborník vedeckých prác a referátov. SPU Nitra, s. 227-235, ISBN 80-8069-809-0

Rózová Z., Mikulová, E., 2011: *Hodnotenie vlastností vegetácie v súvislosti so zmenou klímy v urbanizovanom prostredí*. In: Salaš, P., „Rostliny v podmínkách měnícího se klimatu." Lednice 20.10 - 21.10 2011, Úroda, vědecká příloha, 2011, s. 698-707, ISSN 0139-6013

Scudo G., Dessi, V., Rogora, A., 2002: *Evaluation of radiant conditions in urban spaces. In: Designing open spaces in the urban environment: a bioclimatic approach*. 2002, p. 12-17, ISBN 960-86907-2-2

Slováková, L., Mistrík, I., 2007: *Fyziologické procesy rastlín v podmienkach stresu*, Univerzita Komenského Bratislava 2007, s. 232. ISBN 978-80-223-2322-2.

Small, Ch., Miller, R.B., 2010. *Monitoring the Urban Environment from Space*. In: Digitalcities II. 2010, p. 6

Středová, H., Bokwa, A, Dobrovolný, P., et., al. 2011: *Mikroklima a mezoklima měst, mikroklima porostů*. Český hydrometeorologický ústav, Praha, 1. vyd., 102 s. ISBN 978-80-86690-90-2.

Voogt, J. A., Oke, T. R., 2003. *Thermal remote sensing of urban climates*. Remote Sensing of Environment, 86, s. 370 – 384.

Wardoyo, J., 2011. *Vegetation Configuration as Microclimate Control Strategy In Hot Humid Tropic Urban Open Space*. S E N V A R + I S E S E E 1-3
December 2008, International seminar in sustainable environment & architecture

Acknowledgement

This study is the result of the project implementation: Environmental aspects of the urban environment (Environmentálne aspekty urbanizovaného prostredia) ITMS 26220220110 supported by the Research & Development Operational Program funded by the ERDF and the result of the project: VEGA 1/0042/12 Analysis of selected environmental factors in relation to possible health risks (Analýza vybraných environmentálnych faktorov vo vzťahu k možným zdravotným rizikám).

Summary

Cílem naší studie bylo vyhodnotit vztah mezi strukturou vegetačních ploch a mikroklimatickými podmínkami na sídlišti Chrenová 1 v Nitře. Terenní průskum proběhl v jarní sezoně v letech 2013-2014 na vybraných lokalitách A1, A2, B1, B2, C1, C2 metodou pozemního termálního monitoringu. Sledovali jsme vybrané mikroklimatické faktory – proudění vzduchu [l/s], teplotu vzduchu [°C], relativní vlhkost vzduchu [%], teplotu povrchu [°C] ve dvou typech aktivního povrchu. Jednotlivé měření jsme vyhodnotili v softwaru Statistica 7, pro porovnání mikroklimatických faktorů v závislosti od lokality jsme použili Tukey HSD test. Zjistili jsme, že funkční vegetační plochy svojí strukturou pozitivně ovlivňují mikroklimatické podmínky v urbanizovaném prostředí. Vegetační plochy působí jako tepelný stabilizátor. Kompaktní plochy vegetace zmírňují vzdušné proudění a plní funkci větrolamu na rozdíl od ploch s heterogenní

strukturou. Vegetace v hustém uzavřeném zápoji udržuje teplotu vzduchu v porostu a zvyšuje relativní vlhkost vzduchu. Tyto plochy zajišťují stín a tím regulují teplotní rozdíly v různých typech aktivních povrchů (vegetační plocha – zpevněná plocha). V urbanizovaném prostředí je právě funkční vegetace jedním z nástrojů na eliminaci negativních dopadů změny klimatu. Už plochy relativně malých rozměrů v jednotlivých městských čtvrtích ovlivňují mikroklimatické podmínky a tím kvalitu života ve městech.

CONTACT

Mgr. Katarína Bahnová

Katedra ekológie a environmentalistiky

Tr. A. Hlinku 1, 949 74 Nitra

+421 37 6408 653, katarina.bahnova@ukf.sk

COMPARISON OF MANUAL AND AUTOMATIC MEASUREMENTS OF AIR AND SOIL TEMPERATURE IN THE CZECH REPUBLIC

DANIEL BAREŠ[1], MARTIN MOŽNÝ[1, 2]

1) *Czech Hydrometeorological Institute, Doksany Observatory, 41182 Doksany*
2) *Mendel University in Brno, Zemědělská 1, 61300 Brno*

ABSTRACT

Differences between manual and automatic measurements of air temperature and soil temperature should not be neglected. The average difference between the manual and the automatic measurements of air temperature varied between 0.3 and 2.8 ◦C during suitable weather conditions (wind speed less than 3 m/s, bright and sunny day) throughout the year, during both daytime and nighttime hours. Comparative measurements showed that average monthly differences of air temperature between manual and automatic measurements varied between -0.5 and 0.29 ◦C; differences of soil temperatures at a depth of 5, 10 and 20 cm between 0.3 and 0.83 ◦C, respectively at a depth 50 and 100 cm between -0.13 and 0.28 ◦C.

Key words: Measurements; air and soil temperature; comparison; climatology

INTRODUCTION

Many short-term comparative measurements in wind tunnels and field experiments have been performed in connection with the transition to automated measurements. The studies have revealed relatively large differences in measurements due to variations in instruments' protection from radiation. Differences have been greatest under particular weather conditions (e.g., calm, bright and sunny days with snow cover). Most experiments have investigated differences over monthly and seasonal time scales (Brock et al., 1995; Barnett et al., 1998; Lin et al., 2001; Van der Meulen and Brandsma, 2008). Comparisons among thermometer screens have been reviewed by several authors (Petäjä , 2004; Nagy, 2006; Lacombe et al., 2011).

MATERIALS AND METHODS

Comparative measurements were conducted in the observatory of the Czech Hydrometeorological Institute (CHMI) in Doksany (50◦ 27’ 31’ N, 14◦ 10’ 14’ E,
158 m a.s.l.) between April 2000 and December 2013 (comparative period). The observatory is one of four reference climatological stations of the CHMI. It is situated in a warm and dry area; long-term climatological norms for the years 1961–1990 include an average annual air temperature of 8.5 ◦C and an average annual total precipitation of 456 mm. All measurements of air temperature were conducted at a height of 2 m above a flat, open terrain with short-cut grass cover. The instrument was placed in the middle of a 0.75-hectare plot with no nearby obstacles that may have affected measurement.

Manual measurement of the air temperature was conducted by a station thermometer in a standard Czech-Slovak thermometer screen; the soil temperatures using thermometers placed within the natural soil profile under a closely-cropped grass cover at climatological observation times of 7 a.m., 2 p.m. and 9 p.m. of local mean solar time. For the automated measurements of temperature, platinum resistance temperature sensors Pt100 (four wires, class A) were used. The automated measurements of air temperature were conducted in the naturally ventilated multi-plate shield Met-Cover3.

RESULTS AND DISCUSSION

The median air temperature difference between the automat and manual measurements for the comparative period was positive for the average daily air temperature (M = 0.11 ◦C, standard deviation SD = 0.4 ◦C) and the daily minimum air temperature (M = 0.26 ◦C, SD = 0.84 ◦C) and negative for the daily maximum air temperature (M = −0.63 ◦C, SD = 0.92 ◦C). The differences between the automat and manual measurements for the average, maximum and minimum temperatures were statistically significant at the 5% significance
level.

Average monthly differences between the automat and manual measurements for the comparative period fluctuated between –0.5 ◦C and 0.29 ◦C (Figure 1). Deviations were negative in the winter half-year (October to March), indicating that temperatures measured under the automat were lower than those measured by the manual; the opposite pattern was found in the summer half-year (April to September). A similar distribution was found for the average monthly differences in daily minimum air temperatures, for which the mean differences fluctuated between –0.45 ◦C and 0.96 ◦C. In contrast, the average monthly differences in daily maximum air temperatures were consistently negative; the mean differences fluctuated between –1.22 ◦C and –0.21 ◦C. The average difference in the winter half-year period was –0.19 ◦C for average air temperatures, –0.44 ◦C for maximum air temperatures and –0.25 C for minimum air temperatures. The average difference during the summer was 0.21 ◦C for average air temperatures, –1.13 ◦C for maximum air temperatures and 0.73 ◦C for minimum air temperatures. The average difference between the automat and manual measurements was 0.01 ◦C for the average annual temperature, 0.24 ◦C for the average annual minimum temperature and –0.78 ◦C for the average annual maximum air temperature. Mozny et al. (2012) showed that the differences between automatic and manual measurements of air temperature were caused by the transition measurements from the Czech-Slovak thermometer screen at the multi-plate shield. Size difference depends on meteorological conditions (wind speed, amount of cloudiness and the surface-reflected radiation).

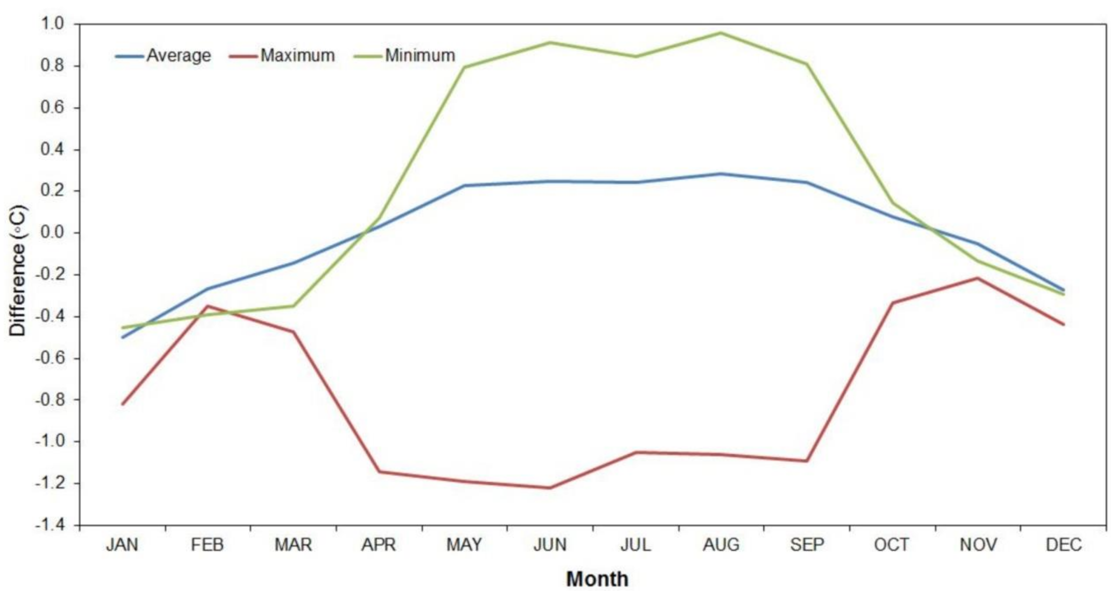


***Figure 1** The average monthly differences in average, minimum and maximum air temperature between the automat and manual measurements from April 2000 to December 2013.*

The median temperature difference between the automat and manual measurements for the comparative period was positive for the average daily soil temperature at a depth of 5, 10 and 20 cm (M = 0.6 ◦C, standard deviation SD = 0.4 ◦C) and at a depth of 50 and 100 cm (M = 0.12 ◦C, SD = 0.3 ◦C). The differences between the automat and manual measurements for the all depth were statistically significant at the 5% significance level.

Average monthly differences between the automat and manual measurements for the comparative period fluctuated between –0.31 ◦C and 0.83 ◦C at the depth of 5, 10 and 20 cm (Figure 2). Deviations were positive in the all months, indicating that temperatures measured under the automat were higher than those measured by the manual. In contrast, the average monthly differences at the depth of 50 and 100 cm were negative in March and April; the mean differences fluctuated between –0.13 ◦C and 0.28 ◦C. Volume changes in the soil in March and April were affected the differences.

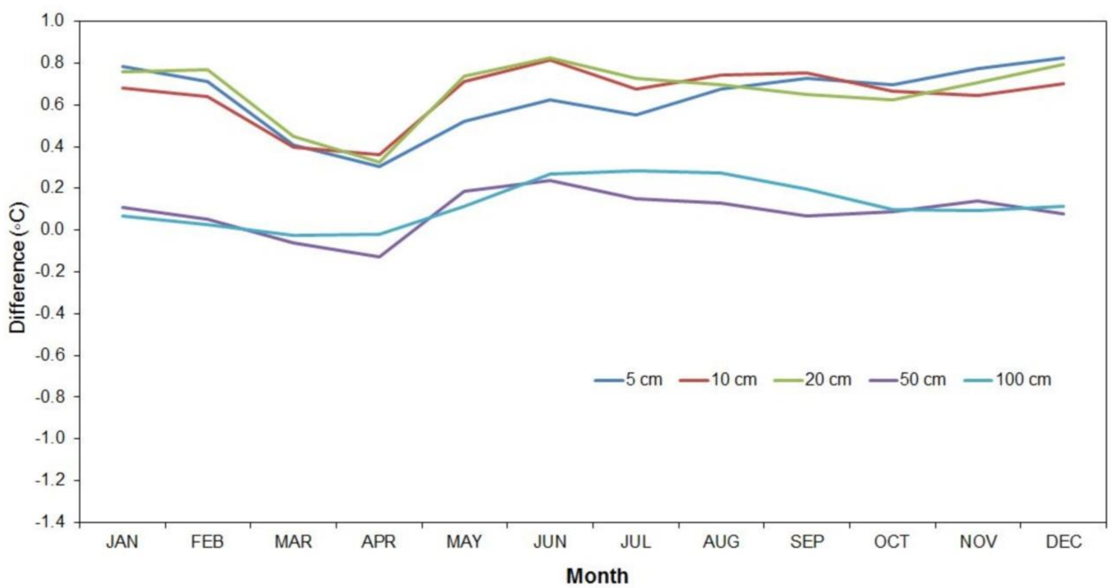


Figure 2 *The average monthly differences in soil temperatures between the automat and manual measurements at the depth of 5, 10, 20, 50 and 100 cm from April 2000 to December 2013.*

Conclusion

The average air temperature difference between the automat and the manual varied between 0.3 ◦C and 2.8 ◦C. The error increased during bright days with wind speed less than 3 m/s, and temperature deviations up to 4.1 ◦C occurred

in the presence of snow cover. Differences between the automat and the manual average air temperature were less than 0.2 ◦C during overcast conditions when the wind speed exceeded 3 m/s.

The median temperature difference between the automat and manual measurements for the comparative period was positive for the average daily soil temperature at the all depth.

References

Barnett, A., D.B. Hatton, D.W. Jones, 1998. Recent changes in thermometer screen design and their impact. – Instruments and observing methods, Report No. 66 (WMO/TD-No. 871),WMO, Geneva), 12 pp.

Brock, F.V., S.R. Semmer, C. Jirak, 1995. Passive solar radiation shields: wind tunnel testing. – Preprints, 9th Symposium on Meteorological Observations and Instrumentation. American Meteorological Society, Charlotte, North Carolina, March 27–31, 179–183.

Lin, X., F.G. Hubbard, G.E. Meyer, 2001:Airflow characteristics of commonly used temperature radiation shields. – J. Atmos. Oceanic Technol. 18, 329–339.

Lacombe, M., D. Bousri, M. Leroy, M. Mezred, 2011: WMO field ntercomparison of thermometer screen/shields and humidity measuring instruments. – WMO report no. 106 , 101 pp.

Mozny, M., Trnka, M., Stepanek, P., Zalud, Z., Koznarova, V., Hajkova, L., Bares, D., Semeradova, D., 2012. Long-term comparison of temperature measurements by the multi-plate shield and Czech-Slovak thermometer screen. Meteorologische Zeitschrift, Vol. 21, No. 2, 125-133.

Nagy, Z., 2006. Effect of thermometer screens on accuracy of temperature measurements. – WMO conference TECO-2006, Geneva, Switzerland, 4–6 December 2006.

Van Der Meulen, J.P., T. Brandsma, 2008. Thermometer Screen Intercomparison in De Bilt (the Netherlands). – Int. J. Climatol. 28, 371–387.

Petäjä, A., 2004. Comparison of radiation screens. – Finnish Meteorological Institute, 34 pp.

ACKNOWLEDGEMENT

We gratefully acknowledge the support of the Ministry of Education, Youth and Sports project CZ.1.07/2.3.00/20.0248.

SUMMARY

Předpokladem studia změn klimatu je vyhodnocení souběžných měření prováděných automatickým a manuálním způsobem. V rámci České republiky došlo u měření teploty vzduchu v rámci automatizace k zásadní změně – k přechodu od měření v meteorologické budce k měření pod radiačním štítem. Tato změna statisticky významným způsobem ovlivnila měření teploty vzduchu. Vlivem automatizace došlo k mírnému „zvýšení“ minimálních teplot a naopak „snížení“ maximálních teplot. Diference teplot mezi budkou a štítem závisí na meteorologických podmínkách (rychlosti větru, oblačnosti a odraženém záření od povrchu).

Automatické měření teploty půdy v hloubce 5, 10 a 20 cm pod travnatým povrchem vykazuje mírný „nárůst“ teploty ve všech měsících oproti manuálnímu měření.

CONTACT

Daniel Bareš, Dipl. Ek.

Czech Hydrometeorological Institute

Doksany Observatory, 41182 Doksany

Phone: 420416861112, e-mail: daniel.bares@chmi.cz

THE SEASONAL RAINFALL VARIABILITY AND A PRECIPITATION SUFFICIENCY OF NORWAY SPRUCE (PICEA ABIES (L.) KARST) IN WESTERN TATRAS AND SURROUNDINGS DURING THE PERIOD FROM 1994 TO 2013

MARTIN BARTÍK [1]; MARTIN JANČO[1]; PETER BORSÁNYI[2]; JAROSLAV ŠKVARENINA[1]

Department of Natural Environment, TU Zvolen[1]; SHMÚ Banská Bystrica[2]

ABSTRACT

In our work we processed monthly precipitation amounts from 28 precipitation-gage stations of SHMU (The Slovak Hydro-meteorological Institute) and from one station of UH SAV (The Institute of Hydrology of The Slovak Academy of Sciences). All of these are located in Western Tatras and close surroundings. We used these data for analysing precipitation sufficiency of Norway spruce during years 1994-2013. Secondly, we compared an average annual precipitation during the last two decades with an average from the period of years 1961-1990. Finally, the extremes were analysed; the driest year 2003 and the most humid year 2010. The results show an evident increase of the rainfall in the research area and also strong rain shadow in Liptov-foothills of Western Tatras.

Key words: Rain shadow, annual precipitation, precipitation sufficiency

INTRODUCTION

A regular and barrier-free water cycle in a natural environment is a necessity not only for forest ecosystems but for the global one as well. Water is an integral part of all forest ecosystems and can be found in every one of its components: in the air, trees, bushes, plants, mosses and lichens, in soils and deadwoods. The trees and the plants slow down the fall of rain drops on the soil surface and retain water for a gradual release during a whole year (Minďáš, Konôpka, Novotný 2006, Holko et al. 2011). The precipitation is indisputably one of the most important factors determining a landscape character. The basic characteristics of precipitation are the amount, the duration and the intensity of the precipitation (Tužinský 2002). Under the term "precipitation sufficiency for a plant" we understand the amount of precipitation necessary for avoiding suffering from a lack of water and the water supplies are high enough for a successful growing of the plant within a specific period of time. We could observe a large-scale decline of spruce stands in Slovakia in recent years. The reasons for this are still not sufficiently clarified. A crucial phase of the spruce stand decline has been influenced by a bark beetle infestation (Grodzki *et al*. 2006; Jakuš *et al*. 2008). The climate change could be one of the possible factors, too. In regard of the expected precipitation deficit increase is Norway spruce considered as one of the most endangered wood species, mainly in an area outside of its native extensions (Škvarenina, Střelcová, Kamenský 1995).

MATERIALS AND METHODS

Characteristic of Western Tatras

Western Tatras cover area of 29 177 ha and are the second highest mountain in Slovakia (Kňazovický 1970). They belong from an geological aspect into the outward arc of Western Carpathians. We distinguish two type of base rock here: the acid extrusive granite and metamorphic bedrocks and the alkaline limestone-dolomite Mesozoic sediments (Sivý vrch, Osobitá, Červené vrchy) (Tajboš 2004). Western Tatras belong to a cold climatic region, and into a moderate cool and cool mountainous subregion (Lapin et al. 2002).

Metrological stations

The table 1 below shows list of used meteorological stations and their altitudes. 28 stations are owned by SHMU and one by UH SAV. For our calculation were used stations located not only in Western Tatras; for better interpolation we used also stations from outside of the Western Tatras area. The graphical outputs were prepared in ArcMap 10.1 and a "Nearest Neighbour" method was used for an interpolation between stations.

Tab.1 List of station

Station	Altitude [m a. s. l.]
Červenec	1420
Tatranská Polianka	975
Skalnaté Pleso	1778
Štrbské Pleso	1322
Podbanské	972

Pribylina	753
Liptovský Hrádok	640
Konská	749
Žiar	747
Chopok	2005
Luková pod Chopkom	1661
Demänovská dolina-Jasná	1196
Bobrovec	632
Liptovská Ondrašová	569
Lazisko	680
Huty	808
Kvačany	620
Lúčky	616
Liptovská Teplá	509
Tvrdošín-Medvedzie	625
Vitanová-Oravice	853
Vitanová	690
Liesek	692
Trstená	608
Zuberec-Zverovka	1030
Zuberec	763
Oravský B. Potok	646
Dlhá nad Oravou	530
Oravský Podzámok	532

Precipitation sufficiency for Norway spruce (Picea abies (L.) Karst)

We calculated an average rainfall amount for every year of the recent decades at all stations based on monthly totals during the vegetation period (May-August). All stations are located in a native extension areal of spruce. The amount of 300mm was set up as a minimum for successful spruce growing. This value is acceptable for the most of authors (Škvarenina, Střelcová, Kamenský 1995).

RESULTS

Precipitation distribution in research area in period 1961-1990

The figures 1 and 2 show precipitation distribution and also precipitation increase in relation to altitude and exposition in the research area. We can see that at an altitude of 1000 m a. s. l. is the difference of annual average in between the SE and NW exposition circa. 300mm. Konček et al (1974) in an analysis of data from stations in Tatras stated a difference of circa 450 mm at the same altitude.

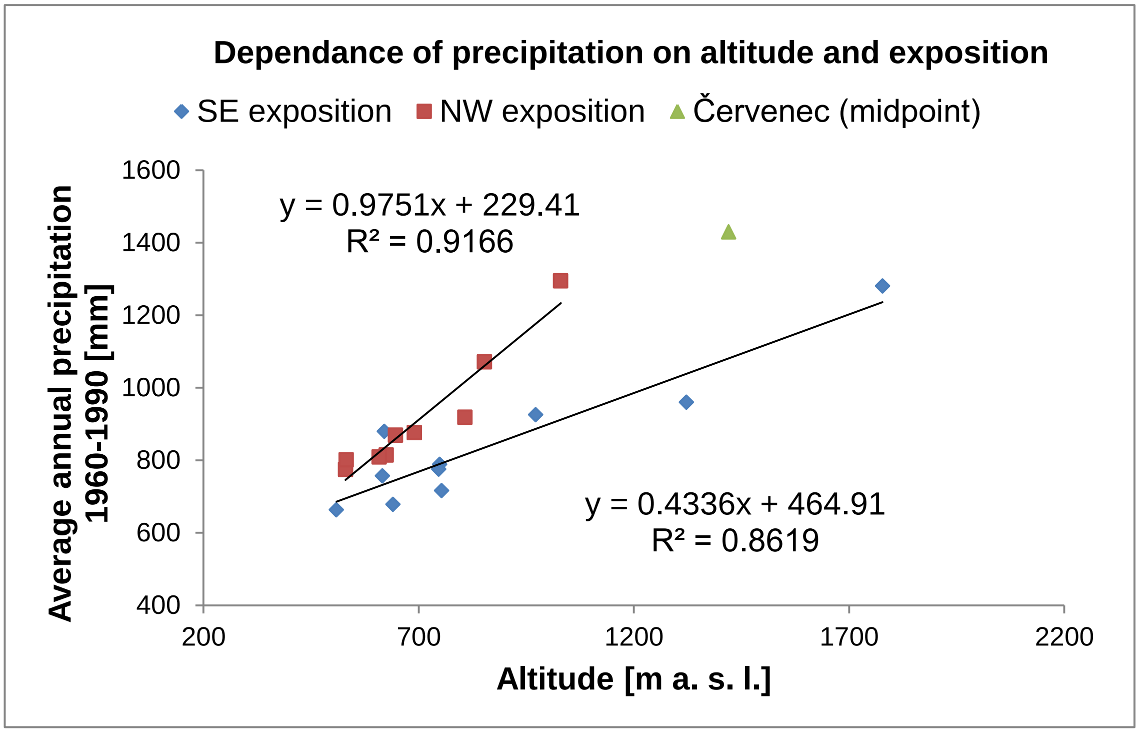


Fig. 1 Average annual precipitation in relation to altitude and exposition

Precipitation sufficiency of Norway spruce (*Picea abies* (L.) Karst.) during the period 1994-2013

Figure 3 shows number of years, when the limit of 300mm of precipitation was not achieved. Although all the stations are located in a native extension areal of spruce, we can see that this limit was not achieved at several of them. The highest number of years with the rainfall amount below the limit was recorded in Pribilina, Liptovský Hrádok, Konská, Bobrovec, and Liptovská Ondrašová. All these stations are located on the leeward side of Western Tatras, with a strong rainfall shadow effect. At other stations, mainly at higher altitude and on a windward side we can see a sufficient level of precipitation for spruce during vegetation period. There are very good conditions for spruce growth in this area. On the other hand, at the stations where the precipitation sufficiency wasn't achieved the growth could have been slowed down or the spruce could have become weaker due to stress.

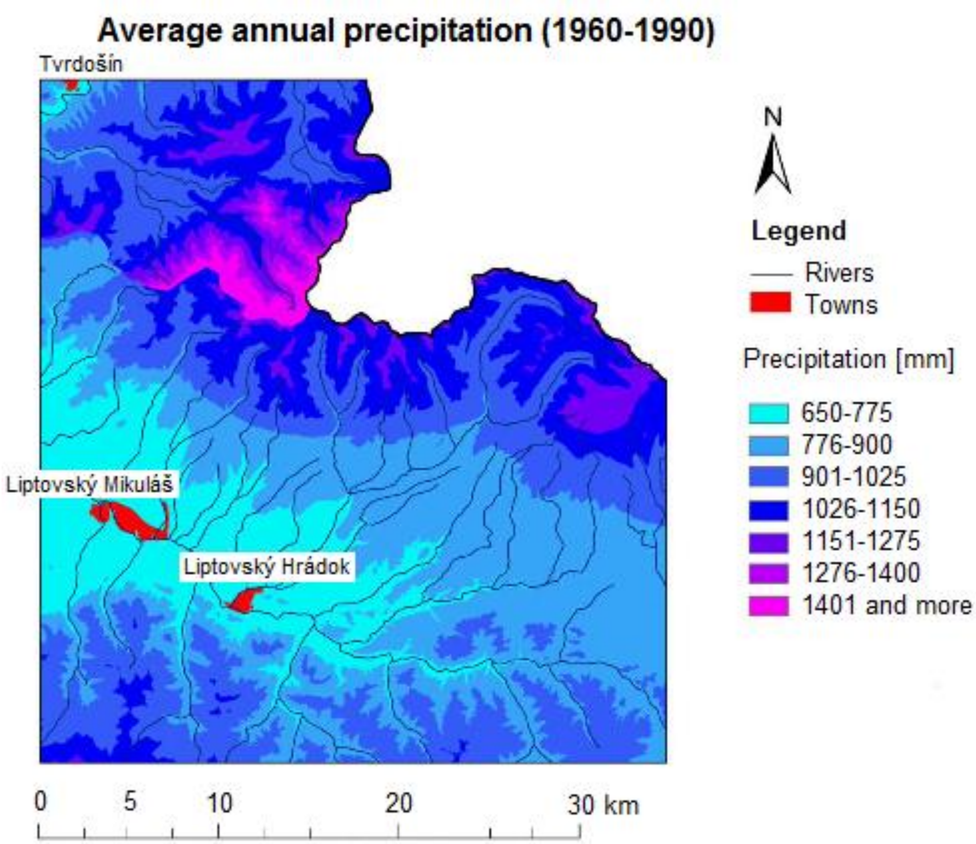


Fig. 2 Precipitation distribution

Changes in average annual precipitation between 1961-1990 and 1994-2013

Figures 4 and 5 show how an average annual precipitation changed in between 1961-1990 and 1994-2013. We can see slightly increased average annual precipitation in years 1994-2013 in compare with a period of years 1961-1990 at all stations. The only exceptions are the rainfall-gauge station Konska with a 6 % decrease and Žiar (without difference). At this point stations Červenec, Tatranská Polianka, Bobrovec, Liptovská Ondrašová, Liesek and Zuberec were disregarded due to a lack of figures from years 1961-1990.

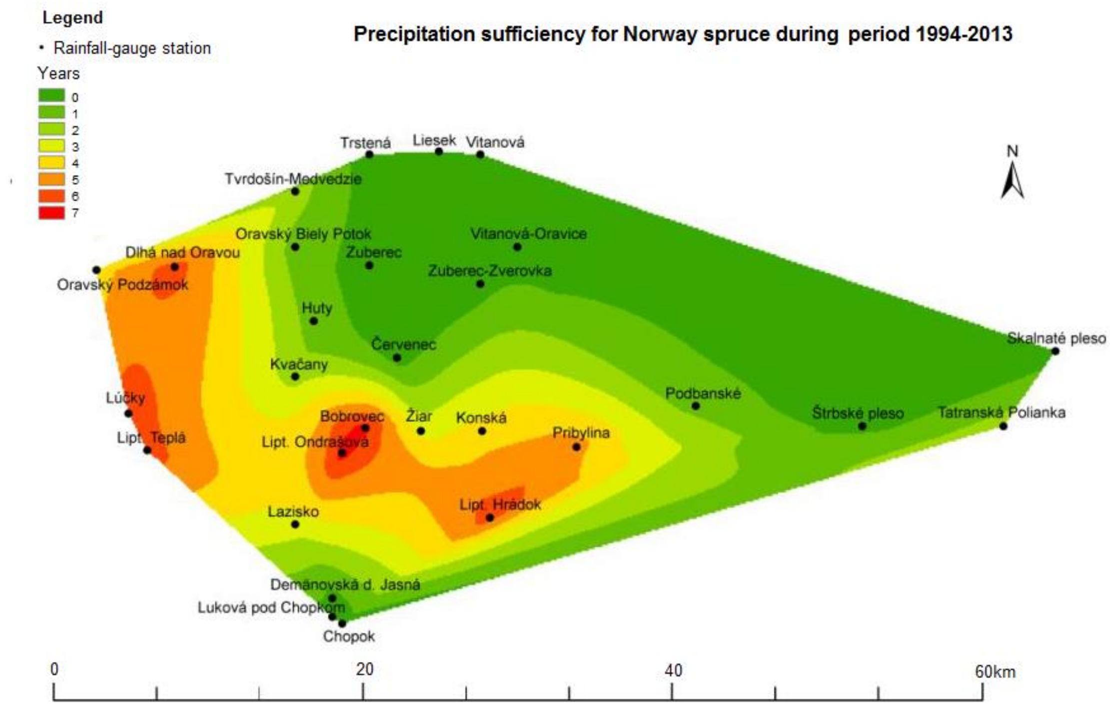


Fig. 3 Number of years, when precipitation sufficiency was not achieved

Extreme years in precipitation during last two decades

In last two decades the driest year was the year 2003 and the most humid one was the year 2010. We used annual precipitation sums from the years (2003 and 2010) and calculated differences in between them and the average annual precipitation in 1961-1990. In the year 2003 (Fig.6) the decrease went up to -40% (Konská -39,2 %) of the average annual precipitation in 1961-1990. In the year 2010 an increase of almost 70% (Luková 68, 4%) of the average was recorded (Fig. 7).

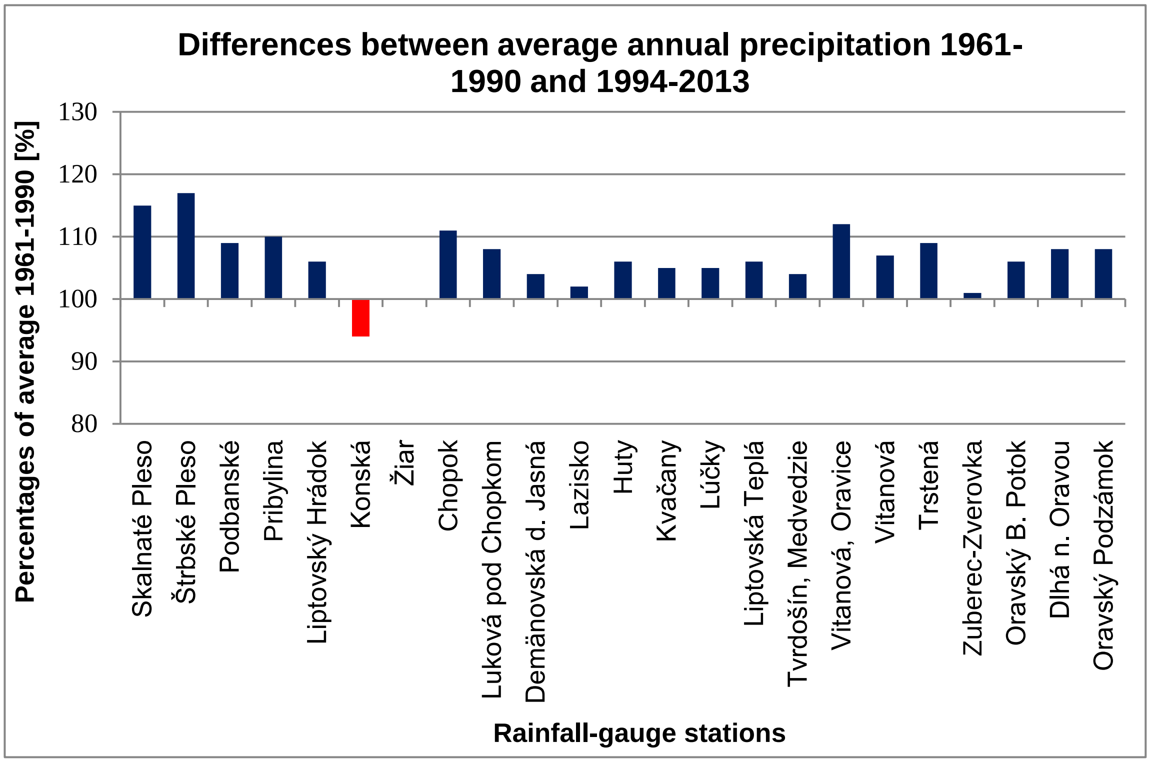


Fig. 4 Comparison of average annual precipitation 1961-1990 with 1994-2003

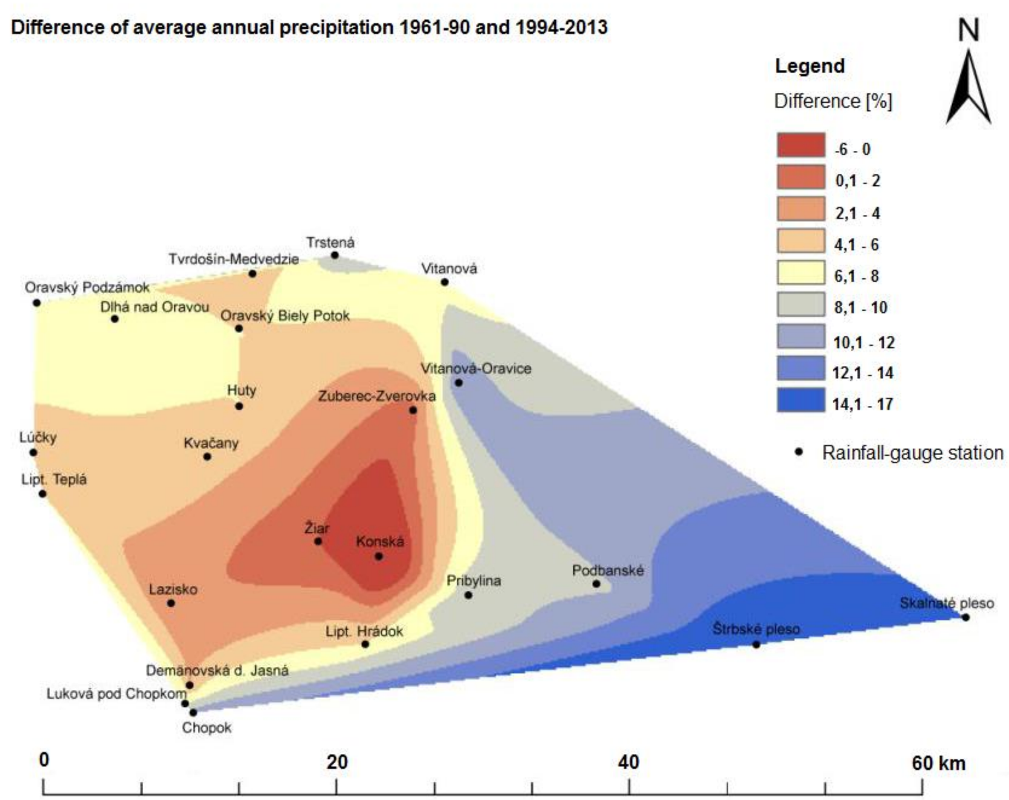


Fig. 5 Graphical result of comparison

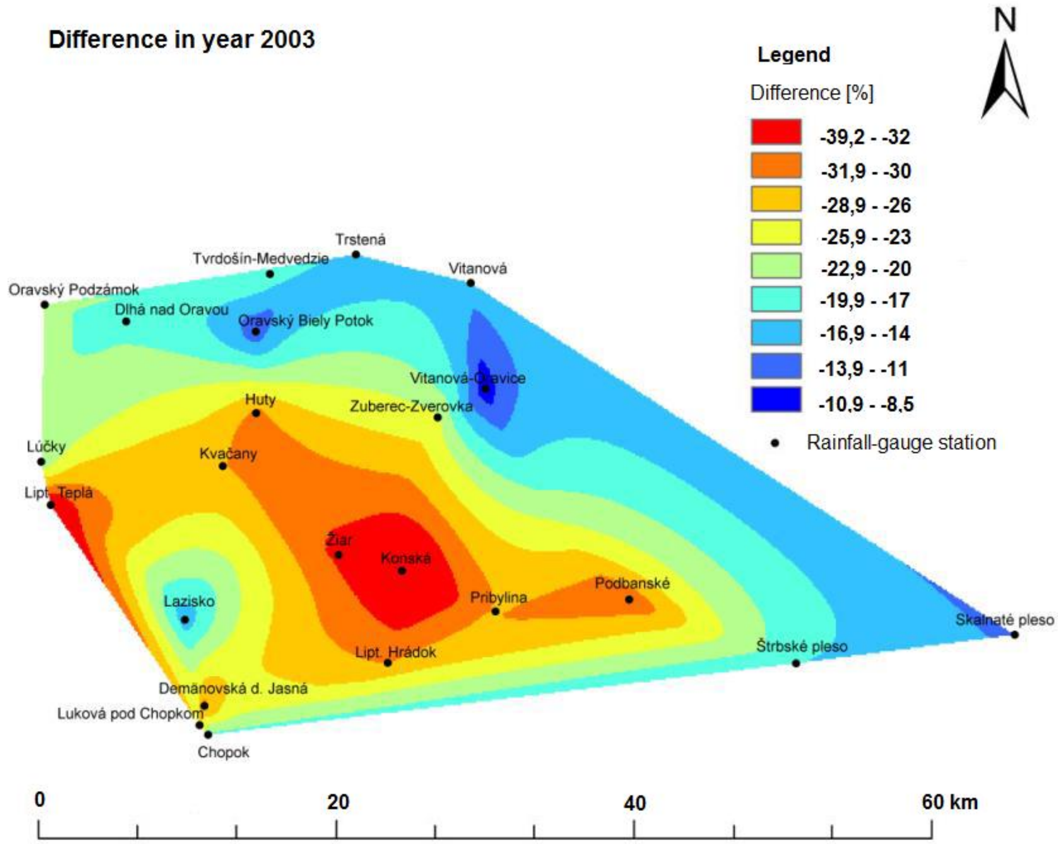


Fig. 6 Comparison of annual precipitation in the driest year 2003 and average annual precipitation 1961-1990

CONCLUSION

This work was aimed on an evaluation of the annual and seasonal precipitation regime in Western Tatras and the surroundings. Our target was also to analyse what impact this mountain range has on the rainfall distribution on the windward (Orava) and on the leeward (Liptov) side of it. The results can be summarized into the following points:

- The leeward side of Western Tatras is located in a strong rainfall shadow. The average annual precipitation difference at an altitude of 1000 m a. s. l. is about 300mm in compare with the windward side.
- In several years the precipitation sufficiency of Norway spruce was not achieved. The rainfall totals in a vegetation period (May-August) were lower than 300mm; more often

at leeward foothills of Western Tatras (Bobrovec, Liptovská Ondrášová, Liptovský Hrádok, and Pribilina). At several stations the sufficiency was not achieved in 7 year during the last two decades.

- By comparing the average annual precipitation in year 1994-2013 and during 1961-1990 we recorded an increase of precipitation in the research area (in average by 7 %, 63 mm)
- The driest year in the last two decades was the year 2003 when annual precipitation sum was 77% of an average annual precipitation in 1961-1990.
- The most humid year was the year 2010 when annual precipitation was higher by 46% than the average annual precipitation in 1961-1990.

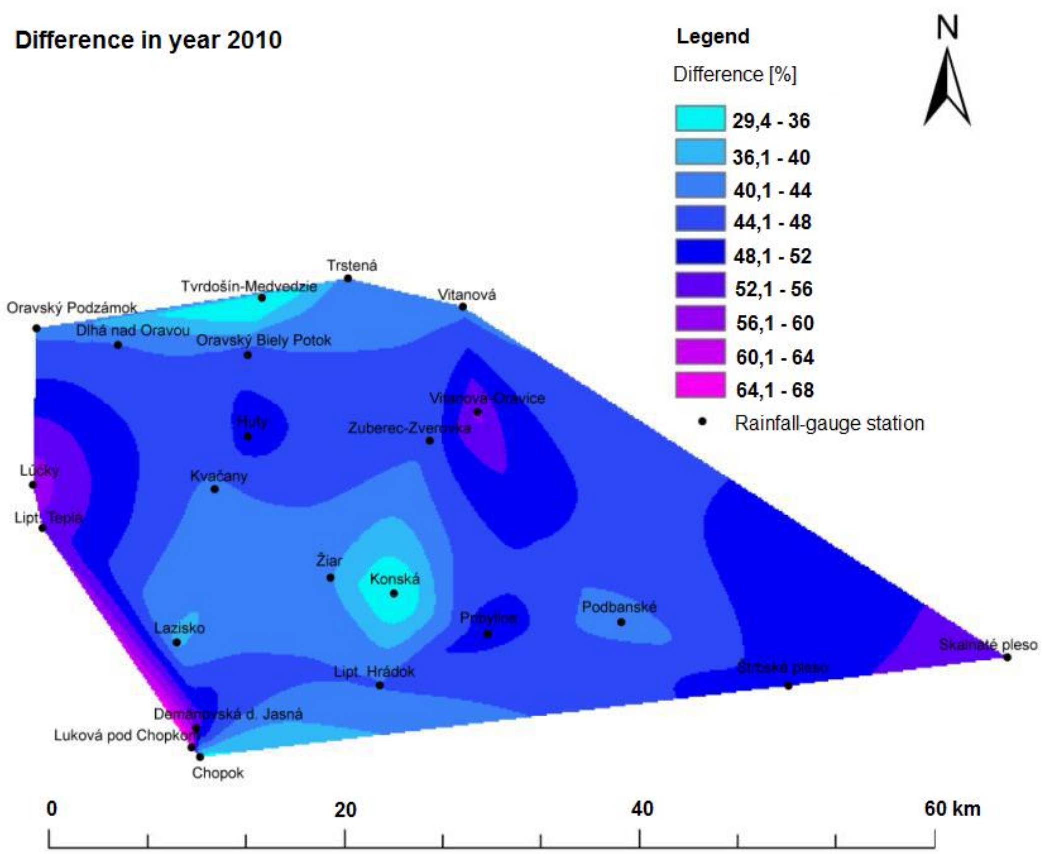


Fig. 7 Comparison of annual precipitation in the most humid year 2010 and average annual precipitation 1961-1990

References

Benčať, T. 2009. Dendrológia a ekológia drevín. Vysokoškolská učebnica. Zvolen: Technická univerzita, 2009. 225 s. ISBN 978-80-228-1996-1.

Grodzki, W., Jakuš, R., Lajzová, E., Sitková, Z., Maczka, T., Škvarenina, J. 2006. Effects of intensive versus no management strategies during an outbreak of the bark beetle Ips typographus (L.) (Col.: Curculionidae, Scolytinae) in the Tatra Mts. in Poland and Slovakia. Ann. For. Sci. pp 63: 55–61.

Hochmuth, Z. 1987. Západné Tatry: Turistický sprievodca ČSSR. Bratislava: Šport, Slovenské telovýchovné vydavateľstvo, 1987. 264 p.

Holko, L., Kostka, Z., Danko, M., Liová, S.2011.Hydrologický cyklus v horskom prostredí. Životné prostredie, 2011.45,2, p. 59-63.

Jakuš, R., Čaboun, V., Kukla, J., Kulla, L., Blaženec, M. 2008. Hromadné odumieranie nepôvodných smrečín severného Slovenska. [online 15.02.2014]. Zvolen: Ústav ekológie lesa SAV. (http://www.savzv.sk.) 20 p.

Kňazovický, L. 1970. Západné Tatry. Bratislava: Slovenská akadémie vied, 1970. 216 p.

Konček , M. et al. 1974. Klíma Tatier. Bratislava: Veda, 1974. 856 p.

Lapin, M. et al. 2002. Klimatické oblasti 1:1000 000. In Atlas krajiny Slovenskej republiky. Bratislava: Ministerstvo životného prostredia Slovenskej Republiky, 2002. ISBN 80-88833-27-2. pp 95.

Lapin, M., FAŠKO. P., Kveták, Š. 1988. Metodický predpis 3-09-1/1. Bratislava: Slovenský hydrometeorologický ústav, 1988. 25 p.

Minďáš, J., Konôpka. J., Novotný, J. 2006. Lesy Slovenska. Zvolen: Národné lesnícke centrum, 2006. ISBN 80-8093-001-5. 222 p.

Škvarenina, J., Střelcová. K., Kamenský, L. 1996. Zrážková zabezpečenosť smreka obyčajného na vybraných lokalitách stredného Slovenska. In Lesné ekosystémy a globálne klimatické zmeny, Zborník referátov z pracovného seminára, Škvarenina, J., Minďáš, J., Čaboun, V. (eds.), Zvolen: Lesnícky výskumný ústav. pp. 69-97.

Střelcová, K., Škvarenina, J. 2004. Bioklimatológia a meteorológia: Návody na cvičenia. Zvolen: Technická univerzita, 2004. 118 p.

Tajboš, J. 2004. Štruktúra porastov a geomorfologické pomery Západných Tatier - časť Liptovské Tatry. In Lesnícky časopis [online]. 2004, roč. 50, č. 2 [cit. 2014-05-05]. Dostupné na internete: <http://www.nlcsk.sk/files/3240.pdf>. ISSN 0323-1046

Tužinský, L. 2002. Bioklimatológia. Zvolen: Technická univerzita, 2002. 140 p. ISBN 80-228-1150-5.

ACKNOWLEDGEMENT

This work was accomplished as a part of the projects VEGA No.: 1/1130/12, VEGA 1/0281/11, VEGA 1/0463/14 of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science; and the projects of the Slovak Research and Development Agency No.: APVV-0423-10, and APVV-0303-11. The authors thank the agencies for the support. Also authors thank the UH SAV in Liptovská Ondrašová for precipitation data from rainfall-gauge station Červenec.

SUMMARY

Príspevok sa venujeme problematike rozloženia a medziročnej variability zrážok v Západných Tatrách a ich okolí. Predmetom výskumu bola zhodnotenie zrážkovej zabezpečenosti smreka obyčajného (Picea abies (K.) Karst) počas posledných dvoch dekád. V práci sme taktiež porovnávali dlhodobý normál z rokov 1994-2013 so zrážkovým normálom 1961-1990. Ďalej sme sa zamerali na vizualizáciu a zhodnotenie zrážkovo extrémnych rokov (2003 a 2010) v danej oblasti.

Z výsledkov je zrejmý zrážkový tieň na liptovskom predhorí Západných Tatier, pričom v nadmorskej výške 1000 m n. m. zaznamenávame rozdiel v zrážkovom normály 1961-1990 cca 300 mm. Aj keď všetky sledované stanice (28 staníc SHMU, 1 stanica UH SAV) ležia v areály prirodzeného výskytu smreka, na niektorých nebola naplnená jeho zrážková zabezpečenosť počas 7 rokov z posledných dvoch dekád. Väčšina staníc, kde k tomu dochádzalo, je lokalizovaná na liptovskom predhorí Západných Tatier. Pri zhodnotení množstva zrážok počas obdobia 1994-2013 so zrážkovým normálom 1961-1990 pozorujeme takmer na všetkých staniciach ich nárast. Výnimkou je len stanica Konská (6% pokles) a Žiar (bez zmeny). Priemerne množstvo zrážok za rok sa zvýšilo o 63 mm (7%). Počas najsuchšieho roku posledných dvoch dekád, roku 2003 ročný

úhrn na pozorovaných staniciach predstavoval 77% zrážkového normálu. Počas na zrážky najbohatšieho roku 2010 sme zaznamenali 46 % nárast zrážok.

CONTACT

Ing. Martin Bartík

Katedra prírodného prostredia, Lesnícka fakulta, TU Zvolen

T. G. Masaryka 24, Zvolen 960 53

00421 908 220 636, bartikmartin@gmail.com

INDICES OF CLIMATE EXTREMES FOR THE GROWING SEASON LENGTH AT FOOTHILL STATION STARÁ LESNÁ (1988-2013)

SVETLANA BIČÁROVÁ[1]; JOZEF MAČUTEK[1]; DUŠAN BILČÍK[2]

1) *Geophysical Institute of the Slovak Academy of Sciences (GPI SAS), workplace Stará Lesná*
2) *Geophysical Institute of the Slovak Academy of Sciences (GPI SAS), workplace Bratislava*

ABSTRACT

This paper presents evaluation of classical climatic measurements at Meteorological Observatory GPI SAS in Stará Lesná carried out in the years 1988-2013. Selected indices of extremes were calculated according to the European project ECA&D (European Climate Assessment & Dataset project) for the growing season length (GSL) period. Duration of GSL on average 195 days, usually from April to October, proves appropriate climatic conditions for the growth of forest vegetation. Interannual variation of GSL indicates no significant changes during considered period. On the other hand, indices derived from daily temperature extremes such as maximum of daily temperature or numbers of summer days show a slight warming at foothill of the High Tatras. Precipitation GSL amount fluctuated around mean value of 539 mm. The longest dry period covering 22 consecutive days without precipitation occurred in 1999, 2009, and during extraordinary dry event in 2011.

Key words: ECA&D indices, submontane climate, growing season, bioclimatology

INTRODUCTION

Meteorological measurements at location Stará Lesná are provided by the Geophysical Institute of the Slovak Academy of Sciences (GPI SAS) since 1987. Research activities are focused on the study of physical and chemical processes in the atmospheric boundary layer, and regional climate of the High Tatra Mts. (Smolen and Ostrožlík, 1998; Bilčík and Mišaga, 1998; Matejka et al., 2008; Holko et al., 2012; Bičárová et al., 2013). Until 2013, experimental programme of GPI SAS included classical climatological observations realised in cooperation with Slovak Hydrometeorological Institute. Climatological weather observations at Stará Lesná for the years 1988-2013 represents the enclosed period of measurement using classical methods. Since 2014, automatic weather station provides continuous, homogenous and high quality measurement data needed for sophisticated models and interdisciplinary research. The purpose of this paper is to evaluate classical climatic observations (1988-2013) and to provide complex characteristic related to key bioclimatological factor such as growing season length (GSL) period for foothill zone of the High Tatra Mts. where the station Stará Lesná is located.

MATERIALS AND METHODS

Daily data of basic climatic elements obtained at station Stará Lesná during period 1988-2013 were used for investigation of climate characteristics typical for growing season of foothill zone in the High Tatras. Standard daily observations covered three different times measurements (7 a.m., 2 p.m. and 9 p.m. of local time) recorded by the observer. Air temperature and air humidity were measured by glass thermometers (dry temperature, wet temperature, minimal and maximal temperature in °C). Daily precipitation total (mm) was measured by standard rain gauge with collecting area of 500 cm^2. The amount of cloudiness was determined visually, in this work we used the data of cloud coverage (in tenths). The Campbell-Stokes recorder equipped with paper tape was used for continuous registration of sunshine duration (hours) as sunlight intensity climatic element. Meteorological instruments were serviced and calibrated in cooperation with the Slovak Hydrometeorological Institute (SHMI). Stará Lesná is part of national climatological station network of Slovakia. Observation area Stará Lesná is situated in submontane zone of the High Tatra Mts. (49°09´N, 20°17´E, 810 m a.s.l.). Forest is dominant vegetation type in the lower (supramontane) part of Skalnatá dolina (up to 1500 m a.s.l). Absolutely dominant tree species is Spruce (*Picea abies*), high percentage reaches also European larch (*Larix deciduas)* (Škvarenina and Fleischer, 2013). Climatic data obtained at station Stará Lesná was processed according to recommendation of the European Climate Assessment & Dataset project (ECA&D). This project (eca.knmi.nl) presents information on changes in weather and climate extremes, as well as the daily dataset needed to monitor and analyse these extremes (Klein Tank, 2002). Descriptions of selected ECA&D climatic characteristics and indices used for evaluation of Stará Lesná dataset are included in the head of result tables.

RESULTS AN DISCUSSION

a) ECA&D groups of selected climatic indices: temperature, heat, cold, sunshine, cloudiness

Air temperature is basic climatic element that reflects heat conditions in the atmosphere and controls vegetation phenological patterns in dependency of latitude and altitude. In much of Europe, daily mean temperature of at least 5 °C is considered to be favourable for growing of indigenous vegetations. The growing season length (GSL), according to ECA&D is expressed as number of days between the first occurrence of at least 6 consecutive days with mean daily temperature (TG) > 5°C and the first occurrence after 1 July of at least 6 consecutive days with TG < 5 °C. At location Stará Lesná, for the period 1988 to 2013 the average GSL was 194 days (6.4 months) and ranged from 166 (min) to 229 (max) days (Tab. 1). Comparison of mean annual GSL courses for different ECA&D climatic stations in Slovakia and that for location Stará Lesná (Fig. 1) shows similar shapes for colder climate locations such as Stará Lesná, Oravská Lesná and Poprad until year 2004. During last years larger differences were identified. GSL values for warmer climatic lowland regions represented by stations such as Bratislava, Hurbanovo, Piešťany, Košice were substantially higher, in same cases exceeded 300 days in year (10 months). Typical GSL lasting from April until October or November. Mean air temperature TGg related to GSL period was 12.3 ±0.8 °C. Both GSL and TGg indices show no significant changes during considered period 1988-2013. On the other hand, indices derived from daily air temperature extremes indicate moderate warming of growing season due to increasing tendency of daily maximal temperature (TXg, TXx) as well as daily minimal temperature (TNg, TNx). Significant correlation for increase of summer days (SU) was also identified (Fig. 2). Annual sum of sunshine duration (SS) was on average 1193 hours per GSL. Annual maximum and minimum SS ranged between 1436 hours in 2000 and 911 hours in 2010, respectively. High cloudiness (CCg) about 7/10 cloud cover suggests rarely occurrence of mostly sunny days and abundance of cloudy days. Interannual variability of SS and CCg is relative stable with no significant changes.

b) ECA&D groups of selected climatic indices: rain, humidity, drought

Climatic indices derived from measurement of daily precipitation amount (RR) show that sum of precipitation aggregated over GSL fluctuated around mean value of 539 mm. The highest precipitation deficit was in 2003. In this year extraordinary heat wave occurred during summer season. It was the hottest summer on record in Europe over centuries. On the other hand, unusual precipitation abundance was in 2010 with the maximum value of 744 mm. Rare abundant rainfall events during May and June 2010 caused devastative floods across several Central European countries. For the last 26 years (1988-2013) no significant trends in GSL precipitation as well as for other climate precipitation characteristics were found (Tab. 2). Wet days (RR1) were almost 1/3 of GSL period. On average 6.7 mm/wet day was calculated as simple daily intensity index (SDII). Average number of heavy precipitation days (RR10) and very heavy precipitation days (RR20) were 17 and 6 days, respectively. Extreme rainfall amounts 88.1 mm for the highest 1-day precipitation (RX1) and 138.7 mm for the highest 5-day precipitation in July 2002 were recorded. Wet periods of consecutive wet days (CWD) were shorter than periods of consecutive dry days (CDD). Maximum with 22 of consecutive dry days (CDD) was recorded during extraordinary dry event in Europe at the end of autumn in 2011 and, in addition, in years 1999 and 2009. Maxima of consecutive wet days (CWD) varied between 5 and 13 days during GSL. Observed RHg values at about 75.2 % with moderate changes from 69.5 to 79.9 1% document high degree of water vapour saturation in air. It corresponds with high cloudiness about 7/10 cloud cover.

CONCLUSIONS

Mountain climate is characterised by a larger variability, both spatial and temporal compared with lowlands at the same latitude. Colder and more humid conditions influence growth of forest vegetation including Spruce-fir-beech, Spruce, Mountain pine and Alpine a typical Carpathian vegetation stages (Škvarenina and Fleischer, 2013). Location Stará Lesná is situated at the foothills of the High Tatra Mts. and represents submontane climate zone favourable for temperate coniferous and mixed forest vegetation. Evaluation of measurements at Stará Lesná (1988-2013) presented in this paper provides information about climate of submontane location useful for interdisciplinary research. Based on this data, location Stará Lesná is characterised by length of grow season on average 195 ±17 days per year. Mean air temperature 12.3 ±0.8 °C and mean precipitation amount 539 ±98 mm were calculated for GSL period. ECA&D indices derived from air temperature extremes show increasing tendency of daily air temperature maxima as well as number of summer days. Average sunshine duration was 1193 ±135 hours per GSL. Most days were cloudy with average cloudiness about 7/10. Relative air humidity 75.2 ±2.6 % corresponds with high number of cloudy days. Maximal wet periods lasted from 3 to 13 consecutive wet days (CWD), substantially longer were dry periods from 8 to 22 days (CDD). The higher air temperature and the sufficient amounts of precipitation can increase the wood production of the tree species growing there. The next negative factors (windstorms and other meteorological extremes, harmful insects, fungi pathogens, acid pollutants, photooxidants etc.) can change the assumed development (Škvarenina et al., 2004).

References

Bičárová S., Pavlendová H., Fleischer P., 2013: Vulnerability to ozone air pollution in different landforms of Europe. In Air pollution, Sources, Prevention and Health effects, R. Sethi (Ed), Nova Science Publishers, New York. Inc., 25-63.

Bilčík D., Mišaga O., 1998: Vplyv oblačnosti na biologicky aktívne ultrafialové žiarenie v Poprade-Gánoviach. In Meteorologický časopis, 1, 2, 25-30.

Holko L., Fleischer P., Novák V., Kostka T., Bičárová S., Novák J., 2012: Hydrological Effects of a Large Scale Windfall Degradation in the High Tatra Mountains, Slovakia. In Management of Mountain Watersheds, Springer, New Delhi, 164-179.

Klein Tank AMG and co-authors. 2002: Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatol., 22, 1441-1453.

Matejka F., Hurtalová T., Střelcová K., 2008: Toky tepla a vodnej pary nad kalamitnou plochou vo Vysokých Tatrách. In 16. Posterový deň s medzinárodnou účasťou - Transport vody, chemikálií a energie v systéme pôda-rastlina-atmosféra, zborník recenzovaných príspevkov, A. Čelková (Ed), ÚH SAV, Bratislava, 972.

Smolen, F., Ostrožlík M., 1998: Effect of albedo, atmospheric turbidity, and cloudiness on the diffuse radiation in the high-mountain positions. In Contributions of the Geophysical Institute of the Slovak Academy of Sciences. Series of Meteorology, 18, 7-18.

Škvarenina J., Fleischer P., 2013: Bioklimatické podmienky a vegetácia. In Observatórium SAV

Skalnaté Pleso-70 rokov meteorologických meraní, Bičárová et. al. (Ed), GFÚ SAV, Stará Lesná, 11-15.

Škvarenina J., Križová E., Tomlain J., 2004: Impact of the climate change on the water balance of altitudinal vegetation stages in Slovakia. Ekologia Bratislava, 23, 2, 13-29.

ACKNOWLEDGEMENT

This research was supported by the Grant Agency of the Slovak Republic under the project VEGA No. 2/0053/14.

SUMMARY

Horská klíma sa vyznačuje väčšou priestorovou a výškovou variabilitou v porovnaní s nížinnými oblasťami. Lesná vegetácia reaguje na rastúcu nadmorskú výšku zmenou zastúpenia dominantých drevín. Na základe lesníckej typológie sa lesné porasty v oblasti Vysokých Tatier zaraďujú do týchto (lesných) vegetačných stupňov (od najnižších polôh): smrekový, kosodrevinový. V alpínskom vegetačnom stupni už stromová vegetácia nerastie (Škvarenina a Fleischer, 2013). Lokalita Stará Lesná sa nachádza na úpätí Vysokých Tatier hôr a reprezentuje podhorské klimatické pásmo s priaznivými podmienkami pre rast ihličnatých a zmiešaných lesných porastov. Z vyhodnotenia klasických meraní na stanici GFÚ SAV v Starej Lesnej (1988-2013) vyplýva, že v podhorskej oblasti Vysokých Tatier vegetačné obdobie trvá v priemere 195 ± 17 dní v roku. Počas vegetačného obdobia je priemerná teplota vzduchu 12,3 ± 0,8 ° C a priemerný úhrn zrážok 539 ± 98 mm. Indexy ECA&D odvodené z meraní teplotných extrémov poukazujú na mierne otepľovanie v dôsledku tendencie nárastu denných teplotných maxím ako aj počtu letných dní. Vo vegetačnom období je priemerná dĺžka slnečného svitu 1193 ± 135 hodín. Väčšinu dní je však zamračené s priemernou oblačnosťou asi 7/10. Relatívna vlhkosť vzduchu 75,2 ± 2,6% zodpovedá vysokému počtu oblačných dní. Najdlhšie neprerušované zrážkové obdobia trvajú 3 až 13 dní, podstatne dlhšie sú periódy bez zrážok a to od 8 do 22 dní. Zvyšujúca sa teplota vzduchu pri dostatočnom množstve zrážok môže priaznivo pôsobiť na rast a produkciu lesných drevín. V oblasti Vysokých Tatier sú pre lesné porasty rizikovejšie víchrice a

ďalšie klimaticky podmienené faktory ako škodlivý hmyz, hubové patogény ako aj fotochemicky aktívne polutanty (Škvarenina et al., 2004).

CONTACT

Ing. Svetlana Bičárová, PhD.

Geofyzikálny ústav SAV, pracovisko Stará Lesná

059 60 Tatranská Lomnica, Slovensko

bicarova@ta3.sk

Tab. 1. Selected ECA&D climate indices for the growing season length (GSL) at foothill location Stará Lesná (1988-2013)

ECA&D climate indices	Abbr.	Unit
Growing season length (6 consecutive days 5°C > TG < 5°C)	GSL	days
Mean of daily mean temperature	TGg	°C
Mean of daily maximum temperature	TXg	°C
Maximum value of daily maximum temperature	TXx	°C
Summer days (criterion: TX >25°C)	SU	days
Mean of daily minimum temperature	TNg	°C
Maximum value od daily minimum temperature	TNx	°C
Sunshine duration	SS	hours
Mean of daily cloud cover	CCg	tenths

Year	GSL	TGg	TXg	TXx	SU	TNg	TNx	SS	CCg
1988	181	12.4	18.1	30.1	14	6.8	15.4	1106	6.0
1989	218	11.3	16.9	28.4	12	6.2	16.6	1150	6.8
1990	207	10.7	16.6	27.7	16	5.0	13.3	1212	6.5
1991	191	11.5	16.8	28.2	11	6.2	17.3	1025	6.9
1992	178	13.2	19.4	31.7	28	7.2	16.5	1252	5.9
1993	187	12.4	18.3	29.2	14	6.5	15.7	1205	6.4
1994	166	14.1	20.1	31.5	29	8.0	14.7	1113	6.4
1995	186	12.1	17.9	28.2	11	6.6	14.0	1125	6.9
1996	186	11.8	17.2	27.8	8	6.4	14.0	1017	7.2
1997	172	12.3	18.3	28.4	5	6.7	14.5	1024	6.8
1998	213	11.2	16.9	31.3	21	6.2	18.7	1138	7.1
1999	198	12.3	18.4	28.6	13	7.1	16.9	1135	7.1
2000	229	11.7	18.1	31.2	20	6.3	15.8	1436	6.3
2001	184	12.7	18.8	28.2	21	7.6	15.5	1125	6.7
2002	179	13.1	19.5	29.4	19	7.8	17.2	1113	6.8
2003	182	13.5	20.3	29.8	40	7.3	16.0	1323	6.5
2004	205	11.1	17.3	28.0	9	6.1	14.5	1162	7.1
2005	208	11.8	18.3	30.6	17	6.6	19.6	1314	6.8
2006	197	12.8	19.8	29.4	34	7.3	17.0	1369	6.8
2007	184	13.2	20.2	34.2	31	7.4	16.5	1376	6.2
2008	197	12.3	18.7	29.3	21	7.1	16.8	1193	6.8
2009	195	12.9	20.1	30.7	26	7.0	18.5	1408	6.0
2010	167	13.3	19.4	30.4	32	8.5	18.3	911	6.8
2011	215	12.0	19.0	29.5	26	6.8	19.5	1362	6.5
2012	200	13.2	19.7	32.2	44	7.6	16.3	1123	6.3
2013	226	11.7	18.5	33.1	30	6.5	18.0	1291	6.5
Summary statistics									
Avg	195	12.3	18.6	29.9	21	6.8	16.4	1193	6.6
SDev	17	0.8	1.1	1.7	10	0.7	1.7	135	0.4

Min	166	10.7	16.6	27.7	5	5.0	13.3	911	5.9
Max	229	14.1	20.3	34.2	44	8.5	19.6	1436	7.2
Statistically significant correlations between variables:Year and TGg elements									
Corr. Coef.	:	:	0.543	0.439	0.597	0.426	0.542	:	:
P-val	:	:	0.004	0.024	0.001	0.030	0.004	:	:

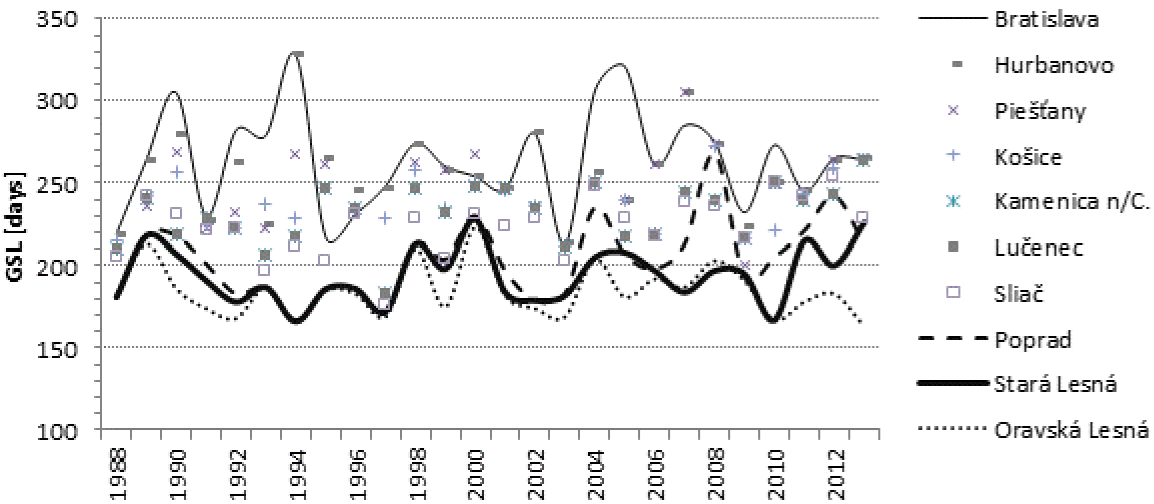


Fig. 1. Growing season length (GSL) at foothill location Stará Lesná in comparison to GSL at Slovak stations including in ECA&D database.

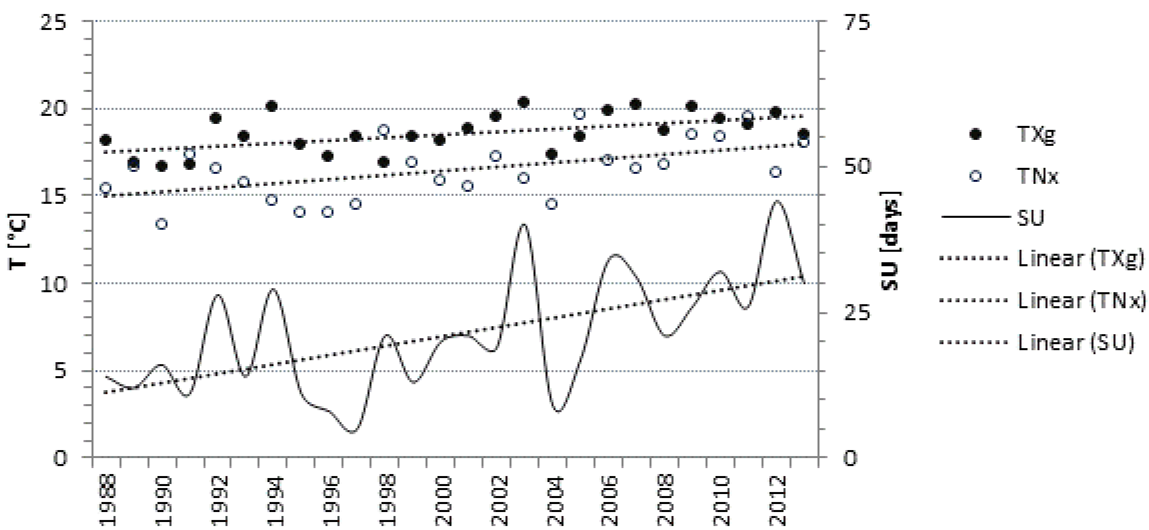


Fig. 2. Statistically significant increase of air temperature extremes (TXg, TNx) and number of summer days (SU) for GSL period at foothill location Stará Lesná during the years from 1988 to 2013.

Tab. 2. Selected ECA&D climate indices aggregated over the growing season length (GSL) at foothill location Stará Lesná (1988-2013)

ECA&D climate indices								**Abbr.**	**Unit**	
Precipitation of daily amount								RR	mm	
Wet days (criterion RR ≥1mm)								RR1	days	
Simple daily intensity index (mean precipitation amount at wet days)								SDII	mm/wet day	
Heavy precipitation days (criterion RR ≥10mm)								R10	days	
Very heavy precipitation days (criterion RR ≥20mm)								R20	days	
Highest 1-day precipitation amount								RX1	mm	
Highest 5-day precipitation amount								RX5	mm	
Maximum no of consecutive wet days (criterion RR ≥1mm)								CWD	days	
Maximum no of consecutive dry days (criterion RR <1mm)								CDD	days	
Mean of daily relative humidity								RHg	%	
Year	**RR**	**RR1**	**SDII**	**RR10**	**RR20**	**RX1**	**RX 5**	**CWD**	**CDD**	**RHg**
1988	461	58	8.0	15	5	37.8	64.3	5	19	74.9
1989	562	76	7.4	20	5	38.9	74.4	9	14	74.2
1990	576	72	8.0	21	4	45.4	95.0	6	12	75.0
1991	500	60	8.3	12	5	47.0	80.6	5	9	74.5
1992	366	47	7.8	9	4	50.5	56.6	3	15	70.3
1993	392	61	6.4	12	4	29.7	60.9	5	11	70.7
1994	338	53	6.4	12	1	24.5	33.9	3	13	69.5
1995	583	53	11.0	20	11	51.5	73.0	4	19	75.7
1996	658	80	8.2	21	7	66.1	126.8	5	10	76.7
1997	548	67	8.2	13	8	68.4	97.3	6	10	76.3
1998	590	88	6.7	19	5	30.1	47.1	10	10	78.3
1999	545	65	8.4	16	6	59.6	80.7	8	22	76.0
2000	560	73	7.7	17	8	39.2	71.6	4	13	76.0
2001	639	67	9.5	21	7	60.8	110.7	13	14	77.7
2002	634	67	9.5	18	7	88.1	138.7	8	18	78.2
2003	388	54	7.2	11	3	34.5	75.6	6	13	73.5
2004	652	79	8.3	24	3	62.6	77.6	7	14	79.9
2005	596	71	8.4	19	5	45.0	71.0	6	21	74.9
2006	476	74	6.4	13	4	30.1	70.2	8	19	73.7
2007	517	61	8.5	21	5	33.4	69.4	5	15	72.9
2008	529	61	8.7	17	8	35.4	84.4	6	8	76.8
2009	548	58	9.4	17	8	43.6	85.1	11	22	74.1
2010	744	75	9.9	25	8	44.8	90.7	11	10	79.6
2011	639	69	9.3	18	8	52.5	86.6	5	22	74.1
2012	477	70	6.8	15	4	23.9	53.8	7	9	75.3
2013	507	62	8.2	18	8	31.6	69.5	8	18	76.0
Summary statistics										
Avg	539	66	8.2	17	6	45.2	78.7	7	15	75.2

SDev	98.0	9.7	1.2	4	2	15.4	22.7	2.5	4.5	2.6
Min	338	47	6.4	9	1	23.9	33.9	3	8	69.5
Max	744	88	11.0	25	11	88.1	138.7	13	22	79.9
No statistically significant correlations between variables: Year and selected indices										

BIOCLIMATOLOGICAL CONDITIONS IN BRNO CITY AND BRNO REGION IN THREE DIFFERENT TIME „SLICES" – FROM MENDEL'S ERA TO PRESENT DAYS

MARIE DOLEŽELOVÁ[1]

[1]Czech Hydrometeorological Institute, regional Office Brno, Kroftova 43, 616 67 Brno, Czech Republic

ABSTRACT

Bioclimatological conditions in urban areas tend to be very specific and they are of high interest thanks to the huge density of settlement in such areas. The paper focuses on the analysis of bioclimatological conditions in Brno region representing currently the second largest concentration of urban population in the Czech Republic. It depicts the situation in three different time „slices" from Mendel's era (second half of the 19th century) when Brno had about 100 000 inhabitants to presents days with its nearly 400 000 inhabitants. These time „slices" are represented by the end of the 19th century (data measured at the station Brno-Pisárky, waterworks), the WMO normal period (1961–1990) and current period 1981–2013 (data measured at various CHMI's stations in Brno city and its surroundings). Comparative analysis of maximum temperatures, number of days with characteristic temperature and the occurrence and length of periods with low daily precipitation sums (dry periods) is performed.

Key words: hot spells, cold spells, dry spells, days with characteristic temperature, trend

INTRODUCTION

Brno is the second largest city of the Czech Republic located in its southeastern part on the „boundary" between hilly landscape of Bohemian-Moravian Highlands and rather flat sceneries of Southern Moravian lowlands. It has basin position with complex terrain characteristic by number of elevations and numerous partial basins. The landscape of Brno is very diverse. In the north and west part of Brno cadastral area we can experience hilly forested countryside in the proximity of Brno Dam Lake and nature reserve of the Moravian karst. While in the south and east we can observe rather flat landscape with strong historic touch of the ancient battlefield

(Battle of the Three Emperors). Brno region provides many beautiful natural sights, amazing cultural heritage and even rich university life. The question is whether it also offers favorable conditions for life. Does it have fresh air and pure water? And what are the bioclimatological conditions like?

Bioclimatological conditions are generally formed by several factors including air temperature and humidity, precipitation, wind speed or sunshine duration. All these together influence our feelings of warmth or chill, fatigue or vitality and so on. Sophisticated bioclimatological indices that make it possible to include numerous parameters and thus describe the real bioclimatological conditions in the most precise way were developped by the scientific community. However, with the regard to data availability, much more simple approach was used in this paper where bioclimatological conditions were evaluated with the help of extreme temperatures and precipitation only. Hot, cold and dry spells were studied as well.

It is not as sophisticated as using some other indices like Heat Index, Humidex, Wind Chill Temperature or Apparent Temperature (for more details see e.g. Novák, 2007 or Błażejczyk et al., 2012 that describe human feelings in better way), but it can be perceived as a first approximation of Brno bioclimatological conditions and their development in time. The usage of precipitation is motivated by the fact that :heat waves: combined with dry weather can lead to severe air pollution that can have negative influence on sensitive persons suffering from cardiovascular or respiratory diseases while the most problematic is pollution by particulate matter (see e.g. Urban, Kyselý, 2014).

MATERIALS AND METHODS

Daily maximum (Tmax) and minimum temperatures (Tmin) measured at several meteorological sites in the cadastral area of Brno were used to compute total number of summer days and tropical days (Tmax ≥ 25 °C or 30 °C) as well as ice days, arctic days (Tmax < 0 °C or -10 °C) and frost days (Tmin < 0 °C). Basic statistic characteristics (including trend) of number of all type of days with characteristic temperatures were computed. Cold spells were defined as the periods of consecutive days with Tmax < 0 °C, while hot spells were defined in the same way but with two different limit values of Tmax (Tmax ≥ 30 °C or 25 °C). Maximum length of both cold and hot spells was found for every year and analysed for trend. Due to its non-normal distribution nonparametric method was used for the trend analysis of these characteristics (Mann-Kendall trend test, Sen's method) Mann, 1945; Kendall, 1976; Sen, 1968). As we know, dry weather can make the effect of extreme temperatures on bioclimatological conditions and human health even worse (via air pollution). For this reason dry spells were studied as well. They were defined with the help of daily precipitation amounts as periods of consecutive days not reaching certain value (three different limits were used: 0,1 mm; 1,0 mm and 3,0 mm). The analysis of their annual maximum length was performed in the same way as for hot and cold spells.

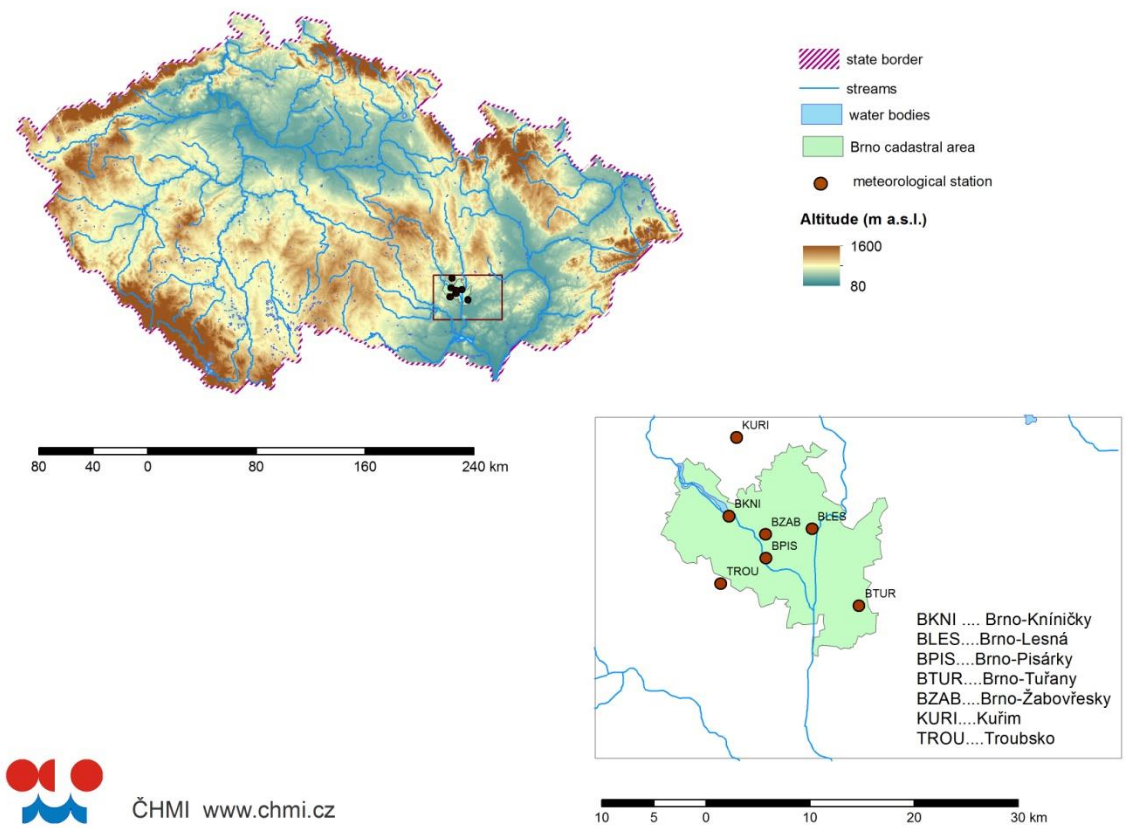


Fig. 1 Location of meteorological stations used in this study

All the analysis covered three different time periods: 1891−1921 (representing the climate in Brno just after the Mendel's era), 1961−1990 (representing „normal period" according to the WMO) and 1981−2013 (representing current climate). For the first period (1891−1921) only one meteorological station was available. This station was located in Brno-Pisárky (the city waterworks) and operated by waterworks employees. The measurements at this station represent the continuation of famous Mendel's measurements at Austin abbey conducted in the period 1878−1883 (the abbey is situated about 2 km far from the waterworks). The second period (1961−1990) is represented by the station in Brno-Tuřany situated at city airport. As far as daily precipitation amounts are concerned, data from three other meteorological stations are available: Brno-Kníničky (NW part of Brno cadastral area, located near Brno reservoir), Brno-Lesná (NE part of Brno cadastral area) and Kuřim (rural area, NW direction from Brno city). Current period (1981−2013) is represented by the data from Brno-Tuřany, Brno-Žabovřesky and Troubsko (temperature and precipitation) and Kuřim (only precipitation). Brno-Žabovřesky station is situated by CHMI's regional office in the urbanized area of NW part of Brno. Troubsko station is located outside of Brno cadastral area in SW direction. The position of all stations used in this study is shown in the figure 1.

RESULTS

Regarding the low temperatures, no significant differences can be seen between particular periods. The number of frost days is always higher compared to the ice days. Frost days occur from September to May and they are the most frequent in January (about 25 days on average). Average annual number ranges from 93 to 108. Ice days can be experienced from November to March. They occur the most often in January (about 12−13 days on average), with the average annual number ranging from 26 to 33. Being defined by the lowest limit value, the arctic days are the less abundant with the shortest period of occurrence (from December to February). Maximum in their annual course is in January just like in the case of frost and ice days. Difference can be seen in their annual average number that reaches the values varying in the order of tenth (see Tab. 1). The trend in number of days with characteristic temperature is rather insignificant with some exceptions including winter and annual values for ice and frost days in the period 1891−1920. Recent period (1981−2013) is characteristic by significant negative trend of April values for frost days. According to the number of days with characteristic temperatures the coldest periods were the first half of the 1890s and 1960s and also the mid-1980s (1985, 1986) and mid-1990s (1996). This corresponds with the results for cold spells that shows the maximum lengths in the above mentioned periods (see Tab. 2).

The conditions with high temperatures can be described by the occurrence of summer and tropical days. In contrast to the low temperature conditions, the differences between particular periods are obvious. Regarding the summer days, we can see that their average annual number gets higher when we go from the most ancient (1891−1920) to the recent (1981−2013) period with the values increasing from about 35 to 69 days per year. According to these average annual values, the highest number or summer days in the recent period shows urban station Brno-Žabovřesky. The occurrence at other stations that represents rather rural environment (margins of urban area) is slightly lower but still higher than in the previous periods (see Tab. 3). Summer days normally occur from April to October being the most frequent in July. Moreover, the latest period differs from both previous by significant positive trend of annual and summer values. Statistically significant trend appears at all stations also in June.

Nearly the same is true for tropical days that are logically less frequent compared to the summer days. Their average annual number more than quadrupled from 4 in the period 1891−1920 at Brno-Pisárky to 19 in the period 1981−2013 at the urban station at Brno-Žabovřesky. The occurrence of tropical days in the annual course is about 1-2 months shorter than for summer days and is restricted to the period from April (May) to September with the maximum frequency in the month of July. Recent period 1981−2013 is characteristic by statistically significant positive trend in number of tropical days for June, July, summer season and year as a whole. As a result of this positive trend, we can see statistically significant prolongation of hot spells defined either by the limit value of Tmax ≥ 25 °C or Tmax ≥ 30 °C (see Tab. 4). According to the number of days with characteristic temperatures and to the maximum length of hot spells, the hottest periods were the very beginning of the 1890^{s}, 1970^{s} and 1980^{s}. In the latest period, the longest hot spell appeared in most cases from the-mid July to mid-August 1994 (see Tab. 4). However, the overall number of summer or tropical days was highest in 2003 when urban station in Brno-Žabovřesky experienced 101 summer days and 42 tropical days.

Regarding the dry spells, we can observe that the average of their maximum annual length decreases as we increase the limit value of daily precipitation amount. Average maximum length of periods completely without precipitation (the limit value of daily precipitation amount is 0,1 mm) is about 17-18 days. When we set the limit value to 1,0 mm, it increases to 25-27 days. The duration of longest dry periods defined by the limit of 3,0 mm ranges from 38 to 47 days while the highest values were reached in the last studied period (see Tab. 5-7). According to the absolute maximum length of dry spells, dry period lasting from the early 1970^{s} to the beginning of second half of 1970^{s} can clearly be seen during the WMO normal period. Dry spell at various stations occurred in winter 1972/1973 lasting from early December to mid-January, in winter/spring 1974 (from the end of February to the first decade of May) and in winter/spring 1976 (from mid-February to mid-April). Two stations show the occurrence of the longest dry spell defined by limit value 1,0 mm at the turn of the year 1989 and 1990 (from last decade of December to first decade of February). In other cases dry period in these days appeared as well, but it was not as long as was the dry spell during the 1970^{s}. During the last studied period (1981−2013) the driest part appeared just close to its end, in the years 2010 and 2011. The period with daily precipitation amount below 3 mm lasted from mid-December 2010 to mid-March 2011. Apparently dry was the autumn 2011. Between the end of October and the beginning of December no precipitation was detected. The period completely without precipitation lasted from 28 days (Troubsko) to 37 days (Brno-Tuřany). However, the trend in the length of dry spells is rather insignificant. Significant trend can be observed in the last studied period in winter and especially in December reaching values from 1,8 day per 10 years in Brno-Tuřany to 3,3 days per 10 years in Troubsko (see Tab. 7).

Conclusions

Bioclimatological conditions in Brno, the second largest city of the Czech Republic, were studied. They were described with the help of temperature and precipitaiton characteristics including number of days with characteristic low and high temperatures (arctic, ice, frost, summer and tropical days), the length of cold and hot spells as well as the length of dry spells. To be able to detect the changes in the bioclimatological conditions in time, three different time „slices“ from after Mendel’s era to present days were used.

It comes from the obtained results, that the biggest changes are experienced in case of high temperatures and hot spells. In the recent period (1981−2013) number of summer and tropical days was slightly higher and the hot spells were longer compared to the preceding periods.

Statistically significant positive trend in number of summer and tropical days was found at all stations. This significant trend applied for year as a whole, as well as for summer season, the month of June (both types of days) and the month of July (only tropical days). The same positive tendency can be seen for the maximum length of hot spells. In the period 1981−2013 hot spells defined by the limit value 25 °C in the month of June prolonged from 2,1 days per decade in Brno-Tuřany to 2,9 days per decade in Brno-Žabovřesky. Hot spells defined by the limit value 30 °C prolonged from 1,4 days per decade in Brno-Tuřany to 1,8 days per decade in Troubsko in the summer season. The trends in both preceding periods were in the majority of cases statistically insignificant. It should be noted that the highest average number of both summer and tropical days and the biggest average and maximum length of hot spells showed urban station Brno-Žabovřesky.

In the last years, hot spells tend to occur together with the dry periods. Examples of this phenomenon can be seen in spring 2011, autumn 2011 or summer 2013. However, the trend of the maximum length of dry spells does not show systematic statistical significance even in the period 1981−2013. Their maximum annual length is on average slightly smaller in the period 1961−1990 while other two periods are comparable. Absolute maximum length of dry spells is for particular definition of the dry spells comparable between all studied periods.

Low temperature conditions and their extremes can have significant influence on mortality of elderly persons or people suffering from some chronic diseases. Regarding the parameters describing such conditions, not many differences between particular studied periods or statistically significant tendencies can be seen. The only exception is the occurrence of significant negative trend in the number of frost days in April reaching values around 1 day per decade in the recent period which corresponds with the tendency for “earlier” beginning of spring in the last years.

Generally, we can say that in the region of Southern Moravia that represents one of the warmest parts of the Czech Republic cold weather is not such a big problem as the warm weather. Last three decades are typical by the prolongation of hot spells and increasing number of characteristic days with high temperature. Hot spells are often accompanied by the shortage of precipitation that is evident in warm and cold part of the year, as well. However, the prolongation of maximum length of dry spells did not reach the statistical significance yet. This may result from changing character of precipitation in the urban environment. They occur more frequently in the form of torrential rains. Despite their short duration, such episodes interrupt long periods without precipitation.

REFERENCES

BŁAŻEJCZYK, K., EPSTEIN, Y., JENDRITZKY, G., STAIGER, H., TINZ, B., 2012: Comparison of UTCI to selected thermal indices. International Journal of Biometeorology, Vol. 56, p. 515–535. ISSN 1432-1254.

KENDALL, M.G., 1976: Rank correlation methods. 4.pub., Griffin, Londýn.

MANN, H.B., 1945: Nonparametric tests against trend. Econometrica, Vol. 13, p. 245–259.

NOVÁK, M., 2007: Problematika komplexních thw indexů a její řešení v biometeorologické předpovědi ČHMÚ. In Střelcová, K., Škvarenina, J., Blaženec, M. (eds.): BIOCLIMNATOLOGY AND NATURAL HAZARDS. International Scientific Conference. Połana nad Detvou, Slovakia, September 17-20, 2007. ISBN 978-80-228-17-60-8.

SEN, P.K., 1968: Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, Vol. 63, p. 1379−1389.

URBAN, A., KYSELÝ, J., 2014: Využití biometeorologických indexů pro hodnocení kardiovaskulární úmrtnosti a nemocnosti související se stresem z horka a chladu. Meteorologické Zprávy, 67, p. 6−12. ISSN 0026-1173.

SUMMARY

Článek se zabývá hodnocením bioklimatologických podmínek na území města Brna, které představuje druhou nejrozsáhlejší urbánní oblast v České republice (ČR). V katastru Brna se nacházejí zajímavá území chráněné přírody, město je významým centrem kulturního i univerzitního života. Otázkou je, zda svým obyvatelům nabízí kvalitní podmínky pro život i po jiných stránkách zahrnujících např. čistotu životního prostředí či bioklimatologické poměry.

Bioklimatologické podmínky lze hodnotit s pomocí speciálních indexů zohledňujících vlivy různých meteorologických prvků. Kromě teploty vzduchu, považované často za nejdůležitější ukazatel, se jedná o charakteristiky vlhkosti vzduchu a rychlost větru, které mají značný vliv na teplotu pocitovou, či o charakteristiky slunečního záření, které ovlivňuje tvorbu sekundárních znečištěnin v ovzduší.

Vzhledem k dostupnosti dat však byly užity pouze charakteristiky založené na maximální a minimální teplotě vzduchu a denních úhrnech srážek. Analýzy byly provedeny ve třech různých časových “řezech” zahrnujících přelom 19. a 20. století (1891−1920), normálové období Světové meteorologické organizace (1961−1990) a současné období reprezentované etapou 1981−2013. Pro všechna období byly stanoveny počty dní s charakteristickou teplotou vzduchu (letní, tropické, mrazové, ledové a arktické dny), výskyt tzv. horkých vln, studených vln a suchých period. Horká vlna byla definována jako období po sobě následujících (minimálně dvou) dní s maximální teplotou vzduchu větší nebo rovnou 30 °C, případně 25 °C (užity 2 různé definice). Studená vlna je obdobím po sobě jdoucích dní s maximální teplotou vzduchu pod 0 °C. Jako “suchá perioda” bylo označeno období, kdy denní srážkový úhrn nedosáhl hodnoty 0,1 mm, resp. 1,0 mm či 3,0 mm (3 různé limitní hodnoty).

Byly stanoveny počty dní s charakteristickou teplotou vzduchu, jejich roční chod a trend a trend maximálních ročních délek horkých a studených vln a suchých period. Vzhledem k charakteru analyzovaných časových řad byly pro určení velikosti trendu a hodnocení jeho statistické významnosti aplikovány neparametrické metody (Senova metoda, Mann-Kendallův test). Pro každé ze studovaných období byl k dispozici jiný počet stanic (1891−1920: 1 klimatologická stanice, 1961−1990: 1 klimatologická a 3 srážkoměrné stanice, 1981−2013: 3 klimatologické a 1 srážkoměrná stanice).

Z dosažených výsledků vyplývá, že největší změny v čase se týkají podmínek s vysokou teplotou vzduchu. V posledním studovaném období došlo ke zvýšení počtu letních i tropických dní a byl detekován statisticky významný trend pro rok, letní sezonu, červen a červenec. Dále se projevilo statisticky významné prodloužení maximální délky horkých vln.

V posledních letech bylo na jižní Moravě extrémně teplé počasí často doprovázeno výskytem nízkých srážkových úhrnů (např. roky 2011 a 2013), což může být z bioklimatologického hlediska nebezpečné kvůli akumulaci znečištěnin. Statistická významnost trendu maximální délky suchých period však potvrzena nebyla.

Charakteristiky založené na nízké teplotě vzduchu nevykazují významný trend ani výrazné změny mezi jednotlivými obdobími. Výjimku představuje pouze počet mrazových dní, u nehož byl v posledním studovaném období detekován významný klesající trend na jaře. Je patrné, že z bioklimatologického hlediska v regionu jižní Moravy, který patří k nejteplejším oblastem ČR, nepředstavuje chladné počasí či výskyt studených vln tak výrazný problém jako počasí extrémně teplé.

CONTACT

Ing. Mgr. Marie Doleželová, Ph.D.

Czech Hydrometeorological Institute, Regional Office Brno

Kroftova 43, 616 67 Brno

+420 541 421 034, marie.dolezelova@chmi.cz

Tab. 1 Basic statistics and trends of days with characteristic low temperatures in 3 different periods

1891–1920					
Station / characteristic	**Occurrence**	**Max.average monthly number, month of occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BPIS- arctic days	XII-I	0,37 (I)	0,47	3 (1893)	–
BPIS- ice days	XI-III	12,87 (I)	29,33	57 (1895)	-0,30 (XII), -0,81(year), -0,64 (DJF)
BPIS- frost days	IX-V	25,83 (I)	107,47	131 (1891)	-0,19 (I), -0,17(II), -0,19 (XII), -0,80 (year), -0,50 (DJF)
1961–1990					
Station / characteristic	**Occurrence**	**Max.average monthly number, month of occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BTUR- arctic days	XII-II	0,47 (I)	0,70	7 (1985)	–
BTUR- ice days	XI-III	13,53 (I)	32,60	70 (1963)	–
BTUR- frost days	IX-V	26,03 (I)	104,23	135 (1965)	-0,29 (XII)
1981–2013					
Station / characteristic	**Occurrence**	**Max.average monthly number, month of occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BTUR- arctic days	XII-II	0,42 (I)	0,61	7 (1985)	–
BTUR- ice days	XI-III	12,15 (I)	31,06	58 (1996)	–
BTUR- frost days	X-V	24,18 (I)	99,49	129 (1996)	-0,10 (IV)
BZAB- arctic days	XII-II	0,27 (I)	0,33	7 (1985)	–
B ZAB- ice days	XI-III	10,70 (I)	25,94	49 (1986)	–
BZAB- frost days	X-V	23,73 (I)	93,90	121 (1996)	-0,11 (IV)
TROU- arctic days	XII-II	0,27 (I)	0,31	6 (1985)	–
TROU - ice days	XI-III	11,64 (I)	29,09	57 (1996)	–
TROU - frost days	X-V	25,00 (I)	107,94	126 (1986)	-0,12 (IV)

Tab. 2 Basic statistics and trends of length of cold spells in 3 different periods

1891–1920			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BPIS	10,83	33 (23.12. 1892 – 24.1. 1893)	-0,09 (II), -0,18 (XII)
1961–1990			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BTUR	11,93	33 (8.1.– 9.2. 1963)	–
1981–2013			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BTUR	11,00	31 (21.12. 1996 –20.1. 1997)	–
BZAB	8,91	29 (24.12.1984 – 21.1. 1985)	–
TROU	9,79	28 (25.12.1984 – 21.1. 1985)	–

Tab.3 Basic statistics and trends of days with characteristic high temperatures in 3 different periods

1891–1920					
Station / characteristic	**Occurrence**	**Max.average monthly number, month of occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BPIS - summer days	IV-X	11,47 (VII)	35,30	73 (1917)	–
BPIS- tropical days	V-IX	1,80 (VII)	4,17	15 (1892)	–
1961–1990					
Station / characteristic	**Occurrence**	**Max.average monthly number, month of occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BTUR-summer days	IV-X	14,97 (VII)	46,53	74 (1983)	–
BTUR- tropical days	VI-IX	6,20 (VII)	7,30	18 (1971)	–
1981–2013					
Station / characteristic	**Occurrence**	**Max.average monthly number, monthof occurrence**	**Average annual number**	**Absolute annual max, year of occurrence**	**Significant trend** (days / year)
BTUR-summer days	IV-X	17,76 (VIII)	55,12	81 (2003)	0,20 (VI), 0,49 (year), 0,34 (JJA)
BTUR- tropical days	V-IX	5,42 (VII)	11,97	28 (1994)	0,15 (VI), 0,18 (VII), 0,32 (year), 0,31 (JJA)
BZAB- summer days	IV-X	20,88 (VII)	69,15	101 (2003)	0,25 (VI), 0,16 (VIII), 0,82 (year), 0,25 (MAM), 0,50 (JJA)
BZAB- tropical days	IV-IX	7,85 (VII)	19,24	42 (2003)	0,16 (VI), 0,25 (VII), 0,55 (year), 0,50 (JJA)
TROU-summer days	IV-X	18,39 (VII)	58,12	89 (2003)	0,17 (V), 0,25 (VI), 0,83 (year), 0,17 (MAM), 0,46 (JJA)
TROU- tropical days	IV-IX	5,85 (VII)	13,03	36 (2003)	0,08 (VI), 0,25 (VII), 0,49 (year), 0,44 (JJA)

Tab. 4 Basic statistics and trends of length of hot spells in 3 different periods (hot spells are defined by 2 limit values of Tmax: 25 °C and 30 °C)

1891–1920			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BPIS (25°C)	7,90	14 (30.7. – 12.8.1904, 18.7. – 31.7. 1911, 2.8. – 15.8. 1911)	–
BPIS (30°C)	2,03	11 (15.8. – 25.8. 1892)	–
1961–1990			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BTUR (25 °C)	11,03	20 (23.7. – 11.8. 1971)	-0,11 (VI)
BTUR (30 °C)	2,73	6 (16.7. – 21.7. 1972)	–
1981–2013			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BTUR (25 °C)	13,58	32 (11.7. – 11.8. 1994)	0,21 (VI)
BTUR (30 °C)	4,52	17 (22.7. – 7.8. 1994)	0,08 (VII), 0,14 (year), 0,14 (JJA)
BZAB (25°C)	17,18	39 (6.7. – 13.8. 1995)	0,29 (VI)
BZAB (30°C)	5,88	19 (21.7. – 8.8. 1994)	0,13 (VI), 0,17 (year), 0,17 (JJA)
TROU (25 °C)	13,42	32 (11.7. – 11.8. 1994)	0,25 (VI), 0,21 (year), 0,21 (JJA)
TROU (30 °C)	4,82	17 (22.7. – 7.8. 1994)	0,12 (VII), 0,18 (year), 0,18 (JJA)

Tab. 5 Basic statistics and trends of length of dry spells in the period 1891–1920 *(dry spells are defined by 3 limit values of daily precipitation amount: 0,1 mm; 1,0 mm a 3,0 mm)*

1891–1920			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BPIS (0,1 mm)	18,70	41 (18.10. – 27.11. 1920)	+0,08 (VI), -0,14 (IX)
BPIS (1,0 mm)	28,63	50 (12.2. – 2.4. 1899)	–
BPIS (3,0 mm)	44,83	90 (24.8. – 21.11. 1891)	–

Tab. 6 Basic statistics and trends of length of dry spells in the period 1961–1990 (dry spells are defined by 3 limit values of daily precipitation amount: 0,1 mm; 1,0 mm a 3,0 mm)

1961–1990			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BKNI (0,1 mm)	16,57	29 (17.2. – 16.3. 1976)	–
BKNI (1,0 mm)	25,37	44 (6.12. 1972 –18.1. 1973)	–
BKNI (3,0 mm)	40,47	81 (20.2. – 11.5. 1974)	–
BLES (0,1 mm)	18,00	34 (13.12. 1972 – 15.1. 1973)	–
BLES (1,0 mm)	27,13	65 (16.2. –20.4. 1976)	–
BLES (3,0 mm)	41,43	75 (28.11. 1963– 10.2. 1964)	-0,44 (IX)
BTUR (0,1 mm)	17,97	39 (8.12. 1972 – 15.1. 1973)	0,14 (V); -0,11 (VI)
BTUR (1,0 mm)	27,60	49 (24.12. 1989 – 10.2. 1990)	–
BTUR (3,0 mm)	41,90	81 (20.2. – 11.5. 1974)	–
KURI (0,1 mm)	18,03	33 (19.3. – 20. 4. 1974)	0,13 (V)
KURI (1,0 mm)	26,33	50 (23.12. 1989 – 10.2. 1990)	0,33 (X)
KURI (3,0 mm)	38,47	69 (16.9. – 23.11. 1969)	–

***Tab. 7 Basic statistics and trends of length of dry spells in the period 1981–2013** (dry spells are defined by 3 limit values of daily precipitation amount: 0,1 mm; 1,0 mm a 3,0 mm)*

1981–2013			
Station	**Average annual max** (days)	**Absolute max** (days)	**Significant trend** (days / year)
BTUR (0,1 mm)	18,00	37 (27.10. – 2.12. 2011)	–
BTUR (1,0 mm)	28,30	49 (24.12. 1989 – 10.2. 1990)	0,18 (XII) ; -0,25 (year)
BTUR (3,0 mm)	43,42	86 (11.11. 1998 – 4.2. 1999; 21.12. 1997 – 16.3. 1998)	–
BZAB (0,1 mm)	18,27	35 (27.10. – 30.11. 2011)	–
BZAB (1,0 mm)	26,42	50 (23.12. 1989 – 10.2. 1990)	–
BZAB (3,0 mm)	44,06	93 (13.12. 2010 – 15.3. 2011)	–
KURI (0,1 mm)	18,15	36 (27.10. – 1.12. 2011)	0,16 (III); -0,11 (XI)
KURI (1,0 mm)	27,55	50 (23.12. 1989 – 10.2. 1990)	-0,30 (II); -0,25 (III); 0,14 (VI); -0,13 (VII); 0,15 (XII)
KURI (3,0 mm)	40,42	85 (21.12. 2010 –15.3. 2011)	-0,33 (X)
TROU (0,1 mm)	17,94	28 (5.11. – 2.12. 2011)	0,14 (XII); 0,18 (DJF)
TROU (1,0 mm)	26,30	42 (6.4. – 17.5. 2000)	0,33 (XII)
TROU (3,0 mm)	46,49	86 (11.11. 1998 – 4.2. 1999)	–

METHODS OF EROSION RESEARCH INDUCED BY OCCURRENCE OF STRONG WIND

JANA KOZLOVSKY DUFKOVÁ[1], LENKA LACKÓOVÁ[2]

1) *Mendel University in Brno*
2) *Slovak University of Agriculture in Nitra*

ABSTRACT

Wind is the most important factor for progress of wind erosion. Generally erosion research is quite difficult process, because it is discontinuous and it is difficult to monitor directly the erosive process. Hence, even impacts of erosion are explored – whether eroded soils or removed soil particles and substances fixed on them. Nowadays, wind erosion research is upgraded with new methods by which means it is possible to explore the wind erosion effectively. On the base of listing of deflametric methods of wind erosion research, a new-developed method is described.

Key words: deflameter, saltation, suspension

INTRODUCTION

Wind erosion research is focused on many factors influencing the formation and process of wind erosion. Atmospheric conditions (e.g. wind, precipitation and temperature), soil properties (e.g. soil texture, composition, and aggregation), land-surface characteristics (e.g. topography, moisture, aerodynamic roughness length, vegetation and non-erodible elements) or land-use practices (e.g. farming, grazing and mining) are studied.

Soil erosion data are generated through field experiments or in simulated conditions in laboratory. In practice, the results of experiments are used in erosion control. Field experiments are also used for verification of efficiency of erosion control measures.

MATERIALS AND METHODS

The success of measures taken against wind erosion of soil may be monitored by volumetric, pedological, morphometric, photogrammetric and historical, as well as by nivelation and vegetation growth methods. Besides these, wind erosion may be investigated using of number specific deflametric methods which focus mainly on the exact determination of the properties of deflates, i.e. particles carried by the wind. By analyzing eroded and blown soil with respect to granulation, structure, and nutrient content, the effect on wind erosion on the soil may be established. These methods may be divided more or less into field or laboratory methods.

The most important data to be obtained on a terrain concerns the quantity and quality of particles carried by the wind under different conditions, and at different heights above ground. Quantitative data on removal are required for determining the intensity of wind erosion and its relationship with other factors and conditions. Qualitative data are required for assessing the selective effect on the soil.

Accurate and reliable methods of measuring windblown sediment are needed to confirm, validate, and improve erosion models, assess the intensity of aeolian processes and related damage, determine the source of pollutants, and for other applications. The type of sampling apparatus and methods used in wind erosion field studies depend upon the specific objectives of the study (Zobeck et al., 2003).

Deflametric methods are the common used research methods for determination of amount of soil blowing by wind. Many samplers have been developed for measuring the material transported by wind. Aeolian sand samplers fall into two broad groups, those with horizontal sampling orifices and those with vertical sampling orifices. Samplers can be classified as either passive or active according to the way in which the air inside the sampler is exhausted. Passive samplers are more popular because they are easy to use and relatively inexpensive. Aeolian sand samplers can be stationary or rotating – the stationary samplers that are usually used in a wind tunnel are always oriented to a single direction, while the rotating samplers that are needed in field measurements are able to change their direction in response to the wind direction. Samplers can be designed as integrating samplers that collect aeolian sediment flux within a relatively greater layer or single-point samplers that collect sediment flux passing a small area (point). The integrated samplers can be either single-slot samplers or segmented samplers. The segmented samplers can collect the sediment flux at different positions respectively and are useful in studying flux profiles.

In later studies of wind erosion, Bagnold (1943) used a slotted collector with an opening 1,25 cm wide and 76 cm high to measure saltating grains and a buried ground trap to measure surface creep (Fig. 1).

Fig. 1 Bagnold collector (www.sensit.com)

The Cox sand catcher is adjusted to a height of 15 cm and have an opening at the top 1,5 cm wide (Fig. 2). As wind driven sand enters the sand catcher, the wind becomes obstructed by the vertical wall of the sand catcher, causing the sand particle to fall into the collection tube. This omni-directional catcher was designed by Bill Cox (www.sensit.com).

Fig. 2 Cox sand catcher (www.sensit.com)

Modified Wilson and Cook (MWAC – Fig. 3, Wilson et Cooke, 1980) and Big Spring Number Eight (BSNE – Fig. 4, Fryrear, 1986) samplers are used for sampling material at different heights in order to calculate the total mass transport associated to soil losses by wind erosion. The sampling efficiency of both traps depends on wind speed and particle sizes. Sampling efficiency of the MWAC remains constant but BSNE's efficiency decreases with wind speed, due to the higher stagnation pressure in the BSNE at higher wind speeds (Goossens, 2004). The stagnation pressure effect is higher for small particles, because they have lesser inertia and response time to changes in the air flow.

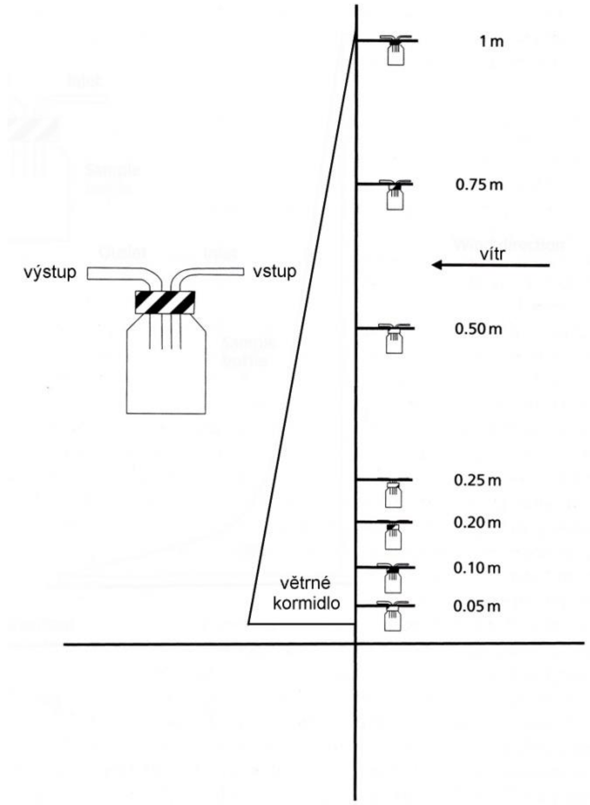


Fig. 3 Modified Wilson and Cook sampler (Toy et Foster, 2002)

Fig. 4 Big Spring Number Eight sampler (Zobeck et al., 2003)

Gillette et Stockton (1986) developed the Sensit (Fig. 5), which is a piezoelectric device that produces a signal upon impact of saltating soil particles. It has been used both in the open field and in wind tunnels. The instrument has proven useful for the determination of the threshold friction velocity at which erosion by wind starts.

Fig. 5 Sensit (www.sensit.com)

The Surface Creep Saltation sampler (Fig. 6) is a wind aspirated isokinetic sampler that samples airborne dust at the soil surface. The sampler is buried with the vertical sampling slot, the air exhaust, and the tail exposed to wind. Surface Creep Saltation sampler collects a sample of dust moving over the soil surface at heights of 3 mm, from 3 to 10 mm, and from 10 to 20 mm. Samples are collected in a divided canister with separate compartments for each height. These samplers operate at peak performance on a flat smooth soil surface (Stout et Fryrear, 1989).

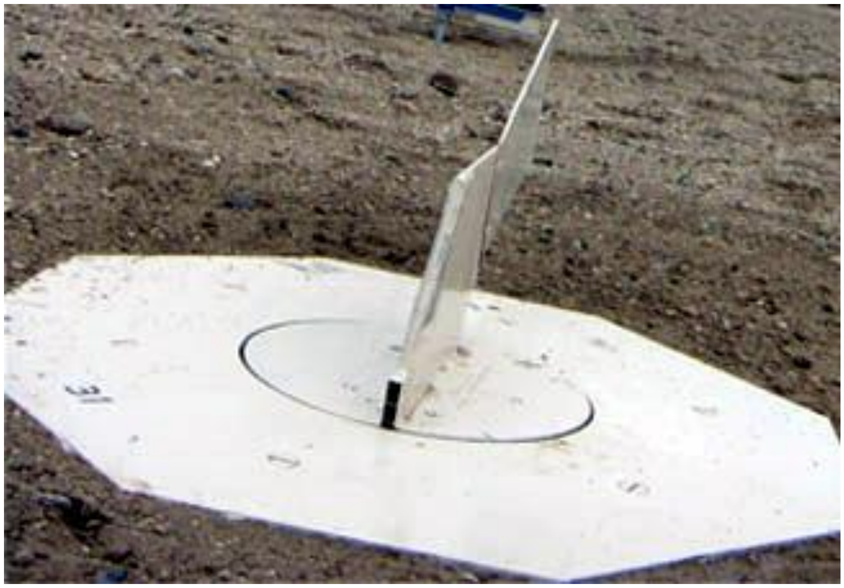


Fig. 6 Surface Creep Saltation sampler (www.fryreardustsamplers.com)

Saltiphon (Fig. 7) is a sensor for measuring the wind erosion according to the acoustic measuring principle. Dusted grains are counted and the digital output signal is registered by a datalogger (Goudie et al., 1999).

Fig. 7 Saltiphon (www.eijkelkamp.com)

The WITSEG sampler is a vertically integrating, passive type that follows an earlier design by Bagnold (1943) (Fig. 8). The WITSEG sampler is designed to measure the flux profile of blowing sand The cross-sectional area of the working section of the wind tunnel is 1,2×1,2 m (Dong et al., 2004).

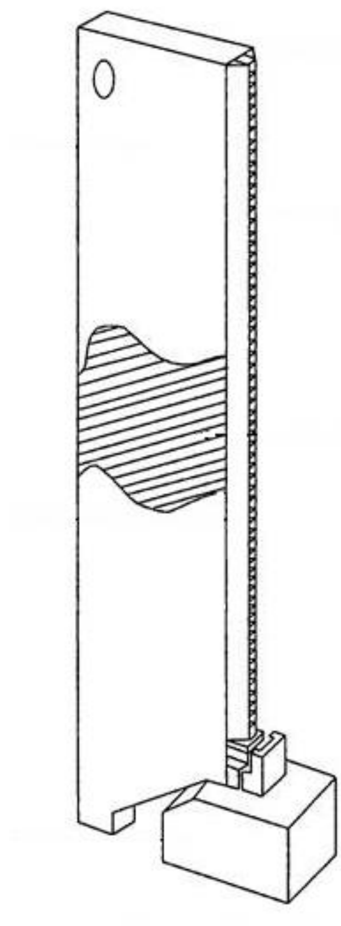


Fig. 8 WITSEG sampler (Dong et al., 2004)

Deflameter with active trap soil particles and time recording (Fig. 9) allows monitor the qualitative and quantitative properties including time recording of macroscopic and microscopic soil particles, carried by the wind. The term of the particle transport can be designated by deflameter. Also the number of soil particles is possibly to quantify and determine the size of it (Středová et al., 2012).

Fig. 9 Deflameter with active trap soil particles and time recording (Krmelová et al., 2012)

Soil particle catcher devices were developed to trap soil particles (Lackóová et al., 2013). With these devices it is able to measure the intensity of wind erosion at six different heights above the soil surface in one location (Fig. 10) or at three different heights in two places. It is possible to use them for six different places at the same time as well. The entrance hole through which the moving particles are trapped in the device has a dimension of 5x5 cm.

Fig. 10 Soil particle catcher devices (Lackóová et al., 2013)

On the basis of comparison of different measuring methods of the material transported by wind, new soil particle samplers called DEF1 and DEF1 were developed. They are described in the next part of the paper.

RESULTS AND DISCUSSION

Deflameter DEF1 (Fig. 11) is intended for soil particles trapping at the heights of 0,5, 1,0 and 1,5 m above the ground. Deflameter DEF2 (Fig. 12) catches soil particles at the height from 0,15 to 0,30 m, depended on the depth of deflameter fitting in the ground. Plastic laboratory bottles with volume of 1 l are used for soil particles collecting. Bottles have an entrance opening in the front of their body and are placed at the supporting arms. Anti-blowing sloping sieve is installed into each bottle to prevent trapped soil particles blow out the bottle. Plastic wing fixed on the back of the bottle enables turning of the bottle with its entrance opening against prevailing wind direction.

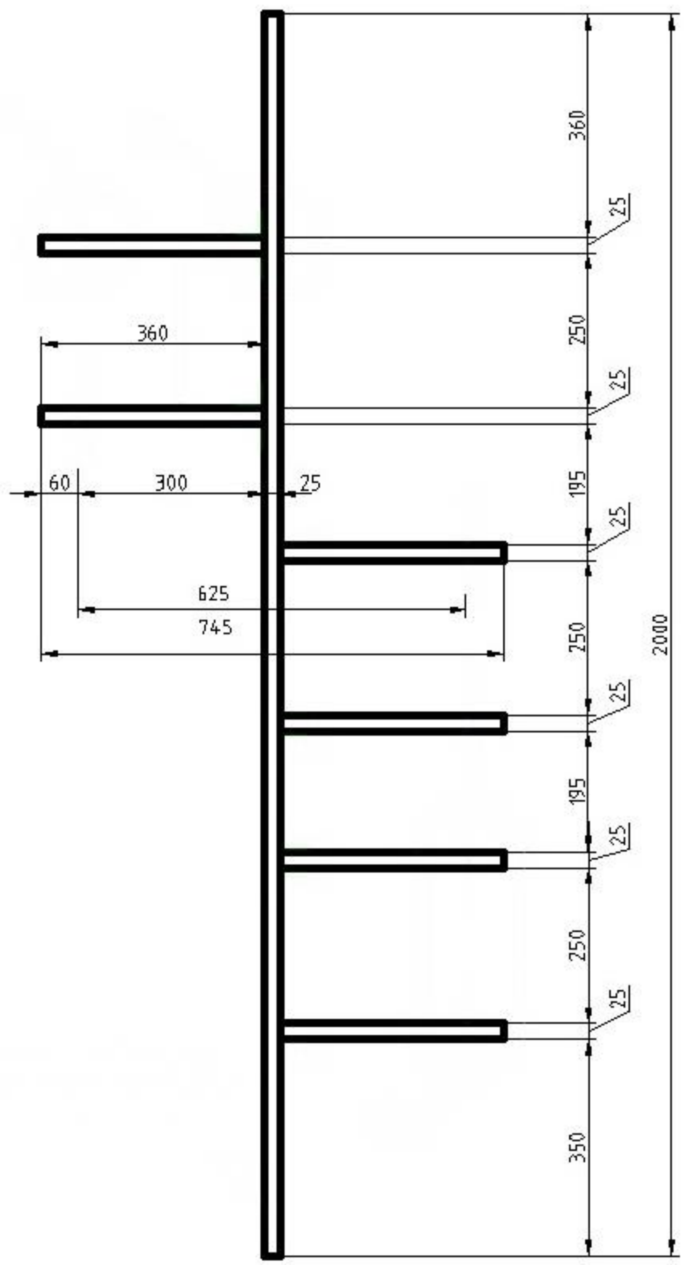


Fig. 11 General view of DEF1

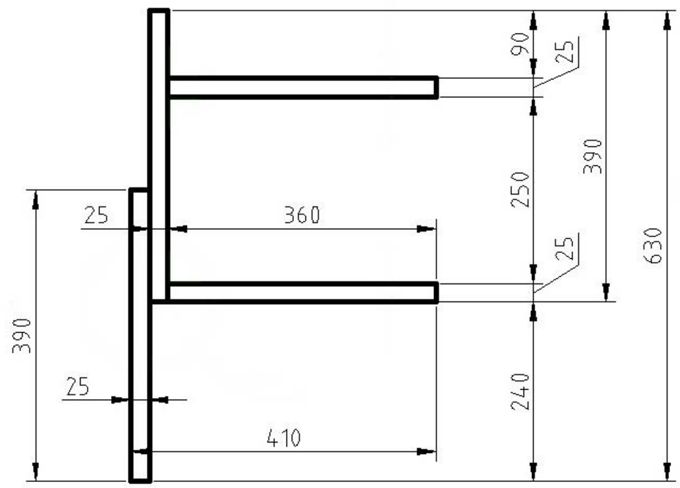


Fig. 12 General view of DEF2

Both types of deflameters were tested on light soils of Southern Moravia, Czech Republic – in Jevišovka (site A) and Hustopeče (site B). Soil particles trapped in the bottles of the deflameters were subject of analysis. They were washed out of bottles on filter paper using distilled water and drying they were weighed.

Comparison of the amount of deflates from four heights of sites A and B for the period March to June 2013 is shown in Fig. 13. Site A has considerably lesser amount of trapped deflates than site B has. The reason is probably thicker vegetative cover (winter wheat) near deflameter that protected soil surface against wind effect.

New-developed deflameters have proven their efficiency. The most deflates were found in the lowest bottle, the least deflates in the highest one. Significant percentage of eroded soil particles (50–80 % of loose soil in total) moves by saltation, i.e. jumps when blown by wind up to height of 30 cm above the surface (Tatarko, 2001).

The question is how to evaluate the amount of trapped deflates per unit of area. Various research works suggest the same essentially – arrange more deflameters in network structure at enclosed experimental site (e.g. Fryrear, 1986; van Donk et Skidmore, 2003; Zobeck et al., 2003; Funk et al., 2004; Sterk et Goossens, 2007; Stout, 2007). However, they do not solve the problem how to prove that trapped soil particles do not come in from another area. This could happened in case of very fine soil particles (< 50 µm) that move by suspension when they are blown high into the air. Actually, these fine particles are blown out hundreds and thousands kilometres from source of erosion. For that reason, any demarcation of experimental site has no function (e.g. sand from Sahara desert blown to Southern Moravia).

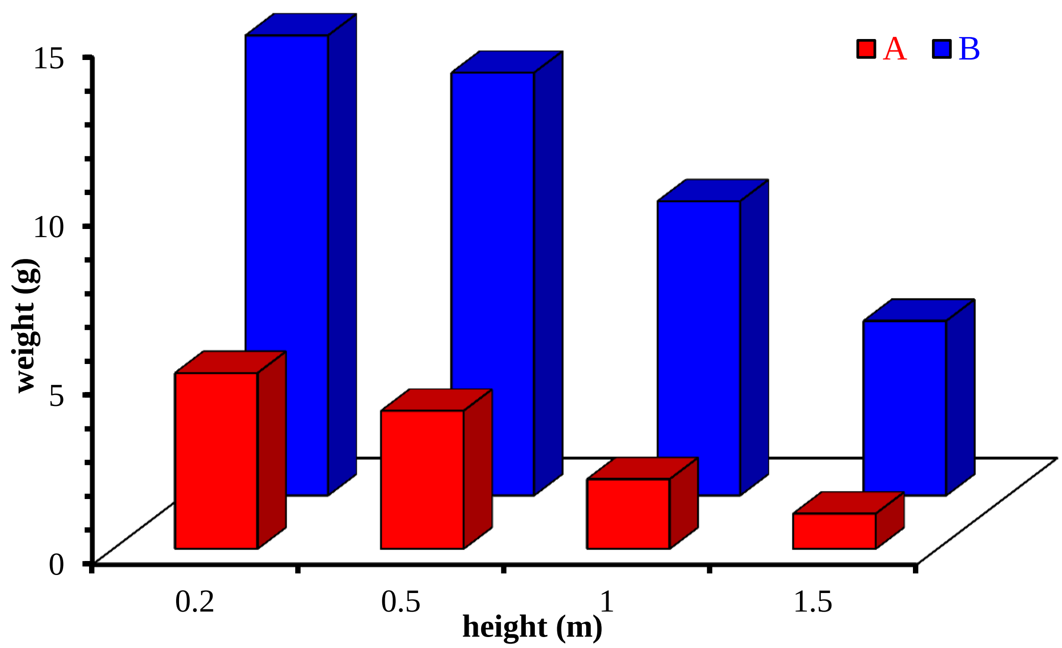


Fig. 13 Amount of deflates trapped by deflameters in various heights from sites Jevišovka (A) and Hustopeče (B)

CONCLUSION

New types of deflameters were developed and they proved their efficiency. Deflameters are able to catch wind-blown soil particles, however it is not possible to make their quantification per unit of area, as they are trapped in the open (non-bordered) space.

Field deflametric methods of wind erosion research are usually used for validation of wind erosion models or verification of wind erosion intensity calculation on the basis of equations. Others research works (e.g. van Donk et Skidmore, 2003; Funk et al., 2004; Skidmore et al., 2006; Buschiazzo et Zobeck, 2008) describe this in detail.

References

Bagnold R.A., 1943. Physics of blown sand and desert dunes. New York: William Morrow & Co.

Buschiazzo D.E., Zobeck T.M., 2008. Validation of WEQ, RWEQ and WEPS wind erosion for different arable land management systems in the Argentinean Pampas. Earth Surface Processes and Landforms 33:1839–1850.

Dong Z., Sun H., Zhao A., 2004. WITSEG sampler: a segmented sand sampler for wind tunnel test. Geomorphology 59:119–129.

Fryrear D.W., 1986. A field dust sampler. Journal of Soil and Water Conservation 41(2):117–120.

Funk R., Skidmore E.L., Hagen L.J., 2004. Comparison of wind erosion measurements in

Germany with simulated soil losses by WEPS. Environmental Modelling & Software 19:177–183.

Gillette D.A., Stockton 1986. Mass momentum and kinetic energy fluxes of saltating particles. .C. Nickling (ed): Aeolian Geomorphology, pp. 36–56.

Goossens D., 2004. Effect of soil crusting on the emission and transport of wind-eroded sediment: field measurements on loamy sandy soil. Geomorphology 58:145–160.

Goudie A.S., Livingstone I., Stokes S., 1999. Aeolian environments, sediments and landforms. John Wiley & Sons, Chichester, 325 p. ISBN 0-471-98573-2.

Krmelová P., Toman F., Středová H., 2012. Spektrální analýza deflametrických záznamů z obodbí výskytu erozně nebezpečných větrů. In MendelNet 2012, Proceedings of International Ph.D. Students Conference, s. 440–448. ISBN 978-80-7375-656-7.

Lackóová L, Halászová K., Kliment M., Urban T., 2013. Wind erosion intensity determination using soil particle catcher devices. Journal of Central European Agriculture 14(4):1364–1372. ISSN 1332-9049.

Skidmore E.L., Liao C., van Donk S., 2006. Simulation of wind speed and direction from limited data. In 14th ISCO conference on Water Management and Soil Conservation in Semi-Arid Environments (proceedings [CD-Rom]). Marrakech: International Soil Conservation Organization, 14.–19.5.2006. ISBN 9954-0-66653-5.

Sterk G., Goossens D., 2007. Emissions of soil dust and related problems in Europe: an overview. In: international conference DustConf 2007: How to improve air quality. 23.–24.04.2007, Maastricht, the Netherlands.

Stout J.E., Fryrear D.W., 1989. Performance of a windblown-particle sampler. Transactions of the American Society of Agricultural Engineers 32(6):2041–2045.

Stout J.E., 2007. Simultaneous observations of the critical aeolian threshold of two surfaces. Geomorphology 85:3–16.

Středová H., Podhrázská J., Středa T., 2012. Deflametr s aktivním lapačem půdních částic a časovým záznamem. Užitný vzor č. 23733, Úřad průmyslového vlastnictví ČR.

Tatarko J., 2001. Soil aggregation and wind erosion: processes and measurements. Annals of Arid Zone 40(3):251–263. ISSN 0570-1791.

Toy T.J., Foster G.R., 2002. Soil erosion: processes, predicition, measurement, and control. New York: John Wiley & Sons, 338 p. ISBN 0-471-38369-4.

van Donk S.J., Skidmore E.L., 2003. Measurement and simulation of wind erosion, roughness degradation and residue decomposition on an agricultural field. Earth Surface Processes and Landforms 28:1243–1258.

Wilson S.J., Cooke R.U., 1980. Wind erosion. In Kirkby M.J, Morgan R.P.C. (ed): Soil erosion. Chichester: John Wiley & Sons, pp. 217–251.

www.eijkelkamp.com URL: <http://en.eijkelkamp.com/products> [cit. 2014-06-28]

www.fryreardustsamplers.com URL: <http://www.fryreardustsamplers.com> [cit. 2014-06-28]

www.sensit.com URL: <http://www.sensit.com> [cit. 2014-06-28]

Zobeck T.M., Sterk G., Funk R., Rajot J.L., Stout J.E., van Pelt S., 2003. Measurement and data analysis methods for field-scale wind erosion studies and model validation. Earth Surface Processes and Landforms 28:1163–1188.

Acknowledgement

Supported by the Ministry of Agriculture of the Czech Republic, project No. MZE QH82099 “Criteria of wind erosion expansion on heavy clay soils and possibilities of its limitation with biotechnological control measures“.

Summary

Vítr je nejdůležitější klimatický faktor pro rozvoj procesů větrné eroze. Působí na povrch půdy svou kinetickou energií, kterou uvolňuje a uvádí do pohybu a jinde opět ukládá jednotlivé

částice půdy vlivem síly vzdušného proudu. Výzkum eroze obecně je docela složitý proces, eroze je totiž jev přerušovaný a těžko se podaří sledovat přímo erozní děj. Z tohoto důvodu se zkoumají až následky eroze, ať již samotné erodované půdy nebo z nich odstraněná zemina a na ni se vážící látky. Výzkum větrné eroze je v dnešní době obohacován o stále nové metody, pomocí nichž lze větrnou erozi zkoumat efektivněji. Příspěvek uvádí výčet deflametrických metod sloužících k výzkumu větrné eroze. Na jejich základě byl vytvořen nový typ deflametru, který byl testován na lehkých půdách lokalit Hustopeče a Jevišovka. Deflametr se prokázal jako funkční – je schopen odchytit větrem odnášené půdní částice, nelze však provést jejich kvantifikaci na jednotku plochy, protože k odchytu půdních částic dochází v otevřeném prostoru.

CONTACT

Ing. Jana Kozlovsky Dufková, Ph.D.

Department of Applied and Landscape Ecology, Mendel University in Brno

Zemědělská 1, 613 00 Brno

tel. +420 545 132 472, janadufkova@email.cz

The positive effect of extreme weather: the new localities of selected endangered plant species found during extremely moist year 2010

Mariana Eliašová[1], PavolEliáš, jun.[2], Veronika Zuzulová[1], Bernard Šiška[1]

1) *Department of Ecology, Faculty of European Studies and Regional Development, Slovak University of Agriculture in Nitra, Slovakia*
2) *Department of Botany, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Slovakia*

Abstract

The saline soils area covered by specific halophytic vegetation was radically decreased during last few decades. The temporary pools in arable fields may provide the environmental conditions favourable for some rare plant species. The year 2010 was defined as extremely moist; and rainy weather favoured the frequency and range of inundated field depressions occurrence in Podunajská nížina Lowland. During field mapping and vegetation inventory, the occurrence of one endangered species (EN) *Cirsium brachycephalum*, five critically endangered (CR) species (*Heleochloa alopecuroides*, *H. schoenoides*, *Lindernia tribracteatum*, *Schoenoplectus supinus* and *Lythrum tribracteatum*) and one potentially extinct species (EX?) *Chenopodium chenopodioides* were recorded. The conservation value of the temporary pools in agricultural field is discussed in terms of long-term survival of the species in cultural landscape.

Key words: field depressions, halophyte, endangered plants, Podunajská nížina Lowland

Introduction

Saline soils belong to hydromorphic soils which are strongly influenced by intensive water evaporation and the salt dynamics of ground water is the most important factor in their formation (Boros, 2003). In Slovakia saline soils covered by halophytic plant communities are distributed in warm and dry lowland regions; the largest area of saline soils area were concentrated in Podunajská nížina Lowland, lesser in Východoslovenská nížina Lowland (Krist, 1940; Krippelová, 1965). The areas of saline soils have all been markedly reduced during last few decades in Slovakia due to human activities. For instance, Osvačilová & Svobodová (1961) mentioned approximately 8300 ha of soil with saline vegetation in Podunajská nížina Lowland but contemporary, only about 500 ha have been re-discovered there (Sádovský et al., 2004). As a consequence, the typical halophytic plant species belongs to the most threatened plant species in Slovakia now. Plant communities of periodically flooded saline habitats represent unique initial stages plant succession. Typical dominants of these habitats are annual saline grasses, as *H. alopecuroides*, *H. schoenoides* or *S. supinus* (Holub, Grulich, 1999b, c; Holub, 1999b). The formation of these plant communities is closely associated with annual water level decrease and we can usually find it in the second half of the vegetation period (Sádovský et al., 2004). Vernally flooded depressions on arable fields can provide secondary habitats and thus serve as the refugium for these specific plant communities in cultural landscape (Eliáš jun. et al., 2008; Lukács et al., 2013; Zlacká et al., 2006). Extremely rainy weather in 2010 has given rise to the inundated field depression on much larger area as during normally moist or dryer years. Therefore, we initiated the field survey devoted to the mapping of inundated field depressions in Podunajská nížina Lowland, and inventory of their flora.

MATERIALS AND METHODS

Field survey was carried out in 2010 since May to October in the territory of Podunajská nížina Lowland (southwestern Slovakia). The method of field mapping and inventory was used - when the inundated field depression was found, the locality was examined for rare plant species occurrence. At the locality the number of individuals and the approximate area (using GPS device) was estimated. Phytosociological relevés were also sampled using modified Braun-Blanquet cover – abundance scale (Barkman et al., 1964). The conservation status of the species was stated according Feráková et al. (Feráková et al., 2001). Geographical coordinates were derived through GPS device Garmin GPSMAP 60CS.

Palmer Drought Severity Index (PDSI) is usually used for the evaluation of drought (PALMER, 1965); here we used the calculation results to demonstrate the opposite extremity – to define moist periods (Table 1.) The index is standardized for various regions and time periods and used for the evaluation of drought in various areas with various climates (DUNKEL, 2009). The program was afforded by Slovak Hydrometeorological Institute. The input data consists of average monthly precipitation totals, average monthly air temperatures, and average temperatures during the evaluated period, latitude and available water capacity. We used the data from Hurbanovo climatological station. The climate data was provided by Slovak Hydrometeorological Institute. Available water capacity was provided by the Soil Science and Conservation Research Institute in Bratislava.

Table 1.*PDSI classification scale for the definition of moist and dry periods*

PDSI value	**Characteristics of the evaluated month**
≥ 4.00	extremely moist
3.00 to 3.99	very moist
2.00 to 2.99	moderately moist
1.00 to 1.99	slightly moist
0.50 to 0.99	weakly moist
0.49 to -0.49	neutral
-0.50 to -0.99	weakly dry
-1.00 to -1.99	slightly dry
-2.00 to -2.99	moderately dry
-3.00 to -3.99	severely dry
≤ -4,00	extremely dry

RESULTS

Although we have examined a relatively large area of the Podunajská nížina Lowland and numerous field depressions were examined, the most interesting findings were recorded mostly on salinized soils around Komárno, Hurbanovo and Štúrovo (south-western Slovakia). Seven endangered plant species were recorded: one endangered (EN) species *Cirsium brachycephalum* Jur.; five critically endangered (CR) species – *Heleochloa alopecuroides* (Piller et Mitterp.) Host ex Roemer, *Heleochloa schoenoides* (L.)Host ex Roemer, *Lindernia procumbens* (Krocker) Philcox, *Lythrum tribracteatum* (L.) Holub, *Schoenoplectus supinus* (L.) Palla.; the species *Chenopodium chenopodioides* (L.) Aellen is considered as probably extinct (EX?) in Slovakia.

Two new localities of ***Cirsium brachycephalum*** were recorded. In addition to the locality near Hurbanovo (tab. 2), another locality situated south-eastern from Trávnica village (district Komárno) was found. There, approximately a hundred individuals were growing at south-eastern part of narrow field depression long about 500m. ***Heleochloa alopecuroides*** was found at one locality (tab.2); few individuals were also growing solitary in adjacent corn field. The discovery of field depression at this locality was interesting because three rare species were found growing at one place. More, it was the only locality with ***Lindernia procumbens*** occurrence, the species very rare in the Podunajská nížina lowland. Another species rarely occurring at our survey area was ***Lythrum tribracteatum***, hence, the records of two new localities were valuable, even though only one individual was found at the locality Zlatná na Ostrove (tab.2). In 2010, we recovered the occurrence of ***Heleochloa schoenoides*** at several recently or longer known localities. Two new localities were found (tab.2), the record at the locality Zlatná na Ostrove was of high value as we found big population reaching several thousand individuals there. The species ***Chenopodium chenopodioides*** was found at one locality (tab. 2). There, the fields all around were completely flooded in spring and in beginning autumn denudated banks were covered with sparse vegetation of segetal or marsh species. ***Schoenoplectus supinus*** was recorded at five localities. The most valuable was the finding of the field depression at the locality Zemianska Olča (south), where we recorded thousand individuals of *S. supinus* growing on rather large area (tab. 2)

The PDSI values given in the Table 3 indicate that every month was defined as moist in 2010 at the surveyed area. The most interesting is the period from May to the end of year – according PDSI these months were defined as extremely moist. This extremely moist year followed after three dry years (Tab. 3)

***Table 2**: The occurrence of selected endangered plant species recorded in field depressions at the localities of Podunajská nížina lowland in 2010. The short description of the localities, approximate area and number of individuals, the measure of abundance/cover according modified Braun-Blanquet cover-abundance scale is given.*

Name of the locality	**date**	**Locality description**	**Approx. area**	***species***	**Approx. number of individuals**	**Braun-Blanquet (abundance / cover level)[1]**
Hurbanovo	5.10.2010	field depression at the edge of corn field	600 m^2	*Cirsium brachycephalum*	20	+
Iža, part hon Konopište	16.9.2010	field depression at the edge of corn field	400m^2	*Heleochloa alopecuroides*	several tens	+
				Schoenoplectus supinus	several tens	2a
				Lindernia procumbens	10	+
Zlatná na Ostrove, part Majer Pavol	16.9.2010	field depressions at the edge of wheat field	1000m^2	*Heleochloa schoenoides*	several thousand	4
		salinized field depression in the wheat field	not estimated	*Lythrum tribracteatum*	1	r
				Schoenoplectus supinus	not estimated	+
Okánikovo	24.8.2010	field depression at the edge of corn field	500m^2	*Lythrum tribracteatum*	several hundred	2a
				Schoenoplectus supinus	not estimated	+
Zemianska Olča, north of village	24.8.2010	field depression in the corn field	100m^2	*Heleochloa schoenoides*	into 50 individuals	1
				Chenopodium chenopodioides	several tens	1
Horná Zlatná	21.6.2010	field depression in the corn field	100m^2	*Schoenoplectus supinus*	several tens	+
Zemianska Olča, south of village	16.9.2010	field depression in the corn field	1200 m^2	*Schoenoplectus supinus*	several thousand	3 to 4

1Modified Braun – Blanquet cover-abundance scale

r solitary, 1-3 individuals
+ few individuals
1 ‹ 4% (cover)
2a 5-10%
2b 11-25%
3 25-50%
4 50-75%
5 75-100%

Table 3: *Monthly values of PDSI in the period 1990 - 2010. The data from climatological station in Hurbanovo (Podunajská nížina Lowland) were used for calculation*

year	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**
1990	-2.65	-3.02	-3.93	-3.16	-4.02	-4.08	-4.41	-5.12	-4.74	-3.79	-3.42	-3.12
1991	-3.52	-3.39	-3.57	-3.33	-2.65	-2.74	-2.26	-2.65	-3.12	-2.98	1.27	1.19
1992	-0.19	-0.5	-0.09	-0.25	-0.9	0.21	1.2	-1.22	-1.45	0.78	0.56	1.22
1993	1.27	-0.11	0.13	-0.45	-1.24	-1.49	-1.82	-2.29	-2.24	1.42	1.99	2.73
1994	3.09	2.72	2.19	2.51	3.07	2.63	1.7	1.89	1.91	2.95	2.41	1.72
1995	1.47	1.33	2.01	2.74	2.64	3.38	2.75	2.83	3.29	2.28	2.38	2.75
1996	3.36	3.5	3.13	3.76	4.67	4.1	4.13	3.65	4.1	-0.08	-0.67	-1.01
1997	-1.27	-1.84	-2.18	-1.68	-1.51	-2.13	-1	-1.63	-1.94	-2.08	-0.92	-1.27
1998	-1.16	-1.89	-2.34	-2.03	-2.41	0.37	0.69	0.24	1.91	2.67	2.7	2.35
1999	1.92	2.47	2.13	1.88	1.5	2.65	4.28	4.23	3.05	2.89	3.1	3.39
2000	3.2	2.71	3.48	0.02	-0.68	-1.96	-1.42	-2.15	-2.5	-2.92	-2.71	-2.56
2001	-2.4	-2.46	-1.61	-1.75	-2.19	-2.62	-1.6	-2.18	-0.97	-1.42	-1.62	-2.01
2002	-2.46	-2.87	-3.12	-2.64	-2.71	-3.34	-3.19	0.56	0.7	1.35	1.04	1.14
2003	1.38	-0.19	-0.83	-1.25	-1.62	-2.39	-2.87	-3.33	-3.87	-3	-3.46	-4
2004	-3.83	-0.03	0.27	-0.18	-0.38	0.93	0.36	1.34	-0.3	-0.38	-0.51	-0.74
2005	-0.93	0.4	0.03	0.44	0.17	0.05	0.1	0.78	-0.07	-0.54	-0.75	1.67
2006	2.59	2.92	3.1	2.69	3.49	3.24	2.54	2.92	-0.47	-0.91	-1.38	-2.33
2007	-2.54	-2.63	-2.42	-3.24	-3.29	-3.62	-4.43	-3.58	-2.68	-2.03	-1.83	-2.06
2008	-2.13	-2.69	-2.15	-1.93	-2.47	-2.2	-1.27	-1.63	-1.28	-1.79	-2.29	-2.14
2009	0.04	0.9	1.17	-0.91	-1.22	-1.14	-1.44	-1.51	-1.77	0.06	-0.07	0.47
2010	0.79	1.13	0.92	2.07	4.29	5.37	6.38	7.18	7.77	7.27	7.62	7.73

Discussion

The rareness of the species discussed in this article has several reasons – most of them has the northern border of their distribution range in Slovakia; they are growing on specific stands - the sites flooded in spring and deeply drying on summer, especially they represents the species of mudflat bottoms; they are halophytes or sub-halophytes; they are mostly minute, low-growing plants with low concurrence ability (Feráková, Grulich, 1999; Holub, 1999a,b; Holub, Grulich, 1999a,b,c; Procházka et al., 1999). We could consider the radical decrease of specific habitats area caused by landscape use change and more frequent occurrence of dry years as two important key factors negatively influencing distribution and occurrence these species in Slovakia now. For this reason temporary pools on arable fields may have considerable importance in survival of these species in cultural landscape. The appearance of waterlogged arable fields is sporadic and irregular; it often happens that the fields are not covered by water for decades, but in some years floods appear because of high precipitation (Lukács et al., 2013). And, this situation happened in the year 2010 in Slovakia. Similar conditions were also occurring in the year 2006 when the first eight months were defined as moderately to very moist; especially May and June were defined as the moistest in the year (tab. 3). In this year Sádovský (Sádovský 2006 ined) recently recorded 10 localities of *Cirsium brachycephalum* at Podunajská nížina Lowland and also *Heleochloa alopecuroides* was recovered at several localities in 2006 in Podunajská nížina Lowland (Sádovský 2006 ined., Sádovský, Eliáš jun. 2006 ined). In 2005 five new localities of *Schoenoplectus supinus* were found in Východoslovenská nížina Lowland (Zlacká et al., 2006), thousands of individuals were recorded at some of the localities. According PDSI calculated using data from Milhostov climatological station (south-eastern Slovakia) every month was defined as moist, and namely May and June were defined as moderately moist (Zuzulová, 2014). Similar to our records, *S. supinus* occupied field depressions, edges of field path or terrain depressions in pasture (Zlacká et al., 2006), so the habitats considered as secondary for the species. The extreme conditions also influenced the population size of *H. schoenoides* in Mostové Nature Reserve (Podunajská nížina Lowland) in 2004, nine months were defined as dry (tab. 3), and population covered 5-10% of area, however in 2006 the population covered up to 50% at the same locality (Eliáš jun. et al., 2008). Vegetation of ephemeral wetlands is growing in specific, highly dynamic habitats. The speed of plant development, short life cycles and long-term survival in dormant propagules is typical for these plants (DEIL, 2005). Large sections of the populations and/or communities of these particular species are at any time hidden in the soil propagule bank (POSCHLOD, 1993). The extreme moist conditions enable the species to supplement or renew the seed bank and increase the probability of their long-term survival.

All the species discussed in this paper belong to the most threatened plant species in Slovakia. The question of conservation management is thus arising. The occurrence of temporary field pools in arable landscape is irregular, considering both temporal and spatial aspect. Lukács et al., (2013) recommend many temporary pools in arable fields left alone (i.e. maintaining traditional farming); and NĚMEC & ŽÁKOVÁ (2012) proposed to eliminate the herbicides use in the surrounding area. At all events, the conservation of endangered species in agricultural landscape, i.e. out of protected area, requires specific approach; and when favourable conditions occur, the repeated observations are necessary to accurate records.

Conclusion

During extreme moist years temporary pools in arable fields may appear more frequently and at larger area than usually. Vernally inundated field depressions at salinised stands at Podunajská nížina lowland may serve as refugium for several rare or endangered halophytous plant species in agricultural landscape, and thus these species are able survive outside of protected areas. The repeated observations of this type of ephemeral wetlands are necessary to clearly understand the long-term dynamics of this specific plant community for effective conservation management of the rare species populations.

References

Barkmann, J. J., Doing, H. & Segal, S. (1964): Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. Acta Botanica Neerlandica, Amsterdam, 13: 394–419.

Boros, E. (2003): Alkaline lakes, National Ecological Network 4. Authority for Nature Conservation, Ministry of Environment and Water, Budapest, Hungary. 28 pp.

Deil, U. 2005: A review on habitats, plant traits and vegetation of ephemeral wetlands – a global perspective. – Phytocoenologia 35: 533–705.

DUNKEL, Z. 2009. Brief surveying and discussing of drought indices used in agricultural meteorology. In Időjárás, Quarterly Journal of the Hungarian Meteorological Service, vol. 113, No. 1 – 2, Januray – June 2009, pp. 23 – 37.

Eliáš P. jun., Dítě D., Grulich V. & Sádovský M. (2008): Distribution and communities of Crypsis aculeata and Heleochloa schoenoides in Slovakia. – Hacquetia, Ljubljana, 7(1): 5–20.

Feráková V. & Grulich V. (1999): Lythrum tribracteatum Salzm. ex Spreng. – In: Čeřovský J.,

Feráková V., Holub J. & Procházka F. [eds.], Červená kniha ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie rastliny, p. 237, Príroda, Bratislava.

Feráková V., Maglocký Š. & Marhold K. (2001): Červený zoznam papraďorastov a semenných rastlín Slovenska (december 2001). – Ochr. Prír., Banská Bystrica, 20: 44–76.

Holub J. (1999a): Chenopodium botryodes Sm. – In: Čeřovský J., Feráková V., Holub J. & Procházka F. [eds.], Červená kniha ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie rastliny, p. 97, Príroda, Bratislava.

Holub J. (1999b): Schoenoplectus supinus (L.) Palla. – In: Čeřovský J., Feráková V., Holub J. &Procházka F. [eds.], Červená knih a ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie ;rastliny, p. 332, Príroda, Bratislava.

Holub J. & Grulich V. (1999a): Cirsium brachycephalum Jur. – In: Čeřovský J., Feráková V., Holub J. & Procházka F. [eds.], Červená kniha ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie rastliny, p. 99, Príroda, Bratislava.

Holub J. & Grulich V. (1999b): Heleochloa alopecuroides (Piller et Mitterp.) Host ex Roem. – In: Čeřovský J., Feráková V., Holub J. & Procházka F. [eds.], Červená kniha ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie rastliny, p. 177, Príroda, Bratislava.

Krippelová, T. (1965): Soľné stepi na Žitnom ostrove. Československá ochrana prírody, Bratislava, 2: 121–133.

Krist, V. (1940): Halofytní vegetace jihozápadního Slovenska a severní části Malé Uherské nížiny. Práce Moravské přírodovědecké společnosti, Brno, 12/10: 1–100.

Lukacs, B.A., Sramko, G, Molnar, A. (2013) Plant diversity and conservation value of continental temporary pools Biological Conservation 158 (2013) 393–400

Němec, R & Žáková, K. (2012): Important findings of hygrophylous vascular plants in wetland on arable land in the Podyjí National Park. Thayensia (Znojmo) (2012), 9: 19-32

Osvačilová, V. & Svobodová, Z. (1961): Floristicko-fytocenologický prieskum Nitrianskeho kraja (tématická mapa). Msc., 10 p.

PALMER, W. C. 1965. Meteorologic Drought : Research Paper NO. 45, Washington, D.C. : U.S. Weather Bureau, 58 s.

Poschlod, P. (1993): „Underground fl oristics“ – keimfähige Diasporen in Böden als Beitrag zum fl oristischen Inventar einer Landschaft am Beispiel der Teichbodenfl ora. – Nat. Landschaft 68: 155–159.

Procházka F, Husák Š. & Oťaheľová H. (1999): Lindernia procumbens . – In: Čeřovský J., Feráková V., Holub J. & Procházka F. [eds.], Červená kniha ohrozených a vzácnych druhov rastlín a živočíchov SR a ČR 5, Vyššie rastliny, p. 225, Príroda, Bratislava.

Sádovský, M., Eliáš, P., ml. & Dítě, D. (2004): Historické a súčasné rozšírenie slaniskových spoločenstiev na juhozápadnom Slovensku. Bulletin slovenskej botanickej spoločnosti, Bratislava, Supl. 10: 127–129.

Zuzulová, V. (2014): Vplyv výskytu sucha na variabilitu produkcie biomasy obilnín v podmienkach meniacej sa klímy. Diplomová práca, Slovenská poľnohospodárska univerzita v Nitre (2014) 98s.

ACKNOWLEDGEMENT

We are grateful to Daniel Dítě, Zuzana Melečková and Gergely Király for their active contribution in the field research. The presented paper was supported by the project VEGA 2/0117/13: Evaluation of state and dynamics of biotops using modelling and remote sensing; and VEGA 2/0030/09: Ecological and taxonomical study of selected halophytous species and their communities in Pannonian region.

SUMMARY

Biotopy slaných pôd sa na Slovensku vyskytovali v teplých a suchých oblastiach Podunajskej a Východoslovenskej nížiny. Ich plocha však bola výrazne zredukovaná počas posledných desaťročí; zástupcovia halofytnej vegetácie sa týmto stali ohrozenými druhmi slovenskej flóry. Rastlinné spoločenstvá periodicky zaplavovaných slanísk predstavujú jedinečné iniciálne štádiá sukcesie a ich vytváranie je závislé na poklese hladiny vody a zvyčajne sa vytvárajú v druhej polovici vegetačnej sezóny. Poľné depresie zaplavované v jarných mesiacoch môžu poskytnúť vhodné refúgium pre tieto rastlinné spoločenstvá v poľnohospodárskej krajine. Počas extrémne vlhkého počasia v roku 2010 boli vytvorené vhodné podmienky pre výskyt poľných depresií v oveľa väčšej miere ako počas normálne vlhkých alebo suchších rokoch. Mapovanie vegetácie zaplavených depresií prebiehalo na Podunajskej nížine počas mesiacov máj až október v roku

2010. Na lokalitách s výskytom zriedkavých a vzácnych druhov bol vykonaný fytocenologický zápis, pomocou GPS bola odhadnutá plocha na ktorej sa spoločenstvo vyskytovalo a odhadnutý bol aj počet jedincov záujmových druhov. Zaujímavejšie nálezy boli zaznamenané na zasolených pôdach polí v okolí Komárna, Hurbanova a Štúrova. Zaznamenali sme nové lokality ohrozeného druhu (EN) pichliača úzkolistého (*Cirsium brachycephalum*), nové lokality piatich kriticky ohrozených druhov (CR): bahienka psiarkovitá (*Heleochloa alopecuroides)*, bahienka šašinovitá (*H. schoenoides*), lindernia puzdierkatá (*Lindernia procumbens)*, vrbica drobná (*Lythrum tribracteatum)* a škripinec nízky (*Schoenoplectus supinus*). Pre mrlík slanomilný (*Chenopodium chenopodioides*), považovaný za pravdepodobne vyhynutý (EX?) na Slovensku, sme zaznamenali jednu novú lokalitu. Odhadovaná veľkosť sledovaných poľných depresií bola rôzna, od 100 do 1200m2, pričom na niektorých z lokalít sme zaznamenali výskyt dvoch aj troch druhov súčasne. Odhadované počty jedincov jednotlivých druhov a ich zastúpenie bolo rôzne na jednotlivých lokalitách, väčšinou sa pohybovali okolo niekoľko desiatok jedincov. Na dvoch najväčších poľných depresiách (1000, 1200m2) sme zaznamenali až tisíce jedincov bahienky šašinovitej a škripinca nízkeho, druhy boli zároveň aj dominantami na týchto lokalitách. Podľa PDSI boli všetky mesiace v roku 2010 definované ako vlhké v sledovanom území, od mája do konca roka boli mesiace definované ako extrémne vlhké podľa tejto klasifikácie. Zriedkavosť sledovaných druhov je spôsobená viacerými aspektmi: druhy majú na Slovensku severnú hranicu svojho areálu, rastú na veľmi špecifických stanovištiach (obnažené dná, zasolené stanovištia), väčšina z nich sú nízkeho vzrastu s malou konkurenčnou schopnosťou. Pokles počtu lokalít a plochy so špecifickými stanovištnými podmienkami a čoraz častejší výskyt suchých rokov považujeme za kľúčové negatívne faktory. Z tohto dôvodu sú zaplavované depresie na zasolených pôdach cennými lokalitami, kde môžu takéto druhy prežívať aj mimo chránených území. Ich výskyt v krajine je však nepravidelný tak z časového ako aj priestorového hľadiska. Vzhľadom na túto skutočnosť ako aj to, že tieto spoločenstvá majú veľmi špecifickú ročnú ako aj dlhoročnú dynamiku sú opakované sledovania potrebné pre pochopenie dlhodobej dynamiky a zabezpečenie efektívneho manažmentu a zachovania týchto vzácnych rastlinných spoločenstiev a druhov.

CONTACT

Ing. Mariana Eliašová, PhD.

Department of Ecology, Faculty of European Studies and Regional Development, Slovak University of Agriculture in Nitra

Mariánska 10, 949 01 Nitra, Slovakia

00421 37 641 5614, mariana.eliasova@uniag.sk

CARBON DIOXIDE FLUXES AND CARBON BALANCE AFTER THE 2004 STAND REPLACING WIND THROW IN THE TATRA NATIONAL PARK

PETER FLEISCHER JR.[1], PETER FLEISCHER[2], KATARINA STRELCOVA[1]

1) *Forestry Faculty TU Zvolen,*
2) *Research station of TANAP, Tatranska Lomnica*

ABSTRACT

Since 2007 CO2 soil fluxes have been measured by chamber method in the larch-spruce ecosystem heavily disturbed by the 2004 windstorm. In 2012 measurement of photosynthesis started and allowed calculation of carbon balance. The instant CO2 fluxes were measured during growing on 14 day cycle on fixed points and the values were extrapolated both spatially and temporally according to the microhabitat types, soil moisture and temperature, PAR and LAI. Carbon balance in 2012 was negative. The affected ecosystem emitted 1.8 t C ha-1 y^{-1}.

Key words: CO2 sequestration**,** carbon balance, forest disturbances, Tatra National Park, spruce forest

INTRODUCTION

Carbon dioxide (CO_2) is an important greenhouse gas and its increasing concentration in the atmosphere is often interpreted as a main reason for global climate change. Accumulation of carbon (C) in plant biomass is one of the most effective ways to reduce CO2 in the atmosphere. Forest ecosystems play an important role in global carbon sequestration. Without forest current global CO_2 concentration would be roughly 510 ppm. Almost 46 % of terrestrial C is stored in forest biomass and forest soils. In recent years forest potential sequestration has been reduced due to increasing disturbances. According to the projected changes destructive storms, floods, drought and insect outbreaks probably would cause even more significant changes of carbon fluxes in both, ecosystem and global cycles (Hasenauer et al., 2012).

Forest of Tatra National Park was strongly affected by an extreme wind throw in November 2004. Wind reaching 230 km/h laid down more than 12 000 ha (2.3 mil m^3) of natural and seminatural larch-spruce forest. This event has initiated international ecological research with special emphasis on energy, water and nutrient fluxes (Fleischer, 2008). In this paper we present data on C efflux (soil and ecosystem respiration) which has been monitored since 2007. We also present amount of C assimilated by vegetation in 2012 and calculate C balance as difference between these two major C fluxes.

MATERIALS AND METHODS

Research site

Our study was conducted on research sites established for long-term monitoring of ecological processes after the 2004 windfall in the Tatra National Park To understand the impact of different disturbance levels and different management on larch-spruce ecosystems the research sites were established on almost identical site conditions (granit moraines, dystric cambisoils, slope 10-25%, altitude 1100/1200 m a.s.l., south oriented, acidophilus vegetation, etc.); EXT – windtrow site, timber removed, FIR – windhrow and fire site, timber remowed, NEX – windthrow site, no management. The fourth site REF represented reference, undisturbed stands (Fleischer, 2008).

Sampling design

CO2 fluxes were measures on fixed points established along transects shaped in 6-arm starr. Meteorological tower formed the cross points of transects on each site. Distance between measuring points along transects was 10 m. Number of measuring points on each site ranged from 8 up to 22 according to the site specific variability. Average frequency of measuring each point was 14 days during growing season (May-September), and monthly during autumn – early spring.

Microsite conditions

The 2004 windthrow, but also previous wind disturbances, formed very dynamic soil surface represented by pit and mound micro topography. Early stage succession vegetation differs according to the soil physical properties (moisture, depth, particle size) and humus content. According to presence of dominant vegetation so far four key rmicrosites with distinct vegetation were identified: 1. Deeper, loamy and moist soil (cambisoil) in terrain depressions with Rubus *ideaus* and *Salix caprea*; 2. Shalow, sandy/rocky soil (ranker) on elevations with *Calluna vulgaris* and *Vaccinium vitis ideae*; 3. Sites with fast decomposing organic material and dominated by *Chamerion angustifolium*, 4. Sites dominated by *Calamagrostis villosa* mostly on Podsolic cambisoils. Site conditions and vegetation types were mapped in the field using fine scale IR aerial photographs and GIS tools. Species specific and seasonal changes of leaf area index (LAI) were estimated by destructive opto-gravimetric method using ImageJ© software and by non-destructive optical method (Licor 2200, Licor, USA).

Soil/ecosystem respiration

Soil/ecosystem efflux of CO_2 was detected by infra-red gas analyzers (Vaisala GMP 343, Vaisala Finland and EGM4, PP Systems USA) applying closed chamber methods. Vaisala sensors were installed inside custom built non- transparent PVC chamber (16 dm^3) equipped with small fan for mixing sampling air. Before each measurement the CO2 probe was adjusted to instant air humidity, temperature and pressure. The CPY4 chamber (2.2 dm^3) was used with the EGM4 instrument. For respiration measurement non transparent cap was placed on the chamber. The chambers were firmly but carefully placed on fixed collars (diameter 30 cm, 10 cm tall and 2-3 cm inserted into the soil) to avoid gas leaking. Measuring interval was 120 s for PP Systems (small chamber), 300 s for Vaisala and sampling frequency 5 s in both instruments. Vegetation from some collars was systematically clipped out, efflux data represented soil respiration (Rs). The other collars and EGM readings represented ecosystem (Re) respiration.

Photosynthesis (GPP)

Both of the instruments have been used also for estimation of photosynthesis. Measured CO2 concentration indicated net ecosystem exchange (NEE), which resulted from instant difference between photosynthesis (or gross primary productivity, GPP) and total (or ecosystem) respiration:

$$NEE= GPP-Re \qquad (1)$$

Applied Plexiglas transparent chambers had different size (from 16 up to 80 dm3) according to the type and height of measured vegetation. Photosyntetically active radiation (PAR) and air temperature were measured during CO_2 sampling. On each point the NEE measurements repeated consequently under modified light conditions. Intensity of solar light entering the chamber was modified by shading the chamber with plastic nets with different transparency.

Microclimate measurement

During CO_2 measurement instant microclimate data near the sampling point were recorded. Soil temperature was measured in 2 and 10 cm by soil thermometer (Ahlborn, Germany) and soil moisture in 0-6 cm by ML2x (Delta theta, UK). Air humidity was measured by Ahlborn (Germany), PAR by Skye Quantum (Ireland), wind speed by Met (Germany). On each research site fixed automatic meteorological stations (AMS) recorded microclimate data (profile soil temperature and moisture, profile air temperature and humidity, wind speed and direction, global and PAR radiation, soil heat flux, precipitation) in 60 min intervals. The CPY4 chamber was equipped with the PAR, air temperature and humidity sensors.

Calculation of fluxes

Data recorded by the Vaisala instruments represented temporal (5 s) CO_2 concentration changes. Values of each measurement were plotted and linear trend was tested (MS Office Excell). Only data showing $R^2>0.96$ were used for flux calculation confirming proper measurement (well sample mixing, no leaking, etc.). According to Drewit et al. (2002) we applied ideal gas law to calculate CO_2 flux (umol.$m^{-2}.s^{-1}$):

$$F_{CO2}= (P*V*{}_{\Delta}CO_2)/(R*T*A) \qquad (2)$$

P-air pressure (Pa)

V – chamber volume

A – chamber surface

${}_{\Delta}CO_2$ - concentration increment (ppm/min)

T – air temperature in chamber (^{o} K)

R – gas constant

Data recorded by the EGM4 were calculated by the instrument software and presented in g CO2.m^{-2}.h^{-1} . The CO_2 fluxes measured in the chambers represented the difference between assimilation (GPP) and respiration (Re) *(1)*. Under dark conditions GPP=0, so NEE=Re (Tagesson, 2006).

Temporal extrapolation of CO_2 fluxes from snap to seasonal scale was based on the regression models (Tuomi et al., 2008; Chen et al., 2010; DelGrosso et al., 2005; Byrne et al., 2005). Soil respiration was extrapolated for the entire year according to the soil temperature and humidity. Photosynthesis was extrapolated across the growing season according to the PAR and LAI using the Michaelis-Menten regression. Nonlinear regression parameters were estimated by Satistica 7. For comparison of different models we used MSE, AIC and ME criteria as proposed by Bauer (2009).

Annual C balance (NEE) was calculated as difference between annual Re and seasonal photosynthesis (GPP). Positive NEE (GPP>Re) means that ecosystem is C sink. Negative balance (GPP<Re) indicates ecosystem as C source.

Results

During field work we interpreted IR ortophotomap from the windthrown area using GIS instruments. Fine scale (20 cm per pixel) allowed reasonable classification of dominant vegetation (Erdas Imagine©). Fig. 1 shows part of the classified area where distinct colors represent different vegetation and land use types. Verification was done on sites 20x20 m (red squares).

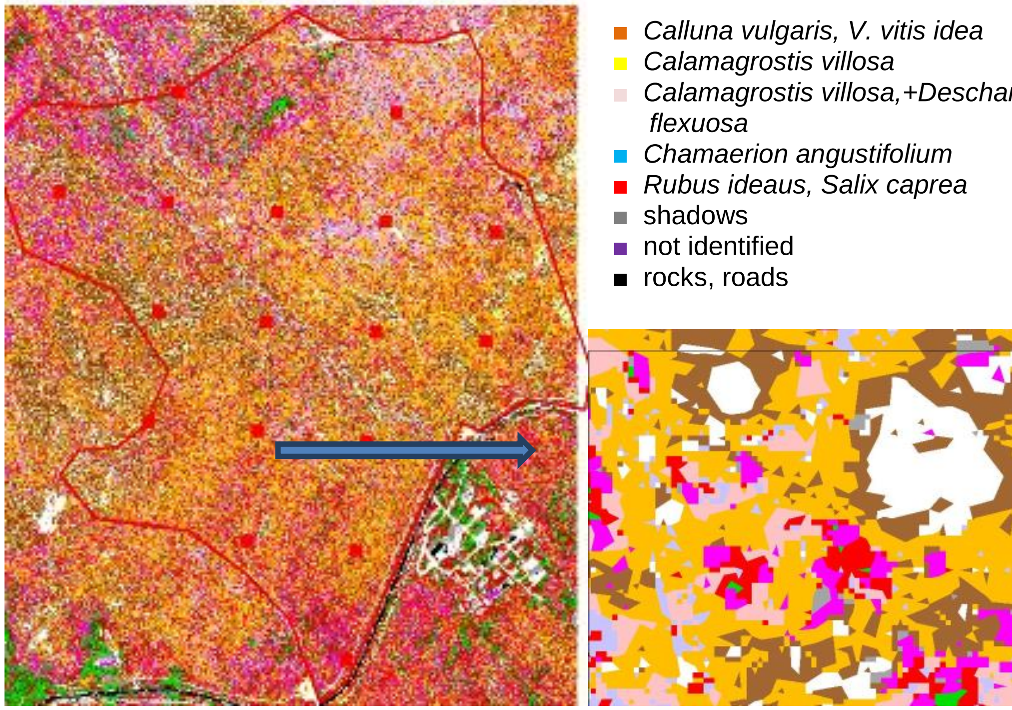


Fig. 1 *Vegetation and land use map and detail (20x20m), study site FIR*

Soil respiration

Between 2010 and 2012 we did more than 1100 soil/ecosystem respiration measurements on the FIR and EXT sites. Less intensive was measurement on the NEX site due to repeated damage on sampling sites by game. So far we did not find any significant difference among sites with soil versus ecosystem respiration. Basic statistics of measured data are presented in Tab.1

In 2012 we noted strong reduction in difference between the FIR and EXT sites. Statistical analysis (Two Sample t test) confirmed no difference between the sites on 0.05 sig level. In previous years soil respiration on the FIR site was much higher than on the EXT.

As in previous years we have observed close relation between microsite conditions (represented by specific vegetation) and soil efflux. For each microsite/vegetation type (*Rubus ideus, Calamagrostis villosa, Chamerion angustifolium, Calluna vulgaris)* we applied available models (Tab. 2).

Tab.1 *Basic characteristic of the soil respiration on EXT and FIR sites (CO_2 in umol m^{-2} s^{-1})*

Year	*Site*	*No Of measurement*	*Average Soil respiration*	*Standard Deviation*	*Coeficient Of variation (%)*
2012	EXT	263	5,50	2,94	53,53
	FIR	124	6,23	3,09	49,63
	sum	387	5,74	3,01	52,45
2011	EXT	138	4,36	2,22	50,97
	FIR	129	5,39	3,05	56,52
	sum	267	4,86	2,70	55,53
2010	EXT	198	5,08	2,40	47,37
	FIR	231	6,86	3,55	51,70
	sum	429	6,04	3,19	52,93

Tab. 2 *Overview of equitations used to model soil respiration on EXT and FIR sites, T– temperature, SM – soil moisture, a-e – parameters*

Model	Equitation
Linear	Y=a+bT
Quadratic (T)	$Y= aT^2$
Kucera, Kirkham	$Y=a(T+10)^b$
Fang, Moncrief	$Y=a(T-T_{min})^2$
Exponential	$Y=ae^{b*T}$
Arrhenius	$Y= ae^{bT^{-1}}$
Quadratic (SM)	$Y= a +b*sm + c*sm^2$
Boltzman S courve	$Y= b + \frac{a-b}{1+e^{\frac{sm-c}{d}}}$
Empirical (T, SM)	$Y=(asme^{bT})$
Mielnick, Dugas	$Y=(a*s_m)e^{bT}2,12(SM-SM_{min})(SM_{max}-SM)^c$
Combined Botzman .	$Y= \left(b + \frac{a-b}{1+e^{\frac{sm-c}{d}}}\right)*e^{eT}$
Del Grosso	Y=(a*(0,56+(1,46*(arctan(π*0,0309)*(T-15,7))/ π))*(5*(0,287+(arctan(π*0,009*SM-17,74)))/ π))

On the example of *Rubus ideaus* we present tested models, fitted parameters and calculated statistical criteria (MSE, AICc, ME). The results are presented in the Tab. 3 and Fig. 4. Red numbers in Tab. 3 indicate statistical significance (<0.05). The order of parameters is the same as in the equitations in Tab. 2.

Tab. 3 *Models, parameters and criteria for estimation of soil respiration for R. ideaus community*

Model	MSE	ME	AICc	parameters
Linear	6.4	0.40	141.3	0.43;0.58
Quadratic (T)				No significant
Kucera, Kirkham	6.43	0.40	-8.67	0.04;1.55
Fang, Moncrief				No significant
Exponential	6.71	0.38	146.94	2.8;0.05
Arrhenius	6.4	0.43	141.4	17.75;-13.24
Quadratic (SM)	8.58	0.26	167.1	-14.26;1.02; -0.01
Boltzman S courve	8.64	0.25	169.598	9.32;1.51;0.28;0.04
Empirical (T, SM)	3.9	0.65	106.72	0.07;0.06
Mielnick, Dugas				No significant
Combined				
Botzman	3.63	0,67	107.48	4.64;.0.34;0.33;0.08;0.06
Del Grosso	4.24	0.61	111.83	6.73

MSE – mean squared error, AICc – Akaike information criterion, ME – Model effectivity

To compare soil respiration in different microhabitat types we chose the best fit models. Annual course of CO_2 efflux is presented in Fig. 4. Annual respiration for distinct vegetation type was as follow*: Rubus ideaus* 13.2 t C ha^{-1}, *Calluna vulgaris* 6.9, Chamerion angustifolium 10.1, and Calamagrostis villosa 8.9 t C ha^{-1}.

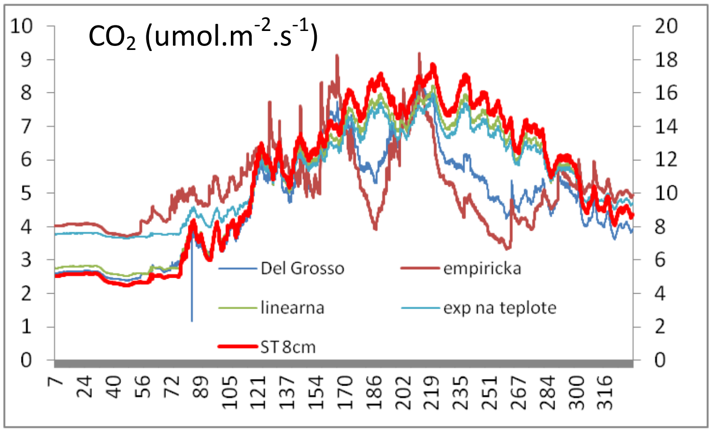


Fig. 3 *Annual courses of soil CO_2 efflux in R. ideaus type calculated by the best fit models, soil temperature in 8 cm is also shown*

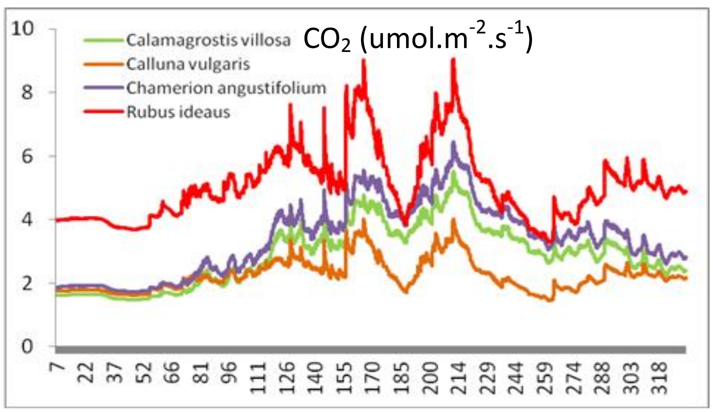


Fig. 4 *Annual course of the soil CO_2 efflux (umol m^{-2} s^{-1}) for the most spread vegetation types*

Total annual respiration for the windthrow site was calculated as area weighted CO_2 efflux for each micohabitat type. According to the proportion of vegetation types (Fleischer et al. 2013) the average CO_2 efflux in 2012 was 8.7 t C ha^{-1}.

Photosynthesis

Estimated instant GPP values were fitted with Michaelis-Menten type of regression:

$$GPP = a_1\left(\frac{PAR}{a_2+PAR}\right)\left(\frac{LAI}{a_3+LAI}\right) \qquad (3)$$

Calculated parameters for selected species (*Calamagrostis villosa, Calluna vulgaris*) are presented in Tab. 6. The parameters for other key species were not significant.

Tab. 6 *Correlation, parameters and LAI for Michaelis-Menten regression (3), (sig of parameters <0.05)*

Vegetation	R^2	a_1	a_2	a_3	LAI
Calluna vulgaris	0,73	2,1	693,78	-0,46	0,9
Callamagrostis vilosa	0,76	3,91	650,21	-0,54	1,1

Continuously measured PAR values were used for extrapolation of instant GPP values across growing season. Diurnal GPP for *C. villosa* is shown in Fig. 5. GPP for *Chamerion angustifolium* and *Rubus ideaus,* which were difficult to measure directly due to their size, was calculated by biometric method (Marek et al., 2011). Total annual sum of GPP reached 6.9 t C ha^{-1}.

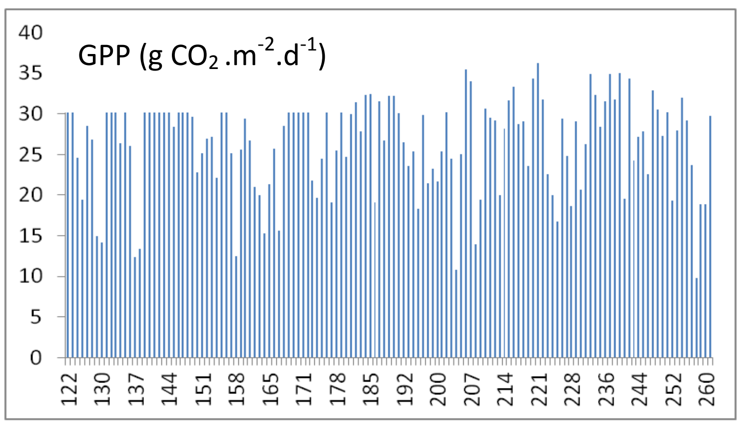


Fig. 5. *Diurnal sum of GPP (g CO_2 m^{-2} d^{-1}) for Calamagrostis villosa during growing season*

Carbon balance

Measurement of the both fluxes in 2012 allowed us to calculate annual C balance on the windthrow site. Assording to the formula *(1)* carbon balance (NEE) as difference between GPP (6.9 t C ha y^{-1}) and Re (8.7 t C ha y^{-1}) was negative (-1.8 t C). It means that the windthrow site was C source.

Discussion

Based on sampling size (number of sampling points per site) and estimated variability of soil efflux we could calculate the accuracy of our sampling. According to the formula:

$$n = \frac{s^2 t_\alpha^2}{D^2} \qquad (4)$$

s – standard deviation, t_α – critical value of Students distribution if α=0.05, n – number of sampling points

The accuracy of C efflux estimation was ± 0.75 umol m^{-2} s^{-1}. In previous years the differences among the sites and individual years were much bigger. Recently, due to progressive homogenization of microclimate and vegetation, the differences are less pronounced. Average soil temperature (in 8 cm) during growing season 2012 was 13.4 °C on EXT and 13.2 on FIR site. In 2011 the difference was 0.7 °C. Soil moisture in 2012 on both the sites was even identical (28 %), a year before the difference was 7%. The source of CO_2 efflux variability raised mostly from the heterogeneity of microhabitat structures. Variation was partly reduces by grouping sampling points into relatively homogenous types identified by dominant vegetation.

We have applied vast range of soil respiration models for estimation of CO_2 efflux. The best fit between modeled and measured values showed models based on both soil temperature and soil moisture, esp. model by DelGrosso and our own,named Empirical model. The largest differences were found during non-growing season (modeled value 4 umol, real value 0.5 umol m^{-2} s^{-1}).

Photosynthetic production (GPP) derived from PAR and LAI yield comparable results than gravimetric method. The difference in C uptake between chamber and biomass methods ranged from 3 (for *C. villosa*) up to 13 % (for *Ch. angustifolium*) (Fleischer et al., 2013). GPP measurement was problematic under intensive PAR and thus elevated temperature in Plexiglass chambers. Measurement was often disturbed when vapour pressure deficit exceeded 2 kPa. At such a level stomata close and CO_2 uptake stops (Marek et al., 2011).

CONCLUSION

Carbon dioxide fluxes, respiration and photosynthesis, were measured by the chamber method on the site heavily disturbed in 2004 by an extreme windstorm. Large differences among sites representing different disturbance agents (wind, fire) gradually declined. Site CO_2 efflux heterogeneity depended mostly on microhabitat variability. Repeated windfalls have formed pit and mound microtopography with contrast soil and hydric conditions reflected by specific vegetation cover. Instant soil respiration values were extrapolated both spatially and temporally. Spatial extrapolation was based on the actual vegetation map derived from fine scale aerial ortophotomaps. Temporal extrapolation of CO2 fluxes was based on soil temperature, soil moisture, PAR and LAI. Difference between carbon efflux and uptake, net ecosystem exchange, showed that balance up to 2012 was negative (the windtrow in 2012 produced 1.8 t C per ha). It is expected that increasing vegetation cover, biomass and LAI under warm and moist conditions might increase carbon sequestration and change the balance to positive (carbon sink). Further research needs to solve GPP measurement of oversized vegetation and overheating inside transparent chambers.

REFERENCES

Bauer, J., 2009 : Analysisis of heterotrophic respiration response to soil temperature and moisture : Experiments and modeling – Diertation thesis.

Byrne K.,A., Kiely G., Leahy P., 2005: CO fluxes in adjacent new and permanent temperate grasslands. Agricultural and Forest meteorology 135 (2005), 82-92

Del Grosso, S.J., Parton, W.J., Mosier, A.R., Holland, E.A., Pendall, E., Scimel, D.S., Ojima, D.S., 2005: Modelling soil CO_2 emissions from ecosystems. Biogeochemistry (2005) 73: 71-91

Drewitt et al., 2002: Measuring forest floor CO_2 fluxes in Douglas fir forest. Agricultural and Forest Meteorology, 110: 299 – 317

Fleischer, P. , 2008 : Windfall research and monitoring in the High Tatra Mts., objectives, principles, methods, and current status. Contributions to Geophysics and Geodesy 2008 , Vol. 38, p. 233 -248.

Fleischer, P., Fleischer, P. jr, Kyselova, Z., 2013: Primary productivity of successional stages in larch-spruce forest after disturbances- methodology and preliminary results (in Slovak). NLC Zvolen, Seminar CD proceedings, p. 27-29.

Hasenauer, H., Petritsch, R., Zhhao, M., Boisvenue, C., Running, S.W., 2012: Reconciling satelite with ground data to estimate forest productivity at national scales. Forest Ecology and Management 276 (2012): 196-208

Chen, X., Post, W., Norby, R., Classen A., 2010: Modelling soil respiration and variations in source components using a multifactor global climate change experiment. Climate Change. DOI 10.107/s10584-010-9942-2. Published on line 14.10.2010, Springer

Marek M. a kol., 2011: Uhlík v ekosystémech ČR v měnícim se klimatu. Academia Praha, 253 s.

Tagesson, T., 2006: Calibration and analysis of soil C efflux estimates with closed chambers at Forsmark and Laxemar. Lund University, 36 pp.

Tuomi, M., Vanhala, P., Karhu, K., Fritze, H., Liski, J., 2008: Heterotrophic soil respiration . comprison of different models desribing its temperature dependence. Ecological Modelling 211 (2008): 182-190

ACKNOWLEDGEMENT

This work was supported by the Slovak APVV Grant Agency, No 0480-12.

SUMMARY

V porastoch postihnutých vetrovou kalamitou v r. 2004 sme komorovou metódou merali okamžité toky CO_2 (pôdnu, resp. ekosystémovú respiráciu a asimiláciu). Aj po 8 rokoch boli poškodené ekosystémy zdrojom uhlíka, keď ročne emitovali 1.8 t C ha^{-1}. Napriek pokračujúcej regenerácii vegetačných a homogenizácii mikroklimatických podmienok, sú rozdiely v emisii CO_2 medzi mikrostanovištnými typmi na postihnutom území stale výrazné.

CONTACT

Ing. Peter Fleischer jr

Forestry faculty, Technical University Zvolen

p.fleischerjr@gmail.com

CLIMATOLOGY AND GENETICS – IS THERE ANY INTERFACE? AN EXAMPLE OF FOREST TREES

DUŠAN GÖMÖRY

Technical University in Zvolen, TG Masaryka 24, 96053 Zvolen, Slovakia

ABSTRACT

In addition to the role of Gregor Mendel as a biologist and founder of genetics, he also devoted a part of this scientific life to weather observation and climatology. This study focuses on possible meeting points of these two roles. On the example of forest trees, it shows how climate information can be useful for population and evolutionary genetics and vice versa. Four studies are used to illustrate this relationship: Holocene migration of beech, genetic variation in Serbian spruce, assessment of adaptive variation in beech in a common-garden experiment, and epigenetic phenomena in Norway spruce.

Key words: local adaptation, postglacial migration, genetic drift, forest trees

INTRODUCTION

When the first edition of Charles Darwin's *Origin of Species* (Darwin 1859) appeared in November 1859, it caused a true revolution in science as well as in society. It was not because Darwin 'invented' evolution (as often suggested by laymen); actually, the idea of biological evolution has been present in naturalist thought long before, starting from Anaximandros, Herakleitos and Empedokles over Buffon to Lamarck (Larson 2006). Darwin's main contribution to biology was the population view of biological change: instead of looking on trait expression in a particular pair of parents and the set of their descendants, Darwin focused on variation in species and populations as large sets of individuals, integrating the available knowledge in geology, biogeography and descriptive biology (Dawkins 2009). Consequently, he was the first to suggest a mechanism underlying evolution, which was able to withstand not only ideological opposition, but also scientific proof, although many aspects and details of his ideas needed to be corrected later. Maybe this was the reason why darwinism provoked vivid controversies lasting until today.

Gregor Mendel owned an outprint of Darwin's book and hand-written remarks on margins document that he studied it with attention and interest (Fairbanks and Rytting 2001). The opinions about Mendel's attitude towards the evolutionary theory diverge, reaching from displaying Mendel as a categorical opponent of darwinism up to portraying him as a good Darwinian (Sapp 1990 and the citations therein). Therefore, today we can only speculate about his motivation for the experiments with plant hybridization, which laid the foundations of genetics (Mendel 1866). He might have intended to provide evidence for (Fisher 1936) as well as against evolution (Bishop 1996). Whatever is true, the fact that hereditary information is transmitted from parents to offspring in discrete units without alteration by the environment has long been used as an argument against evolution. Only the development of quantitative and population genetics in the 1920s and the 'new evolutionary synthesis' in the 1930s–1940s showed that not only there is no contradiction between genetics and Darwinism, but Mendelian inheritance is a basic prerequisite for evolution by natural selection (Fisher 1930, Wright 1931).

Mendel is thus known to everybody who passed secondary school anywhere in the world as the founding father of genetics. This conference is, however, devoted to Mendel as a meteorologist and climatologist (a less known role, but clearly documenting his prominence in natural sciences). So, is there any link between the study of climate and the study of heredity?

There is. Returning to the first paragraph: the keyword is 'evolution'. Mendel himself did not integrate the mentioned two parts of his scientific career, but his successors did. The fact that climate is the main driver of natural selection and largely determines not only biogeographical patterns, but also distribution of genetic lineages and composition of gene pools within a species (especially in plants), has been generally recognized since the foundation of population genetics. On one hand, various components of climate act as factors of selection and provoke local adaptation; this process has broad practical implications in the light of the ongoing climate change. On the other hand, as climate sets limits for persistence of a species at a particular location, it determines population sizes, migration barriers and corridors, stepping stones for gene flow and other factors driving neutral processes in populations and thus shaping their gene pools. Some components of climate even directly affect the hereditary material: polyploidy is correlated with temperature regime reflected in latitudinal or altitudinal gradients (Ramsey and Ramsey 2014), ultraviolet radiation causes non-homologous recombination in plants (Ries et al. 2000) etc.

Forest trees represent an exemplary case of organisms where the interactions between genes and climate are of direct practical relevance. In contrast to agricultural plants, forest trees are practically undomesticated. Moreover, natural stability is expected from forest ecosystems, including commercial forests managed by man. Trees are long-lived organisms, which have to cope with environmental fluctuations, pathogen and pest occurrence and other stresses during their long life span. A sufficient genetic variation of tree populations, sufficient adaptedness to present environments and adaptability of their gene pools to future changes are basic prerequisites of resistance and resilience of forest ecosystems. Therefore, knowledge of genetic variation patterns and their historical as well as current relationships to climate are of essential importance for forestry.

This contribution shortly summarizes four studies documenting the relationship between gene pool composition and climate. First two studies show how climate change in the past shaped ranges and genetic variation levels of tree species and how genetic tools can be applied to reconstruct these changes. Latter two studies document how climatic adaptation is reflected in fitness-related phenotypic traits and what may be the hereditary basis of this adaptation.

MATERIALS AND METHODS

The first study focuses on the colonization of the range of European beech (*Fagus sylvatica* L.) during the Holocene (Magri et al. 2006). It is based on the analysis of 608 populations represented by >50 trees each and genotyped at 7 allozyme loci. Spatial analysis of variance (SAMOVA) based on a simulated annealing procedure was applied to the genotype set to define groups of populations that are geographically homogeneous and maximally differentiated from each other. The outcomes were combined with the reconstruction of postglacial range expansion based on fossil pollen and macrofossils.

The second study focuses on genetic consequences of range fragmentation caused by the Holocene warming in a Balkan endemic, Serbian spruce (*Picea omorika* Purk.). Levels of genetic variation were assayed in 13 populations genotyped at 16 allozyme loci (Ballian et al. 2006) and a mitochondrial marker (*nad1-2*).

In a study of adaptation we examined reactions of 87 beech populations on geographical and climatic transfer in a common-garden experiment. Populations of different origin (provenances) were planted in 24 trial plots over Europe in 1998. A coordinated assessment of growth and survival was accomplished in 2007. Height growth and survival rates of individual provenances were fitted against transfer rate (difference of geographical coordinates or climatic variables between the site of plantation and the site of origin) to estimate optimum site and optimum transfer rate, where fitness attains maximum.

Finally, the effects of climate of the site of juvenile growth on later behaviour of conifer provenances were assessed in a nursery trial. Twelve provenances of Norway spruce (*Picea abies* Karst.) were sown in two climatically contrasting nurseries located at altitudes of 350 and 1100 m a.s.l., respectively. After the first year, half of the material was reciprocally transferred between nurseries, and budburst phenology was assessed at the beginning of third year.

RESULTS

The study of genetic differentiation of beech in Europe revealed 9 lineages (SAMOVA groups), which are, however, not equally differentiated. A comparison of the distribution of lineages with paleobotanical evidence (dating of fossil pollen >2% of the pollen spectrum or macrofossils on ^{14}C-calibrated sites) revealed that they correspond to glacial refugia or refugial areas, which contributed to the recolonization of the continent enabled by climate improvement during the Holocene. The major part of the range was colonized from a single source population located at the eastern foothills of the Alps and in Istria (fig. 1; red lineage).

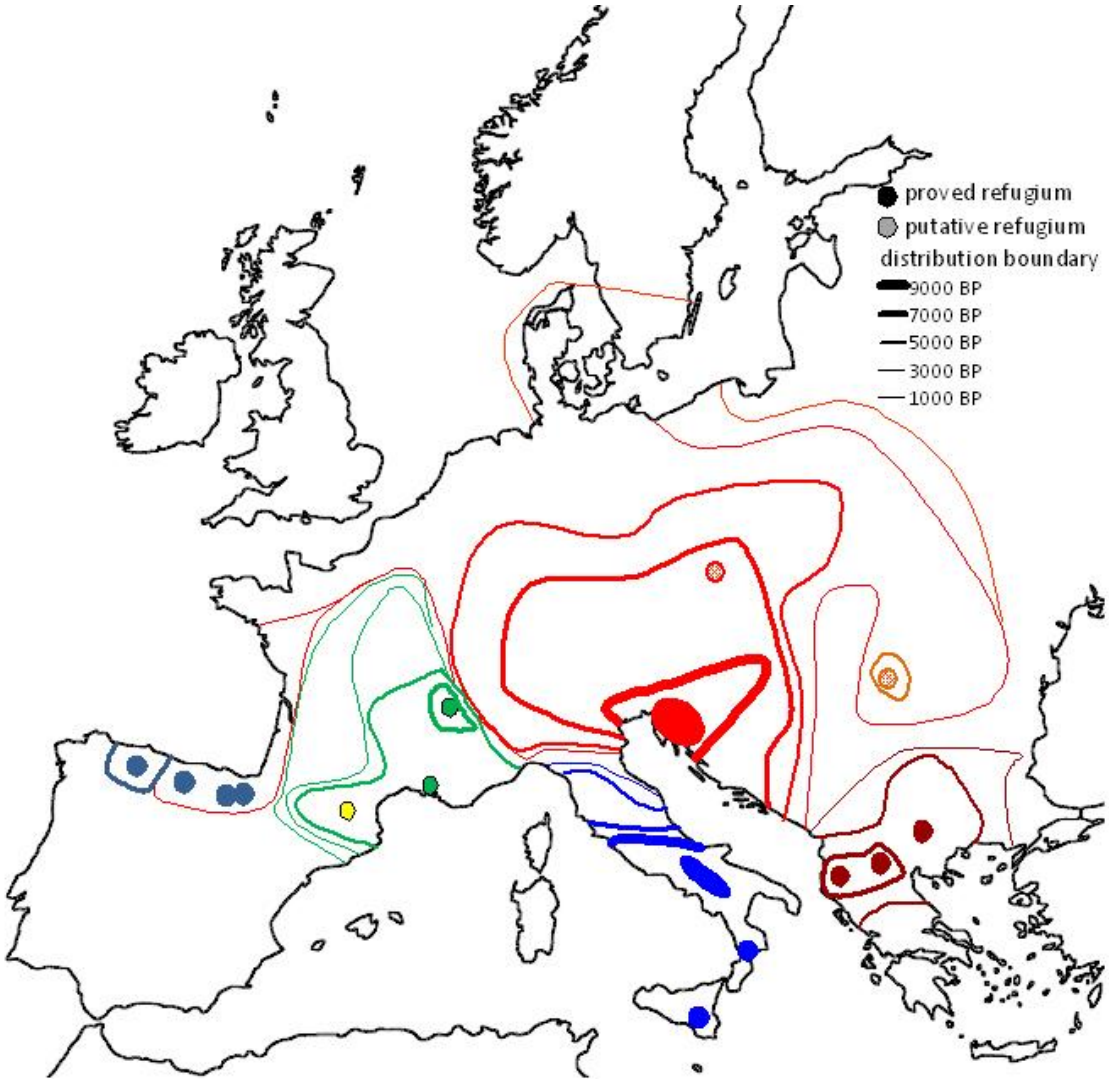


Fig. 1 *Schematic drawing of the distribution of genetic lineages of common beech and their expansion during the Holocene*

This refugial population spread into all directions and succeeded to colonize northern Europe, most of the Alps, the Carpathians, the Atlantic coast, and even succeeded to invade the Pyrenees and overlay the local refugia. Another major refugial population survived the last glacial in southern Apennines, Calabria and Sicily (blue lineage). This population started to expand very early, but colonized only the Apennine peninsula. Several refugia were located in the Maritime Alps, Massif Central and eastern Pyrenees. Although differentiated, all they belong to the same clade and colonized the western Mediterranean area (green/yellow group). Finally, southern Balkans harbours three lineages also belonging to the same clade and representing probably several refugial populations (brown group). Two lineages represented in the Cantabrian range and the Southern Carpathians (Apuseni Mts.) are indicative of local secondary refugia.

The case study of *Picea omorica* was used to demonstrate the effect of range fragmentation. In spite of being a stenoendemite, Serbian spruce is highly polymorphic at the mitochondrial *nad1* gene, 7 haplotypes were found. Most populations were monotypic in the 295 bp allele. However, the largest population on Veliki Stolac lacks this haplotype completely. Similar contrasts were observed for frequencies of allozyme alleles; e.g. the allele *Mdh-B/100* represented in the population Goštilja by 87% is completely lacking 12 km apart in Tovarnica (Ballian et al. 2006). The coefficient of differentiation F_{ST} of 0.261 only illustrates a high overall differentiation level (commonly $F_{ST}\approx 0.05$ in widespread conifers). On the other hand, within-population variation is low, as shows the comparison to a Norway spruce population from the Poľana Mts. (Table 1). Even when all *P. omorica* populations are pooled together, allelic richness ($A_{[20]}$ and $A_{[400]}$; number of alleles recalculated for common sample size of 20 and 400 gene copies, respectively, by rarefaction) is only a half compared to *P. abies.* The same applies to proportion of polymorphic loci (*PP*) and gene diversity measured by expected heterozygosity (H_E).

***Table 1** Genetic variation in Picea omorica compared to P. abies*

Species	*N*	$A_{[20]}$	*PP*	H_E
P. omorica				
average	33.7	19.11	20.9	0.067
pooled	400	22.24*	43.8	0.088
P. abies	200	42.00*	81.3	0.140

*Rarefaction to *g*=400 gene copies

Neutral processes such as genetic drift or gene flow affect also adaptive variation. Although the recent progress in functional genomics allowed identification of genes underlying phenotypic traits and polymorphisms within these genes causing allelic variation, mapping of adaptive genetic variation is still at the very beginning and for practical purposes, we have to rely on the assessment of the genetic component of fitness-related trait variation in common gardens such as provenance experiments. In the case of the international beech experiment we assessed how provenances respond to transfer by height growth and survival. An illustration of the geographical distribution of optimum transfer rates of beech provenances as measured by their height-growth and survival responses is shown in Fig. 2.

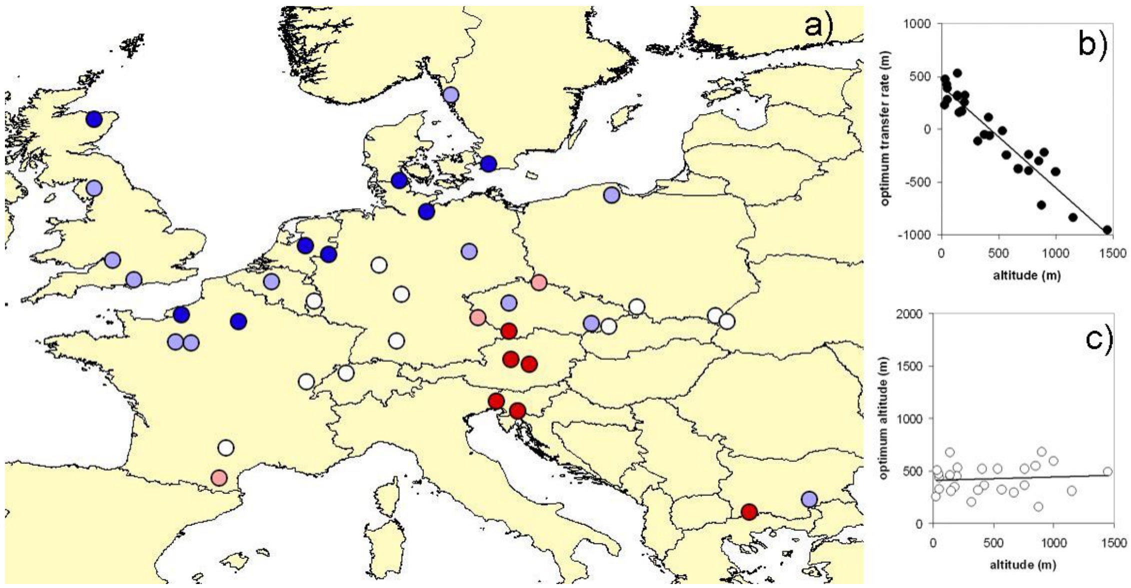


Fig. 2 *Height growth responses of beech provenances to altitudinal transfer: a) optimum transfer rates (blue and red dots: provenances preferring transfer to higher and lower elevations, respectively), b) regression of optimum transfer rates on altitude of origin, c) regression of optimum altitude on altitude of origin*

The pattern is spatially continuous, i.e. spatially proximate populations mostly behave in a similar way: those from mountainous region (Alps and Carpathians) show different preferences compared to lowland populations distributed along the Atlantic coast. Naturally, there are outliers of these general trends, mainly provenances represented in few trial plots (i.e., for which the estimation of regression parameters is less reliable), extremely marginal or non-indigenous. The correlations between transfer rates and the underlying ecological variables are mostly highly significant and negative, meaning that transfer towards the centre (in terms of geography) or towards moderate conditions (in terms of climate) is generally preferred by beech (Table 2). On the other hand, correlations for the optimum site are generally non-significant.

Table 2 *Correlations between optimum transfer rates/optimal climates and underlying environmental variables for provenances*

Climatic/ geographic variable	Height		Survival	
	Optimum transfer rate	Optimum position	Optimum transfer rate	Optimum position
Longitude	–0.368 ns	0.316 ns	–0.329*	0.165 ns
Latitude	–0.925***	0.326 ns	–0.374*	0.246 ns
Altitude	–0.668***	0.057 ns	–0.850***	0.082 ns
MAT	–0.590*	0.573*	–0.675***	–0.116 ns
Precipitations	–0.762***	0.289 ns	–0.544***	0.166 ns
EQ	–0.684***	–0.100 ns	–0.108 ns	0.031 ns

Although expression of a gene in a phenotypic trait may depend from the environmental context, the hereditary material as such should not be affected by the environment. To verify whether it is so we organized a transplant experiment where samples from a population with identical gene pools were initially exposed to different climates (warm/cold) and later their budburst dates were compared. Expectedly, Norway spruce provenances scored in the cold nursery flushed later than those in the warm nursery. However, budburst date was also strongly influenced by the climate of the nursery, in which the material spent the first year of life. Independent of scoring site, all provenances germinating in a warm nursery flushed on average 2 to 7 days later than those growing the first vegetation season in warm climate (Fig. 3)).

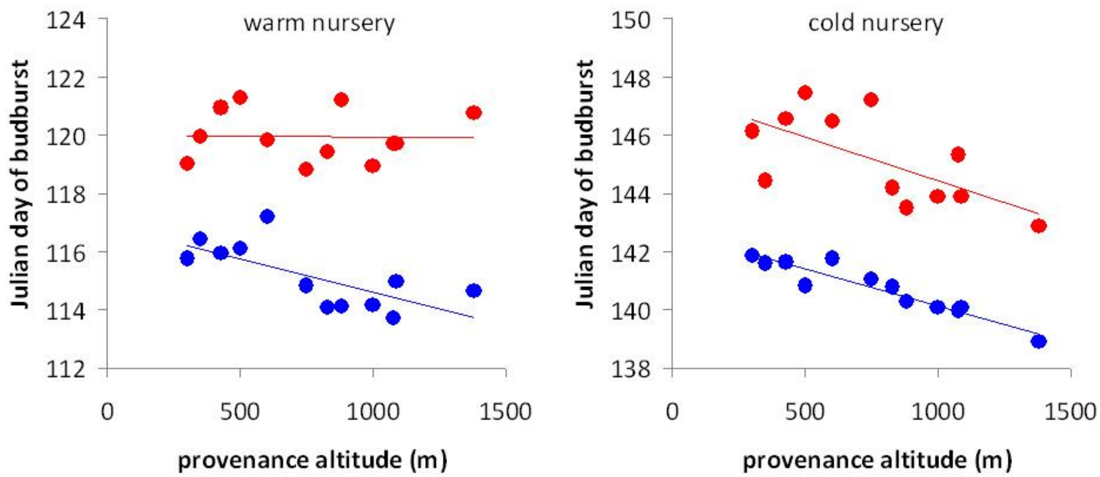


Fig. 3 *Regressions between budburst date and altitude of origin for seedlings grown the first year in a warm (red) and cold (blue) nursery, scored after transplantation in the warm (left) and the cold (right) nursery*

DISCUSSION

The history of populations reflecting population sizes, migration paths and gene flow directions and levels largely determines their present gene pool. Holocene climate changes allowed expansion of tree populations from refugia, where temperate tree species were confined during the glacials, but not all refugial populations were able to profit from this opportunity. The study of European beech points to three facts. First, in contrast to previous paradigm of paleobotany, it demonstrated that effective refugia of temperate species in Europe could have been located farther to the north than on the three main southern peninsulas. Second, it showed that large mountain chains such as the Alps or the Carpathians need not act as migration barriers, as generally postulated (e.g., Taberlet et al. 1998); in the case of beech, it was rather main European rivers and their surrounding lowlands (the Po valley, the Hungarian and Wallachian plains along the Danube) which prevented expansion of the Apennine and Balkan lineages. Finally, it showed that refugial populations in the Cantabrians and Southern Carpathians were unable to expand, although climate improved also here, and were overlaid by newcomers from the main Slovenian refugium. The probable cause was a small population size, leading to gene pools depleted of adaptive alleles and high inbreeding levels, both factors decreasing fitness.

Genetic continuity in widespread tree species such as beech is in a sharp contrast with the endemics with fragmented range. Chaotic patterns of genetic differentiation and low diversity are signs of genetic drift in almost completely isolated small demes. On the other hand, the presence of several genetic lineages in an endemic indicates a larger range in the past. Moreover, Serbian spruce is a species untypical for its present range – the growth habit (tall trees with short branches and slender crowns) indicates that the species developed in areas with a high snow cover. At present it grows in gorges and north-oriented slopes that receive almost no direct sunlight; the microclimate of these sites is characterized by very high air humidity, high precipitation regularly distributed over the year, high snow cover, and low winter temperatures (Vidaković 1991). Refugial areas in the Bosnian and Serbian mountains influenced by the Mediterranean climate with hot and dry summers may thus have become a trap. With the onset of the Holocene warming, the spread of Serbian spruce into climatically more friendly areas could have been hampered by a lack of migration corridors or stepping stones in the close vicinity of the refugia.

Two criteria have been proposed as diagnostic of local adaptation in common garden experiments: local deme should be superior to foreign demes ("local vs. foreign"), and a deme should show higher fitness in its own habitat compared to other habitats ("home vs. away") (Kawecki and Ebert 2004). Provenance experiments allow assessing the response of tree populations to environmental changes simulated by the transfer to different ecological conditions. Response measured by any fitness-related trait is commonly non-linear; transfer exceeding the optimum rate commonly results in lower growth or survival. Under local adaptation, the optimum climate is identical (or positively correlated) with the climate of origin, meaning that optimum transfer rates are expected to be close to zero for each provenance. In contrast, if the optimum climate is the same for all provenances, optimum transfer rates are expected to be negatively correlated with the climate of origin. The presented variation patterns of fitness components (juvenile survival) or fitness-related traits (height growth) in a large-scale provenance experiment with common beech do not give clear indications for the local adaptation, considering the "home vs. away" criterion *sensu* Kawecki and Ebert (2004). The lack of local adaptation may be caused by considerable phenotypic plasticity of beech, allowing it to avoid selection pressures exerted by climate. Alternatively, the time (number of generations) elapsed since the colonization of most of the present range during the Holocene may have been insufficient to develop adaptive differentiation under extensive gene flow.

There are, however, traits always giving indication for local adaptation in practically all provenance experiments, namely those associated with vegetative phenology. Timing of budburst, budset, leaf discoloration etc. generally shows smooth change along geographic and climatic gradients, which has typically been attributed to adaptation by natural selection (Wright 1976). However, both the empirical experience with transferring seed orchards southwards and experimental studies conducted during the last 20 years have demonstrated that climatic conditions during sexual reproduction affect vegetative phenology and frost hardiness (and consequently growth) in conifers (Johnsen et al. 2005): progenies possess a memory of temperature and photoperiod during the embryonal development and seed maturation, whereas the climate during prezygotic stages, i.e. micro- and macrosporogenesis and fertilization itself, does not affect phenological behaviour of the progenies. It has been shown that such memory effects very probably rely on changes of gene expression Yakovlev et al. 2010), although the underlying molecular mechanisms have not been clarified yet. The presented outcomes of the nursery experiment show that the modifying effect of environment need not be restricted to embryonal development, and carryover effects can be provoked by the climate during juvenile growth as well: heredity going beyond Mendel's rules.

CONCLUSION

Mendel himself surely did not anticipate how big branch of science and business will once grow out of his discoveries. His crossing experiments focused on phenotypic traits (logically), but were indispensable for later explanation of cytological and molecular mechanisms of heredity. As mentioned in the Introduction, Mendelian genetics is regarded as indispensable for explaining, how plant population adapt to changes of climate, even without knowing exact details about the molecular basis of this process. This is, however, not all: molecular tools, currently widely used in ecology, biogeography and other fields to follow the interactions between biota and climate *sensu latissimo*, all have their roots in Mendel's experiments. Even if he had never made a single air-temperature measurement, Mendel's contribution to understanding the climate and its effects on living world would be undisputable.

REFERENCES

Ballian D, Longauer R, Mikić T, Paule L, Kajba D, Gömöry D (2006) Genetic structure of a rare European conifer, Serbian spruce (Picea omorika (Panc.) Purk.). Plant Syst Evol 260: 53–63.

Darwin C (1859) On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life. John Murray, London.

Dawkins R (2009) The Greatest Show on Earth: The Evidence for Evolution. Free Press, New York – London – Toronto – Sydney.

Fairbanks DJ, Rytting B (2001) Mendelian controversies: A botanical and historical review. Am J Bot 88: 737–752.

Fisher RA (1930) The Genetical Theory of Natural Selection. Clarendon Press, Oxford.

Fisher RA (1936) Has Mendel's work been rediscovered? Annals of Science 1: 115–137.

Johnsen Ø, Fossdal CG, Nagy N, Molmann J, Dælen OG, Skrøppa T (2005) Climatic adaptation in Picea abies progenies is affected by the temperature during zygotic embryogenesis and seed maturation. Plant Cell Environ 28: 1090–1102.

Kawecki TJ, Ebert D (2004) Conceptual issues in local adaptation. Ecol Lett 7: 225–1241

Larson EJ (2006) Evolution: The Remarkable History of a Scientific Theory. Random House, New York.

Magri D, Vendramin GG, Comps B, Dupanloup I, Geburek T, Gömöry D, Latalowa M, Litt T, Paule L, Roure JM, Tantau I, van der Knaap WO, Petit RJ, de Beaulieu JL (2006) Palaeobotanical and genetic data outline the Quaternary history of European beech populations. New Phytol 171: 199–222.

Mendel JG (1866) Versuche über Pflanzenhybriden. Verhandlungen des naturforschenden Vereines in Brünn, Bd. IV, Abhandlungen 1865, S. 3–47.

Ramsey J, Ramsey TS (2014) Ecological studies of polyploidy in the 100 years following its discovery. Phil Trans R Soc B 369: 1471–2970.

Ries G, Heller W, Puchta H, Sandermann H, Seidlitz HK, Hohn B (2000) Elevated UV-B radiation reduces genome stability in plants. Nature 406, 98-101.

Sapp J (1990) The Nine Lives of Gregor Mendel. In: H. E. Le Grand (ed.), Experimental Inquiries , Kluwer Academic Publishers, Dordrecht, 137–166.

Taberlet P, Fumagalli L, Wust-Saucy AG, Cosson JF (1998) Comparative phylogeography and postglacial colonization routes in Europe. Mol Ecol 7: 453–464.

Vidaković M (1991) Conifers. Morphology and Variation. Grafički zavod Hrvatske, Zagreb.
Wright S (1931) Evolution in Mendelian populations. Genetics 16: 97–159.

Yakovlev IA, Fossdal CG, Johnsen Ø (2010) MicroRNAs, the epigenetic memory and climatic adaptation in Norway spruce. New Phytol 187: 1154–1169.

ACKNOWLEDGEMENT

The study was supported by a grant of the Slovak Research and Development Agency no. APVV-0135-12.

SUMMARY

Gregor Mendel je obecně znám především jako zakladatel genetiky, jeho práce v meteorologii a klimatologii vešla do obecného povědomí v podstatně menší míře. Tento příspěvek je věnován hledání styčných bodů obou těchto aspektů Mendelovy vědecké dráhy. Na příkladu lesních dřevin ukazuje, nakolik jsou informace o klimatu a jeho změnách nutné pro populační a evoluční genetiku, a naopak, nakolik mohou genetické nástroje dopomoci pochopení vývoje klimatu i jeho dopadů na živá společenství. Pro ilustraci jsou použity studie postglaciální rekolonizace areálu buku lesního v Evropě, genetických dopadů klimaticky podmíněné fragmentace areálu u smrku Pančićova, hodnocení adaptivní variability buku lesního v přesazovacím pokusu a epigenetická variabilita vegetativní fenologie u smrku ztepilého.

CONTACT

prof. Ing. Dušan Gömöry, DrSc.

Technical University in Zvolen, Faculty of Forestry

TG Masaryka 24, 96053 Zvolen, Slovakia

phone +42 45 5206226, e-mail gomory@tuzvo.sk

THE COMPARISON OF CALCULATED AND EXPERIMENTALLY DETERMINED AVAILABLE WATER SUPPLY IN THE ROOT ZONE OF SELECTED CROPS

J. HABERLE[1], P. SVOBODA[1], M. KOHÚT[2], G. KUREŠOVÁ[1]

1) *Crop Research Institute, Praha-Ruzyně, Czech Republic*
2) *Czech Hydrometeorological Institute, Brno, Czech Republic*

ABSTRACT

Determination of the water supply available in soils for crops is important for a calculation of the water balance, and the prediction of water shortages. Available water content, at several Czech Republic localities at the start of growth, were calculated with simple pedotransfer functions from the texture of soil layers, and compared to water contents to a depth of 130 cm, determined experimentally. Available water content in the root zone of selected crops was calculated from data on root density distribution and from the estimation of water depletion distribution.

Keywords: water shortage, root system, depletion, texture

INTRODUCTION

Drought poses a serious problem for farmers in a large part of the world. Under the climatic conditions of the Czech Republic, fluctuations of precipitation often cause water shortages at critical stages of growth; especially, during yield formation, when the winter supply of water is exhausted and precipitation is not sufficient to cover the high evapotranspirative demands of a crop.

Farmers have demanded innovations and tools from agricultural researchers to apply measures for reducing the negative impacts of drought. Improvements of water use effectiveness is an urgent task for applied crop research. It is evident that the approach for an effective solution must be complex and needs to include several measures: new stress tolerant and plastic cultivars, innovative technologies of seeding, fertilizing or soil tillage, use of growth regulators and anti-stress compounds, as well as measures for sustaining and enhancing soil water capacity. Root system traits and effective utilization of the water supply from the root zone is recognized as some of key factors in the effort.

Calculation of the available soil water supply for a crop is a need for predictions of the onset of water shortage, and decisions for the support of relevant agronomic measures on both the short- and long-term scales. Considering the water supply of a given field, the site, year, and cultivar-specific crop management demands reliable data on the availability of water from a soil profile. The distribution of roots in a soil profile is the basis for calculations of water and nutrient uptake from the different soil zones. Any description of root development, related to water and nutrient uptakes, includes many physiological, developmental, and morphological traits of greater and lesser importance. When calculating the uptake, the demand for water and nutrients is distributed according to root distribution and the availability of the source (e.g., Kuhlmann et al. 1989). Primarily, it is the root length distribution (root density) used; however, Himmelbauer et al. (2008) did not find significant differences between the water extraction functions (sink term) based on the root dry mass, length, or surface area density distribution of three crops. The maximum root penetration and rooting depth is important for determinations of the potential utilization of water reserves in the deep subsoil layers (e.g., Kirkegaard et al. 2007). The root density of annual crops decreases with depth; in most cases exponentially or near linearly (Haberle & Svoboda 2014, Zuo et al. 2013). Annual crops reach their maximum root length and depth at about the time of flowering; during seed growth the root depth does not significantly increase. In cases of an exhaustion of available water and nutrients from the top soil zones, the deep subsoil layers may represent a significant reserve for overcoming periods of temporary shortage (Kong et al. 2013).

Under farm conditions, simplified approaches for estimations of the available water supply for a given crop must be used. As the first step, the amount of water in the soil at the start of growth must be determined or estimated. It is often assumed in model calculations that soils reach their maximum available water content after winter, at the start of the regeneration of winter crops or at the start of the growth of spring crops. Further, the water available for root uptake needs to be specified. The maximum possible physiological depletion of water from the root zone can only be observed when water in the top soil is exhausted and the demand has been shifted to deeper and less densely rooted soil layers.

The aim of the study was to compare the calculated and observed available water contents in the soil, and to estimate the maximum possible depletion of the supply in relationship to the root distributions of several crops.

MATERIALS AND METHODS

At the start of spring growth of six crops, the soil gravimetric water content to a depth of 130 cm was determined in nine sites with different soil-climate conditions: Praha-Ruzyně, Chrášťany (near Rakovník), Čáslav, Lukavec at Pacov, Valečov, Ivanovice na Hané, Dlouhá Třebová, Sudslava, and Horní Dobrouč (the last three are in the Ústí nad Orlicí region). Winter wheat, oilseed rape, spring barley, potatoes, sunflower, and maize were observed both in field experiments and farm fields. Water content in the soil layers (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-90 cm, 90-110 cm, and 110-130 cm) was calculated from the soil moisture and soil volume weight. The soil texture was determined in the laboratory of Research Institute for Soil and Water Conservation (VÚMOP, Ing. H. Macurová).The available water capacity (AWC) of the soil layers was calculated from the field capacity and wilting point (AWC=FC-WP), estimated with simple pedotransfer functions (Váša 1958, Váša 1960, Saxton et al. 1986, Novotný et al. 1990). Average values of FC and of WP calculated according to the authors were used for the following analysis. The values of AWC were reduced according to the content of soil particles greater than 2 mm in the respective soil layers.

The calculated AWC (to a depth of 100 cm or 130 cm), which represents the theoretical maximum water reserve for a crop, was compared with the experimentally determined available water content at the start of crop growth. For the latter, wilting points, calculated from soil texture were used (as also for the calculation of AWC), as no reliable data on the hydrolimit were available. Further, precipitation and potential evapotranspiration sums calculated (according to Allen et al. (1998) from the 1st of October to the term of sampling are presented for the experimental sites.

Finally, the theoretical available water contents of the soil layers, determined from soil texture (AWC) and with observations in the fields, was corrected according to observed distributions of root density of the crop (Haberle, Svoboda 2012, 2014, Svoboda, Haberle 2006, and others). The roots were sampled after flowering, during seed filling, and tuber growth; at the stage of the maximum rooting depth. The cases with the lowest and highest root depth observed during several years in two or more sites (not only the experimental ones described here) were used to obtain more generally applicable outputs (Fig. 1). For a calculation of available water for the roots, a simplified empirical approach was used, based on previous studies (Haberle, Svoboda, 2012) and field observations of apparent depletion of soil water from the root zones of crops. The maximum utilization of water from the root zone is realized under conditions of well-developed root systems and crop canopy; with great evaporative demand, exhaustion of the available water from the top soil, and gradual depletion of water from the subsoil layers. We assume that 90% of potentially available water (AWC) from the arable layer is available for all crops, as the level of the wilting point is hardly attainable in field conditions, even under severe drought. In the subsoil layers, the potential maximum depletion decreases in direct relationship to the root density (RD). The maximum depletion (90%) of the amount of potentially available water (AWC) is used for RD greater than 0.9 $cm.cm^{-3}$. For the root density under 0.9 $cm.cm^{-3}$, the potential water depletion is proportionally related to root density (e.g., a RD of 0.15 $cm.cm^{-3}$ enables a utilization of up to 15% of AWC).

From the data, root available water contents in a soil profile for the cases of maximum (AWC), as well as for the range (minimum and maximum), of the observed spring water contents for the lowest and the highest root densities were calculated and compared. The results represent ranges of water supply attainable for six crops at nine sites.

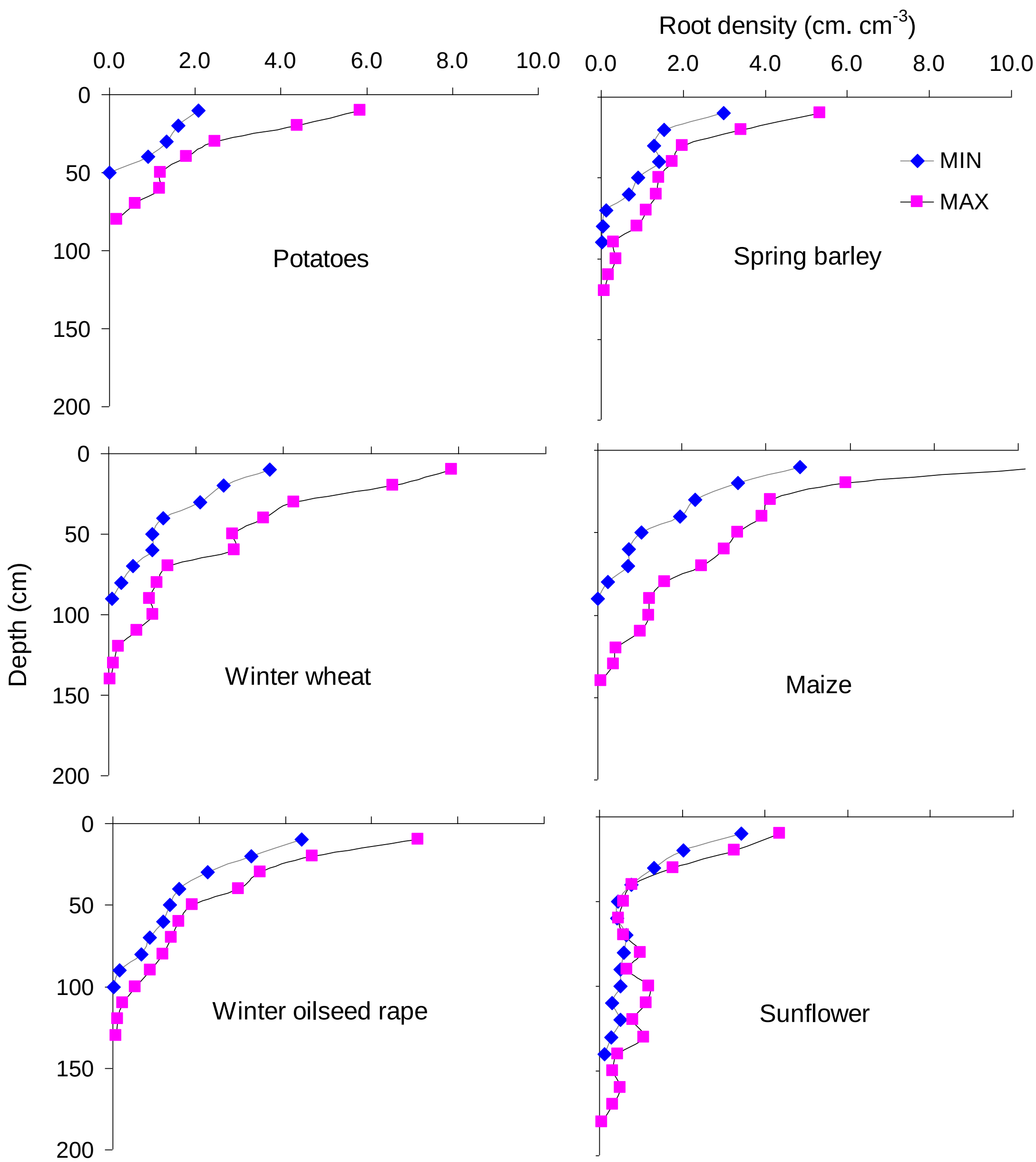


Fig.1: The lowest (MIN) and the highest (MAX) root densities observed in selected crops.

RESULTS AND DISCUSSION

The lowest and the highest observed root depth and density in the field are shown in Fig. 1. The differences are more pronounced in maize and winter wheat than in the other crops; however, the data can not cover the diversity of soil conditions in agricultural regions of the country. Also, the numbers of our experimental data are not balanced; we have gained in past years more results for cereals (especially winter wheat) than for sunflower or maize. Using the crop model CERES-Wheat, we showed that relatively small differences in root distribution had some impacts on simulated yield and water use but the effect seems small in comparison with other sources of uncertainty (Haberle, Svoboda 2014). Generally, the root depth of the crops corresponded to the published data and expected ranking of the crops: from shallow rooted potatoes, with less depth in spring cereals compared with winter one and maize, and a deep root system in the sunflower.

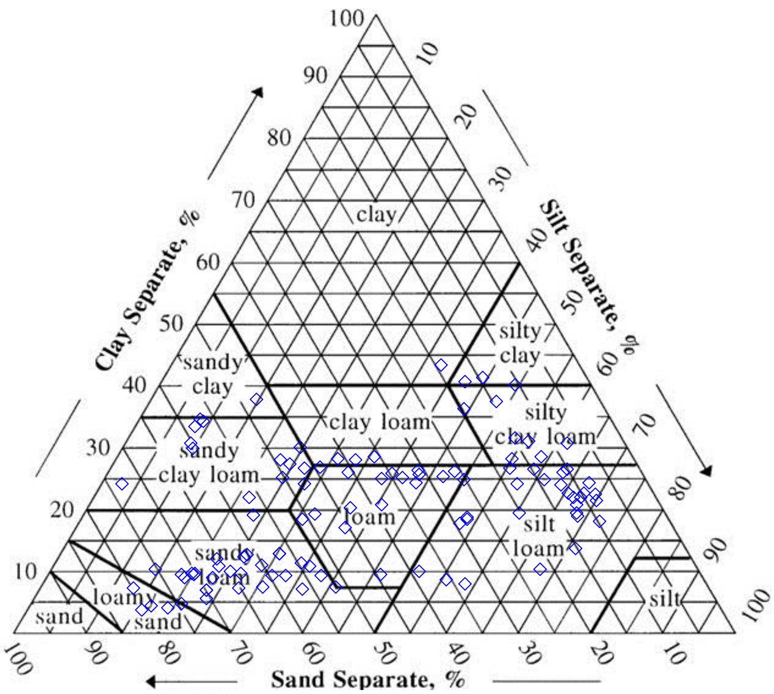


Fig. 2: The texture of soil layers at experimental sites drawn upon a background of a soil texture triangle.

The range of textures of the soil layers in the sites is shown on the basis of a soil triangle classification (Fig. 2). The textures ranged from sandy to clay soils; often but not always, the proportion of sand and gravel increased with depth. The calculated AWC in the 1 m soil layer ranged from 144 mm (178 mm in the 130 cm layer) in Chrášťany to 188 mm (241 mm) in Ivanovice (Fig. 3). When individual PTF were used, the range of AWC was wider - from 126 to 227 mm (150 - 270 mm) (not shown), which shows onother source of uncertainty of the analysis. Comparison with data in the literature is difficult, as the approaches and calculations differ greatly. Often, the classes of soil with ranges of AWC from less than 79 mm to greater than 200 mm, in one meter of soil, are used for Czech soils (e.g., http://sucho.vumop.cz/mapserv/sucho/uvodni.php) or in the AVISO agroclimatic model (Richterová, Kohut, 2013). In the cases gravel and stone content was probably not considered. AWCs used in the current CGMS for the region of the Czech Republic are mostly in the range of 75-175 mm (http://eusoils.jrc.ec.europa.eu/projects/sinfo/5_3_en.htm).

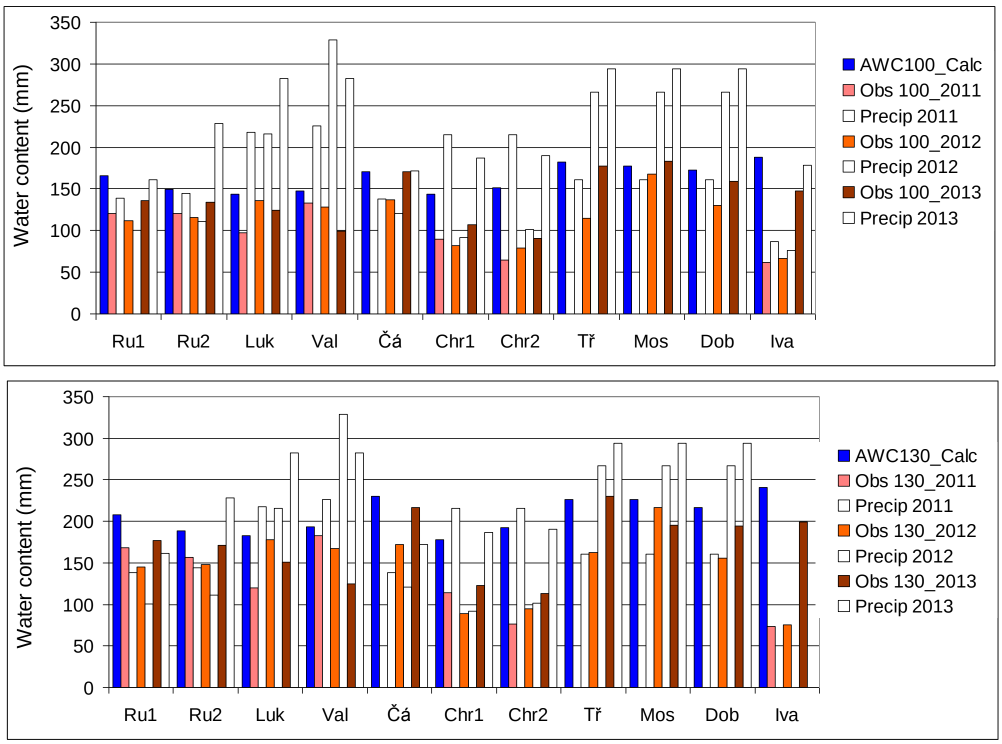


Fig. 3: Comparison of the calculated available water capacity (AWC), in the 100 cm (top) and 130 cm soil layers (bottom), with the observed available water content (Obs) in spring 2011-2013 at several sites. The sum of precipitation from 1st of October of the previous year to sampling term is indicated by white columns.

The observed available water content in the 1 m layer at the experimental sites at the start of growth ranged from 62 to 188 mm (73 mm to 241 mm in 0 - 130 cm) in the experimental years (Fig. 4). Both minimum and maximum values were observed at Ivanovice. Maximum spring water content at 0 - 130 cm, observed during two or three years, was by 0% to 17% lower than the content calculated with PTF functions. This confirms the reasonable prediction of AWC, considering the short experimental period and water losses by evapotranspiration from the soil.

Only in two fields in Chrášťany was the observed AWC (by 37% and 41%) lower than the AWC calculated with PTF. These soils have a high content of gravel and stones, possibly enhancing water percolation and evaporation. Comparison of the observed AWC with the precipitation sums (from October 1st of previous years) (Fig. 4) suggests that the soil traits strongly determine the filling of the soil water capacity. The relatively high precipitation in some sites (Valečov, and Lukavec) was not reflected in a significantly higher filing of soil water capacity. Calculated evapotranspiration from autumn to the sampling term is interesting for the comparison of sites with both a high water capacity and high evapotranspiration.

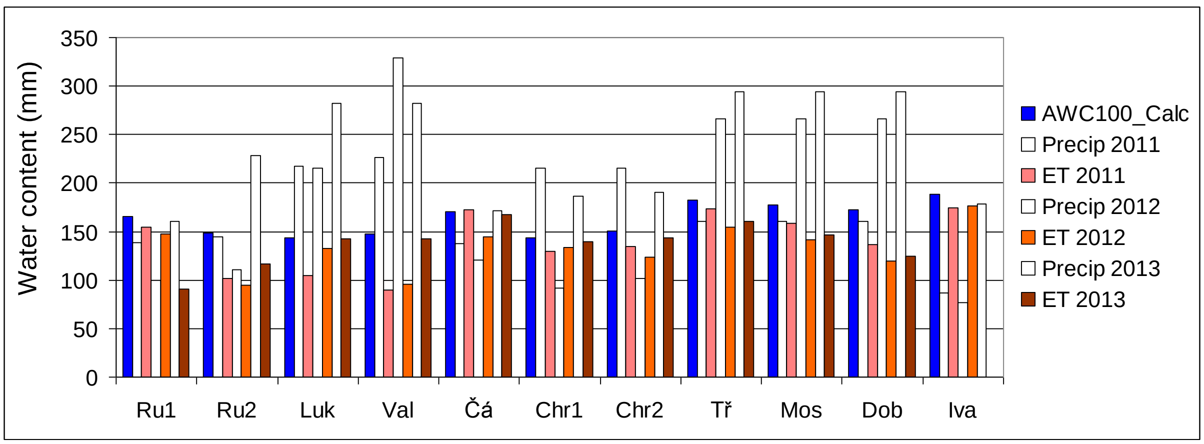
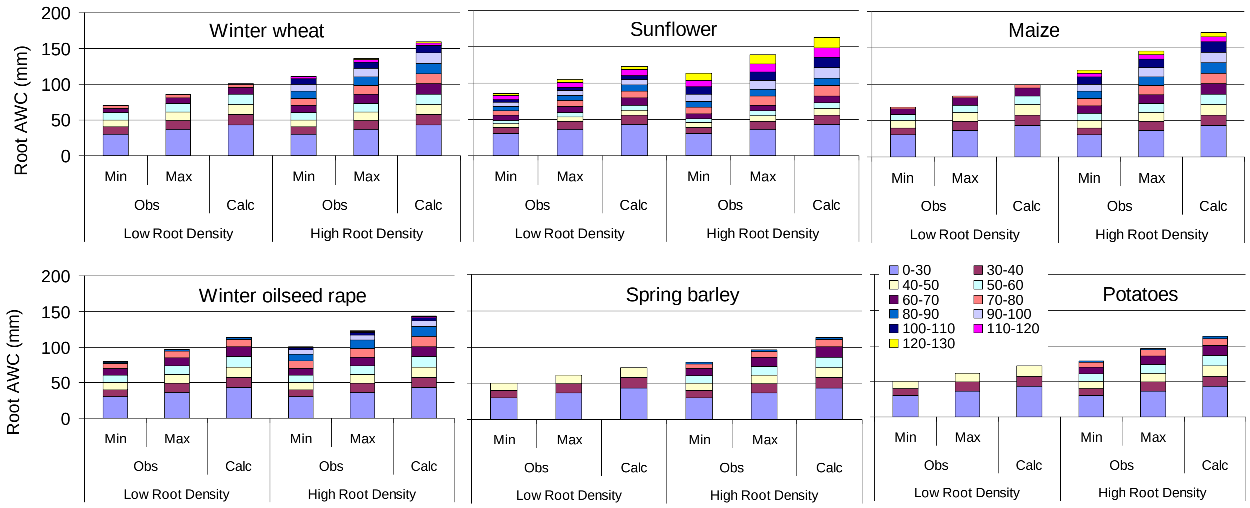
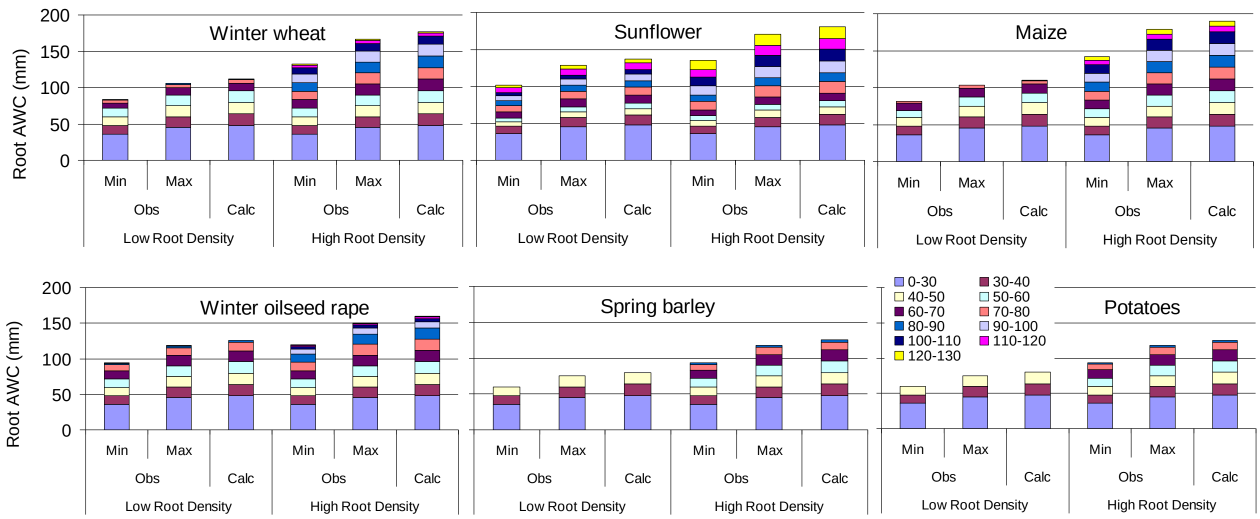


Fig. 4: Comparison of calculated soil AWC in the 100 cm layer, precipitation, and potential evapotranspiration from (1st of October of the previous year to sampling term) in years 2011-2013 at the experimental sites.


Winter wheat
Sunflower
Maize
Winter oilseed rape
Spring barley
Potatoes
Root AWC (mm)
200
150
100
50
0
Min
Max
Obs
Calc
Low Root Density
High Root Density
0-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130


Winter wheat
Sunflower
Maize
Winter oilseed rape
Spring barley
Potatoes
Root AWC (mm)
200
150
100
50
0
Min
Max
Obs
Calc
Low Root Density
High Root Density
0-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130

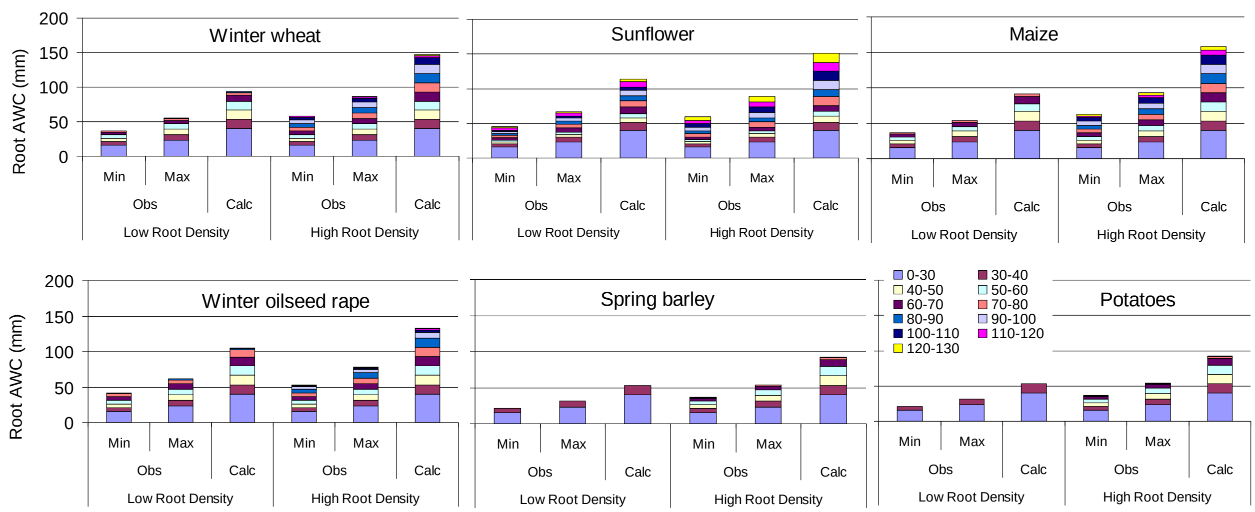

Winter wheat
Sunflower
Maize
Winter oilseed rape
Spring barley
Potatoes
Root AWC (mm)
200
150
100
50
0
Min
Max
Obs
Calc
Low Root Density
High Root Density
0-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130

Fig. 5: Potential maximum depletion of water under combinations of root distributions, and water contents, at selected sites and crops. From top to bottom: Ruzyně, Čáslav, Chrášťany Introduction of an estimation of water depletion distribution, according to root density distribution, significantly modified the amount of available water for the evaluated crops. The combination of the observed low and high root densities, with the calculated and spring water contents, produced a wide range of potentially available amounts of water at the experimental sites.

Conclusion

The calculations presented have a model characteristic, but they represent a range of possible water supply situations, considering distribution of the roots in sites with different soil conditions. The results contribute to a more realistic and reliable estimation of water available to crops, which is especially important under conditions of water shortage.

References

Allen R.G., Pereira L.S., Raies D., Smith M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, United Nations, Rome, I., pp.300.

Haberle J., Svoboda P. 2014. Impacts of use of observed and exponential functions of root distribution in soil on water utilisation and yield of wheat, simulated with a crop model. Archives Agron.Crop Sci. 60: 1533-1542.

Haberle J., Svoboda P. 2012. Distribution of wheat roots in soil profile and available water and nitrogen supply (Distribuce kořenů pšenice v půdním profilu a využitelná zásoba dusíku a vody. Úroda, 60: 79-84 (vědecká příloha, CD).

Himmelbauer M.L., Novák V., Majerčák J. 2008. Sensitivity of soil water content profiles in the root zone to extraction functions based on different root morphological parameters. J. Hydrol. Hydromech. 56: 34-44.

Kirkegaard J.A., Lilley J.M., Howe G.N., Graham J.M. 2007. Impact of subsoil water use on wheat yield. Aust J Agr Res. 58:303–315.

Kong L., Si J., Sun M., Feng B., Zhang B., Li S., Wang Z., Wang F. 2013. Deep roots are pivotal for regulating post-anthesis leaf senescence in wheat (Triticum aestivum L.). J. Agron. Crop Sci. 199: 209–216.

Kuhlmann H., Barraclough P.B., Weir A.H. 1989. Utilization of mineral nitrogen in the subsoil by winter wheat. Z. Pflanzenernaehr. Bodenk.152: 291-295.

Novotný M., Kervališvili D.M., Šanta M. 1990. Závlaha poľných a špeciálnych plodín. 1. vydání, Bratislava, PRÍRODA 2012: 312 s.

Richterová D, Kohut M. 2013. Monitoring of drought on the CHMI website. In: Mendel net 2013: 362-366.

Saxton K.E., Rawls W.J., Romberger J.S., Papendick R.I.1986. Estimating generalized soil-water characteristics from texture. Soil Science Society of America Journal, 50: 1031 - 1036.

Svoboda P., Haberle J. 2006. The effect of nitrogen fertilization on root distribution of winter wheat. Plant, Soil and Environment, 52: 308–313.

Váša J. 1960. Půdní vláhové charakteristiky. Vodohospodársky časopis SAV, VIII: 235- 243.

Váša J. 1958. Měření výparu z vodní hladiny. Vodní Hospodářství, 8: 174.

Zuo Q, Zhang R., Shi J. 2013. Characterization of the root length density distribution of wheat using a generalized function. In: Timlin D, Ahuja L.R. (eds). Advances in agricultural systems modelling. Chapter 4. Enhancing understanding and quantification of soil–root growth interactions: 93-117.

ACKNOWLEDGEMENT

The research was supported by the project of National Agency of Agricultural Research NAZV QI111C080 and by the Ministry of Agriculture, Research Plan of CRI RO0414.

SUMMARY

Určení zásoby vody v půdě dostupné pro plodiny je základem pro bilancování spotřeby vody a predikci nástupu nedostatku vody. Na několika lokalitách v České republice byla porovnána maximální dostupná zásoba vody v půdě vypočtená pomocí jednoduchých pedotransferových funkcí ze zrnitostního složení vrstev půdy a obsah vody do hloubky 130 cm určený experimentálně. Na základě údajů o hloubce kořenů plodin a odhadu distribuce příjmu vody bylo vypočteno množství dostupné vody v kořenové zóně plodin. Výsledky jsou příspěvkem pro spolehlivější odhad nástupu vodního stresu na základě bilance vody.

CONTACT

Ing. Jan Haberle, CSc

Výzkumný ústav rostlinné výroby

Drnovská 507, 101 00 Praha 6

+42 233022254, haberle@vurv.cz

HISTORY AND PRESENT OF PHENOLOGICAL OBSERVATIONS OR PHENOLOGY AT THE CROSSROAD

LENKA HÁJKOVÁ[1], VĚRA KOŽNAROVÁ[2], MARTIN MOŽNÝ[3]

1) *CHMI, Department of Biometeorological Applications, Na Šabatce 17, 143 06 Prague 4 – Komořany, Czech Republic, hajkova@chmi.cz*
2) Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Prague 6 – Suchdol, Czech Republic, koznarova@af.czu.cz
3) CHMI, Agrometeorological Observatory Doksany, 411 82 Doksany, Czech Republic, martin.mozny@chmi.cz

ABSTRACT

Periodicity in the life of plants and animals is considered to be an indirect indicator for the periodicity in the climate. Global climate change impacts can already be tracked in many physical and biological systems; in particular, terrestrial ecosystems provide a consistent picture of observed changes. Therefore phenological observations are among the most sensitive data for climate impact studies on vegetation at midlatitudes (Hájková, Kožnarová, 2013).

Within the last decade the scientific community's view of phenology as a harmless pastime of natural historians has changed dramatically, because the value of phenological data in climate change research has been recognized (Menzel, 2002). The phenological observations recorded significant changes in recent years, except for subjective monitoring voluntary observers under the established methodology; the phenological records are also obtained through the calendar of nature (e.g. USA) and by special cameras designed for phenological monitoring. This paper summarizes the history and present of phenological observations in the Czech Republic; it also describes the cooperation within the phenology field with the aim to unify the analyses, and thus the possibility of further development of this scientific branch.

First results from the records of phenological cameras show the possibility of using this method as a replacement for conventional phenological observations in the Czech Republic.

Key words: phenology, climate change, USA NPN, PEP 725, phenological camera

INTRODUCTION

Phenology, the description of the development stages of wild plants, agricultural fruit and crops, and other organism (for instance insects) has several well-defined applications, in addition to its use in simultaneous models. Commonly observed phenological events include the timing of sprouting and flowering of plants in the spring, colour changes of plants in the fall, bird migration, insect hatches, and animal hibernation. Certain agricultural activities often require advanced information on the dates of specific stages of crop development. Because the occurrences of such seasonal phenomena are generally initiated and driven by climate, phenological record is a sensitive proxy for investigating climate change and its influences on ecosystems over time (Hájková et *al*., 2013). Climate change has both direct and indirect impacts on crop growth and development. Higher ambient levels of carbon dioxide have an impact on C crops by increasing photosynthesis and decreasing water use. Indirect effects result from changes in weather and climate that are caused by higher levels of greenhouse gases. These changes may be within, or beyond, the current observed range of climate variability. Faced with the prospect of global warming, information has been needed about how natural systems may respond. Because of the volume of data, phenology has proved extremely useful in this respect (Menzel and Estrella, 2001). System of phenological observations has changed during the last decades, and the phenology plays more and more important role in the climate change research. The introduction is divided into 4 main parts to describe the history, present and future of phenological observations in the Czech Republic and in the world. Division: 1. History and present of phenological observations in the Czech Republic; 2. Pan European Phenology – PEP 725; 3. USA National Phenology Network and 4. Phenological monitoring by cameras in the Czech Republic.

1. The history of phenological observations in the Czech Republic

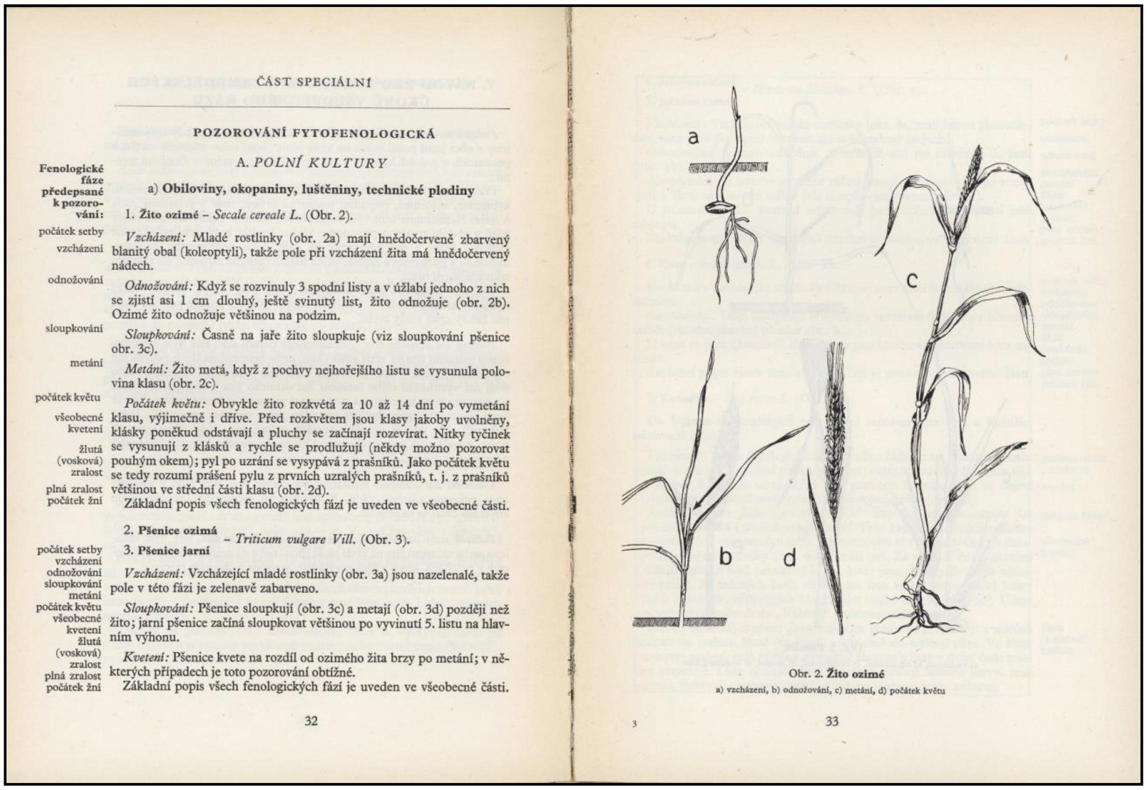
Phenological observations have a long tradition in Czech Lands (Czech Republic later on). The first Czech meteorologists J. Stepling, A. Strnad and M. A. David, whose activities are known from the second half of the 18th century and David's from the 19th century as well, devoted themselves to studying the influence of weather on the life of plants and animals. A. Strnad attached his remarks to regular measures, which he carried out at the Prague observatory from the 1st January, 1775 up to nearly the end of his life (23rd September, 1799). A number of these phenological observations is also attached to his paper "Meteorologischer Beytrag auf das Jahr 1792". A longer article, containing an economic survey of the year 1791, was published by Strnad in Mannheim Eefemeridas Efemeridés with the heading „Conditio anni generalis"(Seydl, 1954). The Mannheim or Falc meteorological society (Societas meteorologica Palatina), was assigned on the 15th September 1780 as a "meteorological class" to the Academy of Sciences, which has been in existence in Mannheim since 1763, and worked till 1799. The first phenological calendar in our literature was published by Med. Dr. Tadeáš Haenke in his longer paper „Blumenkalendar fűr Noumen in Jahre 1786". The author carried out in the years 1784 and 1785 a detailed observation on the earlier and later beginning of spring, on its course and the changes of plants during this time (Seydl, 1954).

The principles for regular and methodologically unified phenological observations in a station net were laid by the Swedish botanist Carl von Linné. He established the network of 18 stations in Sweden in the years 1752–1755. Regular phenological observations in the Czech countries were first introduced by the Patriotic – economic company, the successor of K. k. Ackerbau-Gesellschaft, based in 1769 as an order of the Empress Maria Teresia in Prague for the enhancement of agriculture. The following phenological elements were observed: the development of buds into leaves, the beginning of blossoming, and the end of blossoming, maturation of seeds. Further, some animals e.g. bats, hamsters, badgers, snakes and lizards, frogs, which do not leave our countries and hibernate in winter, mainly their awakening in spring and the beginning of hibernation were observed. The Prague lawyer Karl Fritsch as a significant part of his work in the field of phenology. His first work on phenology was devoted to the influence of weather on vegetation. In the paper „Elemente zu einer Untersuchung űber den Einfluss der Witterung auf die Vegetation"Fritsch explained the link between the yearly amount of warmth and moisture to the most important phases of the development of a plant, he presents eight charts of meteorological data (e.g. gradual total of positive values of the air temperatures, the differences in gradual total of precipitation) (Seydl, 1954).

The state phenological service was organized in Moravia by the Department for soil science and agricultural meteorology of the Regional research office of agriculture in Brno. Novák set up in 1923 one of the first national phenological services in the world. The observation net was soon so extensive (with 650 observers involved in its activities), that it was unsustainable in the long term. The organization of phenological services was so sophisticated, several challenges in newspapers and professional press were published in order to acquire other observation sites, national schools and public corporations were asked for cooperation (Hájková *et al*., 2012). The results of these observations were gradually processed in a long-term average of phenological phases, the so-called phenography. Coming out of these observations, phenological yearbooks were published, with map enclosures for the years 1923 and 1924 – and thus the principles of the beginning of the Czech phenography were laid. The phenological phases follow one after the other in a certain stable order; the first phenological calendar was published by the above mentioned T. Haenke. Arising from these long-term phenological observations, we can create the so called "Calendars of nature" for a certain place and its surrounding. We can also add a border data of the beginnings of these phases (the earliest and the latest, their amplitudes, phenoanomaly, the curve of phenodynamics) (Brablec, 1952).

In 1939, all meteorological services in the area of protectorate Bohemia and Moravia were brought together and the Central meteorological institute for Bohemia and Moravia was established, from the year 1940, phenological observations were overtaken by the Czech meteorological service with the whole net (about 1 000 places) and the archive of data since 1923. From that time up to the present, the phenology makes up a part of the meteorological service, included in 1954 in the Hydrometeorological Institute (Miháliková, 1983; Krška & Vlasák, 2008).

Phenological observations were conducted according to the principles included in the Handbook for phenological observers from the year 1956 (Pifflová *et al*., 1956). It was determined for the observers of the institutes for general phenology, which served mainly the needs of agriculture production (Figure 1).



ČÁST SPECIÁLNÍ

POZOROVÁNÍ FYTOFENOLOGICKÁ

A. *POLNÍ KULTURY*

Fenologické fáze předepsané k pozorování:

a) **Obiloviny, okopaniny, luštěniny, technické plodiny**

1. **Žito ozimé** – *Secale cereale L.* (Obr. 2).

počátek setby

vzcházení — *Vzcházení:* Mladé rostlinky (obr. 2a) mají hnědočerveně zbarvený blanitý obal (koleoptyli), takže pole při vzcházení žita má hnědočervený nádech.

odnožování — *Odnožování:* Když se rozvinuly 3 spodní listy a v úžlabí jednoho z nich se zjistí asi 1 cm dlouhý, ještě svinutý list, žito odnožuje (obr. 2b). Ozimé žito odnožuje většinou na podzim.

sloupkování — *Sloupkování:* Časně na jaře žito sloupkuje (viz sloupkování pšenice obr. 3c).

metání — *Metání:* Žito metá, když z pochvy nejhořejšího listu se vysunula polovina klasu (obr. 2c).

počátek květu, všeobecné kvetení, žlutá (vosková) zralost, plná zralost, počátek žní — *Počátek květu:* Obvykle žito rozkvétá za 10 až 14 dní po vymetání klasu, výjimečně i dříve. Před rozkvětem jsou klasy jakoby uvolněny, klásky poněkud odstávají a pluchy se začínají rozevírat. Nitky tyčinek se vysunují z klásků a rychle se prodlužují (někdy možno pozorovat pouhým okem); pyl po uzrání se vysypává z prašníků. Jako počátek květu se tedy rozumí prášení pylu z prvních uzralých prašníků, t. j. z prašníků většinou ve střední části klasu (obr. 2d).

Základní popis všech fenologických fází je uveden ve všeobecné části.

2. **Pšenice ozimá**
3. **Pšenice jarní** – *Triticum vulgare Vill.* (Obr. 3).

počátek setby, vzcházení, odnožování, sloupkování, metání, počátek květu, všeobecné kvetení, žlutá (vosková) zralost, plná zralost, počátek žní

Vzcházení: Vzcházející mladé rostlinky (obr. 3a) jsou nazelenalé, takže pole v této fázi je zelenavě zabarveno.

Sloupkování: Pšenice sloupkují (obr. 3c) a metají (obr. 3d) později než žito; jarní pšenice začíná sloupkovat většinou po vyvinutí 5. listu na hlavním výhonu.

Kvetení: Pšenice kvete na rozdíl od ozimého žita brzy po metání; v některých případech je toto pozorování obtížné.

Základní popis všech fenologických fází je uveden ve všeobecné části.

32

Obr. 2. **Žito ozimé**

a) vzcházení, b) odnožování, c) metání, d) počátek květu

3

33

Figure 1. Handbook for phenological observers (1956) – demonstration

A constituent part of the handbook was also phenological observations of animals. The following phenomena were observed e.g. the date of arrival, mass arrival, the first singing, herding and departure of thrushes, martins, quails, cuckoos, swifts, larks, starlings and swallows. With bee melliferous, the first flight and the first congeries of pollen were observed.

A significant change in phenological observations came in the year 1983; observation sites were divided into stations observing field crops and fruit trees. Separate instructions for both types of stations were issued for observers. The transformation was finished in the year 1987 by issuing methodological instructions for the activities of phenological stations observing forest plants (from January 1st 1987). From January 1st 2005, Phenological atlas (Coufal *et al*., 2004) became an aid for observers in the net of the CHMI.

In the year 2004 a trial run of the database Oracle Phenodata started, for acquiring and storing phenological data (application pod Clidata in environment Oracle) and since 1st January 2005 phenological data have been stored in this database up to the present. Older data were transferred to this database from environment Excel, where they had been stored till that time.

The phenological net (till the year 2012) in the area of the Czech Republic was consisting of the three types of stations (forest plants, fruit trees, field crops). Voluntary observers monitor the beginnings of phenophase according to the methodological instructions of the CHMI (art. 2, 3 and 10 – in the year 2009 new, updated instructions for observers were issued), data are recorded in the phenological notepad and then transferred to current reports. Part of results of phenological observations in period 1991–2010 (Figure 8) were processed in the Atlas of Phenological conditions in Czechia (Hájková *et al*., 2012).

The latest change in the CHMI phenological observation network happened in the year 2013 January 1st) – the density of phenological stations has dramatically reduced – from more than 160 stations to 25 stations for the whole republic (Figure 2), only wild plants phenological stations have left.

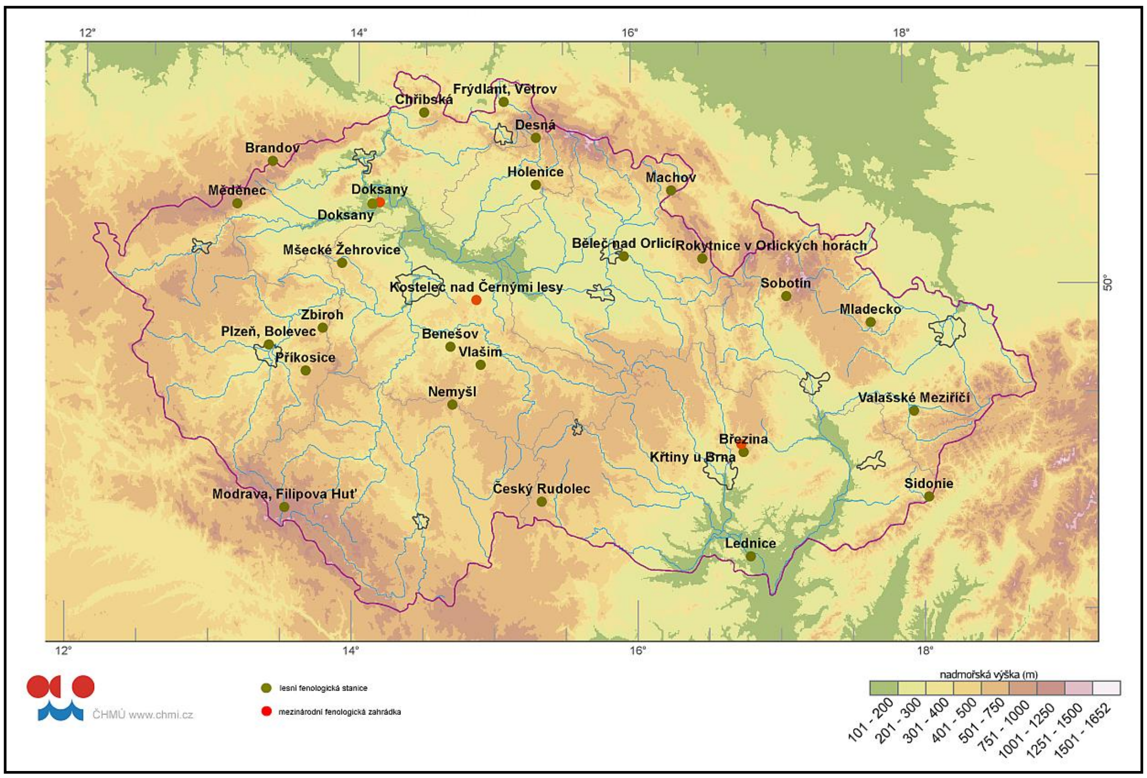


Figure 2. CHMI phenological stations

2. The Pan European Phenological Database (PEP 725)

Most European countries maintain networks that collect phenological data (Figure 3). For instance, the German Weather Service (Deustscher Wetterdienst, or DWD) currently runs a phenological network comprising approximately 1 550 stations. The phenological observation programme of DWD has 167 stages of development.

PEP725 (the successor of the COST Action 725) is a project funded by ZAMG, the Austrian ministry for science & research and EUMETNET (the network of European meteorological services) - with the goal to establish an open access database with plant phenology data sets for science, research and education.

The main objective of PEP725 is to: promote and facilitate phenological research by delivering a pan European phenological database with an open, unrestricted data access for science, research and education (data policy). So far 17 European meteorological services and 5 partners from different phenological network operators have joined PEP725 (Figure 3).

Currently the database implements:

- 9 003 075 observations,
- 20 375 locations,
- 254 different plants/cultivars.

To supply the data in a good and uniform quality it is essential to establish and develop data quality control procedures, so that the collected, partly new digitized historical resp. updated datasets, can be tested in an appropriate way. One of the main tasks within PEP725 was and still is the conception of a MULTI-STAGE-QUALITY CONTROL. Currently some tests are running in operational mode, others are in test or conception phase. They are stepwise performed in 6 various checks from A to F and FLAGGED in an appropriate way (0 default, 1 corrected, 2 interpolated, 3 pests-phases starts earlier, 101 completeness check, 102 plausibility check, 103 time consistency check, 104 spatial consistency check, 105 climatological check, and 106 inner consistency check). You can find more information at PEP 725 (www.pep725.eu).

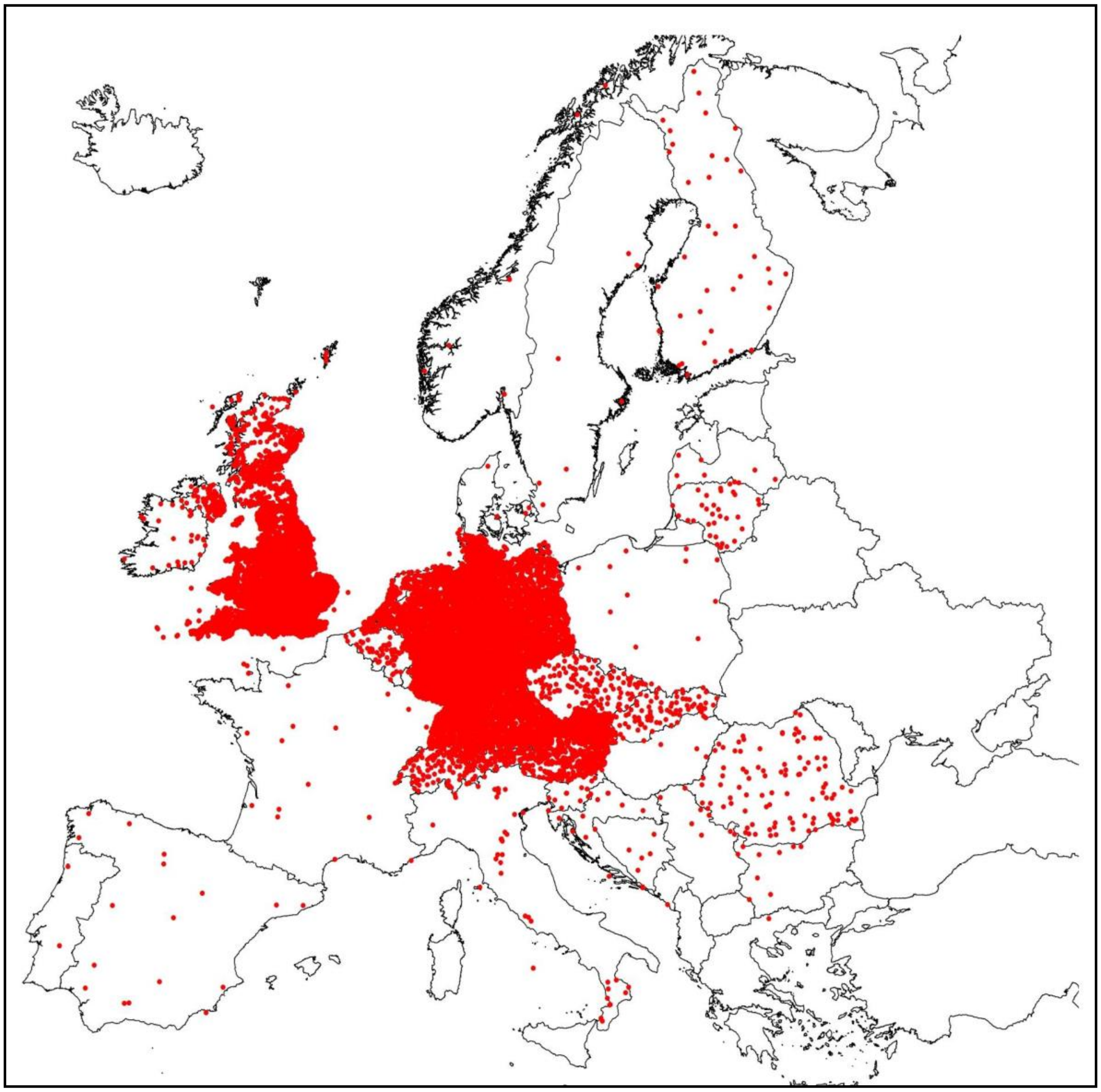


Figure 3. PEP 725 – station network.

3. The USA National Phenology Network

The USA National Phenology Network encourages people of all ages and backgrounds to observe and record phenology as a tool to discover and explore the nature and pace of our dynamic world. The Network makes phenology data, models, and related information freely available to empower scientists, resource managers and the public in decision-making and adaptation in response to variable and changing climates and environments. The National Coordinating Office (NCO) of the Network is a resource centre that facilitates and encourages widespread collection, integration, and sparing of phenology data and related information (for example, meteorological and hydrological data). The NCO develops and promotes standardized methods for field data collection and maintains several online user interfaces for data upload and download, as well as data exploration, visualization, and analysis. The NCO also facilitates basic and applied research related to phenology, the development of decision-support tools for resource managers and planners, and the design of educational and outreach materials and programs.

Changes in phenology affect human health by changing timing and patterns of allergy seasons. The Network is collaborating with many partners on a new project to predict the timing of human allergic reactions caused by juniper pollen. Researches intend to integrate data from citizen scientist observers of juniper phenology, satellite images of tree green-up, and data from health centre to better understand the dynamics of seasonal allergies. Better forecasting of environmental triggers can lead to more effective public health measures and, consequently, improved duality of life for seasonal allergy sufferers. The observations are made through Nature's Notebook all over the country on www.usanpn.org.

4. Phenological monitoring by cameras in the Czech Republic

Phenological observations of forest plants are time demanding and labor-intensive, the automated monitoring with digital cameras can serve as an alternative to substitute traditional phenological observations by human observers. The first results of phenological observation by phenological camera were processed in this contribution.

MATERIAL AND METHODS

The sensing with fixed cameras allows to obtain continuous data with high resolution and to describe the dynamics of canopy development by using simple vegetation indices (proportion of each colour) in deciduous trees.

Digital cameras (Figure 4) for long-term phenological observations of monitored tree are situated at the International Phenological Garden in Doksany (Czech Republic,50°27'31" N, 14°10'14" E, at 158 m asl, 45 km northwest of Prague).

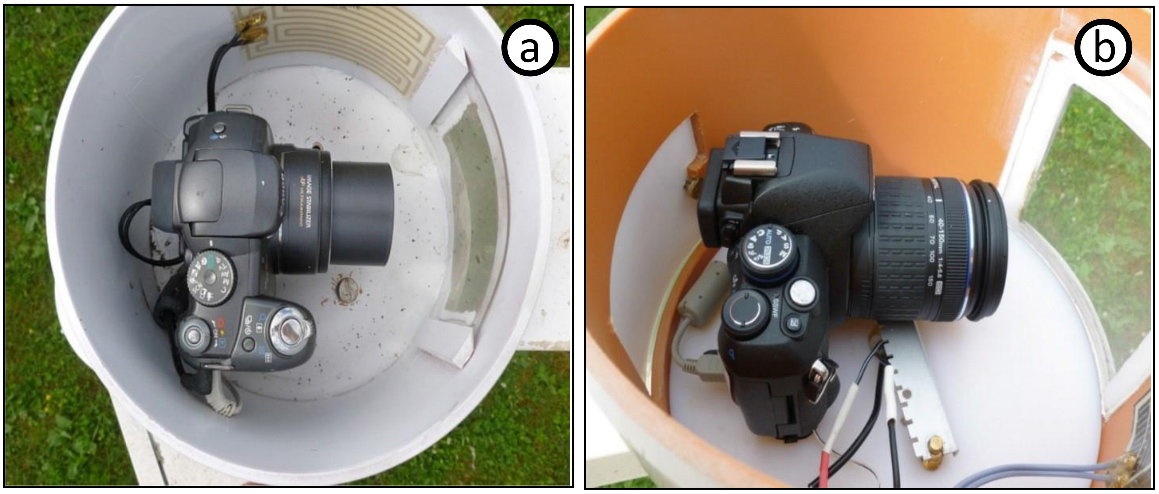


Figure 4. Digital cameras for phenological monitoring: a) Canon PowerShot S3 IS, b) Olympus E-410.

Canon Power Shot S3 IS and Olympus E-410 cameras made images in the automatic mode every hour (05 am – 7 pm) during the whole vegetation period. This monitoring was supplemented by measurements of CO_2 (LI-6252) and Normalized Difference Vegetation Index (sensor Skye SKR-1800). Red-green-blue (RGB) colour channel information from digital images can be separately extracted in digital form (by using Sigma Scan Pro 5.0 software) and subsequently summarized through Green Index (GI = G/[R+G+B]). To reduce the effects of changes in scene illumination we used the method by Sonnentag *et al*., 2012. We used a moving window approach that assigns the 90th percentile of all daytime values within a three-day window to the centre day (per90), resulting in three-day gcc. First, we calculated gcc for each species, then the average value of gcc. Local polynomial regression fitting (Loess curve; Cleveland and Devlin, 1988) with a low degree of smoothing of gcc was used.

Results and discussion

The results demonstrate the possibility of using models as an appropriate tool for monitoring temporal changes in canopy development and phenological events. The relationship between Green Index and optimized Growing Season Index (iGSI) was found (R^2 = 0.92, $p < 0.01$). Subsequently the relationship between iGSI and Normalized Difference Vegetation Index are represented by results R^2 = 0.7, $p < 0.01$ and Net Ecosystem Exchange is characterized by R^2 = 0.81, $p < 0.01$. Comparison of the dynamics of NDVI is shown in Figure 5.

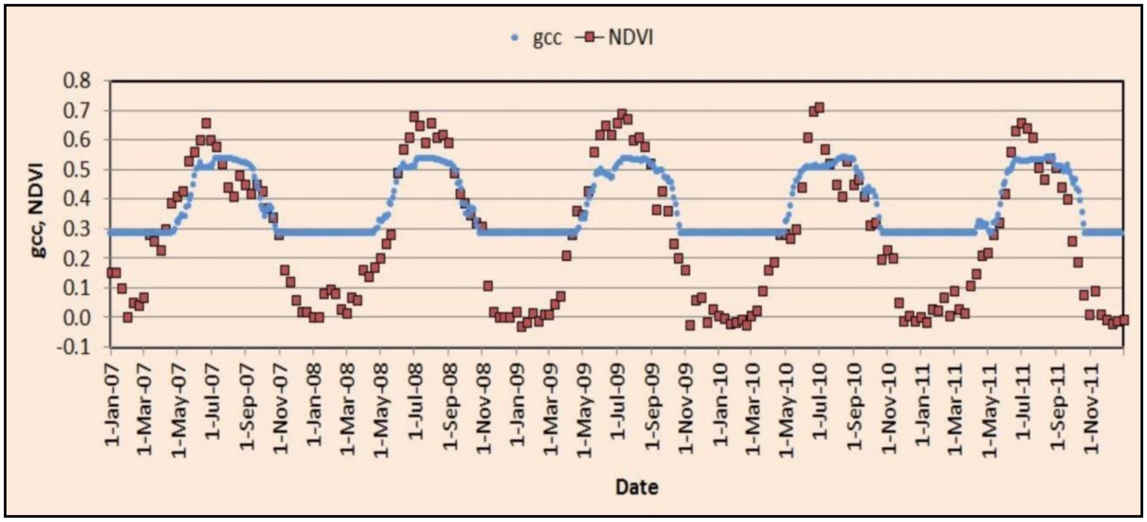


Figure 5. Comparison of the dynamics of NDVI (Source: MODIS – Terra satellite; resolution 250 m) and the green chromatic coordinate (gcc).

The daily gross primary productivity (GPP) in the interval (10 days) is shown in Fig. 6.

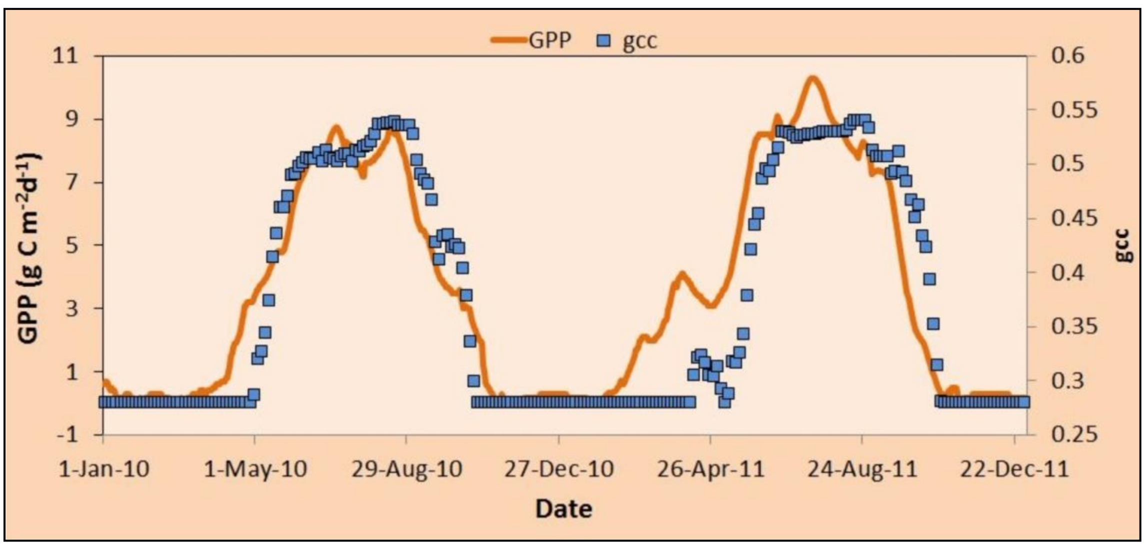
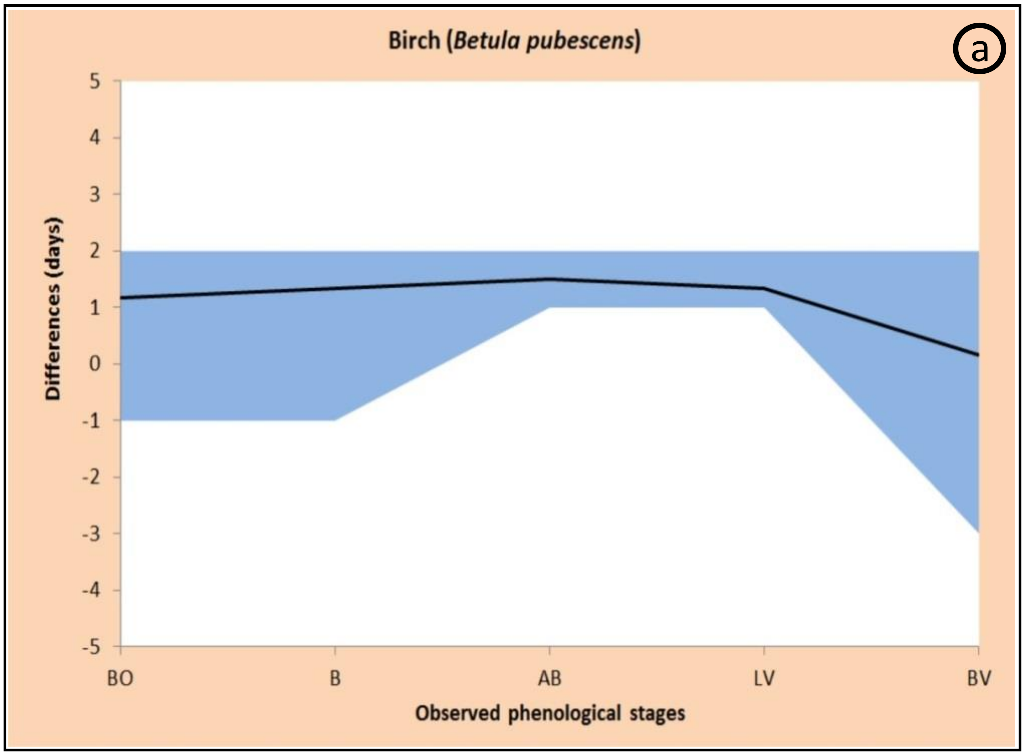
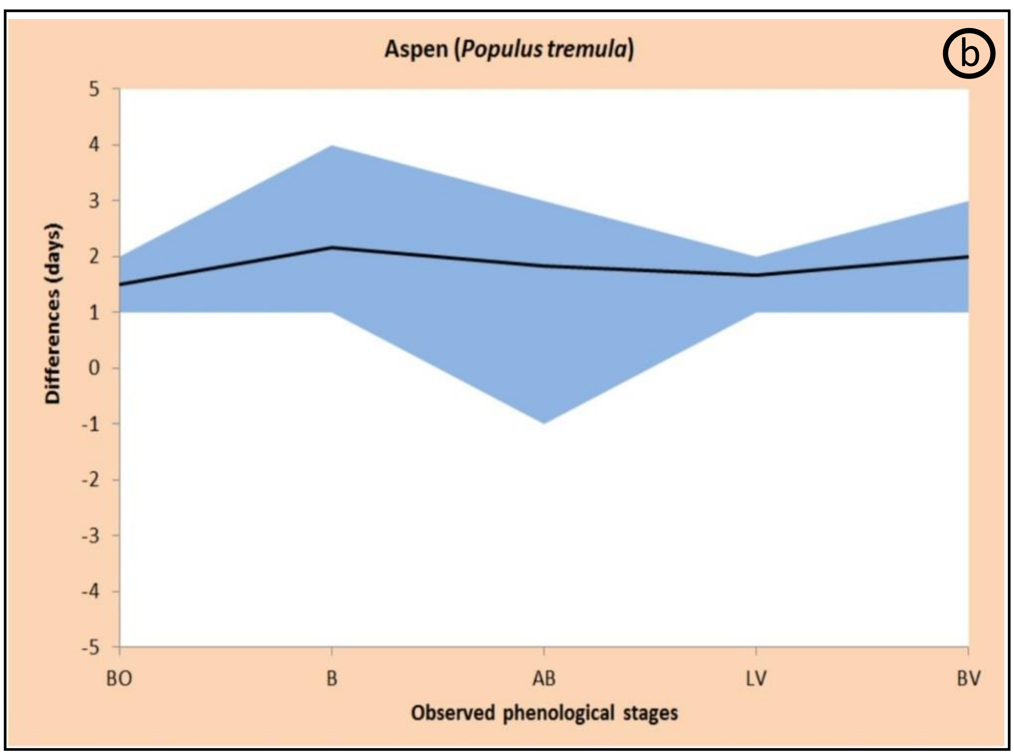
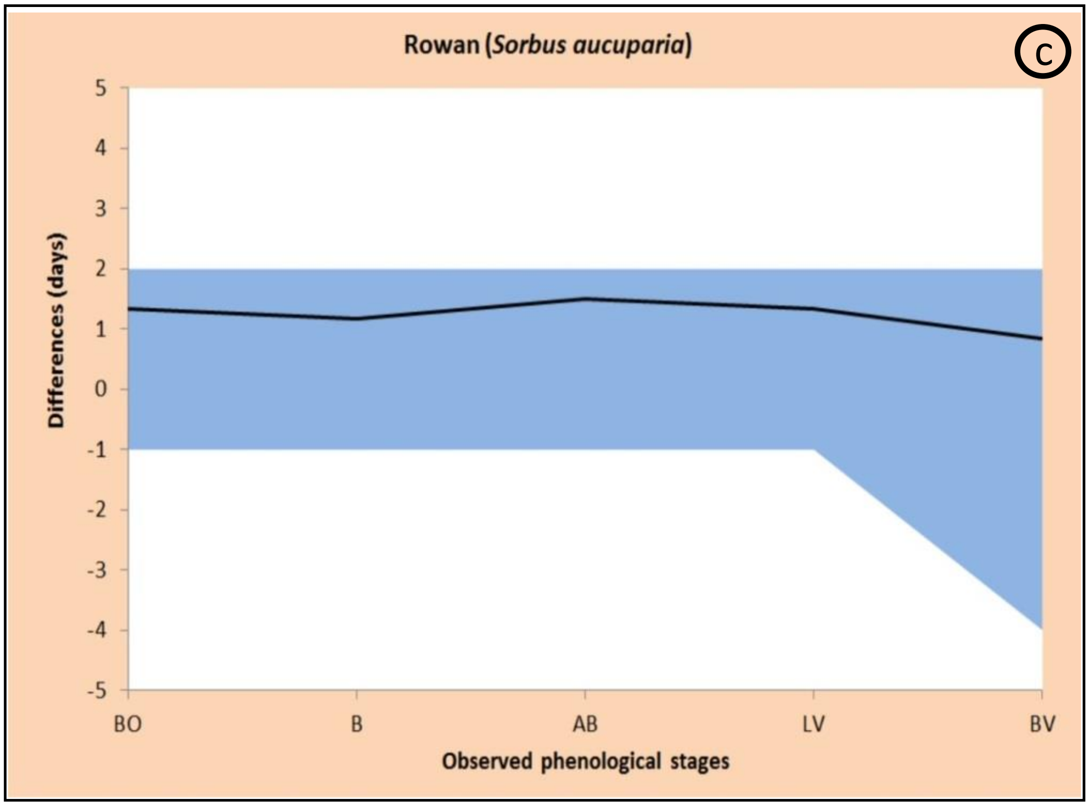


Figure 6. Daily gross primary productivity (GPP) averaged over 10-day intervals and the green chromatic coordinate (gcc) derived from digital camera imagery as the average.

The differences between the traditional manual phenological observations (TM) and the camera systems (CS) fluctuated between –2 and 2 days. These results are shown in Figure 7.


Birch (*Betula pubescens*)
a
Differences (days)
5
4
3
2
1
0
-1
-2
-3
-4
-5
BO
B
AB
LV
BV
Observed phenological stages


Aspen (*Populus tremula*)
b
Differences (days)
5
4
3
2
1
0
-1
-2
-3
-4
-5
BO
B
AB
LV
BV
Observed phenological stages


Rowan (*Sorbus aucuparia*)
c
5
4
3
2
1
0
-1
-2
-3
-4
-5
Differences (days)
BO
B
AB
LV
BV
Observed phenological stages

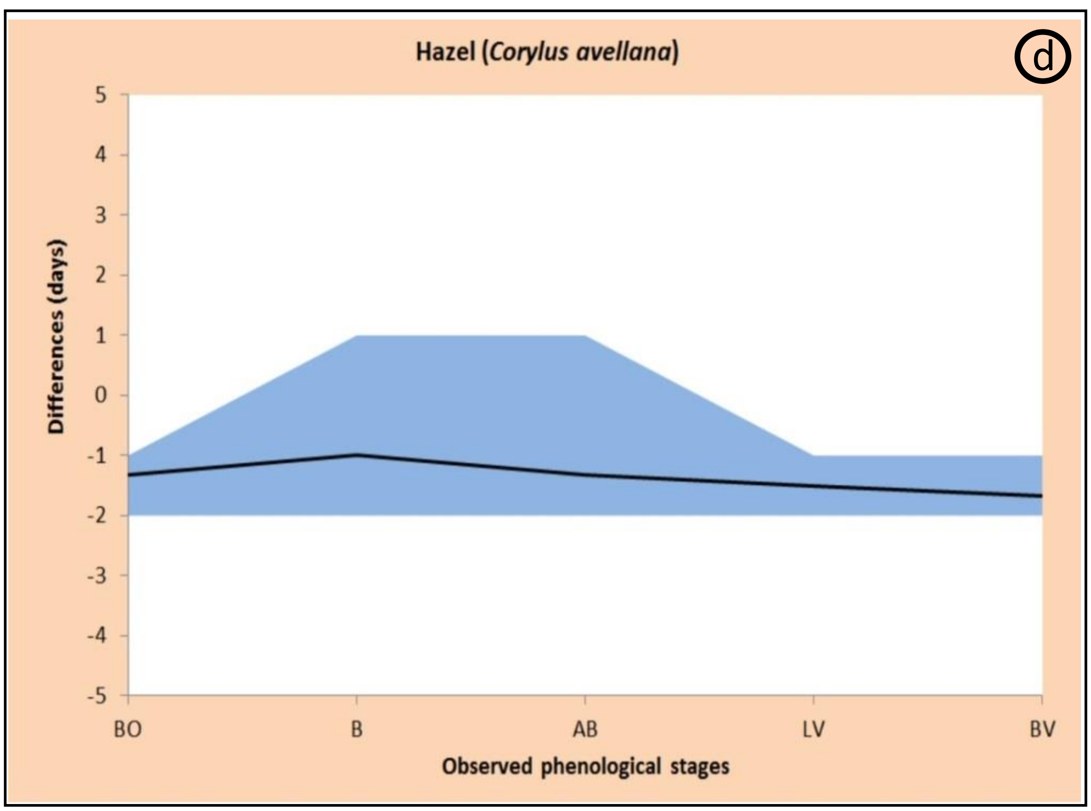

Hazel (*Corylus avellana*)
d
5
4
3
2
1
0
-1
-2
-3
-4
-5
Differences (days)
BO
B
AB
LV
BV
Observed phenological stages

Figure 7. The mean phenophase difference of a) Betula pubescens (birch), b) Populus tremula (aspen), c) Sorbus aucuparia (rowan) and d) Corylus avellana (hazel) between traditional manual monitoring and camera system for the period of comparison 2007–2012 at IPG Doksany. Blue area shows the range of values.

Conclusions

The history of phenological observation in the Czech Republic is rather long, even though there were many changes in the recent years. It is really important to thicken the current phenological network in the Czech Republic by usage of the latest phenological methods used in the world. The CHMI is a member of the PEP 725 (phenological data are supplied continuously every year). The PEP 725 outlook: development of more sophisticated QC routines, data import and exchange in operational mode, implementation of new / historical datasets, implementation of animal observations and definition of pseudo BBCH codes, redesign of table plant with uniform taxonomical descriptions and acquisition of new members/partners

The continuous monitoring with digital cameras can serve as an alternative to traditional phenological observations, the gcc is an appropriate tool for monitoring temporal changes in canopy development and phenological events and the gcc provides data required for the calibration and direct validation of satellite observations and products. The high correlation between the iGSI and the net ecosystem carbon exchange proved that CO_2 exchange processes depend significantly on the canopy development.

References

Brablec, J. (1952). Two studies about phenology. Meteorological Bulletin 5, č. 3, pp. 74 -75.
Cleveland, W. S. and Devlin, S. J. (1988). Locally Weighted Regression: An Approach to Regression Analysis by Local Fitting. Journal of American Statistical Association, Volume 83, Issue 403, 1988, pp. 596–610.

Coufal, L. et al (2004). Phenology atlas. 1. edition. Praha: CHMI. 264 p. ISBN 80-86690-21-0.

Hájková, L., Kožnarová, V. (2013). Variability of phenological stages of Dactylis glomerata in dependence on meteorological conditions in the Czech Republic. Allergo Journal, October 2013, Volume 22, Issue 7, pp. 488-489.

Hájková, L., Kožnarová, V., Bachanová, S. Nekovář, J. (2013). Phenological characteristics of selected forest plants in the Czech Republic. Praha: CHMI. 82 p. ISBN 978-80-87577-22-6.

Hájková, L. et al. (2012): Atlas fenologických poměrů Česka. Praha, ČHMÚ, ISBN 978-80-86690-98-8, 312 s.

Hájková, L., Nekovář, J., Richterová, D., Kožnarová, V., Sulovská, S., Vávra, A., Vondráková, A., Voženílek, V. (2012). Chapter 5: Phenological Observation in the Czech Republic - History and Present. In: Phenology and Climate Change, Dr. Xiaoyang Zhang (Ed.), ISBN: 978-953-51-0336-3, InTech, Available from: http://www.intechopen. com/books/phenology-and-climate-change/phenological-observation-in-the-czechrepublic-history-and-present.

Krška, K. & Vlasák, V. (2008). History and present of hydrometeorological service in South Moravia. Praha 2008, ISBN 978-80-86690-52-0.

Menzel, A., Estrella, N. (2001). Plant phenological changes. In „Fingerprints" of Climate change – Adapted Behaviour and Shifting Species Ranges, Walter G-R, Burga CA, Edwards PJ (eds). Kluwer Academic/Plenum Publisher: New York; 123–137.

Menzel, A. (2002). Phenology, its importace to the global change community. Climatic Change 54: 379–385.

Miháliková, I. (1983). 60 years of phenological network. Meteorological Bulletin 36, č. 6, pp. 187-188.

Pifflová, L. et al. (1956). Methodology instruction for phenological observers. Hydrometeorological Institute, Praha, D-571503, 152 p.

Seydl, O. (1954a). Mannheim society of meteorology (1780–1790). Meteorological Bulletin 7, No. 1, pp. 4–11.

Seydl, O. (1954b). Czech historical phenological studies. Meteorological Bulletin 7, No. 6, pp. 153–164.

Sonnentag et al., (2012). Digital repeat photography for phenological research in forest ecosystems. Agricultural and Forest Meteorology, volume 152, January 2012, p. 159–177.

ACKNOWLEDGEMENT

This work was supported by Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

SOUHRN

Změny a kolísání klimatogenních faktorů (přirozených i antropogenních) jsou příčinou časové variability klimatu na Zemi, která se projevuje jeho změnami a kolísáním. Fenologická pozorování, která se zabývají sledováním časového nástupu každoročně se opakujících vývojových fází rostlin, jsou velmi vhodným prostředkem ke sledování klimatické změny.

Fenologická pozorování mají různě dlouhou historii, nejdelší časové řady jsou v evropských státech včetně České republiky. Systém fenologických pozorování se v posledních letech významně mění, kromě subjektivního sledování dobrovolnými pozorovateli podle stanovené metodiky, jsou fenologické záznamy získávány prostřednictvím tzv. kalendáře přírody (např. USA) a speciálních kamer určených pro fenologický monitoring.

Předložený příspěvek shrnuje historii a současnost fenologických pozorování v České republice a ve světě, popisuje vzájemnou spolupráci a sdílení společných databází fenologických a meteorologických informací s cílem unifikace provedených analýz a tím i možnosti prognóz dalšího možného vývoje.

První výsledky ze záznamů fenologických kamer ukazují na možnost využití této metody jako náhradu za klasické fenologické pozorování.

SELECTED AGROCLIMATOLOGICAL CHARACTERISTICS AT TUŠIMICE STATION IN THE PERIOD 1968–2012

LENKA HÁJKOVÁ[1)], VĚRA KOŽNAROVÁ[2)], DÁŠA RICHTEROVÁ[3)]

[1)] *CHMI, Department of Biometeorological Applications, Na Šabatce 17, 143 06 Prague 4 – Komořany, Czech Republic, hajkova@chmi.cz*

[2)] *Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Prague 6 – Suchdol, Czech Republic, koznarova@af.czu.cz*

[3)] *CHMI, Department of Meteorology and Climatology, regional branch Ústí nad Labem, Kočkovská 18, 400 11 Ústí nad Labem, Czech Republic, dasar@chmi.cz*

ABSTRACT

In this paper were analyzed agroclimatological characteristics of Tušimice observatory. The observatory is located in the catchment of the Ohře River (50°22'36'' N, 13°19'41'' E, and 322 m ASL) and was established on 1st April 1967. Some agroclimatological characteristics recommended in the individual blocks according to the WMO methodology (Kožnarová and Klabzuba, 2010) were chosen into the processing: heat waves occurrence, number of tropical days and drought occurrence. Data were processed within the period 1968–2012. There were 35 heat waves in total (June: 6; July: 17; August: 10) within the 45 years period. The longest heat wave in July has lasted 11 days and it was recorded from July 18th to July 28th. Tropical days occur 7.1 days per year on average with extreme values 29 days in 2003. The longest drought occurrence was registered from 31st July to 31st December 2003.

Key words: heat wave, tropical day, drought, Tušimice station, Czech Republic

INTRODUCTION

Weather and climate are important components of the environment that constantly surround humans. Weather extremes cause a loss of human lives and significant damage every year. The question rises in connection with the observed global warming, whether there is an increase in the frequency and intensity of extremes, the increase of climate variability.

Knowledge of available environmental resources and the interactions that occur in the area below the soil surface, the soil–air interface and the boundary layer of the atmosphere provides essential guidance for strategic agrometeorological decisions in long-range planning of agricultural systems. The aim of the study is the evaluation of selected agroclimatological characteristics (heat waves occurrence, number of tropical days and drought occurrence) of the Tušimice observatory in period 1968–2012 with a particular focus on the elaboration of particular elements of variability.

Figure 1. Tušimice meteorological observatory; source: chmi.cz/observator_tusimice

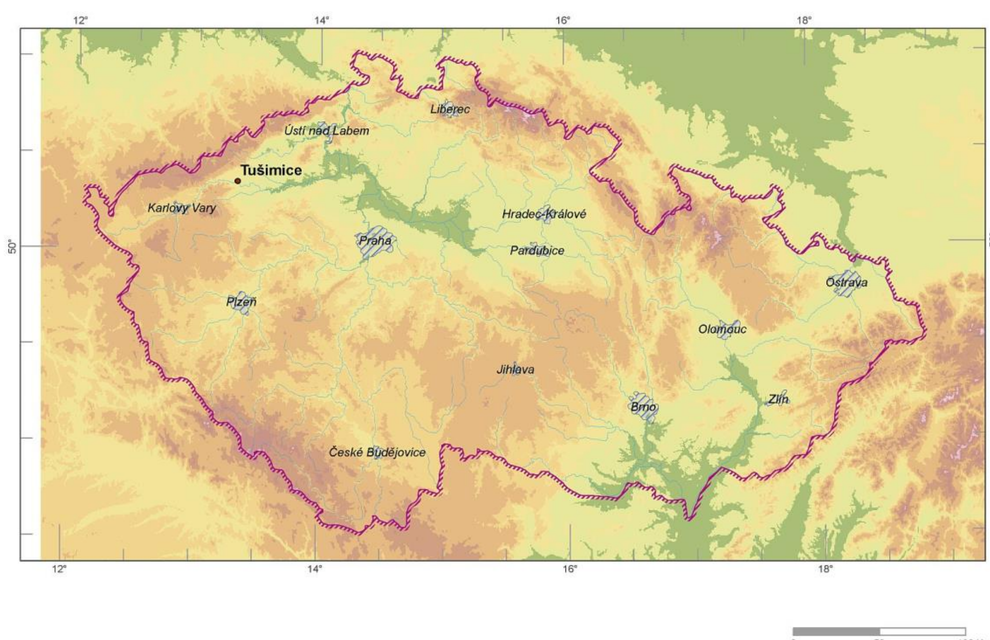


Figure 2. Map of the Czech Republic with Tušimice location

MATERIAL AND METHODS

The Tušimice station (322 m ASL, 13°19'41"E, 50°22'36"N) was established on April 1st, 1967 and it was fully automated on November 30th, 2001 (Figure 1.). The station is located in the Mostecká kotlina Basin in the catchment area of the Ohře River (Figure 2.). According to the Quitt classification the station belongs to MW7 unit (slightly warm area), which is characterized by 30–-40 summer days, 110–130 frost days and 40–50 ice days (Květoň and Vozenílek, 2011). The meteorological data (daily, monthly, and annual) were exported from the CHMI climatological database CLIDATA. The agroclimatological characteristics were described by the following basic statistical variables: mean, absolute maximum and minimum values and years of occurrence, median, upper and lower quartile, the first and ninth deciles, standard deviation, quartile deviation, coefficient of asymmetry and the coefficient of kurtosis. Evaluation of changes in the trend of particular elements and phenological characteristics was carried out using polynomial equation:

$y = b + c_1x + c_2x^2 + c_3x^3 + c_4x^4 + c_5x^5 + c_6x^6$.

The method of cumulative series (Sládek, 2001) was used in the evaluation of drought occurrence.

RESULTS AND DISCUSSION

Selected agroclimatological characteristics in comprehensive form are given in Table 1. Walter-Lieth climagram of Tušimice station describes agroclimatological conditions (Figure 3). Heat wave events are associated with marked short-term increases in mortality.

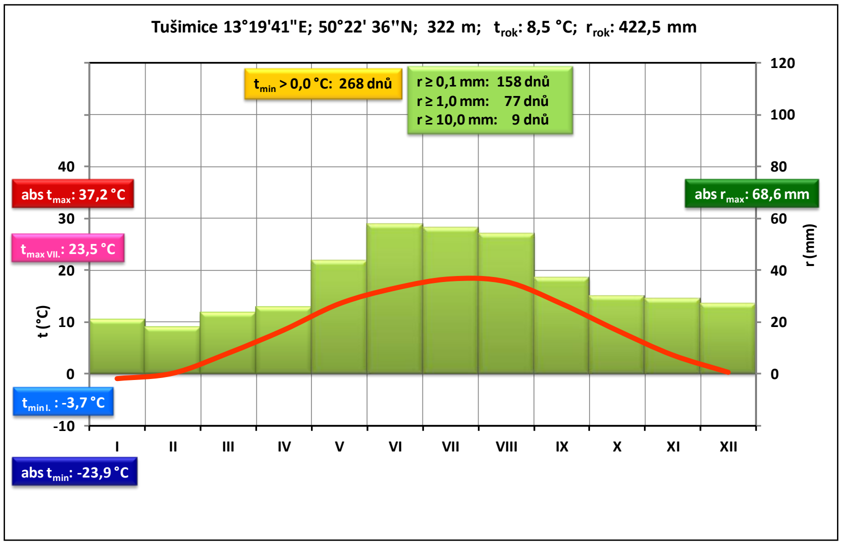


Figure 3. Walter-Lieth climagram (period 1968–2012)

Kyselý a Kalvová (1998) investigated the analysis of heat waves (at least 3 days with maximum air temperature ≥ 30 °C and with average air temperature in given period ≥ 25 °C) in the southern Moravia in the years 1961–1990. There were 35 heat waves in total (June: 6; July: 17 and August: 10) within the 45 years period. The longest heat wave in July has lasted 11 days and it was recorded from July 18th to July 28th. The longest heat wave in August was registered in the year 2003; it has lasted 8 days (August 7th – August 14th). The chart (Figure 4.) shows the variability of heat waves occurrence in particular years, the more frequent occurrence is in the last two decades. The average of maximum daily air temperature is 31.0 °C. Kyselý and Kalvová (1998) found out, that the heat wave lasts 4 to 7 days on average, Tušimice station shows similar results.

Table 1. Annual agrometeorological characteristics at Tušimice observatory (1968–2012)

Meteorological characteristic	**abbreviation**	**value**	**unit**
mean air temperature	t_{rok}	8.6	°C
sum of active air temperature > 5 °C	Σt > 5 °C	3163.6	°C
sum of active air temperature > 10 °C	Σt > 10 °C	2683.4	°C
mean maximum air temperature	t_{max}	13.0	°C
absolute maximum air temperature	abs tmax	37.9	°C
active sum of maximum air temperature > 5 °C	Σtmax > 5 °C	4696.6	°C
active sum of maximum air temperature > 10 °C	Σt_{max} > 10 °C	4249.0	°C

mean minimum air temperature	t_{min}	4,4	°C
absolute minimum air temperature	abs tmin	-23.9	°C
sunshine duration	$ss_{ro}k$	1532.6	h
water vapour pressure	e_{rok}	9.1	hPa
precipitation total	r_{rok}	433.1	mm
number of days with precipitation total ≥ 0.1 mm	r ≥ 0,1 mm	159.6	day
number of days with precipitation total ≥1 mm	r ≥ 1,0 mm	79.2	day
number of days with precipitation total ≥10 mm	r ≥ 10, mm	9.2	day
the highest daily precipitation total	abs r_{rok}	91.7	mm

Figure 5 illustrates the course of maximum air temperature in August 2003, the maximum air temperature during the heat wave was in the frame from 30.5 °C to 37.9 °C (this the absolute maximum air temperature measured at Tušimice station during the 45 years period). The results of heat wave occurrence correspond with Schär *et al*. (2004).

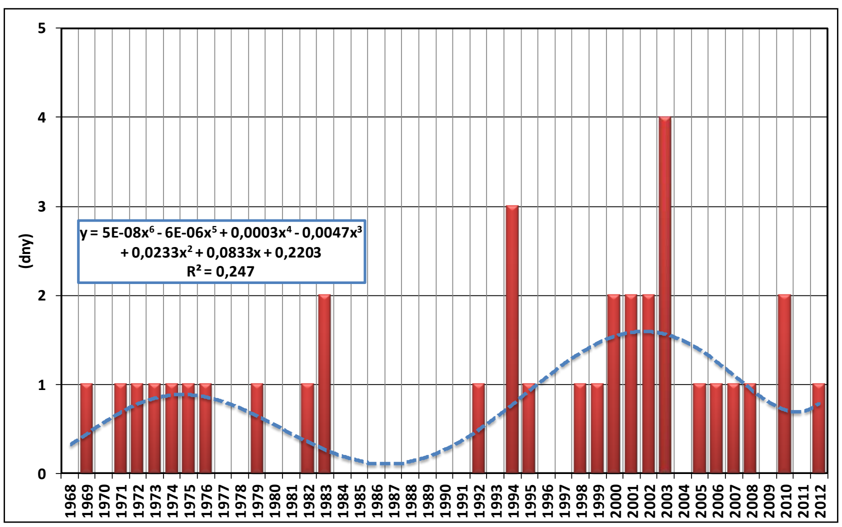


Figure 4. Number of heat waves in particular years

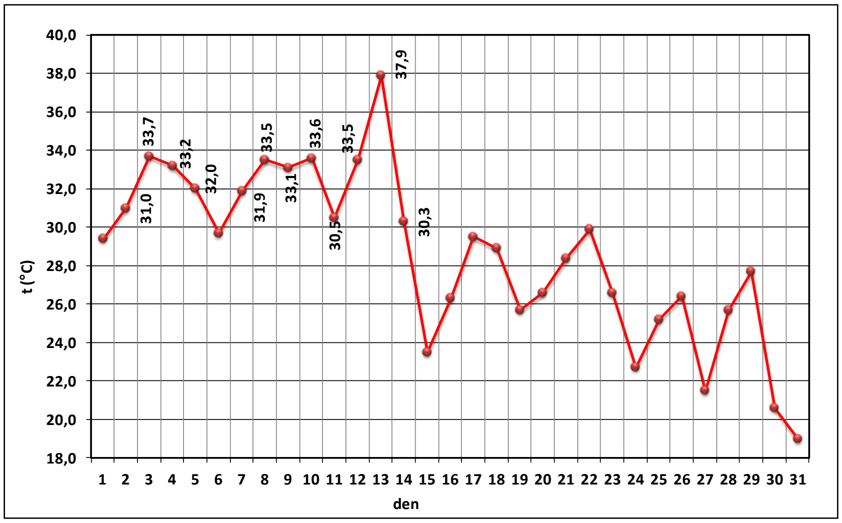


Figure 5. Course of maximum air temperature in August 2003 during the heat wave

Tropical days (it means day with the maximum air temperature 30.0 °C and more) occur 7.1 days per year on average with extreme values 29 days in 2003 and no tropical day occurrence in the years 1980, 1981 and 1987. Tropical days occurrence is typical for June, July and August, even though they can also occur in May (1969, 1999, 2005 and 2007) and September (1973 and 2003). Figure 6 shows the number of tropical days in particular years including polynomial equation:

$$y = -1E-07x6 + 2E-05x5 – 0.0012x4 + 0.0346x3 – 0.4828x2 + 2.4971x + 3.0403;$$

$$R^2 = 0.2584.$$

There were observed 319 tropical days in the sum during the 45years period and from this amount 209 days (i.e. 65.5 %) were recorded in the period from 1991 to 2012. The similar results were found out by Kožnarová *et al*. (2012).

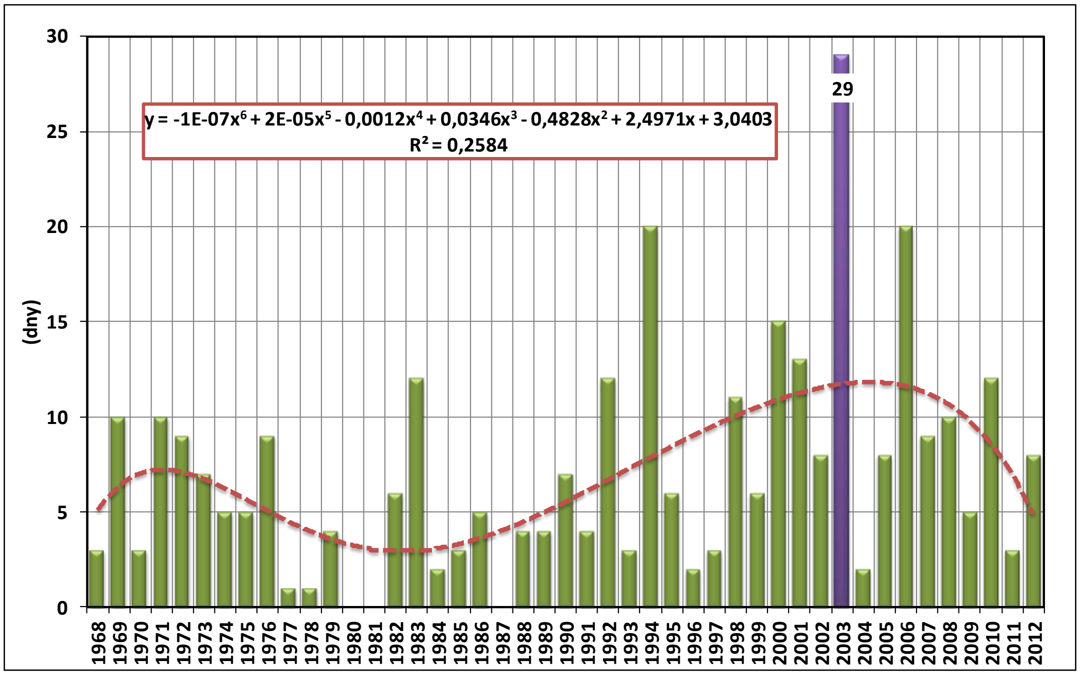


Figure 6. Number of tropical days

Basic statistical characteristics of number of tropical days in the year are given in Table 2.

Fiala (2006) investigated the drought occurrence at Vráž station in the period 1961–2004 using the method of cumulative series. There have occurred 962 drought periods (7 438 days, i.e. 46.3 % of all days) and only 2 461.8 mm of precipitation was measured, i.e. 9.9 % of all precipitation. The drought periods were nearly at the same years 1976, 2003 and 1991 on both stations (Tušimice and Vráž) and in the year 1985 it was nearly the same – the drought period at Vráž station was recorded from 9th September 1985 to 30th October 1985, it has lasted 51 days, the sum of air temperature was 529.9 °C, precipitation total was 10.4 mm and criterion S was 27.02. The spell of drought occurrence at Tušimice station is given in table 3.

Table 2. Basic statistical characteristics of tropical days in the year.

Characteristic	**Value**
mean	7.1
maximum	29
year	*2003*
minimum	0
year	*1980, 1981, 1987*
first decile	1.4
lower quartile	3.0
median	6.0
upper quartile	10.0
nith decile	12.6
quartile deviation	5.0
standard deviation	5.8
coefficient of asymmetry	1.6
coefficient of kurtosis	3.7

Table 3. The spells of drought occurrence.

	from	**to**	**duration (days)**	**Σ temperat. (°C)**	**Σ precipit. (mm)**	**daily mean**	**criterion S**
1	26.2.1976	12.7.1976	136	1522.0	89.1	0.66	63.92
2	28.7.1973	9.10.1973	73	1187.5	105.1	1.44	57.00
3	31.7.2003	31.12.2003	153	1455.2	67.8	0.44	56.75
4	10.8.1991	31.10.1991	82	1019.0	19.7	0.24	35.66
5	13.9.2001	31.12.2001	109	675.6	100.0	0.92	34.45
6	3.1.2003	6.5.2003	123	536.2	35.8	0.29	33.24
7	22.3.1998	23.5.1998	62	694.6	17.5	0.28	22.91
8	9.9.1985	3.11.1985	55	569.6	5.3	0.10	22.78
9	2.7.1971	19.8.1971	48	949.7	16.9	0.35	20.89

CONCLUSION

The study provides an evaluation of the selected agroclimatological conditions at the Tušimice observatory in 45-year-observation (1968–2012), one of the longest continuous observation periods in Podkrušnohorská pánev (the North Bohemian Basin). There were 35 heat waves in total (June – 6; July -17; August - 10) within the 45 years period. The longest heat wave in July has lasted 11 days and it was recorded from July 18th to July 28th 2006. Tropical days occur 7.1

days per year on average with extreme values 29 days in 2003. The longest drought occurrence was registered from 31st July to 31st December 2003 (123 days) with sum of air temperature 536.2 °C and precipitation total 35.8 mm.

REFERENCES

Fiala, T. (2006). Vymezení období sucha a období převládající teploty vzduchu pomocí metody součtových řad na příkladu Vráže u Písku. Meteorologické zprávy, ročník 59, 2006, č. 3, s. 76–79.

Kožnarová, V., Hájková, L., Richterová, D., Novák, M., Bachanová, S. (2012). Special climatological characteristics at the Tušimice station during observation period 1968-2011. In: 20. International Poster Day and Institute of Hydrology Open Day 15. 11. 2012. Institute of Hydrology SAV, Bratislava, p. 382-392 + CD. ISBN 978-80-89139-28-6.

Kožnarová,V., Klabzuba, J. (2010). Tradiční a moderní metody hodnocení počasí a podnebí v biologických disciplínách. Současné možnosti fyziologie a zemědělského výzkumu přispět k produkci rostlin (vybrané kapitoly). Výzkumný ústav rostlinné výroby, v. v. i., Praha 2010, ISBN: 978-80-7427-023-9, s. 4–33.

Květoň, V., Voženílek, V. (2011). Klimatické oblasti Česka: klasifikace podle Quitta za období 1961–2000. Ediční řada M.A.P.S. (Maps and Atlas Produkt Series), Num. 3., Univerzita Palackého v Olomouci, Český hydrometeorologický ústav, ISBN 978-80-244-2813-0 (UP), ISBN 978-80-86690-89-6 (ČHMÚ).

Kyselý, J., Kalvová, J. (1998). Horké vlny na jižní Moravě v letech 1961–1990. Meteorologické zprávy, roč. 51,1998, č. 3, s. 65–72.

Schär, CH. et al. (2004). The role of increasing temperature variability in European summer heatwaves. Nature, 2004, vol. 427, s. 332–336.

Sládek, I. (2001). Spells of drought: climatological treatment. Acta Universitatis CAROLINAE GEOGRAPHICA, No. 2, s. 147–153.

ACKNOWLEDGEMENT

This work was supported by Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

SUMMARY

Observatoř Tušimice se nachází v Mostecké pánvi v povodí řeky Ohře (50°22'36" s. š.; 13°19'41" v. d., 322 m n. m.), byla založena 1. dubna 1967. Od 30. 11. 2001 byla zařazena mezi profesionální stanice s celodenní obsluhou (AMS) a od 8. 12. 2010 až dosud patří mezi profesionální stanice kombinovaného typu (AMS1).

V příspěvku byly zpracovány vybrané agroklimatické charakteristiky doporučené v jednotlivých blocích podle metodiky WMO (Kožnarová a Klabzuba, 2010) – výskyt horkých vln, počet tropických dní a výskyt sucha. Meteorologická data (denní, měsíční, roční) byla exportována z klimatologické databáze ČHMÚ CLIDATA. Statistické vlastnosti agroklimatických charakteristik jsou popsány veličinami: aritmetický průměr, absolutní maximum a minimum a roky jejich výskytu, medián, horní a dolní kvartil, první a devátý decil, směrodatná odchylka, kvartilová odchylka, koeficient asymetrie a koeficient špičatosti. Vyhodnocení změny trendu jednotlivých prvků a fenologických charakteristik bylo provedeno pomocí rovnice polynomu 6. stupně: $y = b + c_1x + c_2x^2 + c_3x^3 + c_4x^4 + c_5x^5 + c_6x^6$. Četnost výskytu sucha byla vyhodnocena metodou součtových řad (Sládek, 2001). Celkem bylo na stanici za 45leté období zaznamenáno 35 horkých vln, z toho v červnu 6, v červenci 17 a v srpnu 10. Nejdelší horká vlna v červenci trvala 11 dní (2006) a nejdelší horká vlna v srpnu 8 dní (2003). V průměru se na stanici vyskytne 7,1 tropických dní (maximální teplota vzduchu 30 °C a více) za rok. Nejvyšší počet tropických dní byl zaznamenán v roce 2003 (29 dní), naopak v letech 1980, 1981 a 1987 nebyl zaznamenán žádný tropický den. Nejdelší období sucha bylo podle metody součtových řad zjištěno v roce 2003 (od 31. 7. do 31. 12.), celkem trvalo 123 dní, suma teploty vzduchu činila v tomto období celkem 536,2 °C a úhrn srážek byl v daném období 35,8 mm.

EFFECT OF AGE OF HORSES ON GAS CONCENTRATION IN THE STABLE

JAN KALÍŠEK [1,2], MILOSLAV ŠOCH[1], PAVEL ONDR[1], IVANA KNÍŽKOVÁ[2], JIŘÍ CIML[1]

[1] *University of South Bohemia in České Budějovice*

[2] *Institute of Animal science in Praha – Uhřiněves*

ABSTRACT

One of the problems currently livestock may be higher densities per unit area. At the same time the animals are increasing demands on their performance. It is therefore necessary to know the demands of animals to their actual needs and is not maintained by subjective human imagination. It is necessary to monitor the effects of individual factors, but also their complex effect on livestock. Animal performance and thus the breeding success of the whole depends on many factors - the nutrition of farm animals for rearing, hygiene environment, veterinary care, livestock breeds and their physiological capabilities and, last but not least, the micro-climatic conditions in the stable.

Measurement of stable gas for its technical difficulty took place at the National Stud Farm in Kladruby 1x per month and the 24-h cycle, from April 2011 to March 2012.

The aim of this study was to investigate the concentrations of stable gases - carbon dioxide, methane, hydrogen sulfide and ammonia in the barn with mares and foals in the stable, where the only adult mares. Of interest were also variations in the concentration of these gases over the year.

Key words: Microclimate stables, stable gases, carbon dioxide, methane, hydrogen sulfide, ammonia, horse breeding, animal welfare.

INTRODUCTION

Before man domesticated the horse and began to use it for their various needs, so the horse naturally occurred in the vast steppes, mostly in Asia. This way of life suited them, they were used to it. But as the man began to treat the horses in the stables, so they significantly changed their living conditions (Dobroruka and Kholová 1992).

Year after year in the Czech Republic increased number of breeding horses (see tab. 1). According Sodeho (1992), but due to poor housing, inadequate or improper care of the horses, poor nutrition and possibly neglected health care leads to many complications veterinarian. These include hoof rot, an infection in the respiratory tract, allergies or digestive problems (Ende 2000).

Tab 1. The number of breeding horses in the Czech Republic

Year	**Number of horses**
2009	28030
2010	29887
2011	31068
2012	33175
2013	34281

From: Český statistický úřad

Stable environment has a major impact on the animals. This is due to the fact that in the stables staying most of the day. Kryptoklima is quite significantly influenced by the environment stable. Affect him but also physiological processes of livestock, number, type and age of animals, type of technology used in the stable and respecting common Breeding-hygiene practices. In their midst, the frequency of removal of manure, irrigation as a means to prevent excessive dust and last but not least, ventilation (Kic 1996).

A properly functioning ventilation system continuously removes stale and stable gases richer air out of the stable area. This technique also diverts and increased humidity (Kic and Brož 2000). It increased relative humidity and stable gases can also be a trigger corrosion of buildings (Hujňák 1997). On the other hand, it must also take into account the air temperature and relative humidity outside team-building. By improper ventilation, can cause great loss of energy as heat (Franěk et al., 1965).

Stable environment can be a limiting factor for the energy metabolism of animals and thus the productivity of livestock (Šoch 2005).

Chemical composition of stable air

In the bodies of animals housed underway metabolic processes that are manifested, inter alia, the production of liquid, solid and gaseous products. Liquid and solid component is then further degraded by microorganisms into simpler substances. Even with these transformations occur other gases that may accumulate in the stables (Doležal et al., 2004).

Carbon dioxide – CO_2

A colorless, flammable gas that is toxic in small concentrations. The air reaches 0.3 percent by volume. Its amount in the atmosphere is still increasing, because it is discharged as a product of combustion of substances containing carbon and at many manufacturing processes.

This gas is primarily a product of stable breathing. Partly but also arises in fermentations in the digestive system and in the litter. Its potential increased concentration is a sign of impaired ventilation.

Tab 2.

Gas	Air		
	atmospheric	exhaled	in the stable
N	78,09	78,09	78,09
O	20,95	16,4	19,6 – 20,7
CO_2	0,04	4,24	0,2 – 0,4

From: Franěk a kol. 1965

Ammonia – NH_3

It is a colorless, eyes irritating gas. It is used for example in the production of fertilizers and nitric acid.

The stables are released during decomposition of metabolites digestion. The concentration of this gas depends on the number of animals (live weight), feed composition and flow rate of air in the barn. If there is this greater amount of gas, it may cause a restriction horses resistance against infections. Sufficient air exchange ventilation rapidly changing content of stable gases in general and therefore ammonia in favor of better environmental cleanliness.

Hydrogen sulfide – H_2S

This gas is colorless, poisonous, foul-smelling, flammable. In the stables created by anaerobic decomposition of organic substances, mainly proteins with sulfur amino acids. Dangerous primarily in those technologies where the scrub areas accumulate liquid exudates. When their removal may lead to sudden release of hydrogen sulfide and exceeding permitted levels.

It has a greater density than the other components of air, and therefore is held in a thin layer near the ground. Slightly higher than normal in a stable condition may be caused by the handling of manure.

Methane – CH_4

It is the simplest organic compound is not toxic. In combination with oxygen to form an explosive mixture. Located in the natural gas and coal gas. Creates the absence of air in the fetid swamps fermentation (Holinka 2003).

Is mainly produced in the digestive processes in cattle. If the concentration is increased, may begin threatening physiological processes in animals.

Navrátil (2007) in their publication lists the recommended maximum concentrations of stable gases for horse breeding as follows: CO_2 = 2500 ppm, 25 ppm = NH_3 and H_2S = 10 ppm. But Kic and Brož (1995) recommend the following maximum concentration: CO_2 = 3000 ppm, NH_3 = 25 ppm and H_2S = 7 ppm. Czech Technical Standard 73 0543-2 specifies the maximum CO_2 concentration of 3500 ppm.

Other gases, such as N_2O or O_3 may result from the use of specific compound feed. They do not set their limit. In agricultural buildings to meet with a characteristic odor. Its agents are the animals themselves and then also decomposing products of digestion. In the premises there is adequate ventilation oblivious to the stables, can occur in the summer months to excessive odor intensity, which then annoys the animals and keepers. The concentrations of stable gases can be well eliminated. It is a hygiene environment, regular ventilation, use of air ionization and adding additives to animal manure. Their effectiveness is however low, ranging between 3-10%. It is more efficient but the addition of certain substances directly into the ration. This we can achieve efficiencies of up to 30-40%. This way, but we can eliminate only ammonia (Doležal et al. 2004).

Description of selected stable

Measuring the concentrations of stable gases was carried out in the stables VIII and IX of the National Stud Farm in Kladruby nad Labem. In the stable No. VIII were housed only mare in the stable and No. IX were mares with foals. Both stables are exactly the same, just inverted mirror image of yourself.

Stables are rectangular footprint measuring 9.4 meters and 46.3 meters. Height Stables is 4.0 meters. Horses but do not have access to the entire stable area, because on the one hand, the stable is a space for temporary storage of hay. Horse, then use area 9.4 meters to 38 meters.

From the stable door leading to the courtyard and the passage to other neighboring stables. The door to the courtyard are 2.9 meters wide and 3.2 meters high. The passage has a width of 2.6 meters and height of 2.9 meters. It is closed during most of the lower half of the door, the door to the courtyard when the weather is opened (the horses in the courtyard to prevent the escape of a double barrier).

The barn is a total of 14 identical windows. On the long side of the barn opposite the gate to the courtyard of the nine windows on the short wall opposite the passage is 1 window and on the other long side of the barn are three windows to the right of the door and one window to the left of the door. The window width is 1.3 meters and height of 1.5 meters. The entire area of the window is divided into two independently doors and shutters. You are December to February is fully closed. For most of the two shutters open at about 30% in the summer to open up completely, but always in a way that did not originate in a stable draft. The windows are about the height of a horse's head.

The whole area of the barn, the horses used is about 15-20 cm tall bedding of straw. On it is a means stables conducted about one meter wide strip of hay. In this way, all horses (mares or mares with foals) ensuring equal access to food. Skybal and wet straw was cleaned every day. Approximately 1x per month cleaning out all the bedding and carried out disinfection.

MATERIALS AND METHODS

To evaluate the concentrations of stable gases were selected stables VIII and IX of the National Stud Farm in Kladruby nad Labem. In the stable VIII No. 10 mares were housed Kladruby horses. This is a free type of housing. In the stable No. IX was housed 9 Kladruby horse mares with their foals. The births occurred from late January to about mid-March. It is again a free type of housing.

The monitored stables conducted continuous measurements of air temperature and relative humidity. In this measuring device was used Cometr. It was fixed in the stable on the wall in a place where it did not have access horses around at 2 meters above the ground. Was selected recording interval of 15 minutes. The measured values are periodically withdrawn to the laptop to Microsoft Excel, which is then processed.

From June to March 1 conducted monthly measurements of stable gases. At this measurement was used ASEKO station. Measurements always took 24 hours. The station itself is placed into the preparation and the sensor is in the middle of the barn hung on a hook from the ceiling in such a way as not to prevent equine handling techniques. The sensors were connected to the station cables, which resulted in the grooves on the ceiling next to electrical lighting. Records of this measurement was set to 10 minute interval.

In parallel with the experienced and airflow inside the barn, the door is open and the courtyard. Unfortunately, this measurement could not be performed continuously.

Starokladrubský horse was declared a national monument. It is a typically Czech breed massive character with a strong klabonosa. Behaves in white at the National Stud Farm in Kladruby nad Labem as a black horse in Slatiňany. Its origin comes from old-spain and old-italy horses. These horses were originally designed for the needs of the imperial court in Vienna in harness. White horse used nobles, black horse again church leaders. Currently mainly used in Driving, for ceremonial purposes in some royal courts as a heavy riding horse. For easy handling it uses cavalry municipal police. Kladruby horse population is not very large, numbering about 1,300 horses. A big reduction in the number marked the first World War. Line Starokladrubské horses with white horses are Generale, Generalissimo, Favor, Rudolfo and Sacramoso; u black horses then Sacramoso (1922 and Napoleone), Solo, Siglavi Pakra and Romke (Navrátil 2007).

RESULTS AND DISCUSSION

First the concentration of the individual gases at the age of stable horses in the stable

1.1 Ammonia

For this gas was found less significant dependence of concentration between the two stables. As the concentration of this gas in the stable depends on bodyweight and thus the amount excluded metabolites digestion, it is clear that for most of the live weight of mares with foals less than a live weight of mares in the second barn.

1.2 Methane

For methane found a very close relationship between the concentration in the stable of mares with foals and mares in the barn. It is therefore evident that the concentration of this gas depends primarily on body weight stabled horses. This gas is relatively well ventilated and even winter in compliance with animal hygiene conditions is not a problem.

1.3 Hydrogen Sulfide

A similar situation is also hydrogen sulphide. The degree of dependence between the concentration of this gas in the barn mares with foals with mares in the stable concentration is very tight.

1.4 Carbon dioxide

Correlation of the concentration of this gas in the barn mares with foals with mares in the stable concentration approaches the value first So there is a very strong addiction.

Tab 3. The concentration of stable gas

Month	Stable with foals				Stable with mares			
	NH_3	CH_4	H_2S	CO_2	NH_3	CH_4	H_2S	CO_2
Year 2011								
June	5,7	14,8	0,8	735,6	5,6	14,6	0,9	648,8
July	5,8	13,3	0,8	742,8	5,7	13,0	0,9	653,7
August	5,7	15,2	0,8	748,9	5,6	14,8	0,9	655,3
September	5,5	14,9	0,8	743,9	5,3	14,3	0,9	622,6
October	5,6	14,3	0,8	734,9	5,1	13,0	0,9	612,2
November	5,7	15,2	0,8	827,3	5,7	15,3	0,9	828,1
December	5,6	15,3	0,8	749,3	5,6	15,3	0,9	750,8
Year 2012								
January	5,6	18,3	0,8	704,2	5,6	18,4	0,9	703,5
February	5,6	15,9	0,8	686,2	5,6	15,9	0,9	684,1
March	5,6	15,4	0,8	829,9	5,6	15,4	0,9	828,2

This table shows the mean values of stable gases. Typically each month held one measurement length of about 24 hours.

Tab 4. Interpolation weights foals (kg) in the barn No. IX

Foal / Month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
1.	0	63	100	145	180	220	260	290	310	335	0	0
2.	0	69	95	140	175	210	250	280	305	320	0	0
3.	68	85	105	145	180	205	245	285	325	370	0	0
4.	0	65	105	140	175	210	245	270	300	325	0	0
5.	0	70	115	150	185	220	255	295	310	335	0	0
6.	0	60	100	140	180	225	265	310	330	350	0	0
7.	0	0	65	105	150	195	240	285	310	330	0	0
8.	0	0	74	110	150	195	240	285	315	335	0	0
9.	0	0	68	105	145	185	225	265	290	315	0	0
9 mares á 700 kg	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300
In sum	6368	6712	7127	7480	7820	8165	8525	8865	9095	9315	6300	6300

Note: red = actual weight of the foal; Yellow = interpolation weights foal

Average monthly growth: 38,857 kg

The average weight of mares during the year varies very little. The production of stable gas these minor variations do not affect. Therefore, the weight of adult mares considered as constant.

Second the concentration of stable gas on the season

2.1 Ammonia

Ammonia gas is easily ventilated, so if compliance with the basic rules for horse breeding, such as regular removal skybals a maximum number of animals in the barn for which it was designed stable and not exceeded the standard concentration. In the stable to accumulate even in the winter months when conditions deteriorated for ventilation air. At this time, namely, in addition to removal of stale air out and supplying fresh air inside take into account the loss of heat.

2.2 Methane

Methane is also among well-ventilated gases. In horse breeding, causing its increased concentration problems even in the winter months when it is necessary to take into account the economic losses in the form of heat escaping from the stable of excessive ventilation.

2.3 Hydrogen sulfide

Hydrogen sulfide is a gas that is in horse breeding does not occur in higher concentrations. It is far more common in cattle or pigs. From a technical point of view it is not possible to record slight variations in the concentration, the more so as regards its threshold concentration. Changes in the concentration of this gas in both the stable mares with foals and mares in the barn alone was in the order of hundredths and thousandths of a ppm. Therefore, the two lines is constant.

2.4 Carbon dioxide

Carbon dioxide is mainly breathing. Its concentration in the enclosure is thus dependent partly on the number and weight of the horses (the livestock units), their physical activity and then the intensity of the ventilation of stables. Live weight of the animals in the barn mares almost unchanged. However, the live weight of mares with foals grow over time. From the graph it is but obvious that the influence of the concentration of carbon dioxide is a natural activity of animals. And that was generally higher in the stable of mares with foals. Therefore, the concentration of carbon dioxide in the barn mares with foals higher. Ventilation rate was stable in both approximately equal. This also corresponds to an increase in the concentration of carbon dioxide in the winter months when there is not enough ventilation.

The actual measured CO_2 values ranged from 600 to 950 ppm, net issuance is obtained by subtracting a constant 380 ppm. The ammonia concentration ranged between 5.6 and 6.0 ppm. Hydrogen sulfide during a measurement interval 0.7 to 0.8 ppm. The above implies that the concentration of stable gases in the stables of the National Stud Farm in Kladruby nad Labem are entirely within the required limits.

Tab 5. Overview of ambulatory measurement values

Date, time	**Air flow in the stable in m/s**		**Air flow in the courtyard in m/s**	
	interval	**median**	**interval**	**median**
1.4.2011, 11:05	0,06 - 0,81	0,27	0,31 - 2,38	0,74
29.4.2011, 11:30	0,07 - 0,41	0,15	0,23 - 2,89	1,43
27.5.2011, 11:00	0,04 - 0,17	0,08	0,10 - 0,19	0,15
9.6.2011, 11:00	0,35 - 1,16	0,80	0,43 - 3,62	2,85
10.6.2011, 10:00	0,08 - 0,42	0,12	1,86 - 2,47	0,43
7.7.2011, 11:00	0,05 - 0,12	0,09	0,15 - 0,71	0,43
8.7.2011, 10:45	0,00 - 0,32	0,03	0,00 - 1,21	0,76
9.8.2011, 9:30	0,00 - 0,82	0,16	0,04 - 1,63	0,86
10.8.2011, 13:00	0,00 - 0,76	0,23	0,00 - 1,96	0,83
11.8.2011, 10:00	0,00 - 0,00	0,00	0,00 - 0,36	0,08
8.9.2011, 10:00	0,01 - 0,46	0,20	0,07 - 0,51	0,25
9.9.2011, 10:00	0,00 - 0,47	0,02	0,00 - 0,61	0,12
6.10.2011, 10:30	0,00 - 0,30	0,17	0,06 - 1,15	0,75
7.10.2011, 10:30	0,00 - 0,00	0,00	0,00 - 0,29	0,03
3.11.2011, 10:15	0,00 - 0,00	0,00	0,00 - 0,10	0,04
4.11.2011, 10:00	0,06 - 0,10	0,07	0,02 - 0,49	0,15
8.12.2011, 10:00	0,07 - 0,54	0,29	1,93 - 3,19	2,65
9.12.2011, 10:00	0,02 - 0,16	0,09	0,05 - 0,79	0,39
5.1.2012, 10:00	0,05 - 1,48	0,30	0,19 - 4,74	2,00
6.1.2012, 9:30	0,08 - 1,83	0,54	0,15 - 3,90	1,78
16.2.2012, 13:30	0,02 - 0,40	0,16	0,08 - 4,93	1,97
17.2.2012, 14:00	0,05 - 0,17	0,08	0,36 - 2,52	1,11
29.3.2012, 10:00	0,19 - 2,64	0,45	0,17 - 3,86	0,96
30.3.2012, 9:45	0,02 - 0,32	0,08	0,05 - 1,29	0,66

CONCLUSION

The concentration of stable gas depends on the number and age of the horses in the stable, their physical activity and ventilation. A close relationship was observed with concentrations of carbon dioxide, hydrogen sulfide and methane when comparing their concentrations in mares with foals barn with stables themselves mares. In ammonia was demonstrated moderate level of dependence. This was probably due to the low concentration of this gas and the fact that it is released continuously from the litter.

Measured gases has been demonstrated that their concentration in the stable of mares with foals is higher than in the barn where they were housed only mares. This fact can be explained by the fact that the Colts for most of the day are physically active, and secondly, by themselves cause their breathing higher concentrations of carbon dioxide and, secondly, how they move the litter and mechanically cause a higher rate of release of gas from skybals.

The concentration of stable individual gases to the season was observed only carbon dioxide and methane even partially. This is due to limited ventilation in the winter months when it is necessary, on the one hand, to ensure a supply of fresh air in stables and on the other, also take into account the loss of heat.

REFERENCES

Dobroruka, J. a Kholová H.: Zkrocený vládce stepi. Panorama, Praha, 1992.

Doležal, O. a kol.: Zásady welfare a nové standardy EU v chovu skotu. VÚŽV, Praha, 2004.

Ende, H.: Die neue Stallapotheke. Müller Rüschlikon Verlags AG, Cham, 2000.

Franěk, B. a kol.: Úprava stájového prostředí. SZN, Praha, 1965.

Holinka, J.: Chemie. Nakladatelství Radek Veselý, Třebíč, 2003.

Hujňák, J.: Přestavby a opravy stájí. ÚZPI, Praha, 1997.

Kic, P. a Brož, V.: Tvorba stájového prostředí. Institut výchovy a vzdělávání Mze ČR, Praha, 1995.

Kic, P. a Brož, V.: Zařízení pro větrání a klimatizaci stájí. Institut výchovy a vzdělávání Mze ČR, Praha, 2000.

Kic, P.: Úprava vzduchu ve stájových objektech. Ústav zemědělských a potravinářských informací, Praha, 1996.

Navrátil, J.: Základy chovu koní. ÚZPI Praha, Praha, 2007.

Sode, M. L.: Kenne ich mein Pferd? Franckh-Kosmos Verlags, Stuttgart, 1992.

Šoch, M.: Vliv prostředí na vybrané ukazatele pohody skotu. Jihočeská univerzita v Českých Budějovicích, České Budějovice, 2005.

Česká technická norma ČSN 73 0543 - 2, Vnitřní prostředí stájových objektů, část 2.: Větrání a vytápění. Český normalizační institut Praha, Praha, 1998.

www.csu.cz

ACKNOWLEDGEMENT

NAZV QJ1210144, GAJU 020/2013/Z a MZE 0002701404

SUMMARY

Jeden z problémů současné živočišné výroby může být vyšší koncentrace zvířat na jednotku plochy. Zároveň se na zvířata zvyšují požadavky na jejich užitkovost. Je tedy nutné znát nároky zvířat na jejich skutečné potřeby a ne je vytvářet podle subjektivních představ člověka. Je potřeba sledovat vlivy jednotlivých faktorů, ale i jejich komplexní působení na hospodářská zvířata. Užitkovost zvířat a tedy i úspěšnost celého chovu závisí na mnoha faktorech – na výživě hospodářských zvířat, na způsobu ustájení, hygieně prostředí, veterinární péči, na plemeni hospodářských zvířat a jeho fyziologických možnostech a v neposlední řadě i na mikroklimatických podmínkách ve stáji.

Měření stájových plynů pro svou technickou náročnost probíhalo v Národním hřebčíně v Kladrubech nad Labem 1x za měsíc a to ve 24 h cyklu, od dubna 2011 do března 2012.

Cílem této práce bylo sledování koncentrací stájových plynů - oxidu uhličitého, metanu, sirovodíku a amoniaku ve stáji klisen s hříbaty a ve stáji, kde byly pouze dospělé klisny. Předmětem zájmu byly rovněž odchylky koncentrací těchto plynů v průběhu roku.

CONTACT

Ing. Jan Kalíšek

Výzkumný ústav živočišné výroby, v. v. i., Praha – Uhříněves, Přátelství 815, 104 00, Praha Uhříněves, Česká republika

Jihočeská univerzita v Českých Budějovicích, Česká republika

Impact of Vegetation on Microclimate in Different Layouts of Built-Up Areas in Urbanised Environment of Nitra Municipality in Spring Period

Ján Klein, Zdenka Rózová

Department of Ecology and Environmentalistics*,* Faculty of Natural Sciences*, Constantine The Philosopher University in Nitra*

Abstract

Vegetation has an important role in urbanised environment, as its functions enhance the quality of life in towns. Its structure shades anthropogenic surfaces, limiting the accumulation of direct solar radiation and subsequent emission of converted thermal radiation. This represents its potential in reducing the urban heat-island effect. It increases relative air humidity and reduces air temperature. Besides microclimatic function, vegetation also has health, aesthetic, recreational and other functions. Research is focused on comparing microclimatic factors (air temperature, relative air humidity, surface temperatures, airflow) between two monitored areas with different vegetation structures. Areas represent an area with vegetation cover (particularly tree plants) and an area without vegetation, respectively with minor representation of vegetation. Microclimatic conditions are also compared for four different types of built-up areas in the town of Nitra, which are represented by a characteristic street.

Key words: surface temperature, vegetation growth, urban texture, street canyon

Introduction

Replacement of natural surfaces like soil and vegetation cover by various urban surfaces – bricks, paving, asphalt, concrete surfaces, glass and iron started modifying urban atmospheric environment at different levels above ground in local geographic scale (Brian - Berry, 2008; Bonan, 2002). Urban climate was created as a result of replacing natural soil by vast areas of impermeable roads, pavements, parking places, roofs of walls with dense and artificial surface of solid and dense structure; reduction of surfaces covered by vegetation; reduction of longwave emissions of surfaces by street canyons and releasing gas, solid and liquid atmospheric polluting substances and waste heat (Kuttler, 2008; Bonan, 2002).

The factor of densely built-up area is considered to be one of the key reasons of UHI effect. Buildings, roads and hard surfaces accumulate heat during the day which is slowly released in the evening, while it maintains the air temperature of town warmer than in surrounding areas (Kantzioura - Kosmopoulos - Zoras, 2012). Changes to urban conditions often cause environment quality deterioration and can result in damage to health of the citizens of towns (Kuttler, 2008). Differences in temperature are also attributed to urban geometry – the size, shape and orientation of buildings and streets as well as the nature of urban areas – their albedo, thermal capacity of materials, thermal conductivity and humidity (Landsberg, 1981). Urban climate is directly connected to street axes configuration, height of buildings and their attributes. Relationship of urban morphology and microclimate change and air quality within a town centre also affects thermal comfort of pedestrians (Krüger - Minella - Rasia, 2011). Orientation and geometry of a street as well as its certain morphological characteristics have a fundamental role regarding surface temperatures. Even temperatures of horizontal earth surfaces are more significant than surface temperatures. Wind direction and speed combined with street orientation, as well as the effect of trees, increase of the height/width ratio, increase of the albedo of earth surface and walls, have the greatest impact on street canyon microclimate in relation to temperatures of air and surfaces (Andreou - Axarli, 2012). Vegetation has a significant impact on energy balance, as even though green areas have low albedo, thus absorbing a great part of emanating radiation, they maintain a lower temperature than usual regarding hard surfaces, as they are cooled by evapotranspiration (Pearlmutter et al. 2014). Vegetation improves environmental variables like solar radiation, temperatures of surrounding surfaces, temperature and humidity of air and wind speed, which are also important for thermal comfort of people due to their qualities – limited emission of direct solar radiation on surrounding buildings and surfaces, air cooling by evapotranspiration and wind speed reduction (Akbari - Pomerantz - Taha, 2001).

The paper aims at comparing microclimatic factors in different vegetation structures as well as within four street corridors representing different types of built-up areas of the town of Nitra. Partial evaluation of the ongoing research has been recorded for the period from April to June.

MATERIALS AND METHODS

Four localities in the town of Nitra were selected. Each locality within a whole street block represents a different urban structure. Particular monitored locality with two monitored areas with different plant structure represents a relatively homogenous character of built-up area. They are particular streets predominantly oriented in north-south direction with different vegetation representations. Individual localities representing certain types of urban built-up areas were selected as follows:

1. Compact layout in the town historical centre, representing typical street canyon (Farská street, Fig. 1). It is a street with 10 to 15 m high historical terraced buildings (Locality 1).
2. Detached layout – family houses with gardens (Moyzesova street, Fig. 2). Detached single-storey family houses with front yards are most frequently represented in this layout. (Locality 2).
3. Industrial layout, industrial part of town (Bratislavská street, Fig.3). It is a broad and open street with a four-lane road, up to 8 m high buildings and spacious parking places with grassy islands (Locality 3).
4. Mixed layout adjacent to the town park (Jesenského street, Fig.4). It is a relatively narrow street (10 – 20 m) and its corridor on the southern part is created by buildings up to the height of 10 m with a gradual continuing to the park on the northern part (Locality 4).

All monitored surfaces in monitored areas are asphalt as the most frequently represented type of surface in urban environment in general. Each locality comprises two monitored areas – an area without vegetation cover, respectively with minimum cover, and an area with vegetation cover. Vegetation cover is represented by plants, particularly trees, representing public greens.

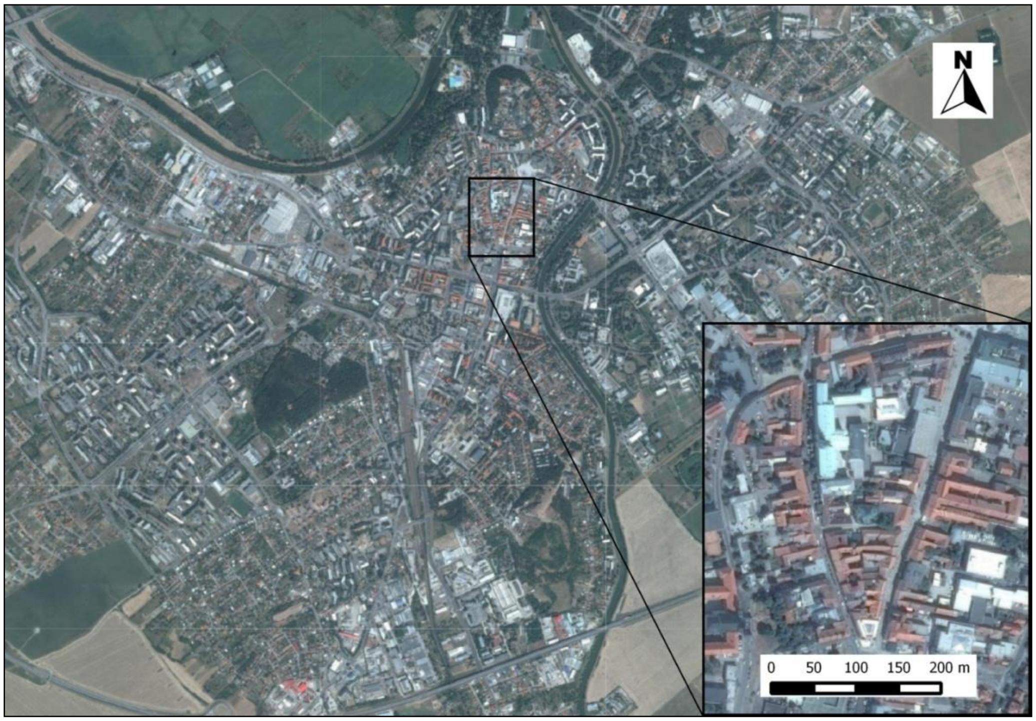


Fig. 1 *Compact layout (historical), Farská street – Locality 1*

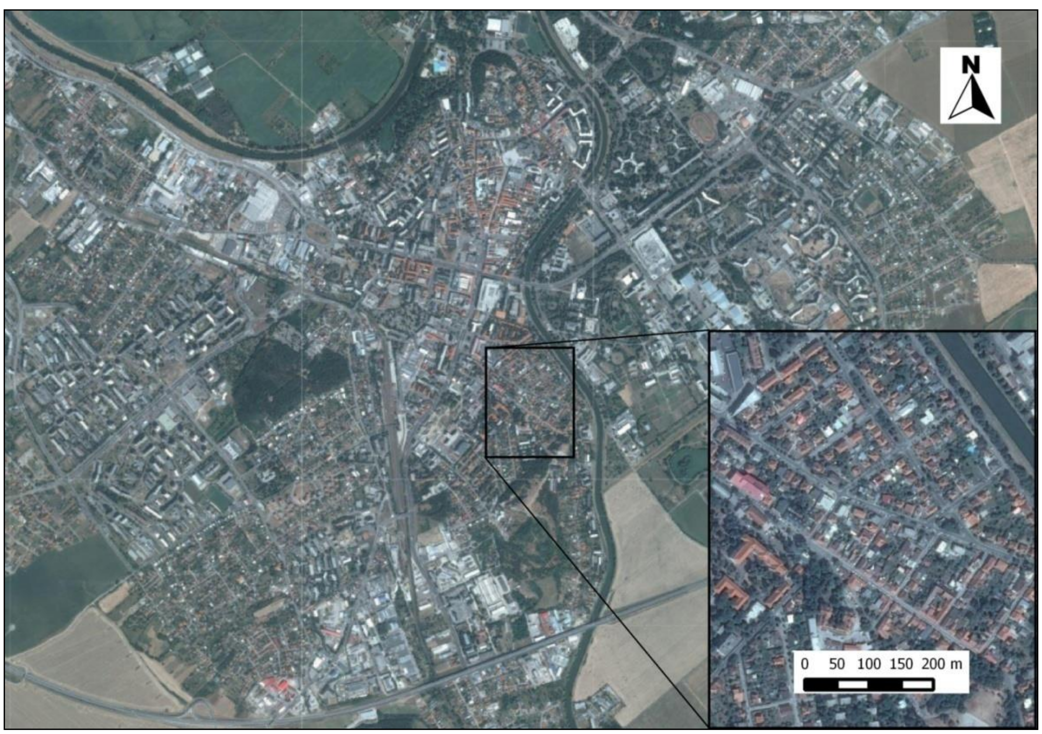


Fig. 2 *Detached layout- family houses with gardens, Moyzesova street – Locality 2*

Fig. 3 *Industrial layout in industrial part of town, Bratislavská street – Locality 3*

Fig. 4 *Mixed layout adjacent the town park, Jesenského street – Locality 4*

Measurements were carried out by anemometer TSI Veloci Cale 9565 – P (air temperature, relative air humidity, airflow, temperature of horizontal surfaces) once a week, three times a day. Monitored day is characterised by anticyclone weather, respectively by a prevalence of direct solar radiation, as the surface and adjacent air layers are intensely heated by solar radiation during the day. Morning and evening measurements were adapted to day-time during the monitored period with morning measurement an hour after sunrise and evening measurement an hour after sunset. We compared differences in measured values in the monitored areas with vegetation cover and without the cover within a single street corridor as well as differences between localities, respectively in different layouts of built-up areas. Data used for this research were recorded in the period from April to June. Data for March were not used as a result of incomparable days (starting vegetation period) because of statistical evaluation. Measurements were statistically evaluated by the one-way ANOVA test and confirmed by the Tukey HSD test. They were compared within monitored areas as well as localities in Statistica 7.

RESULTS AND DISCUSSION

Statistical evaluation was processed complexly for morning, noon as well as evening measurements. Methodically proposed measurements and subsequent processing represent an average range of input data. The most characteristic conditions are presented by noon measurements due to the highest temperatures at which the impact of vegetation in respective area is best shown by shading, airflow reduction or transpiration in a certain extent while pores are open. Leaves prevent excessive vapour by closing their pores, which can cause their significantly greater overheating (Čaboun, 2008). Similarly at evening, respectively morning measurements, vegetation acts as a thermal stabilizer. The vegetation cover has a cooling effect during evening thermal radiation from asphalt surfaces. On the contrary, vegetation maintains a higher temperature than the temperature of its surroundings in the morning. Airflow is affected by the cover structure as well as street configuration. Well placed green lines in urban cities can significantly reduce unwanted airflow in form of gusty winds and thereby prevent soil erosion and influence variable changes of thermal conditions (Kavka - Šindelářová, 1978). Statistically significant difference in airflow in terms of locality was demonstrated in Locality 3 (Fig. 5), using the one-way ANOVA test p<0.05 (Tab. 1), and the Tukey HSD test (Tab. 2) to confirm. The locality represents an industrial layout in which such results were anticipated. Other localities representing a more distinctive street canyon with a similar orientation are not affected by the overall airflow. By their layout and geometry, they limit airflow to the corridor direction. Vegetation cover affects airflow (Akbari - Pomerantz - Taha, 2001). Fluctuating values were predominantly recorded in monitored areas without the cover.

Tab. 1 *One-way ANOVA, p<0,05, variable air flow, Locality 3*

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	0.12669	1	0.12669	45.4753	0.000000
Locality	0.01709	1	0.01709	6.13513	0.02008
Error	0.07244	26	0.00279		

Tab. 2 *Tukey HSD test, variable air flow, Locality 3*

Locality	{1} ,09197	{2},04256
BR_NV		0.02021
BR_V	0.020214	

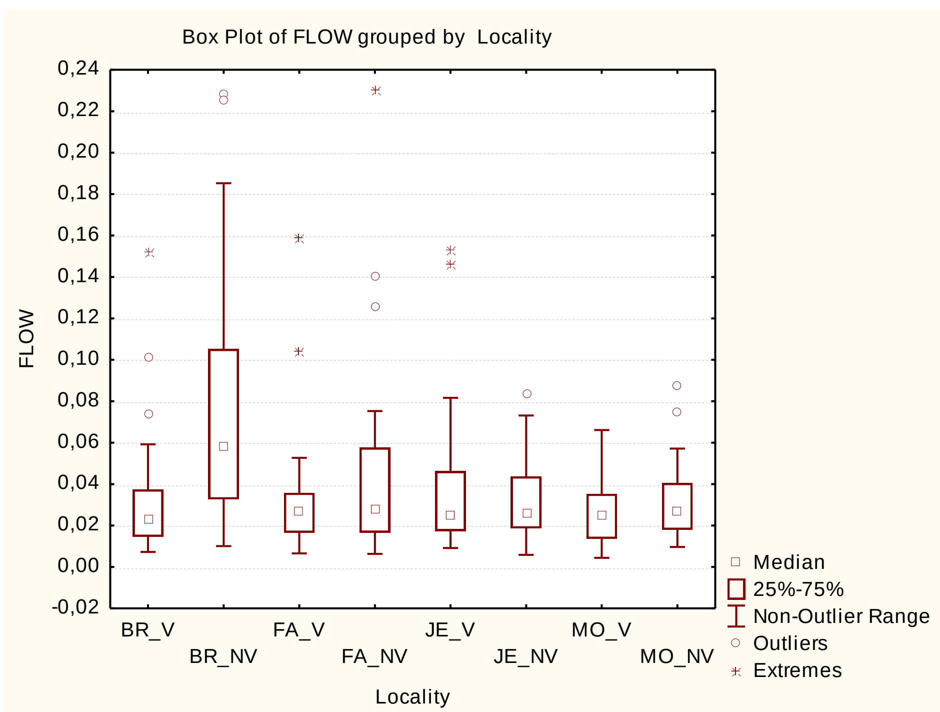


Fig. 5 *Comparison of airflow in localities and monitored areas, airflow (m3/s); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)*

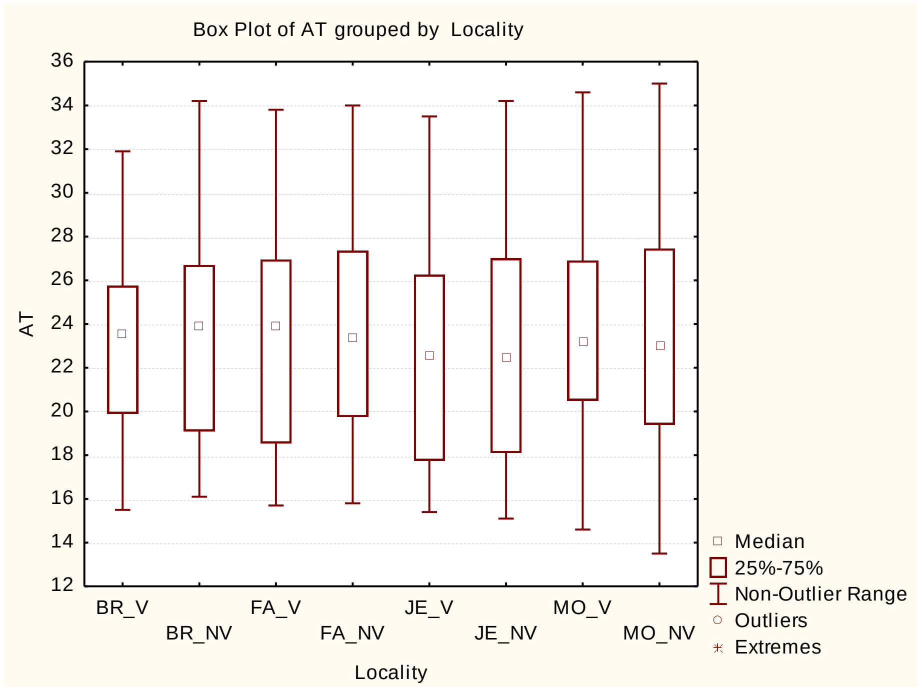


Fig. 6 *Comparison of air temperatures in localities and monitored areas, AT – air temperature (°C); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)*

Within the factor of air temperature, we did not find a statistically significant difference in terms of neither locality nor monitored areas. The greatest differences were recorded in Locality 1 (Fig. 6). Average difference in air temperature between vegetation cover and outside of it at noon in Locality 1 is 0.68 °C. Lower air temperature in the cover was reflected not sooner than in May and June, when the examined covers were fully capable of physiological processes. Average difference in air temperatures in the evening in Locality 1 was 0.59 °C with lower temperatures recorded in the cover. Difference in air temperature in Locality 1 with median higher for vegetation cover is interesting. It can be caused by morning values or e.g. at the surrounding air temperature over 30 °C, higher temperature was recorded in the cover than on a non-covered area. Locality 1 – Farská street represents a typical street canyon and a precondition of higher temperature values due to the layout and configuration of street objects and their materials. Locality 4 – Jesenského street represents the locality with the lowest temperature values, as we had assumed. The street gradually continues as the town park.

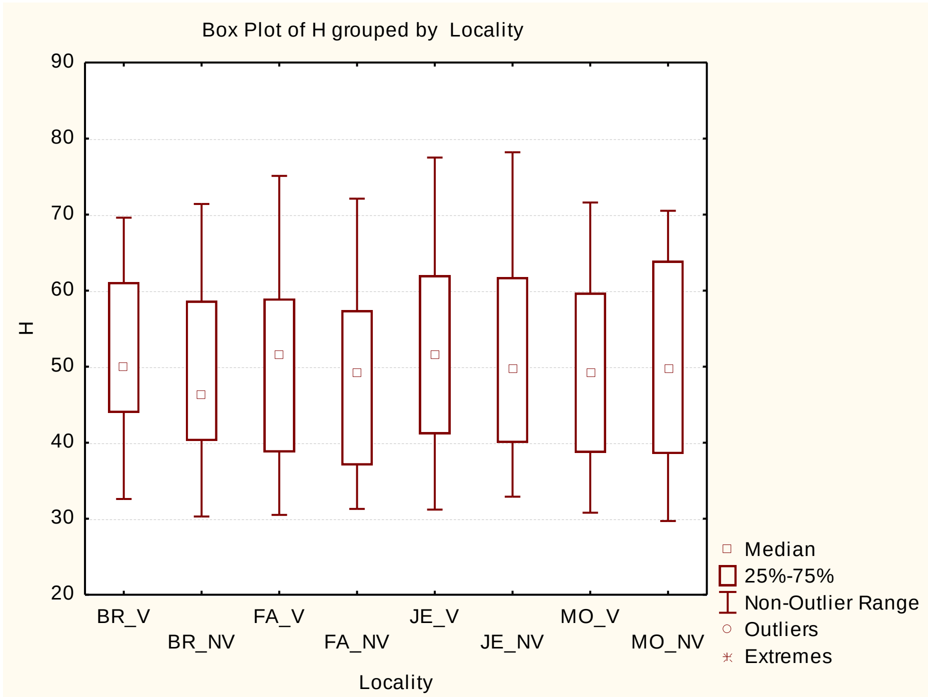


Fig. 7 *Comparison of relative air humidity in localities and monitored areas, H – relative humidity (%); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)*

Within the factor of relative air humidity, we did not find a statistically significant difference neither in terms of locality nor monitored areas. The greatest differences in relative air humidity between vegetation and non-vegetation were recorded in Locality 3 (Fig. 7). Average difference represents 3.78 %. Relative air humidity is most frequently dependent on air temperature, transpiration and airflow. Relative air humidity under vegetation cover is increased due to decreased temperature, transpiration of plants and airflow prevention, thus maintaining such humidity in the air. A greater difference can be seen under broadleaf species than under coniferous species (Čaboun, 2008). In Locality 2 – Moyzesova street coniferous create the monitored area with vegetation cover. Similarly to Čaboun (2008), the difference can be seen in graphic representation (Fig. 7). In Locality 3 a significant difference in airflow was recorded, which can affect relative air humidity. Lower marginal plants along the street are the monitored area with vegetation cover in Locality 3. Compared to Locality 1, difference can be in the transpiration of vegetation cover, whose canopy layer covers the street in the given area. The greatest difference in relative air humidity between localities is approximately 6 % between mixed layout adjacent to the town park and industrial layout of the commercial and industrial part of town. Air humidity, increasing in natural environment, reduces the effect of solar radiation. Vegetation increases relative air humidity compared to uncovered areas by 18 – 22 % (Čaboun, 2008).

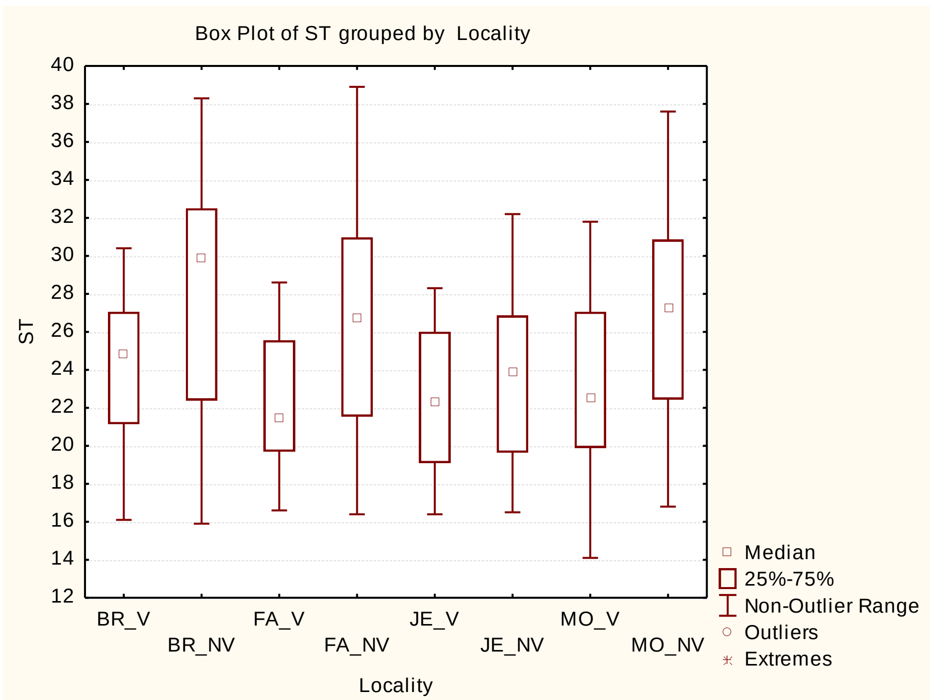


Fig. 8 *Comparison of surface temperatures in localities and monitored areas, ST – surface temperature (°C); BR (Locality 3), FA (Locality 1), JE (Locality 4), MO (Locality 2); V (vegetation), NV (non-vegetation)*

Within the factor of surface temperature, statistically significant difference was not recorded only in Locality 4 – Jesenského street. Differences in values of individual localities are shown in Fig. 8. All monitored surfaces are asphalt with law albedo. Asphalt is capable of long lasting radiation of accumulated converted heat. Temperature of active surface directly influences temperature conditions in ground and boundary atmospheric layer (Středa – Středová – Rožnovský, 2011). Vegetation acts as a stabilizer. Under certain conditions, it can overheat more than artificial surfaces – asphalt, paving and concrete (Čaboun, 2008). Even though vegetation has relatively low albedo, it does not accumulate heat. Its qualities have cooling effects. It absorbs a major part of direct solar radiation, which would otherwise be converted, accumulated and radiated back. Tree vegetation consumes approximately 2 % of solar energy for photosynthesis, 60 – 80 % is absorbed by leaves, 5 – 15 % is reflected back to space (glossy leaves reflect more sunshine than darker ones), the rest goes through leaves. Sparse treetops absorb 60 – 80 % of solar radiation, while only 2 – 3% of solar radiation penetrates through dense treetops (Pauditšová – Reháčková, 2006). Measurements on the monitored areas with vegetation covers were carried out in shades of the given covers. Monitored area without vegetation used shades of buildings of the given street canyon.

Tab. 3 *One-way ANOVA, p<0,05, variable suface temperature, Locality 3*

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	32617.2	1	32617.2	1106.4	0.000000
Locality	195.82	1	195.82	6.642	0.01323
Error	1356.1	46	29.48		

Tab. 4 *Tukey HSD test, variable suface temperature, Locality 3*

Locality	{1} 28,087	{2} 24,048
BR_NV		0.01335
BR_V	0.013347	

Tab. 5 *One-way ANOVA, p<0,05, variable suface temperature, Locality 1*

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	28975.4	1	28975.4	995.968	0.000000
Locality	235.54	1	235.54	8.0963	0.0066
Error	1338.26	46	29.09		

Tab. 6 *Tukey HSD test, variable suface temperature, Locality 1*

Locality	{1} 26,785	{2} 22,354
FA_NV		0.00673
FA_V	0.006732	

Tab. 7 *One-way ANOVA, p<0,05, variable suface temperature, Locality 2*

Effect	SS	Degr. Of Freedom	MS	F	p
Intercept	30235.5	1	30235.5	1037.32	0
Locality	180.58	1	180.58	6.195	0.01649
Error	1340.79	46	29.15		

Tab. 8 *Tukey HSD test, variable suface temperature, Locality 2*

Locality	{1} 27,038	{2} 23,158
MO_NV		0.0166
MO_V	0.016601	

Statistically significant difference in the microclimatic factor of surface temperature was recorded in localities 1, 2 and 3 depending on the presence of vegetation cover at the level of $p<0.05$ (Tab. 3, Tab. 5, Tab. 7) using the one-way ANOVA test, confirmed by the Tukey HSD test (Tab. 4, Tab. 6, Tab. 8). Monitored area with vegetation cover in Locality 3 is a lower scrubland and tree wall not absorbing solar radiation. Stronger airflow was recorded in this locality, however without affecting surface temperature. Effects of vegetation on surface temperature were also recorded in Locality 2 as well as in Locality 1. Monitored area with vegetation cover in Locality 1 recorded the lowest medians.

CONCLUSION

Four localities with different built-up area layouts and vegetation representations were selected in the town of Nitra. Each locality comprises a monitored area with vegetation cover and without vegetation cover. Surface thermal monitoring was carried out in the period from April to June. Microclimatic factors of surface temperature, air temperature, relative air humidity and airflow were recorded. Statistically significant differences depending on the presence of vegetation cover and locality were confirmed for the factors of airflow (one-way ANOVA, $p<0.05$) – industrial layout in the industrial part of town; surface temperature (one-way ANOVA, $p<0.05$) – compact layout in the historical centre of town, detached layout – family houses with gardens and industrial layout in the industrial part of town. Different airflow in industrial layout of the industrial part of town on the monitored area without vegetation is a result of open space of a broad street. Street canyon airflow is limited to its orientation, while it is affected by vegetation cover. Eccentric airflow values were predominantly recorded in monitored areas without vegetation. The surface temperature factor with the greatest values was also reflected in industrial layout of the industrial part of town. It means that airflow does not affect surface temperature; however, on the other hand, it affects air temperature. In compact layout of the historical centre of town, air temperature medians were higher in the monitored area with vegetation cover, while lower airflow medians were recorded there. During hot days, cover closes pores and does not increase air humidity by transpiration; respectively it does not lower air temperature. Area without vegetation recorded lower air temperature medians, which was affected by higher airflow. It did not affect surface temperature.

Vegetation favourably affects microclimatic factors which can affect perceived temperature. Vegetation is necessary in urbanized environment. It affects anthropogenic surfaces radiating accumulated heat by its structure and qualities, thus improving thermal comfort of people. Appropriate proposals of vegetation structures in urban planning as well as its shaping should result in improved urban climate and thus the quality of life of the inhabitants of towns.

REFERENCES

Akbari, H., Pomerantz, M., Taha, H., 2001: Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Elsevier Science Ltd., Solar Energy Vol. 70, No. 3, pp. 295 - 310

Andreou, E., Axarli, K., 2012: Investigation of urban canyon microclimate in traditional and contemporary environment. Experimental investigation and parametric analysis. Renewable Energy 43 (2012), pp. 354 – 363

Bonan, G., 2002: Ecological climatology, Concepts and applications, Cambridge University Press, 2nd ed., 678 pp. ISBN 978-0-521-69319-6

Brian, j., Berry, L., 2008: Urbanization, In: Marzluff, J., M., Schulenberger, E., Endlicher W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., Simon, U., ed., 2008: Urban ecology, Springer, New York, 807p., ISBN 978-0-387-73411-8

Čaboun, V., 2008: Vplyv vegetácie na znižovanie teploty povrchov a ovzdušia pri extrémnych horúčavách. In: Rožnovský, J., Litschmann, T. (ed): „Bioklimatologické aspekty hodnocení procesu v krajine“, Mikulov 9. – 11.9. 2008, ISBN 978-80-86690-55-1

Kantzioura, A., Kosmopoulos, P., Zoras, S., 2012: Urban surface temperature and microclimate measurements in Thessaloniki, Energy and Buildings 44, pp. 63-72

Kavka, B., Šindelářová, J. 1978: Funkce zeleně v životním prostředí. Praha: Státní zemědělské nakladatelství, 1978, 235 s.

Krüger, E. L., Minella, F.O., Rasia, F., 2011: Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil., Building and Environment 46 (2011), pp. 621 – 634

Kuttler, W., 2008: The urban climate – Basic and applied aspects, In: Marzluff, J., M., Schulenberger, E., Endlicher W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., Simon, U., ed., 2008: Urban ecology, Springer, New York, 807p., ISBN 978-0-387-73411-8

Landsberg, E. H., 1981: The urban climate, International geophysics series vol. 28, academic press, INC, New York, 277 p., ISBN 0-12-435960-4

Pauditšová, E., Reháčková, T., 2006: Praktické skúsenosti s hodnotením mikroklimatickej funkcie vegetácie v urbánnom prostredí. In: Sídlo-park-krajina IV. Kultúrna vegetácia v sídlach a v krajine. 2006. SPU, pp. 227-235, ISBN 80-8069-809-0

Pearlmutter, D., Erell, E., Snir, K., Shashua-Bar, R., 2014: The moderating effects of urban vegetation on pedestrian thermal stress in a hot-arid environment, Urban Climate News, (51), pp. 13-18

Středa, T., Středová, H., Rožnovský, J., 2011: Temperature Regime of the Urban Environment. In: Středová, H., Rožnovský, J., Litschmann, T. (eds): Mikroklima a mezoklima krajinných struktur a antropogenních prostředí. Skalní mlýn, 2. – 4.2. 2011, ISBN 978-80-86690-87-2

ACKNOWLEDGEMENT

This study is the result of the project implementation: Environmental aspects of the urban environment (Environmentálne aspekty urbanizovaného prostredia) ITMS 26220220110 supported by the Research & Development Operational Program funded by the ERDF and the result of the project: VEGA 1/0042/12 Analysis of selected environmental factors in relation to possible health risks (Analýza vybraných environmentálnych faktorov vo vzťahu k možným zdravotným rizikám).

SUMMARY

Cieľom tohto príspevku bolo porovnať mikroklimatické faktory v rôznych vegetačných štruktúrach, ako aj v rámci štyroch uličných koridorov reprezentujúcich rôzne typy zástavby mesta Nitra. Čiastkové vyhodnotenie prebiehajúceho výskumu zachytáva obdobie apríl - jún. Marcové dáta neboli použité v dôsledku začínajúceho vegetačného obdobia. V meste Nitra boli vybrané štyri lokality s rôznou štruktúrou zástavby a zastúpením vegetácie. Každá lokalita pozostáva z monitorovacej plochy s

vegetačným porastom a bez vegetačného porastu. Lokality výskumu predstavujú uličnú kompaktnú zástavbu v historickom centre mesta; uličnú voľnú zástavbu - rodinné domy so záhradami; rozptýlenú zástavbu, priemyselnú časť mesta a zmiešaná zástavba priľahlá k mestskému parku. Výskum bol realizovaný metódou pozemného termálneho monitoringu záznamom mikroklimatických faktorov - teplota povrchu, teplota vzduchu, relatívna vlhkosť vzduchu a prúdenie vzduchu. Monitorovacie dni sa vyznačovali prevahou priamej slnečnej radiácie. Vegetácia pôsobí ako tepelný stabilizátor. Večer má ochladzovací efekt, ráno naopak drží vyššiu teplotu ako okolie. Prúdenie vzduchu je ovplyvňované štruktúrou porastov aj konfiguráciu ulice. Štatisticky významný rozdiel v prúdení vzduchu v závislosti od lokality sa preukázal v rozptýlenej zástavbe, priemyselnej časti mesta na monitorovacej ploche bez vegetácie. Vo faktoroch teplota vzduchu a relatívna vlhkosť vzduchu nebol zistený štatisticky významný rozdiel v závislosti od lokality, ani od monitorovacích plôch. Vo faktoroch teplota povrchu vyšiel štatisticky významný rozdiel na troch lokalitách okrem lokality zmiešaná zástavba priľahlá k mestskému parku. Svojimi vlastnosťami má vegetácia ochladzovací efekt. Zachytáva väčšiu časť priameho slnečného žiarenia, ktoré by inak bolo premenené, akumulované a vyžarované späť. Rozdielne prúdenie vzduchu v rozptýlenej zástavbe, priemyselné časti mesta na monitorovacie ploche bez vegetácie je následkom otvoreného priestoru širokej ulice. V uličnom kaňone je prúdenie vzduchu obmedzené na jeho orientáciu, pričom vegetačný porast ho ovplyvňuje. Excentrické hodnoty v prúdení vzduchu sa vyskytli väčšinou na monitorovacích plochách bez vegetácie. Faktor teplota povrchu s najvyššími hodnotami sa prejavil tiež v rozptýlenej zástavbe, priemyselnej časti mesta. To znamená, že prúdenie vzduchu nemá vplyv na teplotu povrchu. Na druhej strane ovplyvňuje teplotu vzduchu. V uličnej kompaktnej zástavbe v historickom centre mesta boli stredné hodnoty teplôt vzduchu vyššie na monitorovacej ploche s vegetačným porastom, v ktorom boli zaznamenané nižšie stredné hodnoty prúdenia vzduchu. V horúcich dňoch porast uzatvára prieduchy a nezvyšuje vlhkosť vzduchu transpiráciou, resp. neznižuje teplotu vzduchu. Plocha bez vegetácie sa vyznačovala nižšími strednými hodnotami teplôt vzduchu, ktoré ovplyvňovalo vyššie prúdenie vzduchu. Na teplotu povrchu tiež nemalo vplyv.

CONTACT

Mgr. Ján Klein

Katedra ekológie a environmentalistiky, Fakulta prírodných vied, Univerzita Konštantína Filozofa v Nitre

Tr. A. Hlinku 1, 949 74, Nitra

+421904362578, jan.klein@ukf.sk

AGROMETEOROLOGICAL AND BIOLOGICAL ASPECTS OF MAIZE TRANSPIRATION

JANA KLIMEŠOVÁ, TOMÁŠ STŘEDA

Department of Crop Science, Breeding and Plant Medicine, Faculty of Agronomy, Mendel University in Brno

ABSTRACT

Maize (*Zea mays* L.) water regime was monitored in the pot experiment in four variants of irrigation. The aim of the study was to identify the influence of air temperature, drought, intensity of solar radiation on the plant water regime. Potential evapotranspiration calculated according to Penman-Monteith transpiration equation was compared with actual plant transpiration in individual variants. Transpiration rate (sapflow) was measured by stem heat balance (SHB) method. Statistical significant correlation was found between the sapflow and global radiation, sapflow and air temperature, sapflow and leaf surface temperature, respectively. Statistical significant difference between transpiration of plant growing under different irrigation variants was also confirmed.

Key words: soil moisture, meteorological elements, root system, irrigation, sap flow

INTRODUCTION

Globally, agriculture accounts for 80 – 90% of the fresh water used by humans, and in many crop production systems, this water use is unsustainable. An interdisciplinary approach involving agronomical opportunities and plant breeding to deliver "more crop per drop" is needed (Davies et al., 2011). For wheat, maize and barley, global yields have clearly responded negatively to increasing temperatures. Moisture certainty analyses in the Czech Republic proved an increase of the driest areas and drought event probability increased in the 1961–2010 period (Středová et al., 2011).

In the field, the upper limit of water productivity of well-managed, disease-free, water-limited cereal crops is typically 20 kg ha^{-1} mm^{-1} (grain yield per water used). The present increase in the CO_2 concentration has also increased root water uptake (Qiao et al., 2010). Therefore, it is surprising that breeding (for example) wheat for drought tolerance has resulted in small root/shoot ratios (Ma et al., 2010).

Effective use of water (EUW) implies maximal soil moisture capture for transpiration, which also involves reduced non-stomatal transpiration and minimal water loss by soil evapotranspiration. Breeding for maximal soil moisture capture for transpiration is therefore the most important target for yield improvement under drought stress (Blum, 2009). Středa et al. (2012) conclude that differences in the EUW expressed as different yields under the same conditions can be partly attributed to different root system sizes (probably due to deeper rooting) and can be improved by breeding.

Based on monitoring the sap flow and meteorological values it is possible to characterize water management in plants, detect stress and rate its intensity. Methods for the detection of sap flow are available that apply heat transmission by water contained in the xylem. These methods include the ‘heat pulse method’ which monitors gradual flow velocity based on a heat pulse motion in a shortly heated part of the trunk/stem. The outcomes completed with meteorological and physiological characteristics can be used to assess individual subjects as well as forest stands and field crops canopies (Středa, 2013).

The aim of this work was to identify differences in transpiration of maize plants exposed to various conditions of water supply, and to characterize the dependence of transpiration on environmental factors (air temperature, global solar radiation etc.) and plant traits.

MATERIALS AND METHODS

A pot trial was established under natural conditions with limited rainfall. Based on physical soil analysis (full water holding capacity: 39 volume percent; permanent wilting point: 21 volume percent), four variants of irrigation. Sap flow measurement was started at the stem elongation in phenological growth stage BBCH 39 (the BBCH – scale is a system for a uniform coding of phenologically similar growth stages of plant species; Meier, 1997): (A) control: 75% available water holding capacity (AWHC); (B) mild stress: 50% AWHC; (C) medium stress: 25%; and (D):

significant stress: 15% AWHC (23% soil moisture). In each pot (200 dm^3), 6 maize plants were sown (breeding line 2087, provided by CEZEA Čejč). Phenological data were monitored continuously and in the later phase of the trial, changes of conformation as a result of stress were studied, too. Transpiration was monitored by means of a continuous measuring of sap flow in 10-minute interval. The EMS 62 system (EMS, Brno) uses the SHB method (Kučera et al., 1977) was used. Sap flow (Q, $kg.h^{-1}$) was measured on two plants per pot from heading (BBCH 50) to full maturity (BBCH 89). Moreover, the following meteorological variables were monitored:

1. relative air humidity (%) and air temperature (°C) by HOBO RH Temp sensors (Onset Computer Co.) in 10-minute intervals,
2. volumetric soil moisture (%) by automatic electromagnetic sensors VIRRIB (AMET, Velké Bílovice) in 15-minute intervals,
3. global solar radiation ($W.m^{-2}$) measured by LI-COR sensors (LI-COR) in 15-minute intervals,
4. leaf surface temperature (°C) by infrared thermometer Raytek MX4 Raynger® MX4™ in 1-minute intervals; the sensor measures the surface temperature with resolution of 0.1 °C and accuracy of 1.0 °C,
5. Wind speed in canopy ($m.s^{-1}$) by anemometer W1 (Tlusťák, Praha) in 10-minute intervals.

Data were processed by MINI32 software (EMS, Brno) and statistically analyzed, i.e. correlation analysis, analysis of variance including mean comparison by Tukey's LSD test, using STATISTICA 10 (StatSoft Inc., Tulsa, OK).

Data of sap flow, i.e. transpiration intensity and meteorological data, were always evaluated only for the light part of a day (from sunrise to sunset).

RESULTS AND DISCUSSION

Differences in transpiration of maize (*Zea mays* L.) plants in four soil moisture regimes were quantified in a pot experiment. The transpiration was measured by "Stem Heat Balance" method. The dependence of transpiration on air temperature, humidity, global solar radiation, soil moisture, soil water potential and soil temperature was quantified.

Cross correlation of data was calculated and time distance of the transpiration reaction to abiotic factors was established (the example on Fig. 1 and Fig. 2). This phenomenon is proved by the course of transpiration in 24th – 26th July, 2013, when the studied meteorological elements were continually recorded in detailed one-minute steps. The fastest reaction was observed when air humidity and temperature and wind speed (0 – 3 minutes) changed. Increase of the leaf temperature caused increased rate of transpiration in a time period of 5 minutes. 10 minutes after changing the radiation intensity, the plant reacted by altering its transpiration.

Significant relationship between transpiration and global radiation and air temperature (in the 1. vegetation period in no-stress variant, r = 0.881**, r = 0.934**) was found out.

Global radiation has a primary effect on transpiration of plants (Gao et al., 2010), however, in case of drought stress occurrence, one may expect a major influence of soil moisture on the course of transpiration (Novák et al., 2005). A crop's reaction to the decrease soil water capacity is different for dissimilar crop species. High evapotranspiration requirements of the environment may cause loss of soil water supplies through excessive transpiration in non-sensitive plants (Yang et al., 2012).

The transpiration was significantly influenced by soil moisture (r = 0.395**, r = 0.528**) in moderate and severe drought stress. Conclusive dependence of transpiration on leaf temperature (r = 0.820**) and wind speed (r = 0.710**) was found. Correlation between transpiration and plant dry matter weight (r = 0.997**), plant height (r = 0.973**) and weight of corn cob (r = 0.987**) was found out.

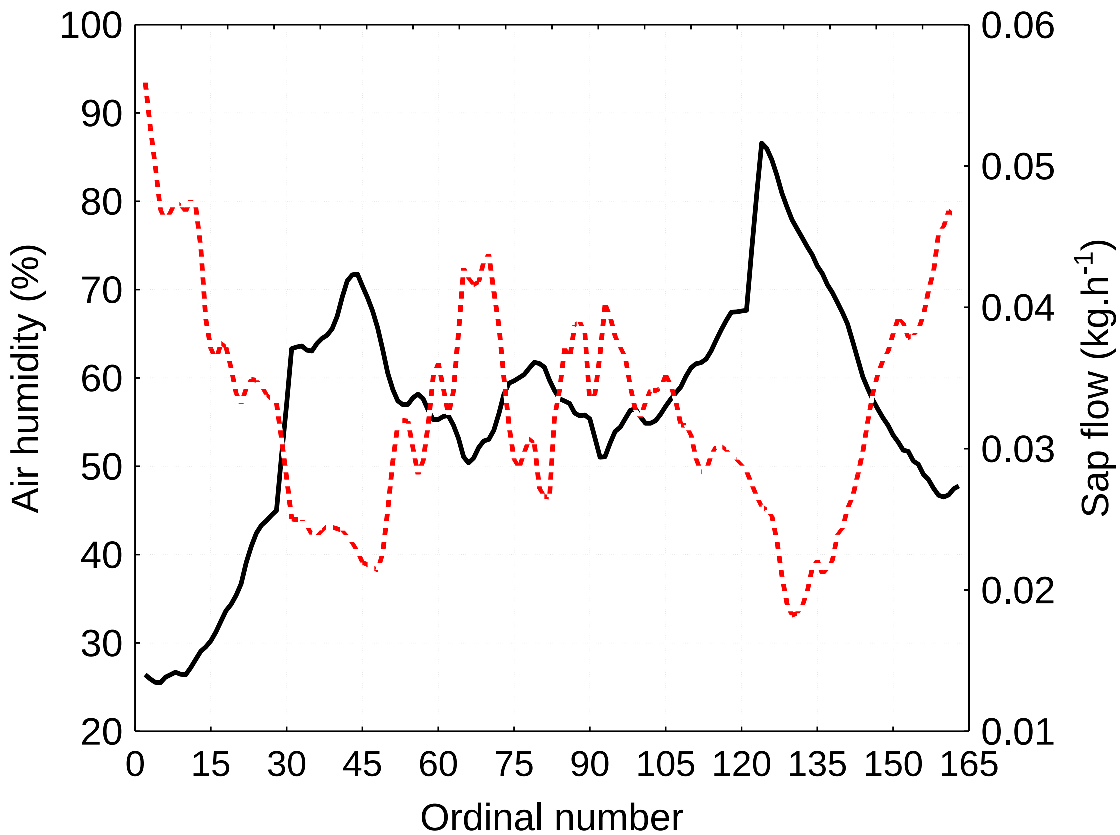


Fig. 1 *Course of sap flow (red line; kg.h^{-1}) in dependence on air humidity (black line; %); correlation coefficient of dependence among transpiration and air humidity r = -0.660*

Potential evapotranspiration calculated according to Penman-Monteith transpiration equation was compared with actual plant transpiration in individual variants (Fig. 3).

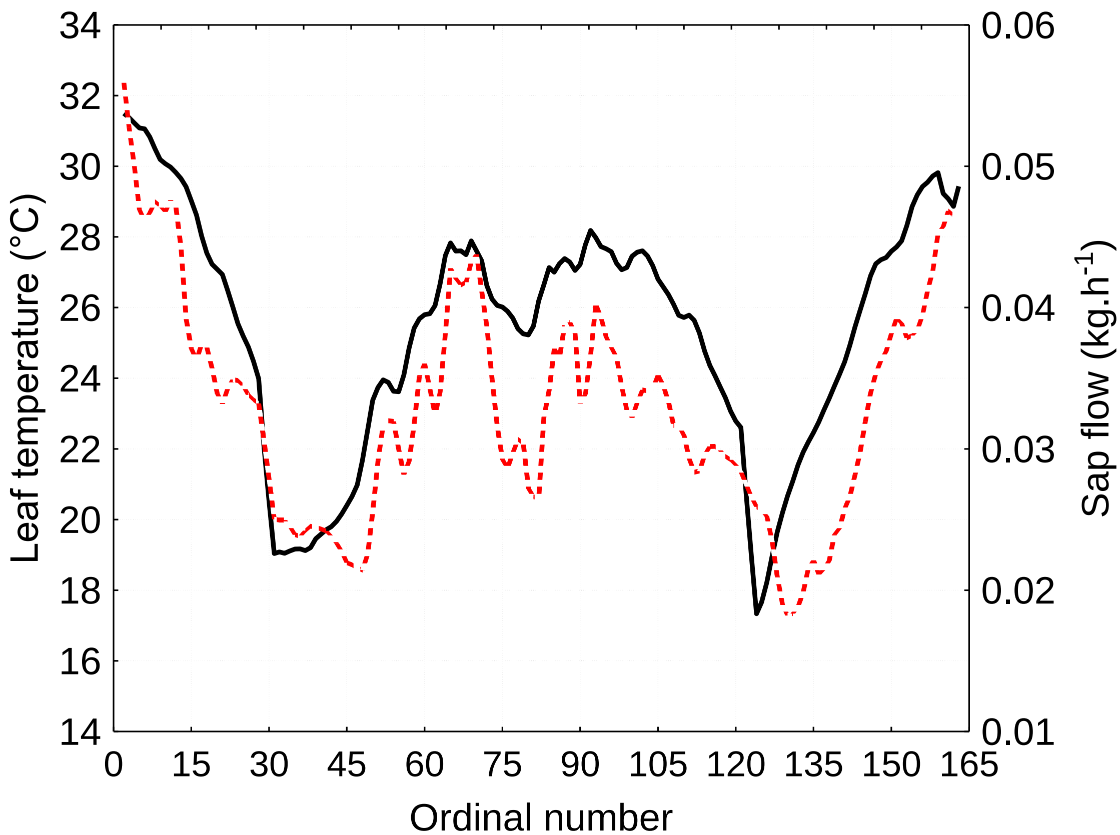


Fig. 2 *Course of sap flow (red line; kg.h^{-1}) in dependence on leaf area surface temperature changes (black line; °C), correlation coefficient of dependence among transpiration and leaf surface temperature r = 0.820*

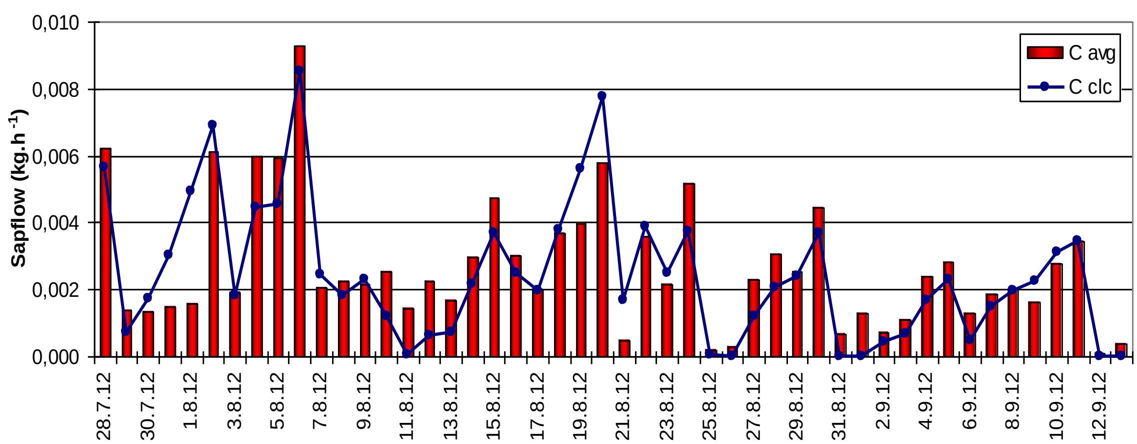


Fig. 3 *The course of measured (C avg) and calculated (C clc) transpiration in variant C (soil moisture 25 % of available water holding capacity)*

The measuring period was divided into three periods according to changes in transpiration and plant phenology. Dependency of transpiration on natural factors was assessed for each period separately so that variability of monitored features was closely recorded. For example, sap flow as per average diurnal radiation level (y) and average diurnal air temperature (x) for period 1 is described by the equation:

$$z = (a+bx+cy)/(1+dx+fy)$$

where: $a = -1.07 \times 10^{-3}$, $b = 8.24 \times 10^{-6}$, $c = 1.92 \times 10^{-5}$, $d = -2.79 \times 10^{-2}$ *and* $f = 5.14 \times 10^{-5}$ (R^2=0.977).

Sap flow impacted significantly dry matter yield, cob weight and plant height of monitored plants. A significant effect of soil moisture on dry matter yield or LAI (leaf area index) was not detected. It is possible to anticipate further consequences of water deficit stress – effect on root system parameters and defence mechanism induction on molecular level. These mechanisms will be studied in further experiments.

CONCLUSION

Abiotic stress is a main cause of reduced yield in case of healthy plants. The main current problem is lack of soil water or soil drought and high air temperatures respectively. Stand monitoring of meteorological elements is crucial for precise description of microclimatic conditions in the stand and their influence on plants physiological processes. Outcomes of microclimate monitoring provide valuable data for growth, phytopathological, yield and irrigation models and wide range of other applications.

The results of instrumental measuring of field crops transpiration under diverse moisture conditions at a concurrent monitoring of the meteorological elements spectra are rather unique. These results will be utilized in the effort to make calculations of the evapotranspiration in computing models more accurate.

Highly significant correlation coefficient values were found for sap flow and global radiation performance and for sap flow and air temperature. Simultaneously, statistically significant differences among sap flow values and selected irrigation regimes were quantified. Although sap flow is strongly affected by the global radiation performance and saturation supplement, the effect of water deficiency became evident. In comparison to field conditions, soil moisture in a pot trial had a greater impact on sap flow (water availability is limited by pot size). Nevertheless, the information capacity of this experiment is significant in this case.

REFERENCES

Blum, A., 2009. Effective use of water (EUW) and not water-use efficiency is the target of crop yield improvement under drought stress. Field Crops Research 112: 119–123.

Davies, W.J., Zhang, J., Yang, J., Dodd, I.C., 2011. Novel crop science to improve yield and resource use efficiency in water-limited agriculture. The Journal of Agricultural Science 149, 123–131.

Gao Y., Duan A. W., Qiu X. Q., Zhang J. P., Sun J. S., Wang H. Z., 2010: Plant transpiration in a maize/soybean intercropping system measured with heat balance method. Chinese Journal of Applied Ecology, 21, 1283–1288.

Kučera J., Čermák J., Penka M., 1977: Improved thermal method of continual recording the transpiration flow rate dynamics. Biologia Plantarum, 19, 413–420.

Ma, S.C., Li, F.M., Xu, B.C., Huang, Z.B., 2010. Effect of lowering the root/shoot ratio by pruning roots on water use efficiency and grain yield of winter wheat. Field Crops Research 115, 158–164.

Meier U., 1997: BBCH-Monograph. Growth stages of plants – Entwicklungsstadien von Pflanzen – Estadios de las plantas – Développement des Plantes. Blackwell Wissenschaftsverlag, Berlin und Wien, 622 p.

Novák V., Hurtalová T., Matejka F., 2005: Predicting the effects of soil water content and soil water potential on transpiration of maize. Agricultural Water Management, 76, 211–223.

Qiao, Y.Z., Zhang, H.Z., Dong, B.D., Shi, C.H., Li, Y.X., ZHai, H.M., Liu, M.Y., 2010. Effects of elevated CO2 concentration on growth and water use efficiency of winter wheat under two soil water regimes. Agricultural Water Management 97, 1742–1748.

Středa, T., Dostál, V., Horáková, V., Chloupek, O., 2012. Effective use of water by wheat varieties with different root system sizes in rain-fed experiments in Central Europe. Agricultural Water Management 104, 203–209.

Středa, T., Vahala, O., Středová, H., 2013. Prediction of adult western corn rootworm (Diabrotica virgifera virgifera LeConte) emergence. Plant Protection Science 49, 89–97.

Středová, H., Chuchma, F., Středa, T., 2011. Climatic factors of soil estimated system. In: International Scientific Conference on Bioclimate - Source and Limit of Social Development. Topolcianky, Slovakia. Nitra: SPU v Nitre, 137–138.

Yang Z., Sinclair T. R., Zhu M., Messina C. D., Cooper M, Hammer G. L., 2012: Temperature effect on transpiration response of maize plants to vapour pressure deficit. Environmental and Experimental Botany, 78, 157–162.

ACKNOWLEDGEMENT

This work was supported by a project of the Czech Ministry of Agriculture, QI111C080.

SUMMARY

Měření transpiračního toku (sapflow) je jedním ze způsobů jak kvantifikovat využití/tok vody rostlinami v závislosti na faktorech prostředí. Metoda stem heat balance (SHB) byla zvolena jako přesná, citlivá metoda pro detekci sapflow u kukuřice s cílem zjistit míru ovlivnění transpirace vybranými meteorologickými prvky. Zároveň byl pozorován stres suchem a jeho vliv na průběh transpirace. Na základě rovnice pro výpočet potenciální evapotranspirace Penman-Monteith byla vypočtena potenciální transpirace pro 4 varianty závlahového režimu. Byly nalezeny vysoce průkazné hodnoty korelačního koeficientu pro sapflow a příkon globální radiace resp. sapflow a teplotu vzduchu, sapflow a teplotu povrchu listů, stejně jako pro rychlost proudění vzduchu. Současně byly potvrzeny statisticky vysoce průkazné rozdíly hodnot sapflow mezi všemi variantami. Přestože je transpirace silně ovlivněna výkonem radiace, teplotou vzduchu a sytostním doplňkem, projevil se vliv vodního deficitu. V závěru vegetace byla transpirace ovlivněna stárnutím rostlin. Můžeme předpokládat další důsledky stresu suchem na rostlinný metabolismus a jeho projevy na růstu nadzemní části rostlin i kořenového systému. Pro přesnější identifikaci stresových projevů byly hodnoceny fytometrické charakteristiky pokusných rostlin a identifikován nástup stresu i na molekulární úrovni.

CONTACT

Ing. Jana Klimešová,

Department of Crop Science, Breeding and Plant Medicine, Faculty of Agronomy, Mendel University in Brno,

Zemědělská 1, 613 00 Brno, Czech Republic

+420 545 133 121, jana.klimesova@mendelu.cz

THE OCCURRENCE OF HAIL IN SELECTED LOCATION WITHIN SOUTH MORAVIA REGION IN THE PERIOD 2003 – 2013

GRAŽYNA KNOZOVÁ

Czech Hydrometeorological Institute

ABSTRACT

The aim of the study is to characterise hail occurrences in long-term, yearly and daily periods, and evaluation of meteorological conditions, typical for their occurrences in central and south Moravia. The study is based on materials measured and observed at 15 Czech Hydrometeorological Institute's (CHMI) climatological stations in years 2003 – 2013. Daily and 10-minute period recordings of air temperature and precipitation sums have been used. A close attention to rainfall intensity and surface temperature variability in 2 meters layer during the specific events has been paid. Additionally an analysis of storms movement in connection to hail occurrence in particular locations has been done.

The hail appears more frequently during storms than during showers, and approximately a third of hail is accompanied by downpours. The maximum precipitation intensity was between 2.0 mm/min – 4.1 mmm/min in observed locations. A temperature inversion is usually created on the surface level during hail, which for a short time influences microclimatic conditions. In general, hailstorms in Moravia usually come from the west sector and move in east direction. The influence of local terrain morphology on hailstorm is minor, because the hailstorm development is conditioned mainly by synoptic situation in mesoclimate scale.

Key words: extreme weather, precipitation, rainfall intensity, downpour, thunderstorm

INTRODUCTION

The climate is often perceived indifferently as we have managed to adapt well to the geographical climatic conditions in the Czech Republic. Extreme weather, including hail, however, evokes considerably more emotions, because of its negative consequences, like property damage, e. g. broken windows and greenhouses, damaged cars or damaged crop in orchards and fields. Hail also affects other elements of geographical environment like plants, animals and, less apparently, abiotic components. Hail occurrence is characteristic to Moravia region and thus its study requires systematic updating and deeper climatological research.

Hail occurrence, especially its negative consequences, has been a subject to scientific studies since the beginning of the 20th century. “Hail in Moravia in the period 1896 – 1906” (Koutný, 1908) includes a detailed list of dates and hail-stricken places. From newer studies dealing with hail in Moravia region should be mentioned a detailed case study by Šálek (1989) and complex climatological evaluation by Brázdil et al. (1989) and Chromá et al. (2005). Currently, modern database systems collating all the information about hail occurrence and its consequences are created in the world, e. g. American National Weather Service (Gourley et al., 2013) with up to date and also historical information. In Europe there is European Severe Weather Database – ESWD (http://www.eswd.eu) with archive updated with extreme atmospheric phenomena like tornado, severe wind, large hail, heavy rain, funnel cloud, gustnado, dust devil, heavy snowfall/snowstorm, ice accumulation, avalanche, damaging lighting (Krennert et al. 2013).

MATERIALS AND METHODS

We are aware that it is impossible to count and describe all the hail occurrences in such a large area like Moravia, since hail occurs in local restricted areas. The study is based on precise evaluation of hail in specific locations. The subjective method of the occurrences recording has to be taken into consideration and it is supposed the records are not complete since volunteers attend most of the climatological stations. The study is based on hail database prepare from materials measured and observed at 15 Czech Hydrometeorological Institute’s (CHMI) climatological stations Brno region (Fig. 1) in years 2003 – 2013. The studied period is specified based on automatic machines’ homogeneity measurement during past 11 years. For each hail occurrence a detailed characteristic of accompanying meteorological conditions has been drawn. Daily and 15-minute or 10-minute period recordings of air temperature and precipitation sums have been used. A close attention to surface temperature variability in 2 meters layer and rainfall intensity during the specific events has been paid. For the evaluation also image of radar reflectivity have been used and along with storm records they served for the analysis of convection cell, which have caused hail, and the course of their movement.

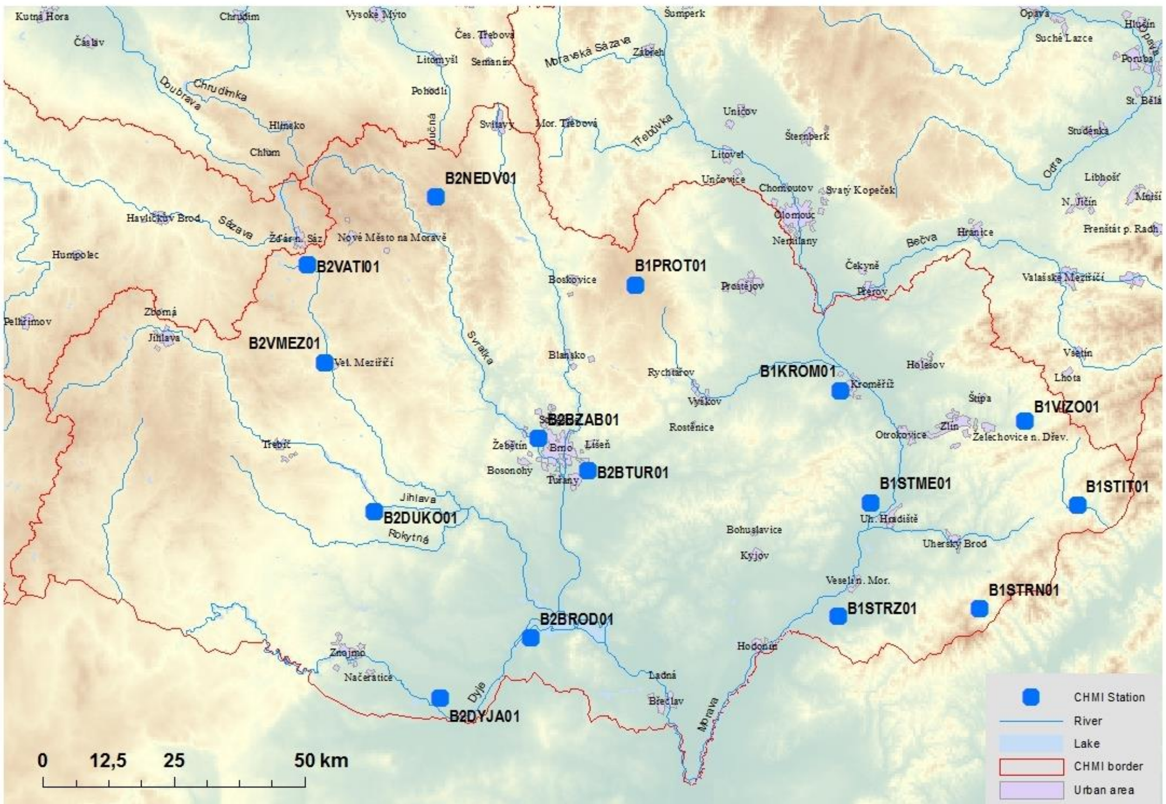


Fig. 1. The location of ČMHI climatological stations used in the study

The aim of the study is to characterise hail occurrences in long-term, yearly and daily periods, and evaluation of meteorological conditions, which are typical for their occurrences in the specific locations in central and south Moravia.

RESULTS

During the evaluated 11 years period, 2 to 3 cases of hail were recorded at the climatological stations in Strání and Staré Město, and up to 27 cases in Vatín (Fig. 2). Relatively small number of hail occurrences was recorded at the stations in Strážnice and Dyjákovice, while in Nedvězí and Velké Meziříčí hail occurred quite often. From the comparison of geographical layout of hail frequency in observed locations can be draw that the east part of Bohemian-Moravian Highlands is hail-stricken significantly more often than Dolnomoravský ravine, The White Carpathians and Dyje River Valley. This fact is due to the locations altitudes. At the stations in lower altitudes to 400 m the hail frequency is between 2 - 17 cases in 11 years, while in altitudes above 400 m the frequencies is between 12 – 27 cases in 11 years. The hail threshold value in 1 season is 7 cases at the station in Nedvězí, which is located in the highest altitude 722 m. The hail occurrence frequency dependence on altitude was elicited in Chromá et al. work (2005).

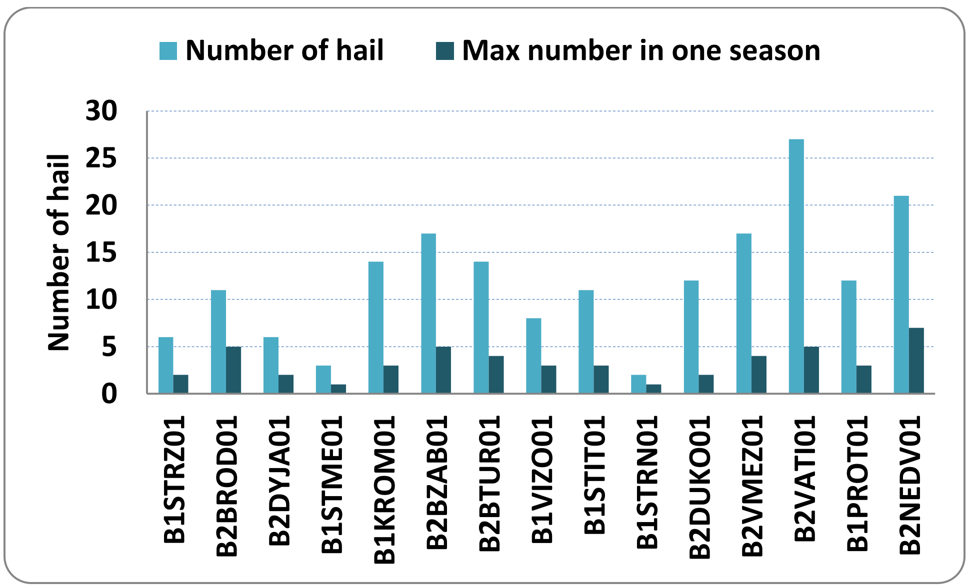


Fig. 2. The number of hail occurrences in selected locations in central and south Moravia in the period 2003 – 2013

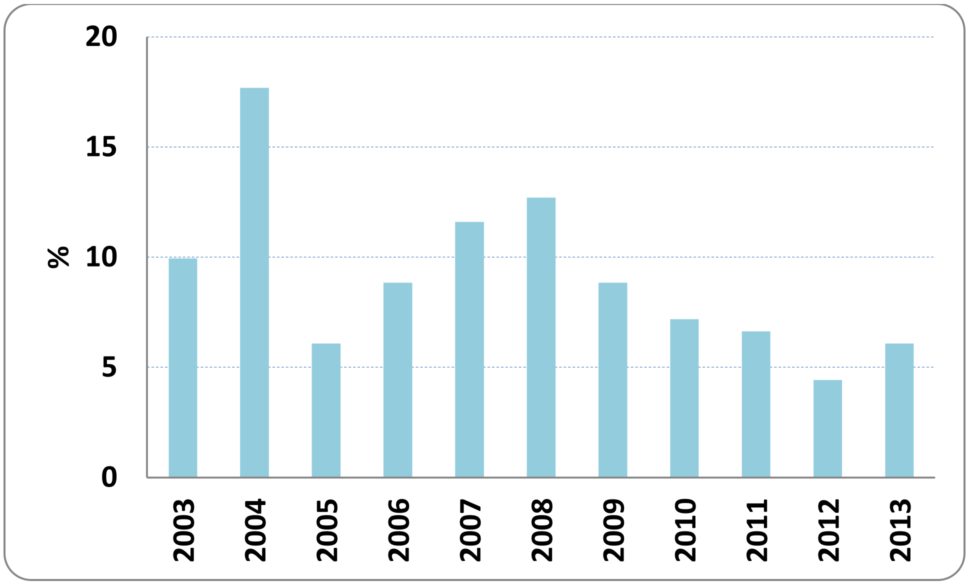


Fig. 3. Hail occurrence frequency in selected locations within central and south Moravia regions in particular years in the period 2003 – 2013

To characterize the hail occurrence all the cases from all the stations were evaluated together. There were 181 events in total. In 2004 hail occurred the most – 17.7% all occurrences (Fig. 3), followed by the years 2007 and 2008. The studied period is unfortunately too short to evaluate trends in long-term changes in hail frequency. According to Brázdil et al (1998) and Chromá et al (2005) studies the number of hail occurrences in Moravia is decreasing.

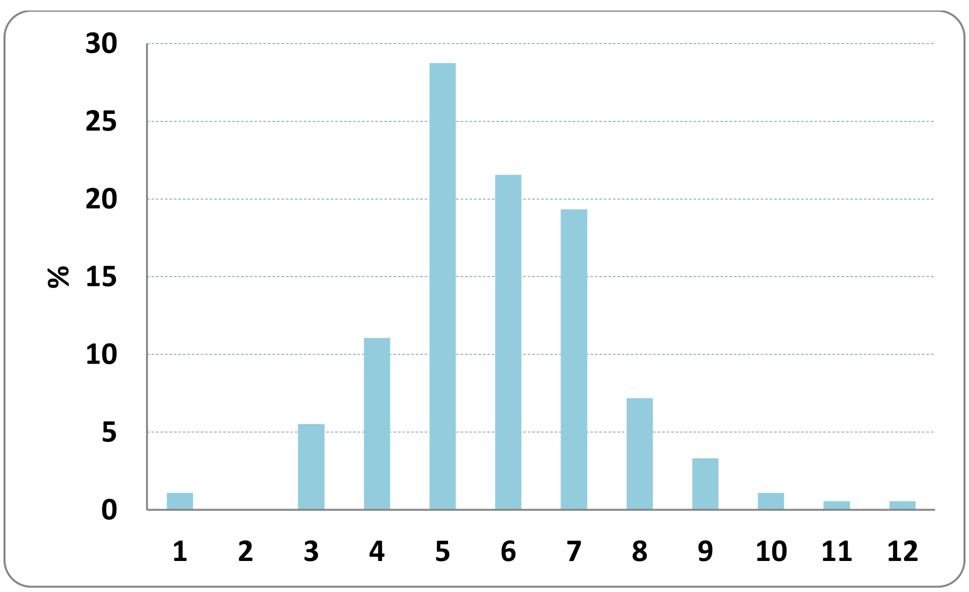


Fig. 4 Hail occurrence frequency in selected locations within central and south Moravia regions in particular months in the period 2003 – 2013

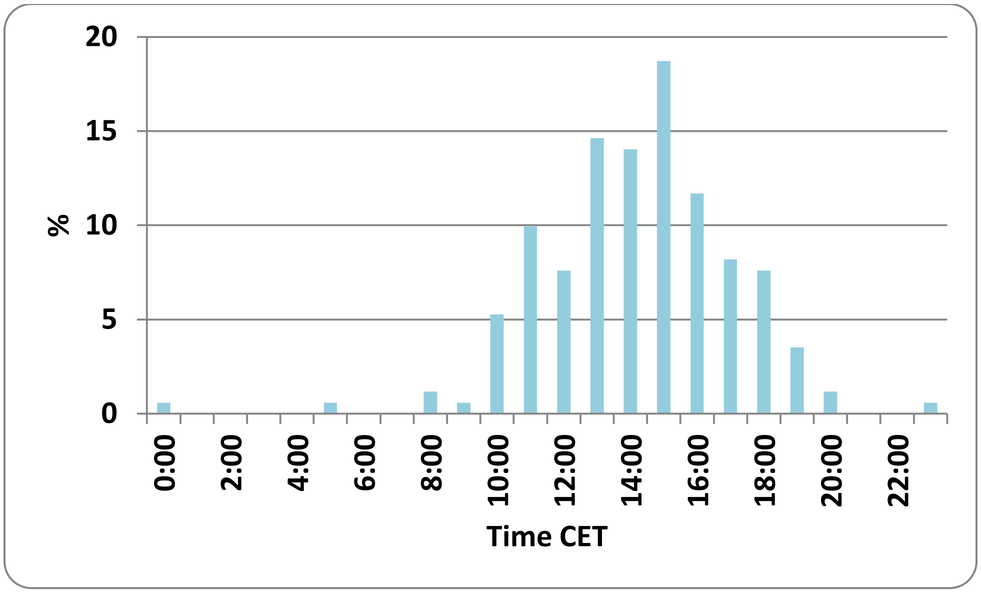


Fig. 5 The time of hail occurrence in selected locations within central and south Moravia regions in the period 2003 – 2013

In a year laps hail appears mostly in warm season – the maximum is in May when 28.7% all cases were recorded (Fig. 4). Similar year cycle is typical for other European regions (e. g. Twardosz et al, 2011, and Bielec-Bąkowska, 2013).

Significant hail occurrence day laps frequency is 1600 – 1700 CET, when 18.7% all cases were recorded (Fig. 5). During night hail occurrences were scarcely recorded. The time duration is usually short and in 68.2% cases not longer than 5 minutes (Fig. 6).

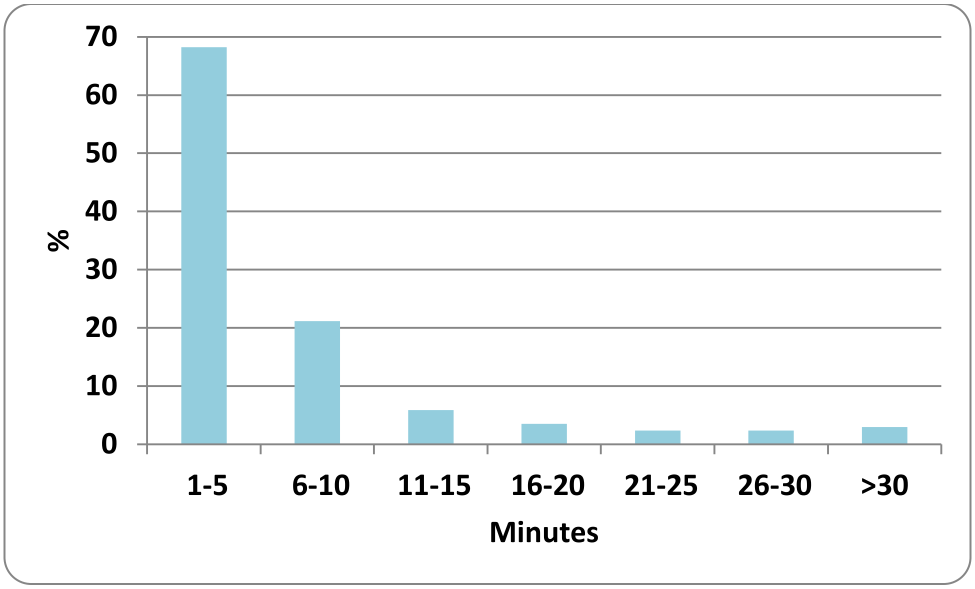


Fig. 6 The duration of hail occurrence in selected locations within central and south Moravia regions in the period 2003 – 2013

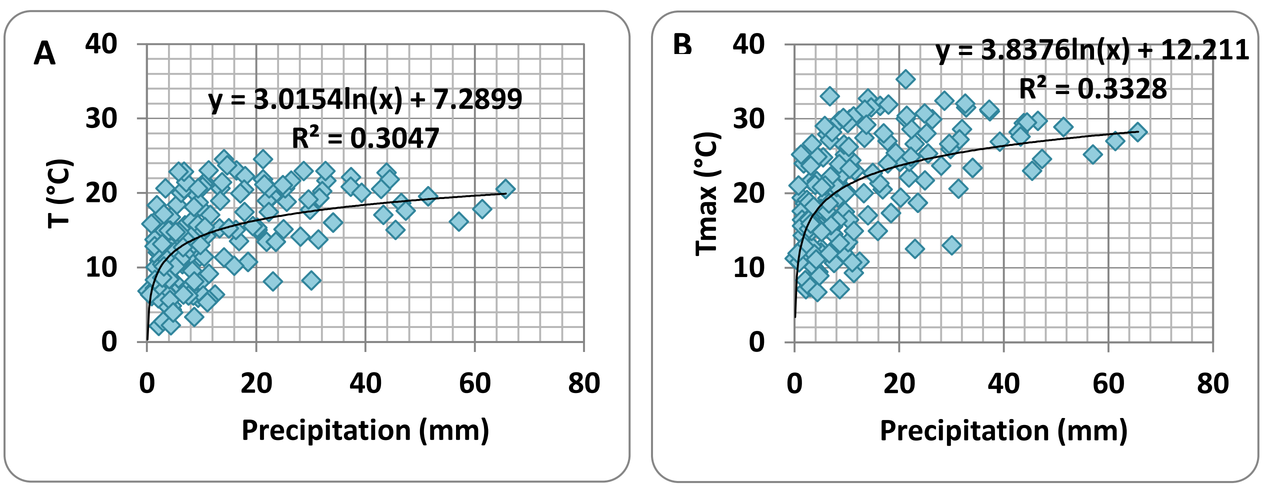


Fig. 7 Average day temperatures and precipitation (A), maximum day temperature and precipitation (B) in hail days (15 ČMHÚ stations, south Moravia, 2003 – 2013)

The following part of the study is focused on characterising meteorological conditions during hail days occurred in general. In this case, all the days were evaluated collectively not differentiating between individual locations. Average daily temperature, maximum daily temperature and average daily precipitation analysis has shown most of the hail occurs in days with average temperature 10.1°C – 20.0°C (in 52.8% cases) and precipitation 0.1 mm – 10.0

mm (53.9% cases), while maximum temperature is 15.1°C – 30.0°C (67.2% cases). A logarithmic dependence between temperatures, both average and maximum, and precipitation was determined in hail days (Fig. 7).

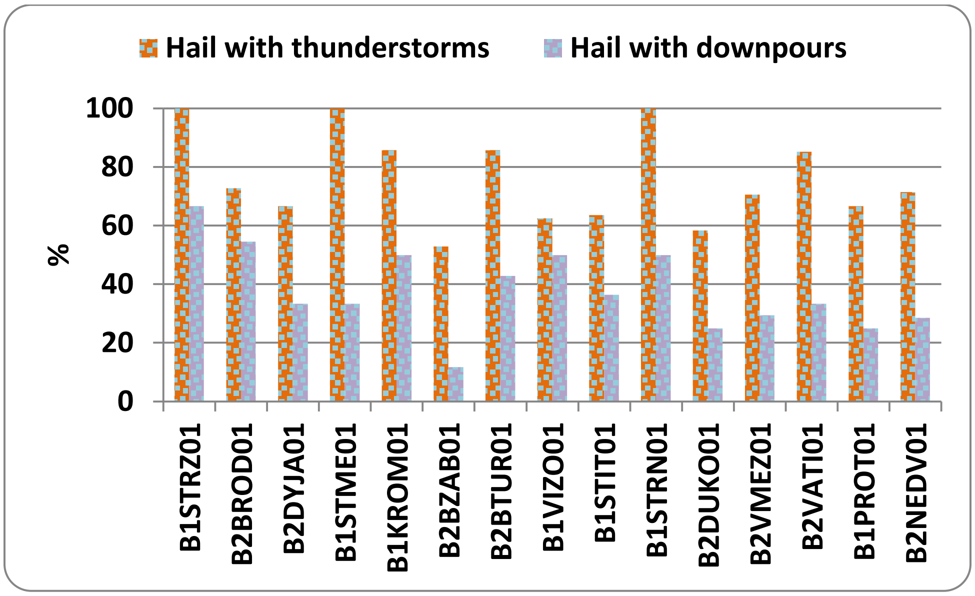


Fig. 8 Thunderstorm and downpour occurrence frequency in days with hail in selected locations within central and south Moravia regions in the period 2003 – 2013

The temperature characteristics correspond to season with most hail days. Should be noted there is rain along with hail. The observed phenomenon is usually dynamic, however, the maximum daily precipitation is scarcely over 45 mm – during the 11 years, there were only 7 such days and of which 3 at station in Vatín. The precipitation is usually not extreme, because the convection cells causing hail are prevalently frontal. Frontal processes are more powerful than free convection processes (Dimitrova et al, 2009). A slow movement of convection cells allows the cells to mature over a particular location and thus increases the potential for downpour (Řezáčová et al., 2007). Using the Wussow method (1922) for evaluation has been determined in 34.8% hails the precipitation is of downpour character. On the other hand, 73.5% hails are accompanied by thunderstorm (Fig. 8), while the rest by showers.

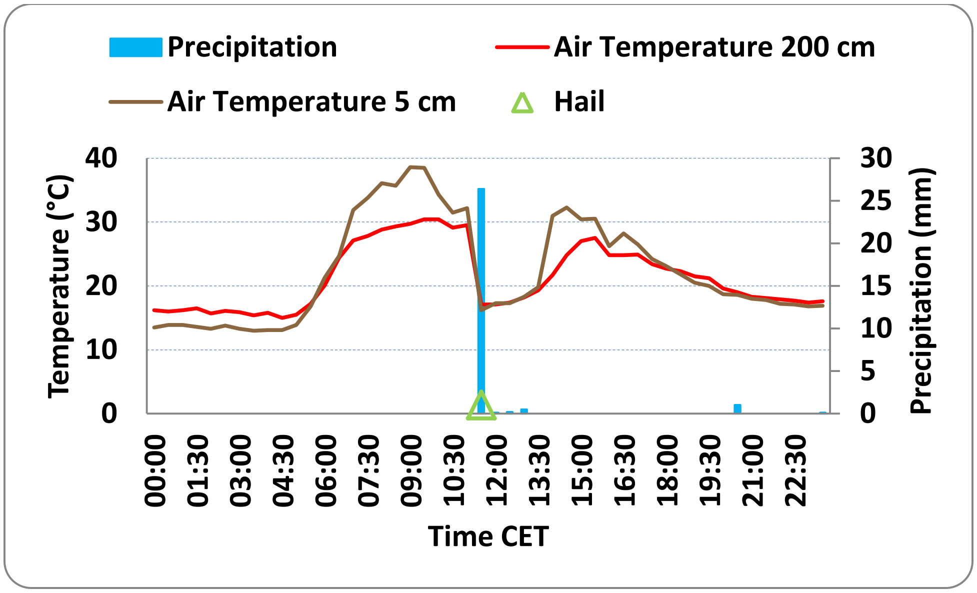


Fig. 9 Temperature and precipitation dynamics at station in Vizovice on 29th Jul 2006

The maximum precipitation intensity was between 2.0 mm/min – 4.1 mmm/min in observed locations. In several cases, the intensity could not been established due to obstruction in rain gauge. During extreme convection phenomena accompanied by strong wind, it is quite common for contamination like leaves, twigs, etc. to get in the rain gauge and bias the measurements.

The detailed analysis of particular hail occurrences, accompanied with the dynamics of surface temperature has shown an influence of hail precipitation on the microclimate in hail-stricken locations. It has been determined during hail there is a rapid drop in temperature both in 5 cm and 200 cm above surface. The rapid drop causes inversion, because the surface, which was hotter than air before the hail occurrence, is intensively cooled by the hail and then adopts the thermal energy from subsurface and upper parts of air. The drop in temperature corresponds with the hail occurrence, or more precisely, follows with a little delay and is by few degrees Celsius. The inversion duration depends on the time of the hail occurrence and the whole precipitation event duration. Around noon, when the sun is up high, inversion dissolves when hails melt (Fig. 9). During hail occurrences in the evening, the surface is not reheated and thus radiation inversion is formed (Fig. 10).

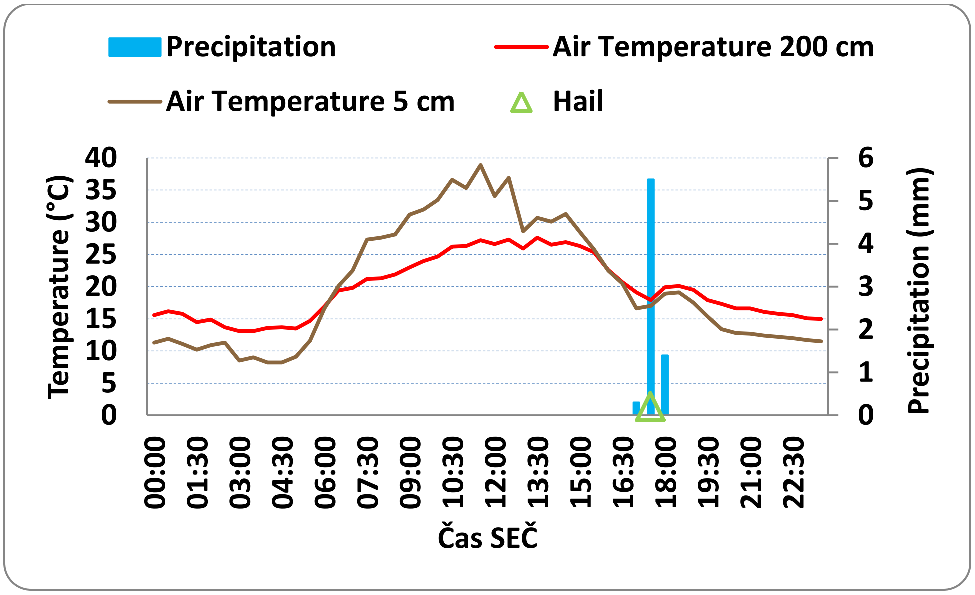


Fig. 10 Temperature and precipitation dynamics at station in Vatín on 18th Jul 2004

To determine whether and how can local conditions influence hail occurrence development an analysis of storms movement in connection to hail occurrence in particular locations has been done. The data was processed based on the volunteers' attending the stations notes.

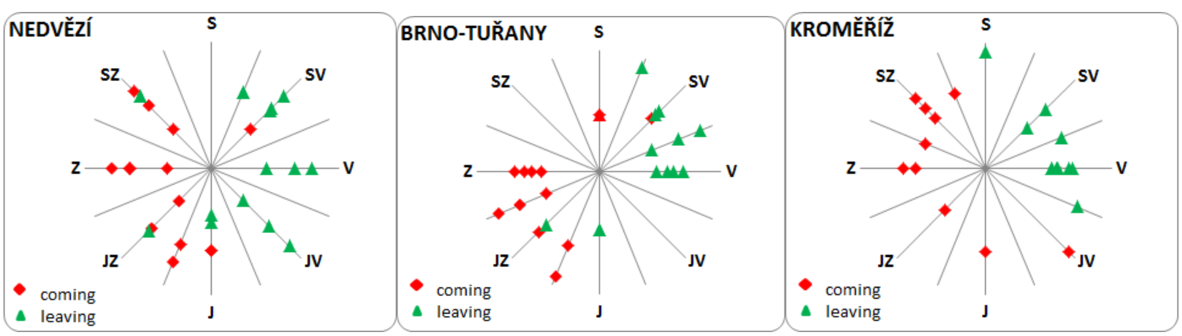


Fig. 11 Hailstorms movement directions at the stations in Nedvězí, Brno-Tuřany and Kroměříž (2003 – 2013)

In general, hailstorms in Moravia usually come from the west sector and move in east direction. It is most obvious at the stations located in Bohemian-Moravian Highlands, where 12 – 15 cases at particular station were examined. Only in few locations it is possible to determine specific dominant directions, e.g. in Brno-Tuřany, where most of the hailstorms come from the southwest continuing to northeast. Other case is a station in Kroměříž, where hailstorms come from northwest and leave in east direction. Specific case is also the station in Vizovice, where there is a significant dependence on the terrain morphology and hailstorms come from northeast and northwest and leave in southeast and southwest directions. In Dyjákovice hailstorms move in southwest – south – southeast sector. Examples of Nedvězí, Brno-Tuřany and Kroměříž stations are shown in Fig. 11.

However, the observers' subjectivity causes rising of doubts concerning the presented results. In several cases the convection cells movement evaluations, identified by meteorological radar clashes with the observers' notes and have to be evaluated separately. Based on the analysis of selected cases of radar reflectivity, can be concluded, despite the discrepancies, the thesis that hail occurrences are due mesoclimate causes. The influence of terrain morphology is only minor. According to Brázdil et al (1998), storm and extreme weather phenomena is depended on cyclone situation. According to CHMI standardization of weather conditions, hails appear mostly during types: SWc, SWc_2, C, SWc_3 and Wal. The dominance of cyclone situation is due to more frequent frontal storms occurrence than local storms created from heat during anticyclonic situations.

Conclusion

The analysis is focused on time characteristics of hail occurrence and evaluation of the accompanying weather conditions. The results concerning yearly and monthly hail frequency in Moravia are consistent with previous research. The analysis of weather conditions in hail days revealed that hail appears more frequently during storms than during showers, and approximately a third of hail is accompanied by downpours. A temperature inversion is usually created on the surface level during hail, which for a short time influences microclimatic conditions. Analysis of the terrain morphology influence based on the hailstorm development and movement observation has shown that the influence of local terrain morphology on hailstorm is minor, because the hailstorm development is conditioned mainly by synoptic situation in mesoclimate scale. However, the role of hill slope exposition or the characteristics of the surface (water areas, forests, fields, urban areas, etc.) influence on hail occurrence deserve an individual analysis. Acquired knowledge can be useful in creating local weather forecast concerning extreme atmospheric phenomena occurrences.

REFERENCES

Brázdil, R. Štěpánek, P., Vais, T., 1998, Časová a prostorová analýza bouřek, krupobití a extrémních srážek v jižní části Moravy v období 1946–1995. Meteorologicke Zpravy, 51, 45–52.

Bielec-Bakowska Z., 2013, Burze i grady w Polsce, Prace Geograficzne, 132, 99-132.

Chromá, K., Brázdil, R., Tolasz, R**.,** 2005, Spatio-Temporal Variability of Hailstorms for Moravia and Silesia in the Summer Half-Year of the Period 1961 – 2000. Meteorologický časopis – Meteorological Journal, 8(2): 65 – 74.

Dimitrova, T., Mitzeva, R., Savtchenko, A., 2009, Environmental conditions responsible for the type of precipitation in summer convective storms over Bulgaria, Atmospheric Research , 93, 30–38.

Koutny, J., 1908, Krupobití na Moravě v letech 1896 – 1906. Zprávy komise pro přírodovědecké prozkoumání Moravy. Oddělení meteorologické, č.1., Brno, 117 s.

Krennert T., Chimani B., Türk K., 2013, Trusted Spotter Network Austria – New Developments and Applications at ESWD. 7th European Conference on Severe Storms (ECSS2013) , 3 - 7 June 2013, Helsinki, Finland.

Gourley, J. J., Hong, Y., Flamig, Z. L., Arthur, A., Clark, R., Calianno, M., Ruin, I., Ortel, T., Wieczorek, M. E., Kirstetter, P. E., Clark, E., Krajewski, W. F., 2013, A Unified Flash Flood Database across the United States. Bulletin of the American Meteorological Society, Volume 94, Issue 6, pp. 799-805.

Řezáčová, D., Novák, P., Kašpar, M., Setvák, M., 2007, Fizyka oblaků a srážek. Academia, Praha, 576 str.
Šálek M., 1998, Silné krupobití na okrese Žďár nad Sázavou ze dne 30.6.1997, Meteorologicke Zpravy, 51, 73–80.

Twardosz, R., Łupikasza, E., Niedźwiedź, T., 2011, Zmienność i uwarunkowania cyrkulacyjne występowania postaci i typów opadów atmosferycznych na przykładzie Krakowa, Wydawnistwo Uniwersytetu Jagiellońskiego, Kraków, 173.

Wussow, G., 1922, Untere Grenze dichter Regenfälle. Meteorologische Zeitschrift, 39, 173–178.

http://www.eswd.eu

SUMMARY

Cílem práce byla charakteristika výskytu krupobití v dlouhodobém, ročním a denním chodu a také vyhodnocení meteorologických podmínek, typických pro jejich výskyt v konkrétních lokalitách na střední a jižní Moravě. Základem předkládané práci byla databáze krupobití připravená z materiálů naměřených a napozorovaných na 15 klimatologických stanicích Českého hydrometeorologického ústavu (ČHMÚ), nacházejících se na území brněnské pobočky ČHMÚ, zaznamenaných v letech 2003 – 2013. Pro každý případ krupobití byla vyhotovená detailní charakteristika doprovázejících meteorologických podmínek. Použité byly jak denní, tak 10-minutové záznamy o teplotě vzduchu a srážkových úhrnech. Velká pozornost byla věnovaná chodu teploty vzduchu v přízemní dvoumetrové vrstvě a chodu intenzity srážek, během konkrétních událostí. Navíc byla provedená analýza směru pohybu konvekčních buněk, jež způsobily výskyt krup.

Ve zpracovávaném období 11 let bylo na jednotlivých lokalitách zaznamenáno od 2 do 27 případů krupobití. V jednotlivých letech se krupobití vyskytovalo s největší četností v roce 2004, kdy bylo zaznamenáno 17,7% všech případů. Poměrně bohaté na kroupy byly také roky 2007 a 2008. V ročním chodu se krupobití vyskytuje nejčastěji v teplé sezoně, s maximem v květnu, kdy bylo zaznamenáno 28,7% všech případů. Výskyt krupobití má výrazný denní cyklus s odpoledním maximem mezi 16:00 a 17:00 hodinou SELČ, kdy bylo zaznamenáno 18,7% všech případů. V nočních hodinách případy krupobití byly zaznamenaný zcela ojediněle. Doba trvání krupobití je nejčastěji krátká a v 68,2% případů nepřesahuje 5 minut. Analýza průměrné denní teploty, maximální denní teploty a denního úhrnu srážek ukazuje, že většina krupobití se ve střední a jižní Moravě vyskytuje ve dnech s maximální teplotou vzduchu v intervalu 15,1°C až 30,0°C, průměrnou teplotou v intervalu 10,1°C až 20,0°C a úhrnem srážek v intervalu 0,1 mm až 10,0 mm. Po vyhodnocení intenzity srážek metodou Wussowa, bylo zjištěno, že srážky svázané s krupobitím mají přívalový charakter v 34,8% případů krupobití. Maximální intenzita srážek byla naměřená ve sledovaných lokalitách v intervalu od 2,0 mm/min do 4,1 mm/min. Krupobití v 73,5% případů doprovází bouřky a ve zbývajících případech je doprovází přeháňky. V průběhu krupobití dochází k prudkému poklesu teploty vzduchu, jak ve výšce 5 cm nad povrchem, tak i ve výšce 2 m nad povrchem, při čemž vzniká přízemní teplotní inverze. Teplotní inverze dosahuje

několik desetin až jednotek stupňů Celsia. Doba trvání takové teplotní inverze závisí na času výskytu krupobití a délce celé srážkové události. Pro zjištění zda a jakým způsobem lokální podmínky mohou ovlivňovat vývoj krupobití byla provedená analýza směrů pohybu bouřek, svázaných s výskytem krup v konkrétních lokalitách. Obecně lze řičí, že na území Moravy bouřky nesoucí kroupy přichází většinou ze západního sektoru a vzdalují se k východním směrům. Zkoumaní vlivu morfologie terénu na výskyt krupobití ukázalo, že krupobití je podmíněné především cirkulačními podmínkami v mezoklimatickým měřítku a role místní morfologie terénu je v tomto druhořadá.

CONTACT

Gražyna Knozová, Dr.

Czech Hydrometeorological Institute, Brno Regional Office

Kroftova 43, 616 67 Brno

+240 541 421 034, grazyna.knozova@chmi.cz

DROUGHT MONITORING ON THE CHMI WEBSITE

MOJMÍR KOHUT, ROSTISLAV FIALA, FILIP CHUCHMA,

JAROSLAV ROŽNOVSKÝ, PETR HORA

Czech Hydrometeorological Institute, Brno branch office,

Kroftova 43, 616 67 Brno

ABSTRACT

The presented paper briefly summarizes the analysis of Drought monitoring, which is regularly performed at the Czech Hydrometeorological Institute (CHMI) during vegetation period. The system was completely innovated and significantly expanded in 2014, with many new map outputs for the region of the Czech Republic, which are the result of expert cooperation between the Prague and Brno branch offices of the Czech Hydrometeorological Institute. The outputs are published on the website in weekly intervals and contain detailed assessment of the risk of potential development or continuation of climatological, soil or hydrological drought. Apart from the actual measured values, the Drought monitoring also includes maps and graphical representations of selected agrometeorological and hydrological parameters, which can be used to characterize the current humidity situation in the landscape of the Czech Republic, particularly concentrating on the possible occurrence and duration of drought.

The presented paper only concentrates in detail on the meteorological part of drought (climatological and soil drought), not the hydrological one.

Keywords: drought, precipitation, evapotranspiration, balance, soil humidity

INTRODUCTION

In meteorology, drought is an often used, yet very unspecific term, which in fact means insufficiency of water in the atmosphere, soil or plants. There are no unified criteria for quantitative definition of drought, especially with respect to various aspects of meteorological, hydrological, agricultural, pedological, bioclimatological and many other conditions, and also with respect to the damages caused in various areas of national economy. The definition of drought is therefore not unified. Based on the causes one can characterize it from various points of view (meteorological or climatological drought, agricultural or soil drought, hydrological drought, socio-economical drought).

Drought is usually a random phenomenon. It mostly occurs irregularly during periods of below-average or significantly below-average precipitation and can last for several days, but in extreme cases up to several months. In the Czech Republic, the primary cause for the development of drought is always precipitation deficit at a certain time period and at a particular location, and it often develops for example during vegetation period or during its part. Drought is often accompanied by above-average or significantly above-average air temperatures, lower relative air humidity, less cloud cover and increased number of sunshine hours. The mentioned meteorological parameters then lead to a higher rate of evaporation (evapotranspiration), which further increases the insufficient water availability in soil and in the atmosphere and this then intensifies the drought period.

Due to its unexpected and irregular occurrence in space and time, drought is a very dangerous natural phenomenon. A reliable and scientific prognosis of drought is therefore very complicated and can even be seen as problematic. A high level of importance is currently seen in special methods and approaches, which, based on operational weather information, can assess the current humidity balance in landscape, especially with respect to the fact whether some form of drought can be expected and its potential progress.

This year, Drought monitoring on the CHMI website, the subject of this paper, has undergone a substantial expansion and quality improvement in comparison to the previous years. Since 2014, apart from the meteorological part, which is concerned with the climatological and soil drought, also the hydrological part (hydrological drought) is now included. The system is a result of tight cooperation between meteorologists and hydrologists (Department for Biometeorological Applications in Prague, Meteorology and Climatology Department in Brno and Hydrology Department in Prague).

MATERIALS AND METHODS

In weekly intervals, the Drought monitoring on the CHMI website presents the results in a form of nice and easily understandable maps, graphs and texts, divided into "Climatological and soil drought" and "Hydrological drought" sections. From now on, this paper will only deal with the outputs of the "Climatological and soil drought" section, which, within the Drought monitoring, are processed in the Brno branch office or the branch is partly involved in their development.

Apart from the actual measured values (precipitation, soil humidity and evaporation from water level at selected climatological stations), the outputs include modeled data of selected agrometeorological parameters (potential evapotranspiration of grasslands, basic, i.e. potential water balance of grasslands, available water capacity in the soil profile under grass cover), which are then used to assess natural conditions and potential risk of drought development in the region of the Czech Republic.

Drought monitoring is based on two agrometeorological models – the BASET (Bilance Atmosferických Srážek a EvapoTranspirace, Atmospheric Precipitation and Evapotranspiration Balance, administered at the Department for Biometeorological Applications in Prague) and AVISO (Agrometeorologická Výpočetní a Informační SOustava, Agrometeorological and Computational Information System), which is managed by the Meteorology and Climatology Department at the Brno branch office. AVISO model, outputs of which will be described in detail later in the text, is a modified model based on the methodology of water given out by the evaporation from the surface using modified Penman-Monteith algorithm. The modeled soil humidity is based on a dual-layer model of water circulation in soil profile to the depth of active roots and both layers are separated from each other by the point of lowered availability (lentocapillary point).

The basis of the input data is formed, apart from selected phenological parameters, exclusively by measured data of basic meteorological parameters (air temperature and humidity in the form of calculated water vapor pressure, amount of sun shine, wind speed and precipitation) from 198 automated professional and voluntary climatological stations from the CHMI observation network. The source of data is then the CLIDATA database of the Czech Hydrometeorological Institute.

The AVISO model works in operational and regime manner in daily intervals. Operational assessment is regularly used in the Drought monitoring, regime analysis forms the basis for assessments of selected characteristics in long-term (in this case 1961-2010).

Apart from soil temperature and air temperature, soil humidity is one of the most important meteorological factors that influence plant growth. It is dependent on the amount, intensity and temporal distribution of precipitation, on evaporation and on the soil properties described by the so-called hydrolimits.

The basic hydrolimit for model analysis is available water capacity (AWC) as a difference between soil humidity at its field water capacity and the wilting point. It is reported in mm and the model allows two settings – standard for previously specified soil types, or a more accurate one, which classifies soil types into 5 classes. In Drought monitoring, the available water capacity in soil is set to the following values:

AWC = 70 mm/1m: light or lighter soil (sandy and loamy sand soil), granularity 0%-20%, i.e. 0%-10% and 10%-20%);

AWC = 120 mm/1m: heavy or heavier soil (loamy clay, clay soil), granularity 45%-75%, i.e. 45%-60% and 60%-75%);

AWC = 170 mm/1m: medium or medium-heavy soil (sandy and loamy soil), granularity 20% -45%, i.e. 20%-30% and 30%-45%).

Drought monitoring uses the following current outputs from the AVISO model:

- Potential evapotranspiration of grasslands;
- Basic (i.e. potential) soil water balance of grasslands;
- Available water capacity in medium-heavy and heavy grass-covered soils.

The major output of the model for balancing soil humidity is the current water deficit of the soil type in mm, which characterizes the amount of available water in soil that remains to achieve field water capacity. The water capacity in soil, which in terms of the Drought monitoring is used for the analysis of the state of soil humidity, is then calculated for every day and for every calculated location (climatological station) using the current water deficit in soil and its available water capacity.

Long-term values of the above mentioned agrometeorological characteristics are essential for the comparison of current state with long-term conditions at particular locations in the region of the Czech Republic. They were analyzed by the model in a regime manner using technical series of the individual meteorological parameters. In practice this means daily data from the period between 1961 and 2010.

The map data for the region of the Czech Republic are generated automatically in the GIS environment using interpolation methods of local linear regression with respect to the altitude and the measured and modeled data from the climatological stations. Spatial resolution of the output raster is 500x500 m.

In natural conditions, the primary cause of all drought types in the Czech Republic is deficit (insufficiency) of atmospheric precipitation, which is also most commonly used to define climatological drought. Climatological drought is usually defined by comparing the amount of precipitation (less often the evapotranspiration or balance conditions) of the current period with the long-term average for that same period. Precipitation deficit means a negative difference between the currently observed precipitation amount and the long-term average for a particular time period.

When classifying climatological drought it is necessary to take into account the extent of precipitation deficit including temporal precipitation distribution in a given time period. Many authors have developed various definitions of climatological drought using climatological indexes, which are derived from other meteorological parameters (air temperature, wind speed, amount of sun shine, air humidity, evaporation etc.) which can either mitigate or significantly worsen the effects of the precipitation deficit.

The basic assumption for the identification of potential climatological drought is therefore comparison analysis of values of selected climatological parameters from the current time period with their long-term average. Within the Drought monitoring, the analysis was successively performed for precipitation amount, evapotranspiration and water balance. An important prerequisite is the fact that climatological drought analysis does not take into account properties of the subsoil.

In general, the soil drought analyzed using the Drought monitoring can be defined as insufficiency of water in the root zone of the soil profile. It causes abnormalities in water regime of both agricultural crops and wild growing plants. Water deficit in the upper parts of soil horizon is caused by previous or still present climatological drought. The effects of soil drought on the individual plant species are highly variable and also to a great extent depend on the developmental stage of the plant, its water requirements, age etc.

One big disadvantage is the fact that within the region of the Czech Republic, there is a relatively low number of stations with direct measurement of soil humidity. This also means that it is necessary to suitably supplement the measured data with modeled values. It could be said that soil drought is the basic prerequisite for the development of agricultural drought.

RESULTS

The following text shows easily-understandable and clear maps and graphical representations that analyze the humidity-water situation in the Czech Republic during vegetation period in regular weakly intervals based on selected agrometeorological parameters (potential evapotranspiration of grasslands, basic water balance of grasslands, current water deficit, available water capacity in soil profile covered with grass) with respect to the potential development of drought. All the presented results are current as of Sunday 10th August 2014.

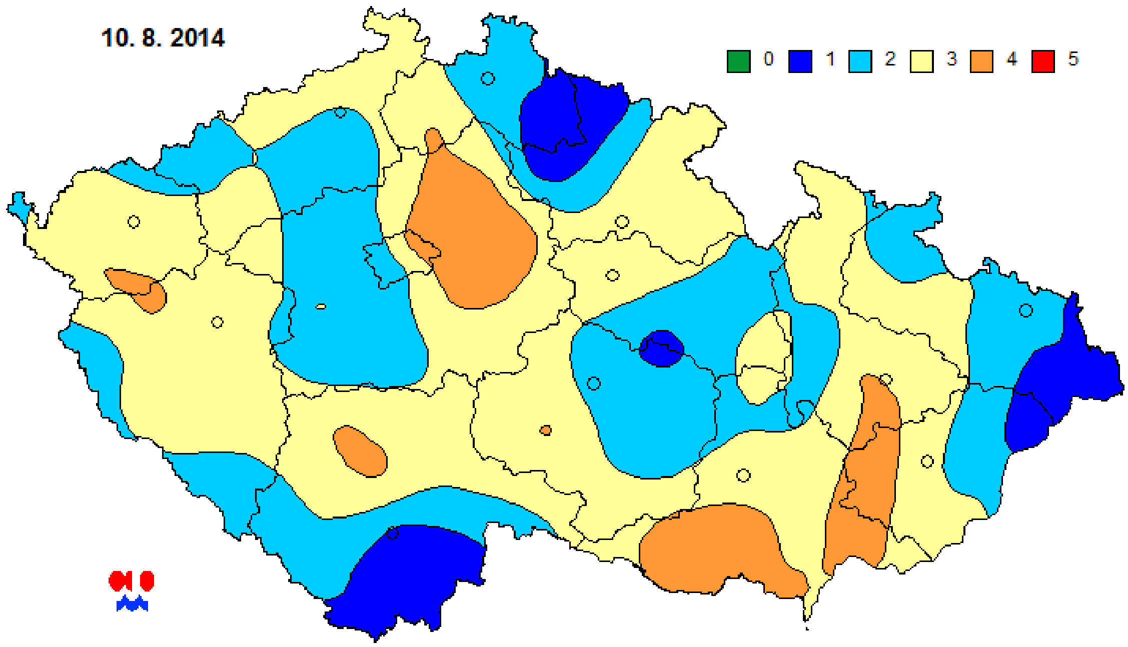


Fig. 1 *The level of risk of soil drought development at depths 0 to 20 cm in the Czech Republic as of Sunday 10th August 2014*

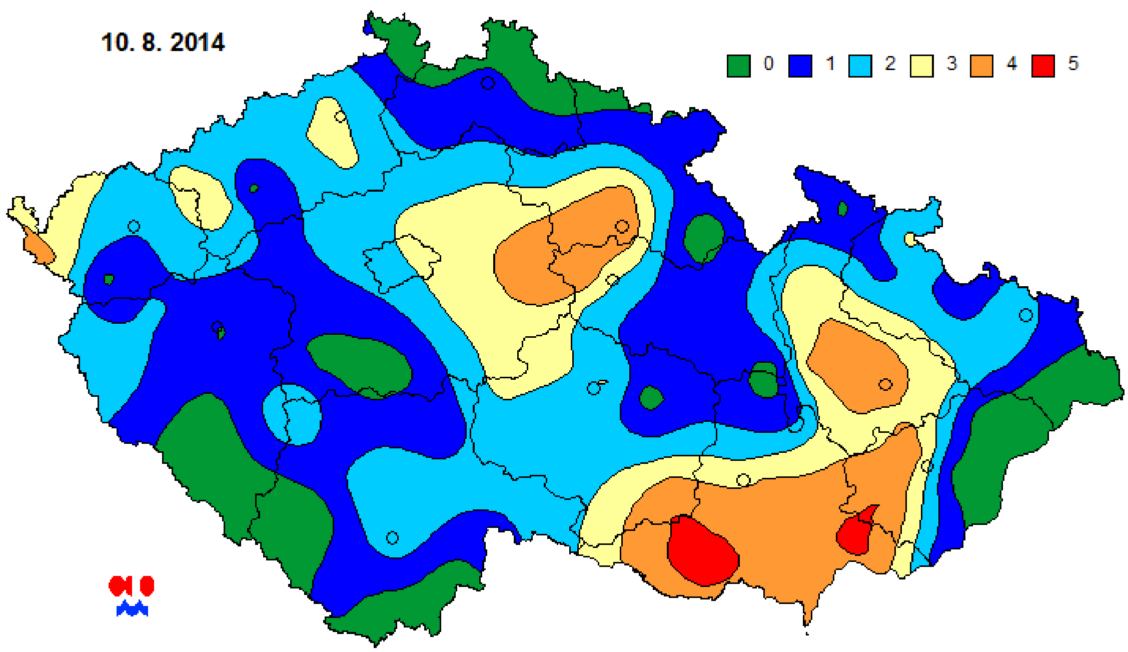


Fig. 2 *The level of risk of soil drought development at depths 0 to 100 cm in the Czech Republic as of Sunday 10th August 2014*

The first two maps (**Fig. 1** and **Fig. 2**) in the meteorological Drought monitoring part show the level of risk of soil drought in grasslands. Due to substantial differences in soil humidity in the subsoil and deeper layers (for example at the beginning or end of heavy-precipitation period, or at the beginning of a period without precipitation), the level of risk of soil drought is assessed individually in two maps, one for soil profiles 0 to 20 cm (BASET model) and one for 0 to 100 cm (AVISO model). Both model approaches used to identify development of drought in various soil depths are based on a combination of measured and modeled data regarding soil humidity (measured by humidity sensors VIRRRIB or TRIFO3G, and calculated values from 198 climatological stations). Both values are given in % of available water capacity of a given soil type and are then finally analyzed and transformed into a basic scale that characterizes the level of risk of drought as follows:

0 – no risk	3 – medium
1 – small	4 – high
2 – low	5 – very high

The meteorological part of Drought monitoring is divided into two sections (“Climatological drought” and “Soil drought”). As was already mentioned earlier, this paper is only concerned with the model outputs that are related to the Drought monitoring regularly processed by the Brno branch office of the CHMI, or the branch office is at least partly involved.

“Climatological drought” section includes:

1) Weekly amount of precipitation – current state, measured values (Fig. 3);
2) Amount of precipitation since 1st Jan – long-term comparison, measured values (Fig. 4);
3) Evaporation from water level – current state, measured values;
4) Basic water balance of grasslands – current state, model values (Fig. 5);
5) Basic water balance of grasslands – long-term comparison, model values (Fig. 6);
6) Basic water balance of grasslands – current state at selected climatological stations at altitude below 300 m (Fig. 7);

7) Basic water balance of grasslands – current state at selected climatological stations at altitude above 300 m (Fig. 8);
8) Potential evapotranspiration of grasslands – long-term comparison, model data (Fig. 9).

"Soil drought" section includes:

1) Soil humidity under grass cover at 0 to 10 cm depth – current state, measured values;
2) Soil humidity under grass cover at 10 to 50 cm depth – current state, measured values;
3) Soil humidity under grass cover at 50 to 100 cm depth – current state, measured values;
4) Soil humidity under grass cover at 0 to 20 cm depth – current state, model values;
5) Available water capacity at medium-heavy soils under grass cover – current state, model values (Fig. 10);
6) Available water capacity at medium-heavy soils under grass cover – long-term comparison, model values (Fig. 11);
7) Available water capacity at medium-heavy soils under grass cover – current state at selected climatological stations at altitude below 300 m, model values (Fig. 12);
8) Available water capacity at medium-heavy soils under grass cover – current state at selected climatological stations at altitude above 300 m, model values (Fig. 13);

For the region of the Czech Republic, the major input to the water cycle in natural environment is atmospheric precipitation. The analysis of precipitation amount is represented in two maps, which show the current state in the form of precipitation observed in the previous week from Monday until Sunday (**Fig. 3**) and the percentage comparison of cumulative amount since 1st January with long-term average from 1961 to 2010 (**Fig. 4**). Unlike all the other remaining agrometeorological characteristics, these are measured, not model data.

Climatological drought is a convenient characteristic of basic (potential) water balance of grass cover, defined as the difference between precipitation and potential evapotranspiration of grass cover. It is analyzed as current cumulative amount since 1st March (**Fig. 5**) and meanwhile also in a form of a comparison with the long-term average from 1961 to 2010 (**Fig. 6**). Both values are given in mm. Higher numerical value of water balance in the current meteorological conditions (i.e. precipitation is higher than evapotranspiration) is favorable and means lower probability of potential occurrence of climatological drought at that particular location and on that particular day (and vice versa). Similar conclusions also apply for the comparison of current water balance with the long-term averages.

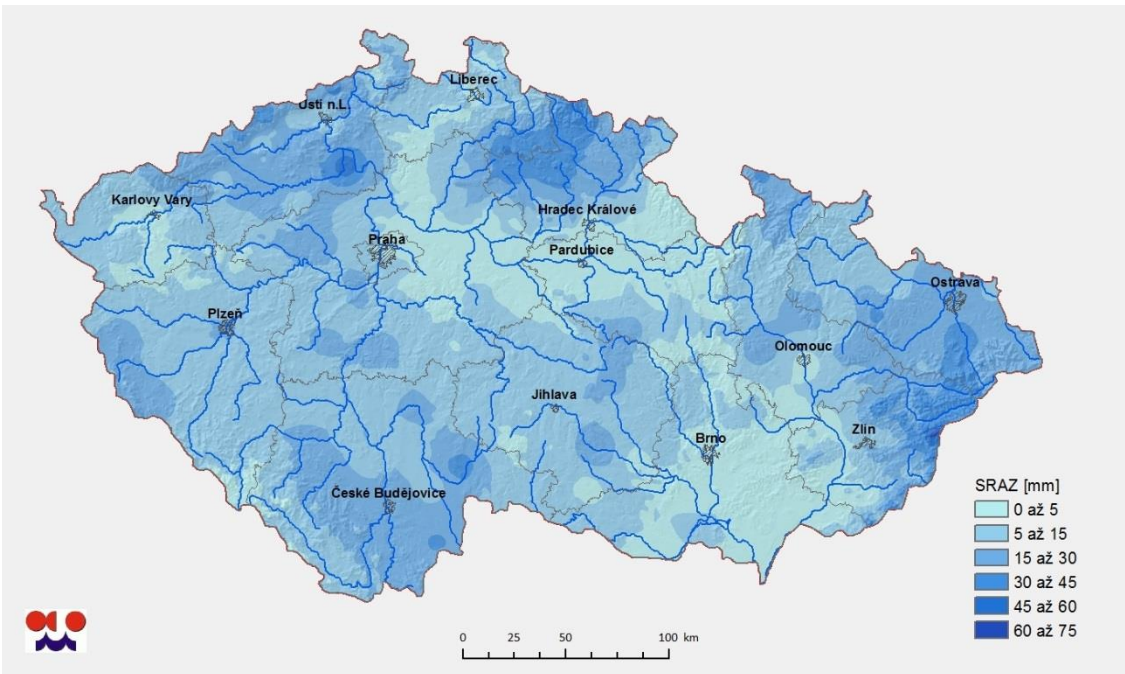


Fig. 3 *Precipitation amount in the Czech Republic from 4th August to 10th August*

Current state of water balance of grass cover on selected climatological stations at altitudes below 300 m above sea level (Doksany 158 m, Dyjákovice 201 m, Semčice 234 m, Kroměříž 233 m, Ostrava-Poruba 239 m and Hradec Králové 278 m) and at altitudes above 300 m (Temelín 503 m, Vatín 555 m, Vrchlabí 482 m, Košetice 534 m, Rýmařov 578 m and Kralovice 468 m) are presented using graphs in **Fig. 7** and **Fig. 8**.

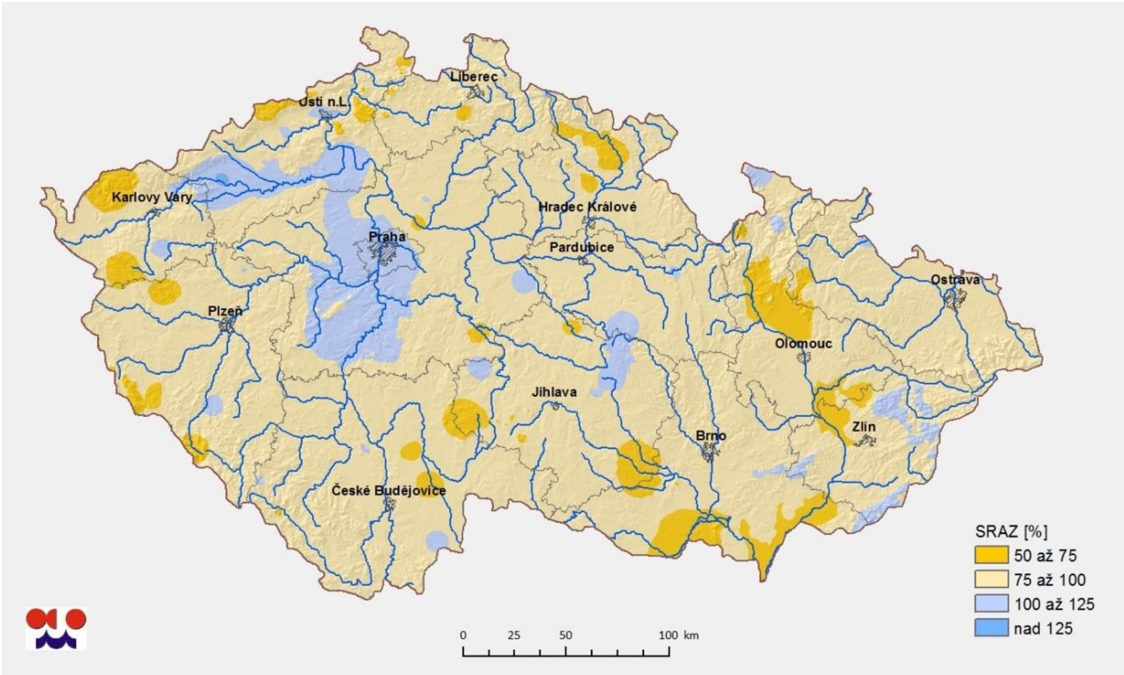


Fig. 4 *Comparison of the precipitation amount in the Czech Republic from 1st January to 10th August 2014 with the 1961-2010 long-term average.*

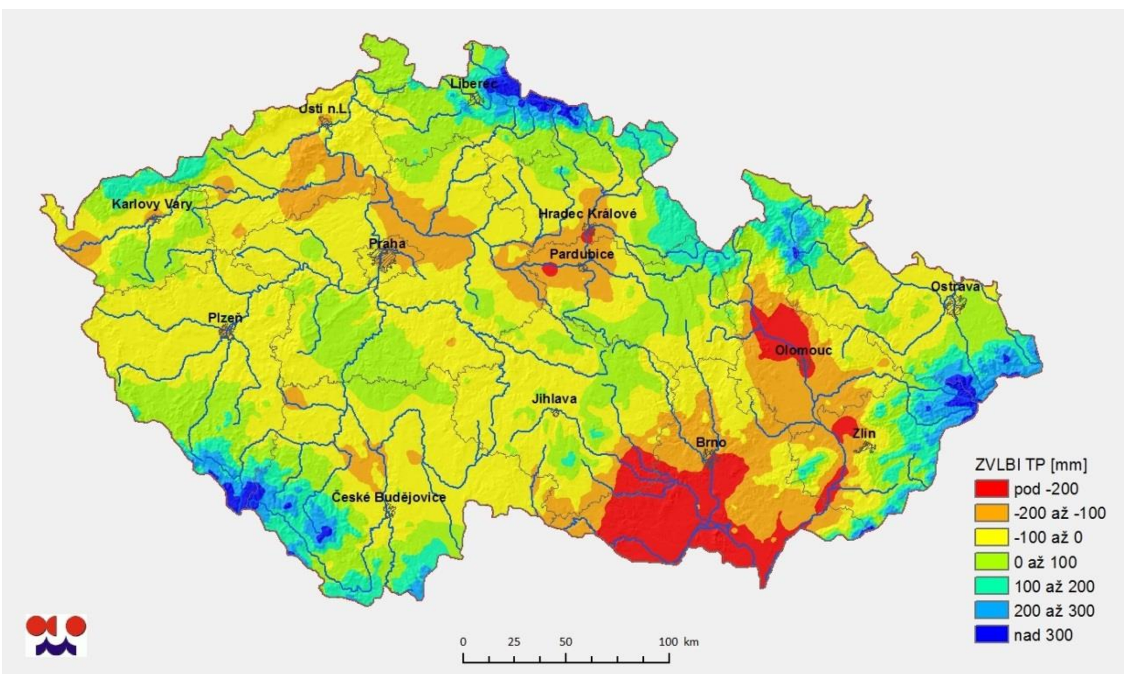


Fig. 5 *Basic water balance of grasslands (difference between precipitation and potential evaporation) in the Czech Republic from 1st March to 10th August 2014*

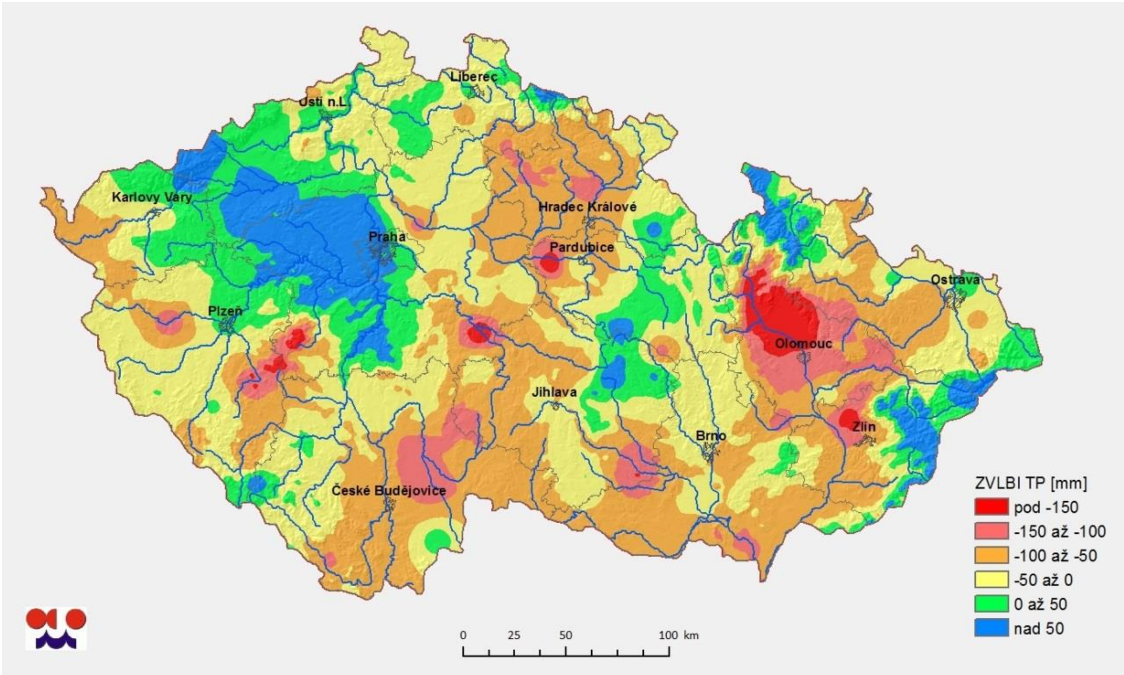


Fig. 6 *Basic water balance of grasslands (difference between precipitation and potential evaporation) in the Czech Republic, comparison of the period from 1st March to 10th August 2014 with the 1961-2010 long-term average*

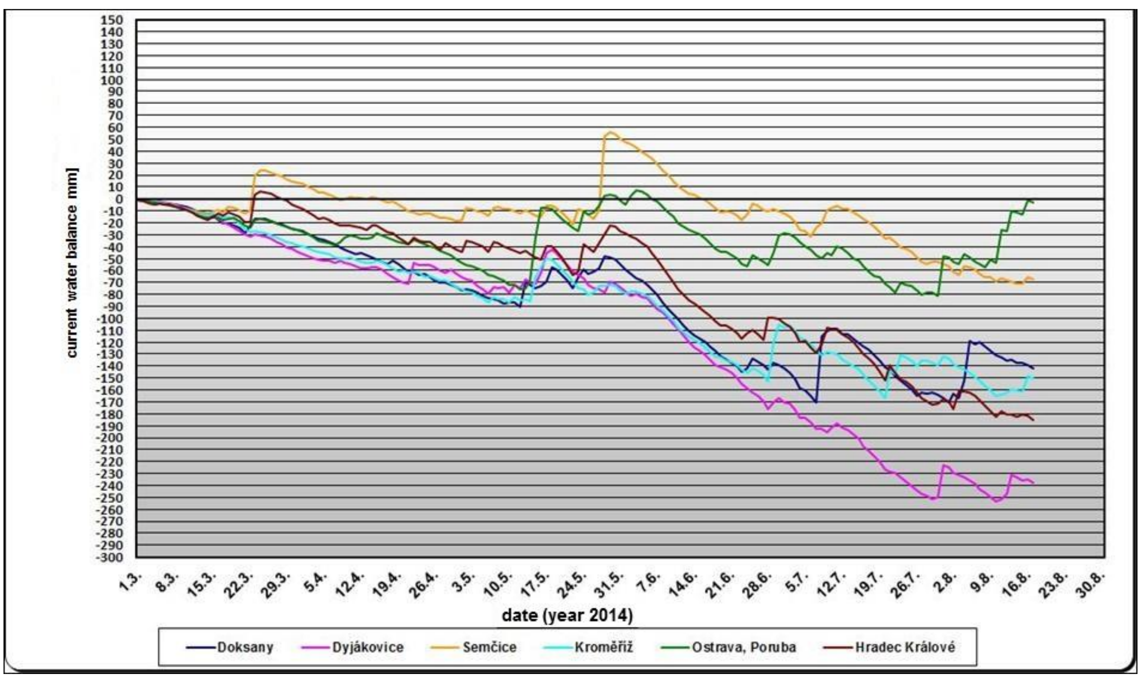


Fig. 7 *Basic water balance of grasslands, current conditions at selected climatological stations in the Czech Republic at altitudes below 300 m above sea level, as of Sunday 10th August 2014.*

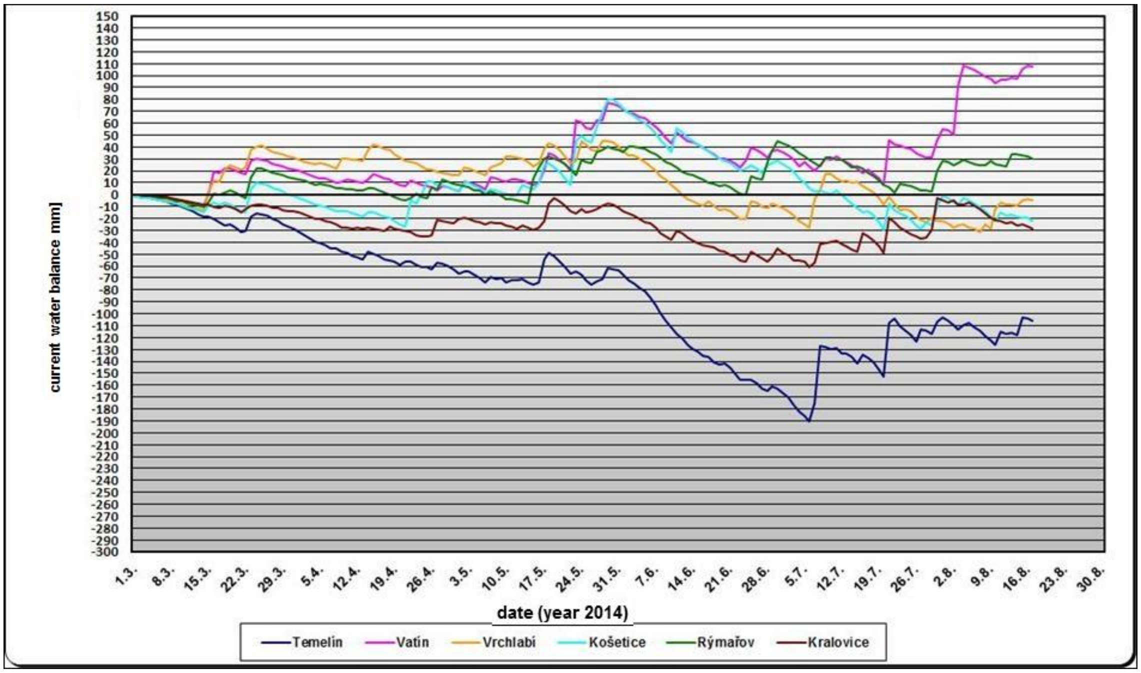


Fig. 8 *Basic water balance of grasslands, current conditions at selected climatological stations in the Czech Republic at altitudes above 300 m above sea level, as of Sunday 10th August 2014.*

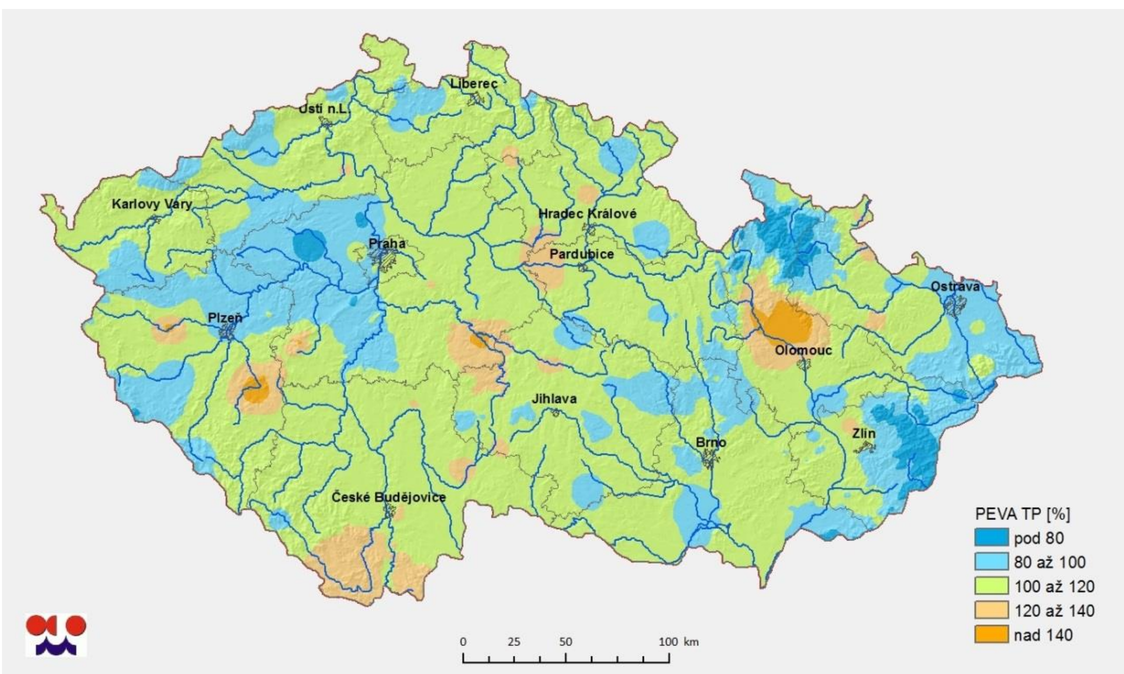


Fig. 9 *Potential evapotranspiration of grasslands in the Czech Republic, comparison of the amount from the period from 1st March to Sunday 10th August 2014 with the 1961-2010 long-term average.*

The final characteristic of this section is the potential evapotranspiration of grass cover, which is calculated using modified Penman-Monteith algorithm. The current state is not included, instead only the percentage comparison with the long-term average from 1961 to 2010 is given (**Fig. 9**). The higher the final % value (i.e. currently calculated potential evapotranspiration is higher than the corresponding long-term average), the less favorable the water balance situation is and means a higher probability of potential occurrence of climatological drought and its effects in that particular location on that particular day (and vice versa).

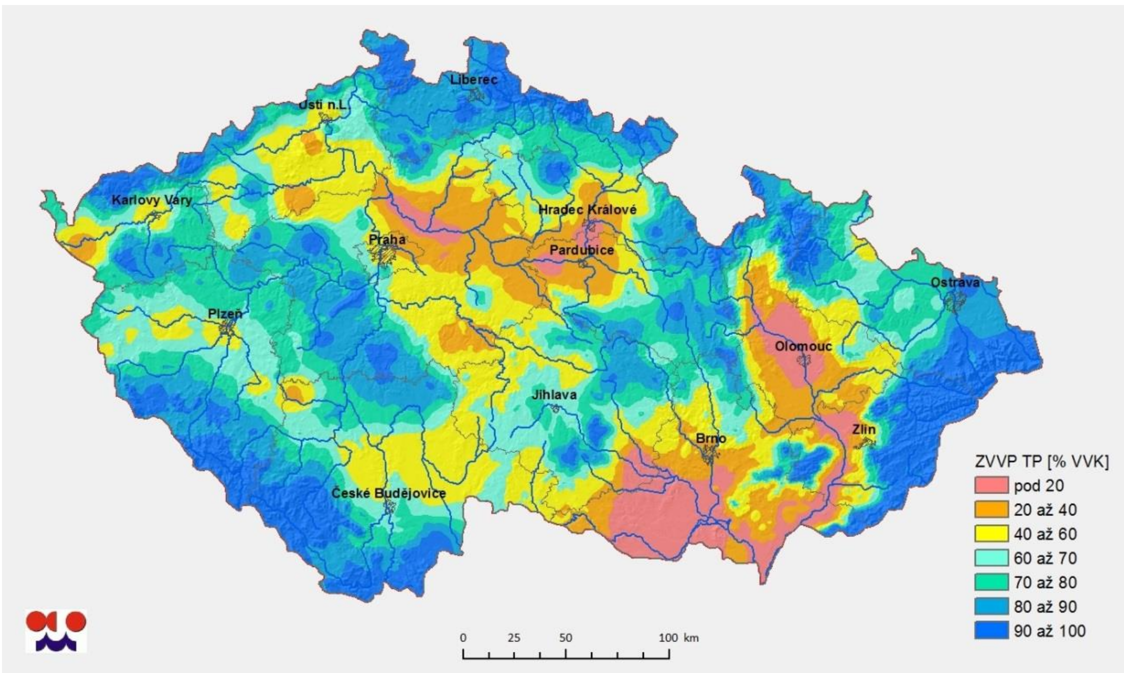


Fig. 10 *Amount of usable water in loam soils (AWC = 170 mm/1 m of soil profile) under grass cover in the Czech Republic, current state as of Sunday 10th August 2014.*

The basic agrometeorological parameter for the analysis of soil drought within the Drought monitoring is the amount of available water capacity in soil profile under grass cover. It is shown as modeled values given in % of available water capacity and calculated for medium-heavy soils with available water capacity 170 mm / 1 m of soil profile. The current state is monitored (**Fig. 10**) and also a comparison with long-term average from 1961 to 2010 is given (**Fig. 11**). Higher values of available water capacity in soil at the current meteorological conditions mean more favorable humidity conditions of soil and therefore lower probability of potential occurrence of soil drought in that particular location on that particular day (and vice versa). Similar conclusions also apply for the comparison of the current state of available water capacity in soil with long-term conditions.

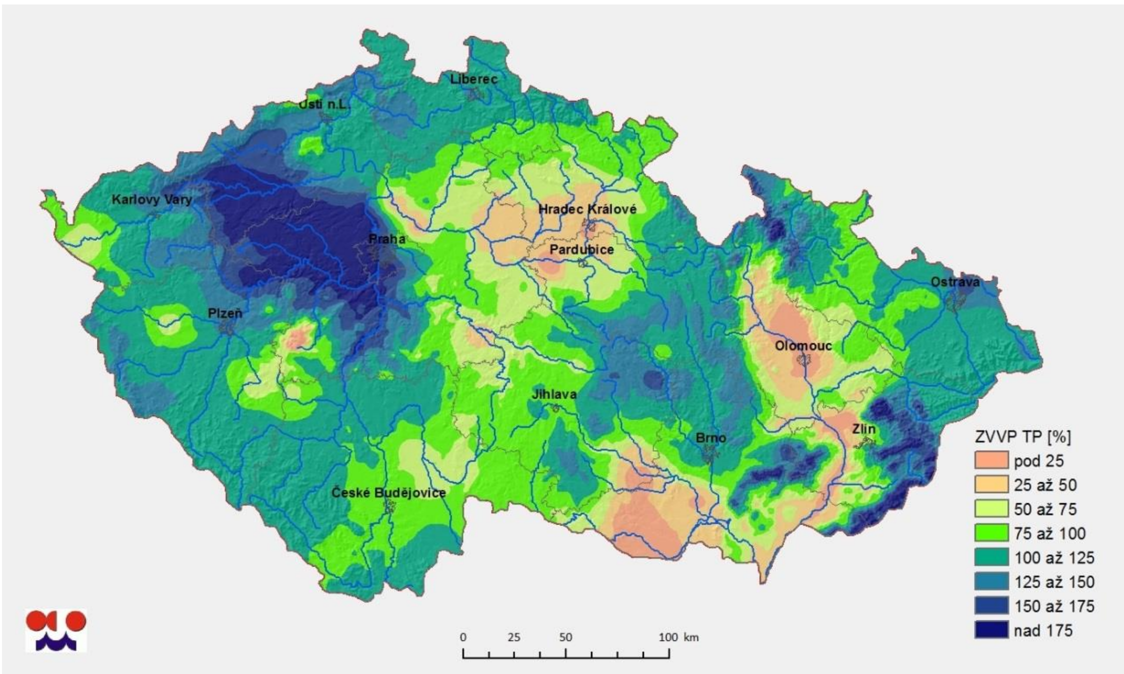


Fig. 11 *Amount of usable water in loam soils (AWC = 170 mm/1 m of soil profile) under grass cover in the Czech Republic, comparison with the 1961-2010 long-term average, as of Sunday 10th August 2014*

Current state of available water capacity in soil under grass cover for selected climatological stations with altitude below 300 m above sea level (Doksany 158 m, Dyjákovice 201 m, Semčice 234 m, Kroměříž 233 m, Ostrava-Poruba 239 m and Hradec Králové 278 m) and at altitudes above 300 m (Temelín 503 m, Vatín 555 m, Vrchlabí 482 m, Košetice 534 m, Rýmařov 578 m and Kralovice 468 m) are presented in graphs in **Fig. 12** and **Fig. 13**.

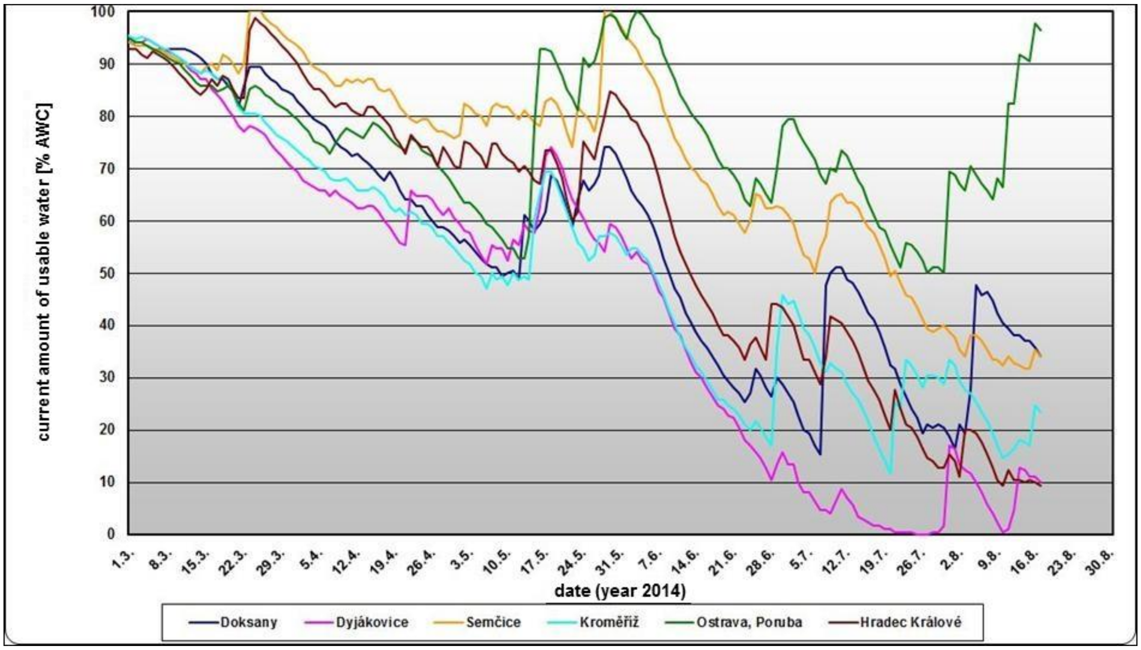


Fig. 12 *Amount of usable water in loam soils (AWC = 170mm/1 m of soil profile) under grass cover, current state at selected climatological stations in the Czech Republic with altitude below 300 m above sea level, as of Sunday 10th August 2014*

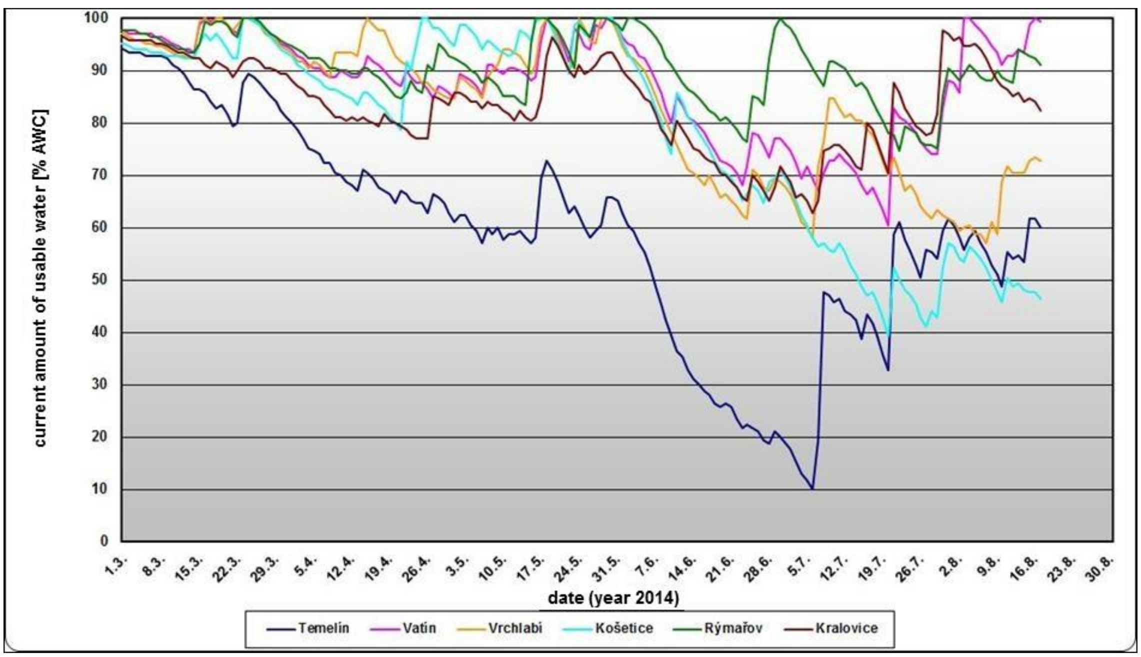


Fig. 13 *Amount of usable water in loam soils (AWC = 170mm/1 m of soil profile) under grass cover, current state at selected climatological stations in the Czech Republic with altitude above 300 m, as of Sunday 10th August 2014*

DISCUSSION

Drought can be described as one of natural weather extremes with irregular and unexpected occurrence in space and time. Due to the fact that it is a dangerous natural phenomenon with far-reaching consequences for national economy, it is very important to monitor weather conditions in real-time with particular focus on analysis of those agrometeorological parameters, which can be used to identify potential development and duration of drought.

This paper briefly describes Drought monitoring, which has undergone a substantial innovation and expansion compared to previous years. During vegetation period, the outputs are available at the CHMI website.

Both general public and scientific community would definitely welcome a drought forecast. It is however a very complicated issue even when trying to make medium- or short-term prognosis. If modified, and especially with the pre-requisite of using prognosis data of basic meteorological parameters, the AVISO model could be used for making forecasts and this can be seen as one of the key activities in the upcoming future to further enhance the quality of the Drought monitoring project.

CONCLUSION

The presented paper briefly introduces the Drought monitoring regularly performed during vegetation period at the Czech Hydrometeorological Institute. In 2014, the entire system has undergone a substantial innovation and expansion in comparison to the previous years and now includes many map outputs for the region of the Czech Republic, which are the result of expert cooperation between the Prague and Brno branch offices of the Czech Hydrometeorological Institute. The outputs are published weekly on the CHMI website and contain detailed analysis of potential development or duration of climatological, soil and hydrological drought. Apart from the actual measured values, Drought monitoring also includes maps and graphical representations of selected agrometeorological and hydrological characteristics, which can be used to describe the current water situation in the Czech Republic, with particular focus on potential occurrence and duration of drought.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., Smith, M.: Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56, FAO, Roma 1998, 301 p.

Atlas podnebí Česka. ČHMÚ Praha, UP Olomouc, 2007, 256 p.

Gardner, C. M. K., Field, M.: An evaluation of the success of MORECS,
a meteorological model, in estimating soil moisture deficits. Elsevier Science Publishers B. V., Amsterdam 1983, Agricultural Meteorology, 1983, 29, p. 269-284.

Hough, M., Joned, R. J.: The United Kingdom Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0 - an overview. Hydrology and Earth System Sciences, 1997, 1(2), p. 227-239.

Hough, M., Palmer, S., Weir, A., Lee, M., Barrie, I.: The Meteorological Office Rainfall and Evaporation Calculation System: MORECS version 2.0. Meteorological Office Bracknell, Meteorological Office Wolverhampton, Bracknell 1997, 82 p.

Kott, I., Valter, J.: Nová metoda operativního vyhodnocování povrchových zásob vláhy v půdě v závislosti na počasí (2007, in print)

Matejka, F., Rožnovský, J., Hurtalová, T., Kohut, M.: Atmosférické sucho na začiatku tretieho tisícročia. In: Sborník abstraktů z konference „Extrémy počasí a podnebí“, Brno, 11.3.2004. Česká bioklimatologická společnost v nakladatelství Českého hydrometeorologického ústavu, p. 11, 41 p., CD-ROM, 2004, ISBN 80-86690-12.

Meteorologický slovník výkladový a terminologický. Academia, Ministerstvo životního prostředí ČR, Praha 1993, 594 p.

Novák, V.: Vyparovanie vody v prírode a metódy jeho určovania. VEDA, Slovenská akadémia ved, Bratislava 1995, 256 p.

Pal Arya, S.: Introduction to Micrometeorology. Academic Press, 2nd Edition, London 2001, 421 p.

Štěpánek, P., Zahradníček, P., Skalák, P. (2009): Data quality control and homogenization of air temperature and precipitation series in the area of the Czech Republic in the period 1961–2007. Advances in Science and Research, 3, 23–26.

Štěpánek, P., Zahradníček, P., Huth, R. (2011): Interpolation techniques used for data quality control and calculation of technical series: an example of Central European daily time series. Idöjárás, 115, 1-2, pp. 87-98.

Thompson, N., Barrie, I. A., Ayles, M.: The Meteorological Office Rainfall and Evaporation Calculation System: MORECS. Hydrological Memorandum, Bracknell 1981, No. 45, 71 p.

ACKNOWLEDGMENT

This paper was supported by the NAZV QI111C080 project „Zpřesnění dostupné zásoby vody v půdním profilu na základě modelu kořenového systému plodin pro efektivní hospodaření s vodou a dusíkem“.

SUMMARY

Předkládaný příspěvek se stručně věnuje analýze Monitoringu sucha pravidelně provozovaného ve vegetačním období na Českém hydrometeorologickém ústavu. V roce 2014 byl celý systém oproti rokům předcházejícím inovován a výrazně rozšířen o řadu mapových výstupů pro území České republiky, které jsou výsledkem odborné spolupráce mezi pracovišti Praha a Brno Českého hydrometeorologického ústavu. Výstupní sestavy publikované v týdenních intervalech na webových stránkách obsahují podrobná hodnocení týkající se možného nástupu či trvání případného klimatického, půdního a hydrologického sucha. Monitoring sucha vedle měřených hodnot obsahuje mapová a grafická zpracování vybraných agrometeorologických a hydrologických charakteristik, pomocí nichž lze charakterizovat aktuální vlhkostní situaci v krajině na území České republiky, a to se zvláštním zřetelem na možná výskyt a trvání sucha.

Předkládaný příspěvek se podrobněji zabývá pouze částí meteorologickou (klimatické a půdní sucho), nikoliv částí hydrologickou.

CONTACT

RNDr. Mojmír Kohut, Ph.D.

Czech Hydrometeorological Institute, Brno branch office

Kroftova 43

616 67 Brno

tel. 602591518, e-mail: mojmir.kohut@chmi.cz

RAINFALL EROSIVITY RESEARCH ON THE TERRITORY OF THE CZECH REPUBLIC

JOSEF KRÁSA1), HANA STŘEDOVÁ2), TOMÁŠ DOSTÁL1), IVAN NOVOTNÝ3)

Czech Technical University in Prague[1], Mendel university in Brno[2], Research Institute for Amelioration and Soil Conservation[3]

ABSTRACT

Water erosion is a main factor of degradation of soils used for agriculture in the Czech Republic. For landscape conservation purposes the soil erosion risk is defined here mostly by USLE method published by Wischmeier and Smith (1978). Within USLE the precipitation impact on erosion is a function of rainfall kinetic energy and intensity represented by R-factor. In the Czech Republic historically and recently several research teams have analyzed rainfall data to assess rainfall erosivity. The article is based on review of different approaches and results of recent rainfall erosivity studies. Those studies differ in both the data used for erosivity definition and the methodology applied. At the end the article presents results of the most recent study on rainfall erosivity spatial distribution over the Czech Republic performed by Research Institute for Amelioration and Soil Conservation (VUMOP), Czech Hydrometeorological Institute (CHMI) and Czech Technical University in Prague (CTU). The analysis was based on digital rain gauge data from automatic stations of the CHMI. The erosive rains were derived from continuous 1 minute step 10-year rainfall data (2003-2012) from 245 stations, all necessary quality checks and corrections were adopted. Based on the research recent annual R-factor values in the stations vary from 37 to 239 [$N.h^{-1}$] (values over 100 are located in mountain regions with minimum agricultural land). The raster based R-factor map used for erosivity definition in cross compliance soil erosion risk maps of Ministry of Agriculture adopted values varying from 37 to 110 [$N.h^{-1}$] over the Czech territory.

Key words: Erosion, R-factor, rainfall, comparison

INTRODUCTION

In the Czech Republic water erosion on agricultural lands is extremely important degradation process. Based on the historical evolution context – mainly collectivization of agriculture in the socialist period in 20th century – the soil loss on arable land reaches very high values (Van Rompaey et al. 2003). Arable land extent is continuously decreasing but proportion between arable/grassland is still unbalanced in hilly regions (database LUCC Czechia – Charles University in Prague). Land fragmentation was totally destroyed by collectivization and current process of land consolidation is unable to reconstruct the original landscape mosaic. Significant erosion vulnerability is also caused by insufficient protection of soil, growing unsuitable crops on sloping land and ultimately climate.

To evaluate the significance of climate for erosion is quite difficult. It is not the same as to assess the overall balance of precipitation and runoff or long-term precipitation coverage. The erosion process is episodic and in the Czech Republic it takes place almost exclusively in extreme precipitation events (summer thunderstorms and torrential rains). Procedure for the evaluation of erosion vulnerability of agricultural land in the Czech Republic and in the outside world is mostly based on the USLE method (Wischmeier and Smith, 1978). In the rainfall erosivity factor of the USLE the episodic nature of the erosion process is being considered.

USLE is a typical representative of empirical methods for calculating soil loss. It is a simple relationship with six parameters, the accuracy of which, however, contributes significantly to the results obtained. The basic shape of the universal soil loss equation is formed by multiplication:

$A = R \,.\, K \,.\, L \,.\, S \,.\, C \,.\, P$

- A is the average long term soil loss [t. ha^{-1}.y^{-1}];
- R is rainfall erosivity factor [N. h^{-1}.y^{-1}];
- K is soil erodibility factor [t.N^{-1}];
- L is slope length factor [-];
- S is slope steepness factor [-];
- C is crop management factor [-];
- P rates erosion control practices [-].

All factors were determined empirically by statistical evaluation of the soil loss on the unit plots (22 m length and 9% slope) and on different parcels compared with the unit plots. The first two factors determine the actual soil loss on unit plots for defined soils and rainfalls and can therefore be expressed in physical units. Other factors are dimensionless and represent the ratio between soil loss on a unit plot and other parameters of analyzed parcels.

In the Czech Republic in engineering practice USLE is commonly applied for several purposes:

- assessment of vulnerability of land in the design of protective measures (common facilities) within land consolidation;
- assessment of vulnerability of land and sediment transport in the basin revitalization projects and dredging of small water reservoirs;
- to identify endangered parcels under the application of EU cross compliance subsidy policy (part of the GAEC standards defined by the Ministry of Agriculture);
- as part of the calculation of sediment transport and silting reservoirs within the implementation of the Water Framework Directive (USLE here is part of a more complex model);
- other purposes (calculations of the importance of erosion for the eutrophication of reservoirs, computing infrastructure vulnerability for erosion, etc.).

The correct identification of soil loss rate by USLE is therefore a prerequisite of realistic implementation of measures against erosion in many fields of engineering.

From the above it is clear that the climate in the evaluation of erosion risk is most often expressed in terms of R-factor. Because the total soil loss defined by USLE is simply the multiplication of the individual factors the effect of R-factor on the overall result is in direct proportion (twice the value of R-factor results in twice the soil loss). In the Czech Republic, R-factor research have been conducted at several sites continuously for the past decade and gradually brought refined results for the whole country and different regions, however the official engineering practice did not reflect the research.

In late eighties the official methodologies, defining the standards for engineering practice, recommended the use of constant R-factor of 20 [$N.h^{-1}.y^{-1}$] for the entire country. It have kept the constant recommended value for the last 30 years (Janeček et al. 1992-2012a) also at a time when research clearly demonstrated significantly higher rainfall erosivity in the last 50 years in the Czech Republic and in its neighborhood (Dostál et al. 2006). High quality data from measurements on automatic precipitation and climatological stations of the Czech Hydrometeorological Institute (CHMI) have currently allowed assembly of representative maps of rainfall erosivity in the Czech Republic over the last ten years. The density, coverage and quality of data output from automatic stations significantly exceed the outputs achieved by processing of paper ombrometer data or other previous solutions based on long-term precipitation totals (Rožnovský et al. 2013).

MATERIALS AND METHODS

According to measurements with the unit plots (Wischmeier and Smith, 1978) rain erosion efficiency is determined by its kinetic energy and intensity. The empirical relationship assumes that for the other factors constant, soil loss is directly proportional to the total kinetic energy of rain (Ed) multiplied by the maximum thirty-minute intensity (I_{30}).The annual value of the R-factor (based on continuous records of rainfall) is determined as the sum of erosivities of individual rains with amounts of more than 12.5 mm or of rains with maximum intensity exceeding 6 mm in 15 minutes. As an individual rainfall a rain-period separated from other rains by more than 6 hours is considered. Long-term average value of R-factor is then defined as the average annual value (annual totals) for the entire study period:

$$R = \frac{1}{n} \times \sum_{1}^{n} \sum_{1}^{k} (E_d \times I_{30})$$

R average annual rain erosivity factor [$N.h^{-1}.year^{-1}$]

E_d the total kinetic energy of a single rain [$MJ.ha^{-1}$]

I_{30} maximum thirty-minute intensity of the rain [$cm.h^{-1}$]

n number of years (seasons from April to October), for R-factor assessment

k the number of erosive rainfalls in a particular year

The total kinetic energy of the rainfall according to the original manuals (after conversion to SI units) is then:

$$E_d = \sum_{1}^{s}\left[\left(0{,}119 \; + \; 0{,}0873 \log I_s\right) \times \; H_s\right]$$

E_d	the total kinetic energy of a single rain [MJ.ha^{-1}]
I_s	constant intensity of the uniform rain section [mm.h^{-1}]
H_s	the sum of the rain section [mm]
s	the number of sections of rain with constant intensity

In the publications of the last 20 years it is more often recommended to use the following updated and better calibrated equation for calculating kinetic energy (Brown and Foster, 1987).

$$E_d \; = \sum_{1}^{s}\left[0{,}29 \times \left(1 - 0{,}72 \; e^{(-0.05 I_s)}\right) \times H_s\right]$$

This relationship is used in the Revised Universal equation (RUSLE - Renard et al. 1997) and it better defines the lower kinetic energy of light rains. For rain intensity exceeding 25 mm.h^{-1} it is almost identical to the original relationship.

Van Dijk et al. (2002) conducted an extensive search and analysis of the relationships used to calculate the kinetic energy and recommended the equation, giving values approximately between the above two relations. Nevertheless the most commonly used procedure remains currently the equation of Brown and Foster.

Actual soil loss values of similar rainfall episodes show high variance (Wischmeier et al. 1959). Even though the dependence of soil loss on rainfall erosivity is relatively loose the long-term erosivity average is uniquely determined by this addiction. The original methodology for R-factor determination is still the world considered the most accurate way - as regards the empirical soil erosion models. More precisely, it is possible to determine the soil loss only by episodic physical models working directly with the hyetographs of individual rainfall events accounting for the distribution of rainfall and infiltration over time. That is not a solution for soil erosion risk assessment in large scales.

Alternative methods of deriving the R-factor are always applied in cases where no information is available about the actual characteristics of torrential rains for research locations. Since the acquisition of continuous rainfall data at high spatial resolution is problematic for many regions worldwide in the literature there is a number of ways how to approximate R-factor described. These methods are based on long-term measurements (daily, monthly, or yearly rainfall sums).Calibrations of these methods are usually not performed directly against the measured soil losses, but almost always against the values of R-factor calculated by the original Wischmeier's methodology for single stations. The procedures have three main benefits:

- data on long-term precipitation totals are much more accessible, cheaper and more available at higher spatial resolution;
- data are "robust", they may be better spatially interpolated, totals are correlated with altitude and better preserve the long-term trends;
- these data are contained in the current climate scenarios for future development and there are higher probabilities of achieving attached to them.

However, these methods have a fundamental disadvantage. Even at the higher level of correlation with EI_{30} R-factor in some studies the original direct translation between a given parameter and soil loss is missing. In other words, soil loss is mainly driven by torrential rains but the studies working only with rainfall totals do not include the share of torrential rains in the datasets.

In the world, Europe and the surrounding area of the Czech Republic the following procedures are used:

- R-factor depending on the total annual rainfall sums derived for Austria by Strauss et al. (1995) or analogous solutions for very remote regions - Hawaii, North Africa, some areas of China, etc. (Renard et al. 1994).
- Fournier index.
- Modified Fournier index and its conversion to the R-factor by Arnoldus (1977, 1980) or by Sauerborna et al. (1999).
- The relationship derived for Bavaria depending on summer totals (sums for May-October) according Rogler and Schwertmann (1981) and modified for use in the Pan-European R-factor Map (Van der Knijff et al. 2000).

- Adoption of Wischmeier's equation using the reduction of daily precipitation sums into torrential rains (reduction formulas are published by various authors for rainfall-runoff modelling purposes).
- Wischmeier's method of EI derivation applied to design rainfalls with 10 year periodicity (referred to as EI_{10}).

In Europe, it would be possible to find even more attempts to determine R-factor by long-term rainfall sums, but these are inaccurate procedures that in many countries are increasingly being replaced by new conversions utilizing the RUSLE methodology (combination of Wischmeier's and Brown and Foster equations) and correcting erosivity values on the basis of the torrential rains from continuous rainfall data (Meusburger et al. 2011; Klik et al. 2012 etc.).Applications adapting directly EI_{30} methodology for the calculation of the monthly or daily totals also occur (Loureiro et al. 2001), but not for the climatic conditions corresponding to the Czech Republic. The aforementioned relationships are not described in detail because all the current detailed solutions for the CR are already based on accurate data by equations of Wischmeier's (1978) and Brown and Foster's (1987).

Recent computations and mapping R-factor in the CR

Already 40 years ago Pretl (Holý et al. 1975) derived Czech values of the R-factor according to the original methodology (Wischmeier and Smith, 1965). Based on data evaluation of long-term monitoring of precipitation at the erosion plots in Velke Zernoseky and in eight other stations in the northern and north-eastern Bohemia he found the range of annual R-factor of between 30 and 72 [$N.h^{-1}$]. On the basis of his own assessment of a correlation between the calculations and total annual precipitation amounts with regard to morphology he then compiled a map of R-factor isolines for the entire territory of the Czech Republic proposing the annual R-values in the range 30-100 [$N.h^{-1}$].

Precipitation measurements and calculations of the erosivity index continued in the following years, not only in Velke Zernoseky, but also in other stations. However, during the eighties and nineties, a simplified practice was adopted that minimized the rainfall erosivity contribution to the soil loss assessment. On the basis of experimental data from the stations in Prague -

Klementinum, Tabor and Bila Tremesna the average R-factor value 20 [$N.h^{-1}$] was proposed by Research Institute of Amelioration and Soil Conservation (VUMOP). Based on a few erosion plot experiments this value has been derived by modified methodology, in which rainfall totals used to calculate kinetic energy were reduced by 12.5 mm rainfall as a base before invoking surface runoff (Janeček et al. 2007). Involved in this experimental research Toman in the nineties published the results of calculating the rain erosivity and erosion vulnerability based on the assessed ombrographs from Telc station (Toman, 1995) and for a number of stations in South Moravia (Toman et al. 1993). The resulting R-values are in the range from 17.6 to 25.7 [$N.h^{-1}$]. Based on experimentally verified assumption that the erosive effect of rainfall is subject to a minimum total rainfall of 10 mm, he again substracted 10 mm from the data before rainfall energy computation. This assumption corresponds to the empirically validated values at other locations and also to the Wischmeiers' observations. But according the USLE methodology (Wischmeier at al. 1978) the effective rainfalls have to be assessed in total. Methodology used in conservation planning in the Czech Republic then (and recently) conserved the underestimated R-factor value 20 (Janeček et al. 1992). In the handbook regional values for a number of stations in the Czech Republic were published but not recommended to use and the values differed only slightly from proposed constant of 20 [$N.h^{-1}$]. Also these values were reduced by reduction of input rainfalls. The methodology (Janeček et al. 1992) also proposed a modified threshold for erosive torrential rainfalls selection. According the plot experiments, only rainfalls meeting both criteria (exceeding both 12.5 mm amount and 6 mm/15 min intensity) caused runoff and soil loss. This way only intensive storms are selected while Wischmeier computes R-factor for all rains above 12.5 mm (and intensive smaller rains). The stricter criteria were used in most studies during following research in the Czech Republic.

In 2004 R-factor was computed for complete ombrometer data (ca 50-years) for 4 stations by Krása (2004) in Czech Technical University in Prague (CTU). Using the original Wischmeier's method for rainfall kinetic energy computation but only the rains matching both intensity and amount criteria he found the long term R-factor varying from 34-56 [$N.h^{-1}.year^{-1}$]. Using these data for calibration he then in cooperation with CHMI developed an R-factor map for the Czech Republic. The map was based on monthly precipitation sums for 87 stations for 1962-2001

(Dostál et al. 2006). This map brought already much more accurate spatial distribution of rainfall erosivities, yet it binds to a number of uncertainties, especially given very loose dependency between long-term (monthly) precipitation totals and torrential rainfall (see Fig. 1).

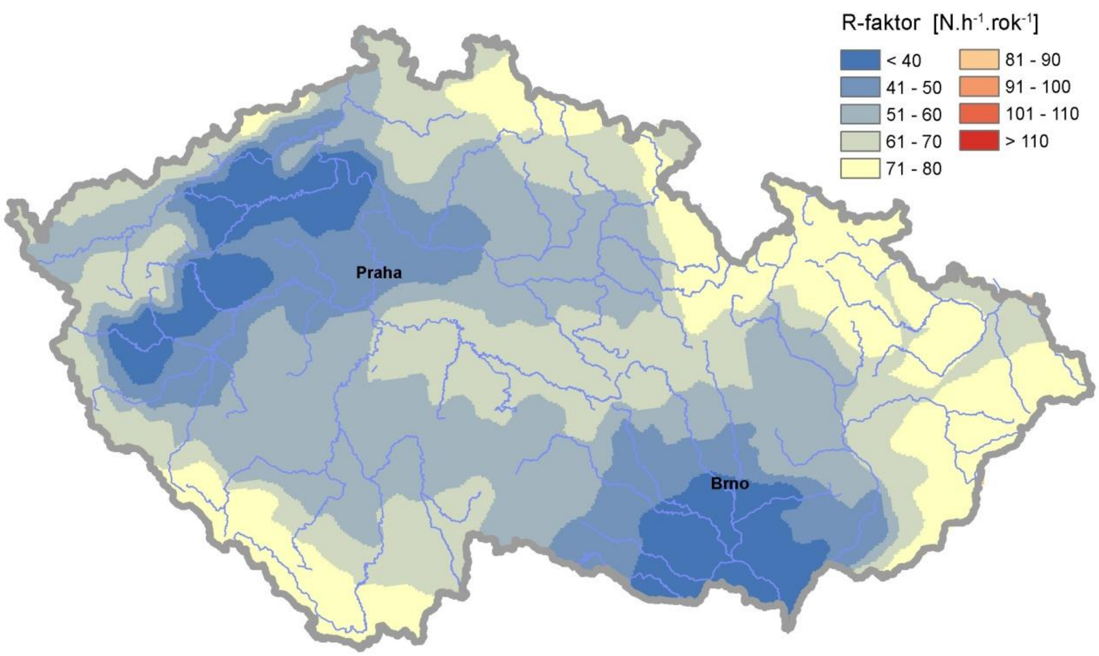


Fig. 1: R-factor map (Dostal et al., 2006) prepared by a modified methodology based on monthly totals of 87 stations (1962-2001).

At the end of 2005 (Dostál et al. 2006) in cooperation of CTU and CHMI, the R-factor was calculated by the original Wischmeier's methodology for data from minute rainfall records for 37 automatic stations. It was the first processing of digital records for this purpose in the Czech Republic and the processed data were only six seasons (2000-2005). Yet in the group 1372 torrential rainfalls were identified, representing an average of more than 6 erosive precipitation events in each station annually. On the basis of the derived digital map the average value of R-factor for the entire Czech Republic was 69 [N.h^{-1}.year^{-1}]. Given the short time period of processed data and the limited number of stations the regionalization in Bohemia is rather course and it is significantly affected by European extreme flood event in summer 2002 (see Fig. 2).

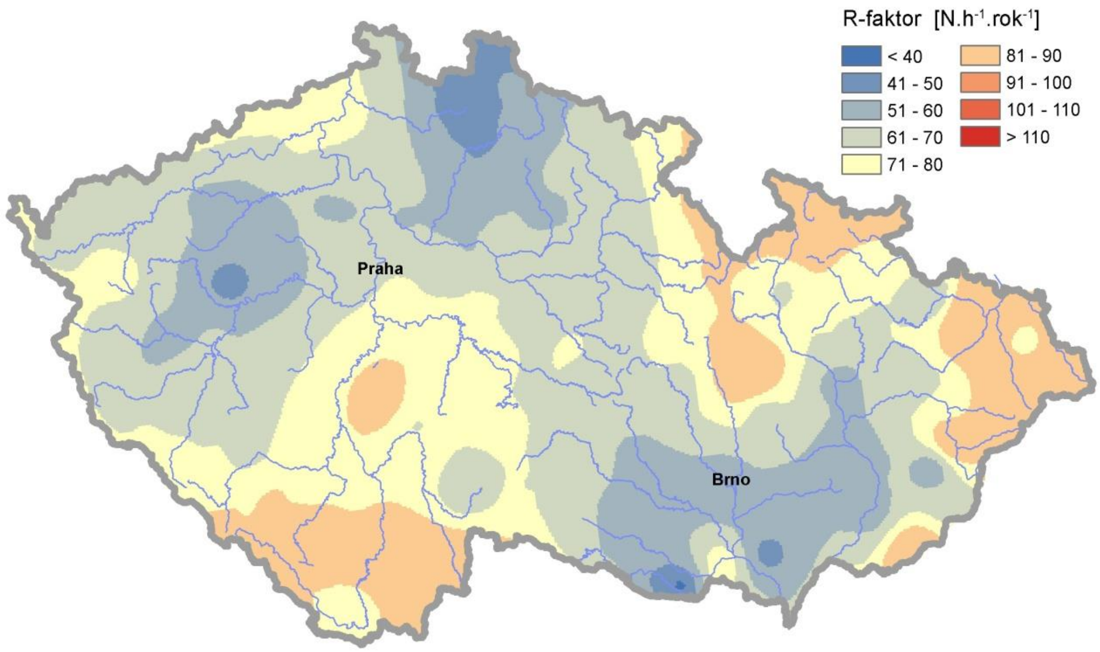


Fig. 2: R-factor map according the Wischmeier's method (Dostal et al., 2006), but only for 37 stations (2000-2005).

Bek (Charles University) tried to improve the regionalization of R-factor using weather radar data (Bek et al. 2010). Radar data show relatively high precision of localization of storm cores and storm precipitation. According the authors preparing actual R-factor maps based on radar data, however, still faces in particular following issues:

- The derivation of the actual rainfall intensity based on the reflectance is not always precise, in particular for certain types of precipitation (eg stake hail) and for extreme intensities the radar data may not be accurate (rather leads to underestimation than vice versa). It is therefore necessary to fit the data on the data from rain gauges, which, however, do not have the same time distribution. The methodology is developing rapidly and the future seems to bring much more accuracy.
- High spatial resolution of radar data is generally accurate, but there are also data errors (spatial noise) when the radar signal is damaged (eg disturbed by external phenomena), relating in particular to peripheral sites where only one of the opposing signal monitoring radars in our country is giving a close data. The error usually occurs in the form of stripes in the data only for a specific period of observation. These errors cannot

be completely eliminated in the future, but the methods of filtering the measured data would improve.

- The existing time series do not cover enough years of continuous monitoring, as it is a relatively new method. According to estimates of the authors it should be relevant to obtain a time series of observed radar data for approximately twenty years, to which we will have to wait. However, the combination of the radar and rain gauge data is promising, the correlation between the datasets justifies the use of combined data.

Prof. Janeček research group works now in Czech University of Life Sciences (CULS) and also continues assessing the rainfall data for erosivity. Kubátová et al. (2009) focuses on the distribution of erosive rainfall during the growing season. Data from her evaluated stations confirm previous trends, most erosion is caused by summer storms with a peak in June and July. In cooperation CULS–CHMI Janeček et al. (2012b) processed data from 31 ombrometric stations for the 1971 (1961) - 2000. The measured period at individual stations was variable (range 19-40 years). After separation of torrential precipitation (by the stricter criteria) file contained an average of two to three erosive rainfall at each station annually. The average value of R-factor based on the data from these stations was 48 [$N.h^{-1}.y^{-1}$], with fluctuations from 25.3 to 74.9 [$N.h^{-1}.y^{-1}$].Stations were underrepresented for regionalization in the Czech Republic, hence the data were subsequently combined with long-term daily totals of 257 CHMI rain gauge stations (1971-2000). For spatial interpolation also the altitudes of the stations were taken into account. The problem of the database is the interrupted time series used and a simplified interpretation of the calculated values. The paper presents a map created from the "clipped average" (omitted every two years with the highest and lowest values of R-factor). Statistically, it is a common practice, when we want to get closer to the median of the data set. However in the case of R-factor this procedure is irrelevant. R-factor has not an even probability distribution. The smallest rainfalls do not contribute and long term soil loss is caused mainly by extreme events, specifically those with the highest totals and intensities. To calculate the average R-factor these episodes cannot be omitted (see Fig. 3).

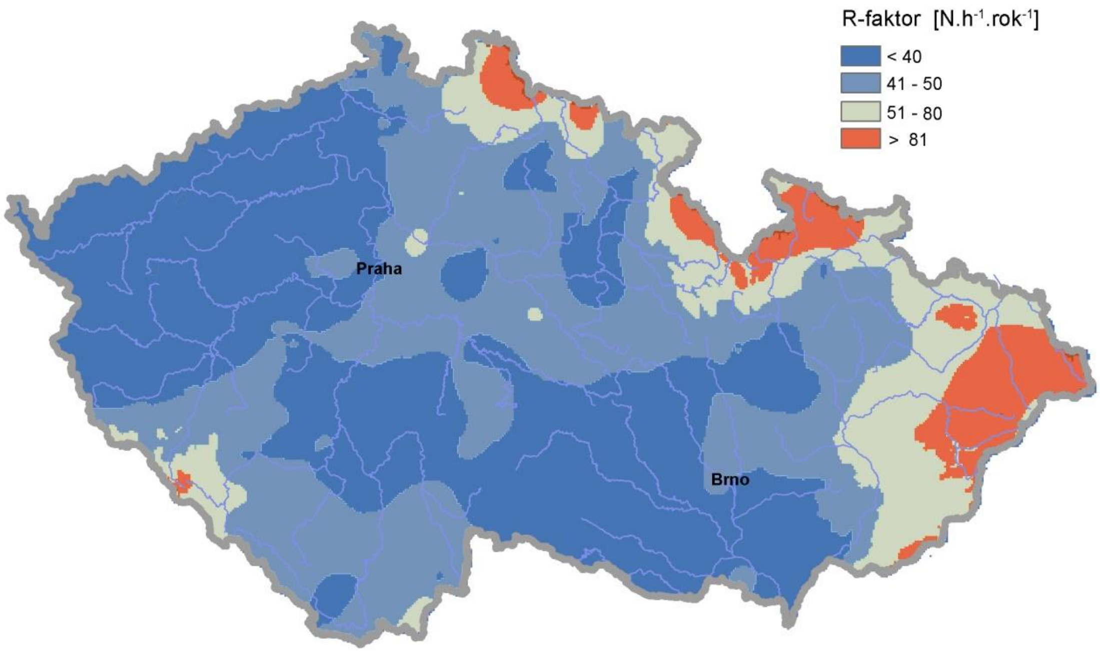


Fig. 3: R-factor map for the period 1971 - 2000 (Janeček et al., 2012b), compiled from continuous data and daily totals, based on the modified methodology with erased maximum and minimum years in considered stations.

Within a project focused on urban vulnerability for erosion risk in climate change Hanel (2013) at T. G. Masaryk Water Research Institute (WRI TGM) derived the R-factor map by original Wischmeier's methodology. He used the processed ombrometric records from 1989-2003 for 96 stations. The rainfalls exceeding 12.5 mm were selected together with torrential rains exceeding 6 mm in 10 minutes. The newer method for determining the kinetic energy of rain by Van Dijk et al. (2002) was used. The average value for the Czech Republic from the resulting digital map (see Fig. 4) is 64 [$N.h^{-1}.y^{-1}$].

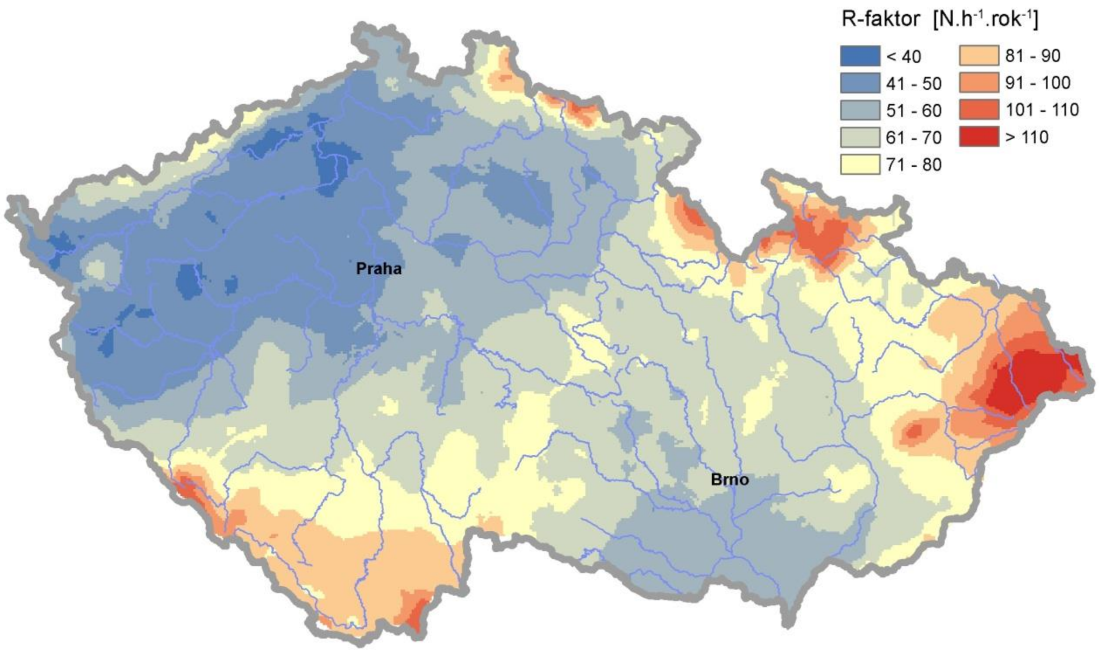


Fig. 4: R-factor map based on processed ombrometer data for 96 stations for 1989 – 2003 (Hanel, 2013).

Recent R-factor values for the Czech Republic

Finally, the most detailed and accurate current solution is based on an evaluation carried out by CHMI for the period 2003-2012. The analysis was performed in cooperation of VUMOP, CTU and CHMI and the network of 245 automatic stations was used, measuring precipitation parameters in 1 minute step. Processed rainfall intensities were available in the CLIDATA database in December 2012. After all checks outages and the initial data analyses for the direct calculation of the 10-year period R-factor 106 stations were used. Remaining stations were used for interpolating the missing values at selected stations in case of errors in the data in some years.

For its quantity and limited human resources at CHMI the 1-minute rainfalls are not systematically checked, hence in the CLIDATA database of the minute totals (precipitation intensity tables) errors can be expected. Therefore before the calculation the input data were subjected to quality control. The daily precipitation data at the stations served as the basis for the comparison and quality check. At CHMI these data pass quality control and revisions after the end of each month (control equations are applied, surface inspection is carried out in a GIS environment, missing data are substituted by neighborhood stations etc.).

In the first phase minute rainfalls greater than 10 mm were selected and subject to control (0.6% of the total number of over 11 million records per minute from 300 stations with automatic rain gauge - stations were taken without limitations regarding the minimum length range). These data were manually scanned and assessed together with other information (weather phenomena, other elements, etc.), and have been found to be faulty (in the sense of manifest error) they were excluded from further processing.

Basic control of rainfall intensities was based on a comparison of the revised (ie expired by CHMI on quality control) daily total precipitation with daily rainfall sums computed of minute totals (for the same station a day when the day is set from 07:00 CET the day to 07:00 the next day). The audit was based mainly on a comparison between the two datasets using the differences and ratios. A huge amount of data has undergone a control (about 400 thousand daily sums) and the actual process went in loop: setting up criteria for the selection of suspicious values; application of the criteria; selection of a sample of data; expertise, whether the application of the criteria did not result in leaving considerable number of errors in the database or on the contrary, the data have not been excluded that could be considered reliable; repeating the analysis. Finally, about 6 percent surveyed days were excluded from further processing. For these days, minute records were replaced by a code for missing values and they were not further processed. Missing values supplementing went up on the basis of the final results - the annual R-values, and only for stations showing the risk of undetected erosive rains (a significant daily precipitation sum recorded in the revised database). For the addition R-factor of appropriate surrounding stations the IDW interpolation was used (the reciprocal of the distance to the third power).

Result is a detailed map of the R-factor for the 2003-2012 period showing a relatively significant regional differences in the R-factor in the Czech Republic and corresponding surprisingly well with previous regionalization of other working teams (see Fig. 5). The values of the average R-factor in the stations range from 37 to 239 [N.h-1.y-1], but values above 100 are found exclusively in mountain stations (except the Radostín station near Zdarske Hills). The values in the map are therefore exposed in the range 37-110 [$N.h^{-1}.y^{-1}$].

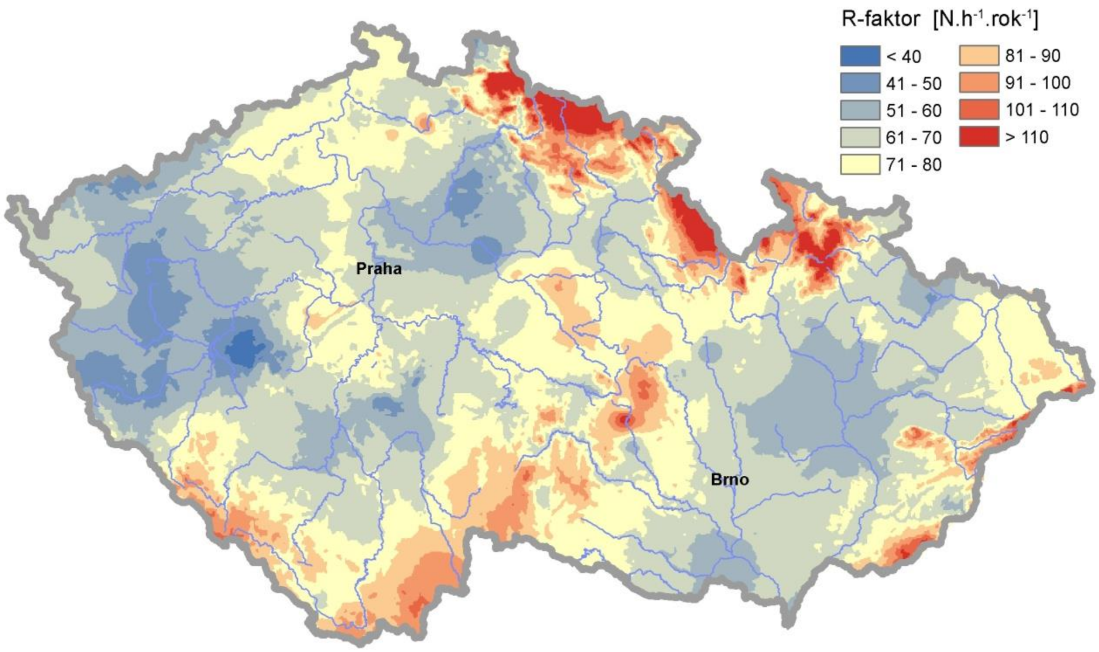


Fig. 5: Detailed map of the R-factor for the 2003-2012 period based on 106 (243) automatic rain gauge stations (Rožnovský et al. 2013).

CONCLUSION

Calculations of rainfall erosivity in the Czech Republic were implemented by numerous scientific teams repeatedly from the beginning of international publications of the USLE methodology in 60's of the last century. Yet since the beginning of the 80's the R-factor underestimating case study lead in to the preservation of constant value 20[N.h^{-1}.y^{-1}] used in the R-factor engineering practice, values significantly undervalued according to the latest calculations, and also when compared with neighboring countries (with the exception of Slovakia, which uses identical value since the time of Czechoslovakia). Table 1 summarizes recent results of nationwide R-factor calculations. The regionalization attempts made with a use of significant number of measurement stations are shown in Fig. (1-5).

Table 1: Overview of the results of nationwide R-factor calculations.

Publication	Data period	The number of stations *	min/max R in the map **	average R-factor of the Czech Republic ***
Holý et al. 1975	1965-1974	8	30/100	Not specified
Janeček et al. 1992	different lengths	3/102	5/34	20
Krása, 2004	1949-1990	4	34/56	Not specified
Dostál et al. 2006	1962-2001	4/87 month sums	35/80	57
Dostál et al. 2006	2000-2005	37	44/85	69
Janeček et al. 2012	(1961) 1971-2000	31/257 daily sums	25/75	48
Hanel, 2013	1989-2003	96	35/150	64
Rožnovský et al. 2013	2003-2012	106/245	37/110	69

Grey lines indicate solutions where regionalization did not proceed according to Wischmeier's methodology and was not based on continuous data.
** Number of stations listed after the slash indicates the stations used only for regionalization. To calculate the R-factor stations listed before the slash were used.*
*** Maximum values in the created maps are always arbitrary. Actual long-term maximum R-factors for some stations in the mountain regions always exceeded these maxima listed in maps (up to several times).*
**** Except Janeček et al. (1992, 2012) it is an average derived from raster maps, indeed relate to the whole territory of the Czech Republic, not the simple arithmetic average of the values at stations.*

Regarding the spatial variability of the R-factor in the Czech Republic, a few basic facts can be stated:

- In the regions with a large share of agricultural land long term rainfall erosivity ranges from about 35 to 90[$N.h^{-1}.y^{-1}$], with both values less than 50, so values greater than 70 occupying a significant area, always more than ¼ of the country.
- Extensive agricultural areas exist where rainfall erosivity is doubled (Czech-Moravian Highlands) compared to other regions (western Bohemia, southern and central Moravia).

- In mountainous areas in the periphery of the Czech Republic the R-factor is proven to be even higher.
- Defined regions with above-average and below-average precipitation erosive effect are permanent in nature (as demonstrated in solutions based on data since 1961) despite significant fluctuations in each period and generally high variability of R-factor in specific years.

ACKNOWLEDGEMENT

The paper was prepared within the project of Ministry of Agriculture QJ1230056 "Impact of expected climate change on soils in the Czech Republic and evaluation of their production functions" and the project of Ministry of Interior VG 20122015092 "Erosion runoff - increased risk of the residents and the water quality exposure in the context of the expected climate change."

REFERENCES

Arnoldus, H. M. J.: Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. FAO Soils Bulletin, 34 (1977), 1977, pp. 39–51

Arnoldus, H. M. J.: An approximation of the rainfall factor in the Universal Soil Loss Equation, pp.127-132. In DeBoodt, M. and Gabriels, D. (ed.) Assessment of erosion. John wiley & Sons, Chisester. 1980

Bek S., Ježek J., Krása J.: Mapping Rainfall Erosivity using Weather Radar Data, poster, proceedings of IPC-10, Coimbra, Portugal, 2010

Brown, L.C., Foster, G.R., 1987. Storm erosivity using idealized intensity distributions. Transactions of the American Society of Agricultural Engineers 30, 379-386.

Dostál T, Vrana K, Krasa J, Jakubikova A, Schwarzova P, David V,Novakova H, Becvar M, Vesela J, Kavka P. 2006. Metody a zpusobypredikce povrchoveho odtoku, eroznich a transportnich procesu v krajine(The methods of prediction of surface runoff, erosion and transportprocesses in a landscape), annual research report from COST634 action,CTU Prague (in Czech).

Hanel M.: information of the author – not published results within the project VG 20122015092 "Erosion runoff - increased risk of the residents and the water quality exposure in the context of the expected climate change."T. G. Masaryk Water Research Institute, Prague, 2013

Holý M. et al.: Experimentální a teoretické vyšetření vztahů mezi základními erozními faktory a intenzitou erozních procesů, závěrečná zpráva výzkumného úkolu P 16-329-059-01/1.1 (Experimental and theoretical examination of the relationship between basic erosion factors and the intensity of erosion processes, the final report of the research project P 16-329-059-01/1.1), CTU Prague, Faculty of Civil Engineering,, 1975 (in Czech)

Janeček M et al.: Ochrana zemědělské půdy před erozí (Protection ofagricultural lands from erosion), ISV Prague, Prague, ÚVTIZ Praha, 1992.(in Czech)

Janeček M et al.: Ochrana zemědělské půdy před erozí (Protection of agricultural lands from erosion), VUMOP, v.v.i., ISBN 978-80-254-0973-2, Prague, 2007.(in Czech)

Janeček M et al.: Ochrana zemědělské půdy před erozí (Protection of agricultural lands from erosion), Česká zemědělská univerzita, ISBN 978-80-87415-42-9 Praha, 2012a. (in Czech)

Janeček M., Kubátová E., Procházková E.: Vliv úhrnů a intenzit dešťů na ztráty půdy vodní erozí (Influence of rainfall totals and intensities on soil loss by water erosion), Vodní hospodářství (Water Management), 4/2012, p. 134-137, 2012b (in Czech)

K.G. Renard, J.R. Freimund: Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology, 157, 1994, pp. 287-306

Klik A., Konecny F.: RAINFALL EROSIVITY IN NORTH-EASTERN AUSTRIA, ASABE, in review – information of the autor, 2012

Krása J.: Empirické modely vodní eroze v ČR - nástroje, data, možnosti a rizika výpočtů. (Empirical models of water erosion in the Czech Republic - tools, data, options and calculation risks). Habilitation thesis.CTU Prague, Faculty of Civil Engineering, Prague,2010. 159 p.(in Czech).

Krása J.: Hodnocení erozních procesů ve velkých povodích za podpory GIS(Evaluation of soil erosion processes in large catchments using GIS), doctoral thesis,CTU Prague, Faculty of Civil Engineering, Prague, 2004. 175 p. (in Czech)

Kubátová E., Janeček M., Kobzová D.: Time Variations of Rainfall Erosivity Factor in the Czech Republic, Soil & Water Res., 4, 2009 (4): 131–141

Loureiro, N., Coutinho, M.: A new procedure to estimate the RUSLE EI30 index, based on monthly rainfall data and applied to the Algarve region, Portugal. Journal of Hydrology, Volume 250, Issues 1–4, 1 September 2001, Pages 12–18

Meusburger, K., Steel, A., Panagos, P., Montanarella, L., Alewell, C.: Hydrol. Earth Syst. Sci. Discuss., 8, 8291–8314, 2011, ONLINE from: www.hydrol-earth-syst-sci-discuss.net/8/8291/2011/, doi:10.5194/hessd-8-8291-2011

P. Sauerborn, A. Klein, J. Botschek, A. Skowronek. Future rainfall erosivity derived from large-scale climate models – methods and scenarios for a humid region. Geoderma, 93 (1999), pp. 269–276

Rogler, H., and U. Schwertmann, 1981. Erosivität der Niederschläge und Isoerodentkarte von Bayern. Z. f. Kulturtechnik u. Flurber. 22: 99-112. (in German)

Rožnovský J., Středová H., Středa T.: Analýza souboru podkladů k určení a výpočtu R faktoru, přehled dosavadních postupů, výzkumná zpráva (Analysis of the data to the identification and calculating the R-factor, an overview of current practices, research report), CHMI, Brno, 2013 (in Czech)

Schwertmann U., Vogl W., Kainz M., (1990): Bodenerosion durch Wasser. Ulmer, Stuttgart. ISBN 3-80001-3088-2, 64 s.(in German)

Strauss, P., K. Auerswald, E. Klaghofer, and W.E.H. Blum, 1993. Erosivität von Niederschlägen: ein Vergleich Österreich-Bayern. Z. f. Kulturtechnik und Landentwicklung 36: 304-308.(in German)

Toman F., Sanetrník J., Filip J.: Vliv klimatických podmínek na faktor erozní účinnosti přívalových dešťů, Agrometeorologická konference 93 (The influence of climatic conditions on the factor of erosion efficiency of torrential rains, meteorological conference 93). proceedings. ČBkS, Brno, 25.-26.11.1993, p. 67-69, 1993 (in Czech)

Toman F.: Výskyt erozně nebezpečných dešťů ve stanici Telč, zpráva výzkumného záměru J08/98:43210001 (The occurrence of erosive rains in Telc station, the report of the research project J08/98: 43210001), MZLU Brno, 1995 (in Czech)

Van Dijk, A., Bruijnzeel, L., Rosewell, C. (2002) Rainfall intensity–kinetic energy relationships: A critical literature appraisal. Journal of Hydrology, 261(1), 1–23.

VAN ROMPAEY A. J. J., KRÁSA J., DOSTÁL T., GOVERS G.: Modelling Sediment Supply to Rivers and Reservoirs in Eastern Europe during and after the Collectivisation Period. Hydrobiologia. 2003, no. 494, p. 169-176. ISSN 0018-8158

WISCHMEIER W. H., SMITH D. D.: Predicting Rainfall-Erosion Losses from cropland east of the Rocky Mountains – Guide for Selection of Practices for Soil and Water Conservation. Agriculture Handbook No.282, ARS, US Dept.of Agriculture, Washington, D.C. 1965

WISCHMEIER W. H., SMITH D. D.: Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. Agr.Handbook No.537, US Dept.of Agriculture, Washington, 1978

SUMMARY

Vodní eroze je u nás hlavním degradačním faktorem zemědělských půd a riziko zvýšeného smyvu je pro účely ochrany půdy v ČR vyjadřováno především pomocí Univerzální rovnice ztráty půdy. Erozivita srážek je v této rovnici vyjádřena R-faktorem. V České republice výzkum R-faktoru probíhal na několika pracovištích od šedesátých let 20. století a postupně přinášel zpřesňující výsledky, nicméně oficiální praxe tento výzkum nereflektovala. V oficiálních metodikách byla dosud doporučována neměnná hodnota R-faktoru 20 [$N.h^{-1}.rok^{-1}$] pro celé území ČR. A to i v době, kdy výzkum jednoznačně prokazoval významně vyšší hodnoty erozní účinnosti srážek na území ČR i v jejím bezprostředním okolí. Kvalitní data z měření na automatických klimatologických a klimatologických srážkoměrných stanicích ČHMÚ již v současné době umožňují sestavení reprezentativní mapy erozní účinnosti srážek České republiky za období posledních deseti let. Svou hustotou pokrytí a kvalitou dat výstupy z automatických stanic výrazně převyšují výstupy dosažené zpracováním ombrogramů nebo jiná předchozí řešení postavená na dlouhodobých srážkových úhrnech. Nejpodrobnější a nejpřesnější dosavadní řešení vychází z vyhodnocení provedeného ČHMÚ za období 2003-2012. K analýze byla použita databáze Clidata ČHMÚ ze sítě 245 automatických stanic měřících parametry srážek v 1 minutovém kroku. Po všech kontrolách výpadků a analýze dat bylo k přímému výpočtu R-faktoru využito 106 stanic, zbylé stanice byly využity pro interpolační doplnění chybějících hodnot u vybraných stanic v případě chyb v datech v některých letech.

Výsledkem je podrobná mapa R-faktoru ukazující na poměrně výrazné regionální rozdíly v R-faktoru na území ČR a korespondující překvapivě dobře s předchozími regionalizacemi ostatních řešitelských kolektivů. Hodnoty průměrného R-faktoru v řešených stanicích se pohybují v rozmezí 37 – 239 [$N.h^{-1}.rok^{-1}$], nicméně hodnoty přesahující 100 se vyskytují výhradně v horských stanicích. Hodnoty v mapě se proto pohybují v rozmezí 40 – 110 [$N.h^{-1}.rok^{-1}$].

Pokud se týká prostorové variability R-faktoru na území ČR, lze konstatovat několik základních faktů: Erozní účinnost srážek se dlouhodobě v jednotlivých regionech s významným zastoupením zemědělské půdy pohybuje v rozmezí cca 35 – 90, přičemž jak hodnoty menší než 50, tak hodnoty vyšší než 70 zabírají významnou rozlohu, vždy více než ¼ území ČR. Existují rozsáhlé zemědělské oblasti, kde je erozní účinnost srážek dvojnásobná (Českomoravská

vrchovina) oproti regionům jiným (západní Čechy, jižní a střední Morava). V horských oblastech v okrajových partiích ČR je erozní účinnost srážek prokazatelně ještě vyšší. Vymezené regiony s nadprůměrnou a podprůměrnou erozní účinností srážek mají trvalý charakter (jak prokazují řešení postavená na datech od roku 1961) i přes výrazné výkyvy v jednotlivých obdobích a obecně vysokou variabilitu R-faktoru v konkrétních letech.

Příspěvek byl připraven v rámci projektů QJ1230056 „Vliv očekávaných klimatických změn na půdy České republiky a hodnocení jejich produkční funkce“ a VG 20122015092 „Erozní smyv – zvýšené riziko ohrožení obyvatel a jakosti vody v souvislosti s očekávanou změnou klimatu“.

CONTACT

Doc. Ing. Josef Krása, Ph.D.

Department of Irrigation, Drainage and Landscape Engineering, Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic, Thákurova 7, 166 29 Praha 6, josef.krasa@fsv.cvut.cz

METEOROLOGICAL MEASUREMENTS IN THE ST.THOMAS´S ABBEY IN BRNO

TOMÁŠ LITSCHMANN[1], *JAROSLAV ROŽNOVSKÝ*[2]

1) *AMET Corporation, Žižkovská 1230, 691 02 Velké Bílovice*
2) *Czech Hydrometeorological Institute, Brno branch office, Kroftova 43, 616 67 Brno*

ABSTRACT

The above work describes the previous and contemporary history of meteorological measurements in the St Thomas´s Abbey in the Old Town Brno. The measured temperatures are compared with temperatures from the same time period determined in Prague Klementinum. It turns out that the temperature difference in case of measurements made from the window is virtually zero, after homogenization or in case of a Stevenson screen placed 2 m above grass cover in the Abbey, the temperature differences lie in the interval of 0.7 and 1.1 °C, with Klementinum being warmer. The yearly pattern of average monthly differences shows variable thermal continentality of both locations and in the colder half-year the differences become more significant.

Key words: temperature, urban heat island, St Thomas´s Abbey Brno, Klementinum Prague

INTRODUCTION

Meteorological observations in Brno have a relatively long tradition, dating as far back as the end of 18th century. The work of Brázdil et al (2005) gives a time series of meteorological measurements prepared from various sources from the 1801-1950 period. Documented continuous measurements then start in 1848 thanks to Dr. Olexík, a senior doctor at the St.Anne´s Hospital on Pekařská Street in Brno. His measurements were continued for several years by G. J. Mendel at the St Thomas´s Abbey located in Old Town Brno. These measurements are relatively well described in some of his biographies, especially those, in which also meteorologists contributed, for example the compilation from Kolektiv (1965), where M. Nosek evaluated the significance of Mendel in this field. The fact that the meteorological station was placed in a city built-up area was quite common at that time. It was only later with the gradual standardization of measurements in the 20th century that climatological stations were moved to open air areas outside city centers. A good example of such station in Brno is the climatological station on Květná Street, not far from the Abbey, where measurements were performed until 1971. With respect to the planned climate research of the city of Brno within the project "Multilevel analysis of the urban and suburban climate taking medium-sized towns as an example", an automated meteorological station was set up in the area of the Abbey in 2005, which sends measured data at regular intervals to a remote web server. The measured values are then used to study the effects of urban development on meteorological and bioclimatological parameters compared to open landscape. This means that in the upcoming year there will be a decade-long time series of contemporary measurements available.

MATERIALS AND METHODS

G. J. Mendel performed his measurements in the Abbey in the period from July 1878 to July 1883. From August 1883 until November 1883 the meteorological measurements were continued by the monk Leo Ledwina. There is no data for the following month of December 1883 and the observations in Brno then follow from January 1884 thanks to Alfred Lorenz, the head imperial engineer and a professor of railway, road and water constructions at the Brno University of Technology. This is the end of the history of Mendel´s meteorological observations. As Nosek (Kolektiv, 2005) writes, a detailed description of the location of the devices is given by Josef Liznar 1886 based on his inspection, which he performed at Mendel´s meteorological station as a clerk of the imperial Central Institute for Meteorology and Geodynamics in Vienna in 1881. He states that "Thermometers were placed on the Northern side of the wing parallel to the church on the first floor. This and two other wings together with the church enclose a rectangular courtyard, longer side of which (east-west) is 30 to 35 m long and the shorter one (north-south) measuring approximately 25 m. The maximum and minimum thermometer was placed in a "bee garden", hanged on a pillar of a pavilion facing North and well-exposed, however from the North quite close to a relatively steep hillside of the Žlutý hill. The rain gauge was in the "prelate garden", with the retaining flask being one meter above the ground. Wind direction was determined based on observing numerous chimneys that were in the surrounding area (and also on the Špilberk castle)".

This description corresponds to the temperature measuring areas highlighted in Fig. 1. Measurements were performed using a pair of thermometers from the Kappeller Company, placed in a metal booth approximately 6 m above the ground (fig. 2).

Fig. 1 *St Thomas´s Abbey with Mendel´s and contemporary place of measurements marked.*

Contemporary measurements have begun on 7th March 2005 using an automated meteorological station in a classical Stevenson screen placed in an open space on the Abbey grounds (fig. 1, fig. 3). Apart from the automated station, there are also devices, which until recently, represented the standard voluntary climatological station equipment, i.e. August psychrometer, thermograph, hygrograph, hair tension hygrometer, maximum and minimum thermometer. The door is, according to regulation, oriented north and made from Perspex blinds, so museum visitors can see inside and get to know the devices that have been used for gathering data about the climate for many decades. With respect to the location of the station, the following meteorological parameters are measured: air temperature and humidity, precipitation and soil humidity. Data from the station were analyzed in several works, for example one from Litschmann and Rožnovský (2009), Litschmann and Rožnovský (2012) etc., which focused on the effects of urban heat island phenomenon on selected bioclimatological factors – in other words the effects of what Mendel pointed out already in 1863 (Munzar, 1994).

Fig. 2 *Metal booth with thermometers from the Kappeller Company, most likely used by G. J. Mendel*

Taking into consideration the fact that the measurements are performed in an urban area of the Abbey, it is sensible to compare the data with another similar meteorological station in Prague Klementinum. This station is also placed on a first floor of a wing, which together with 3 other wings encloses a rectangular space (fig. 4, fig. 5). The window with the thermometers is also facing north. The thermometers were moved several times in the past (Pejml, 1975), however they were always in a window facing north, alternating between the first and second floor. Jírovský (1976) says however, that “Thermometers are right from the beginning of observations placed in a metal booth approximately 1 m from the northern wall of the building, 10 m above the courtyard. In order to maintain homogeneity, the position has been kept the same until today.”

We therefore compared monthly air temperature values from various time periods at both locations including two other homogenized series for Brno and assessed the differences in monthly intervals.

Fig. 3 *Stevenson screen with automated station including standard equipment for demonstration purposes*

Fig. 4 *Detail of the placement of the thermometers at the station in Prague Klementinum*

Fig. 5 *Klementinum area with the position of current meteorological station marked*

RESULTS AND DISCUSSION

The results of the temperature comparison for the individual time periods are given in Table 1 and Figure 6. It is worth noting that the average temperature measured by G. J. Mendel in his "window observatory" agrees with the average temperature measured with approximately similar radiation shield in the window in Klementinum. After homogenization of this data performed by the CHMI, the temperature for Brno is 0.9 °C lower. An approximately equivalent difference also applies for comparison of data from Klementinum and homogenized series of Brázdil et al (2005) from the first half of 19th century in Brno. In the period measured by us between 2005 and 2011, the determined temperature is 0.7 °C lower than in Prague Klementinum.

Table 1 *Average temperature from the individual time periods and differences in comparison to Prague Klementinum*

Location	**Time period**	**Average [°C]**	**Difference [°C]**
Klementinum	I.1801 – XII.1850	9.5	
Brno (homogenized data based on Brázdil, 2005)	I.1801 – XII.1850	8.4	1.1
Klementinum	VII.1878 – XI.1893	9.1	
Brno, Abbey (Mendel´s observations)	VII.1878 – XI.1893	9.1	0.0
Brno (CHMI homogenized data)	VII.1878 – XI.1893	8.2	0.9
Klementinum	IV.2005 – XII.2011	11.6	
Brno, Abbey (aut. station measurements)	IV.2005 – XII.2011	10.9	0.7

Figure 6 is a detailed comparison of the differences for individual months during the analyzed time period. What is common for the measurements performed in the Abbey is the fact that the differences are smaller during the summer; in case of Mendel´s measurements there are even higher temperatures in Brno than in Klementinum, while in the colder half-year, the differences get more apparent. This can be explained by the different thermal continentality of both locations, because as we have found out, the temperature difference between Klementinum and a station in Doksany, located in approximately the same climate area, but outside urban development, do not show any regular pattern during the year and are almost same during the entire year. The yearly pattern of differences is disrupted in the summer months in the case of the homogenized series from 1801 to 1850, but taking into consideration that this time series was generated from measurements performed at several locations in Brno, this discrepancy of just several tenths of a degree are understandable.

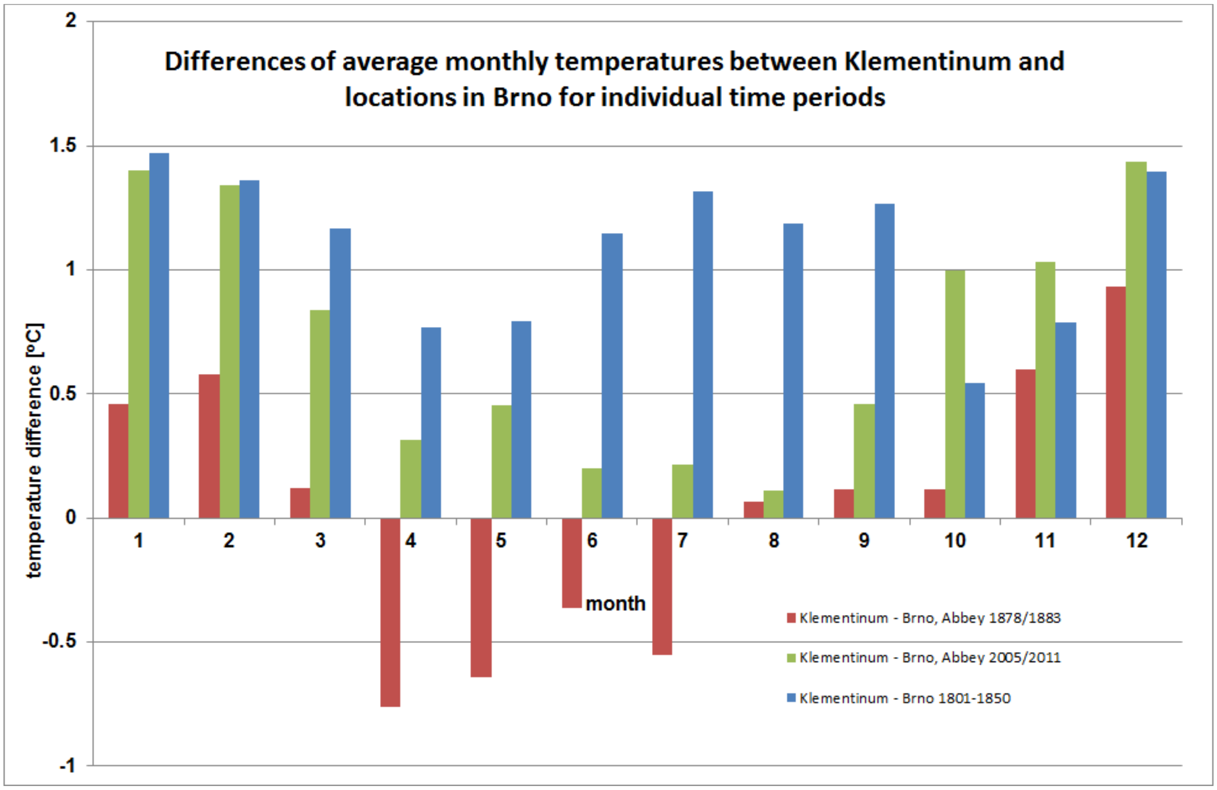


Fig. 6 *Differences of average monthly temperatures between Klementinum and locations in Brno for individual time periods*

Conclusion

Based on the comparison of temperatures in Prague Klementinum and several temperature series from Brno from various time periods it turned out that for measurements that were not performed directly in the "window observatory", or homogenized measurements, the difference is within the interval of 0.7 and 1.1 °C, with Prague Klementinum being warmer. This can lead to the conclusion that:

- the extent of urban heat island in both of the cities analyzed is increasing at an approximately same rate and it cannot be proved that the temperature increase would be more significant in the Prague city center than in Brno
- temperature measurements performed in the vicinity of a building wall can be to a certain extent biased with the measured values being slightly higher in comparison to measurements from opened areas.
- if the observations performed at the St Thomas´s Abbey continued even after Mendel´s death in the "window observatory", it is quite likely that the "warmest place of the Czech Republic" would not be just Klementinum, but also the Abbey in Brno. However, it must be said that nobody competent would probably consider such measurements as regular measurements of a climatological station.

REFERENCES

Brázdil, R. et al. (2005): Meteorologická pozorování v Brně v první polovině 19. století. Historie počasí a hydrometeorologických extrémů. Archiv města Brna, 450 s., ISBN 80-86736-00-8

Jírovský, V. (1976): Meteorologická pozorování v Praze – Klementinu 1775 – 1975. Hydrometeorologický ústav Praha, 460 p.

Kolektiv, (1965): Gregor Mendel, zakladatel genetiky. Blok, Brno, 206 s.

Litschmann, T., Rožnovský, J. (2009): The incidence of heat index levels in urban areas of Brno. Sustainable Development and Bioclimate, Proceedings. Eds. Pribullová and Bičárová, Stará Lesná 2009, ISBN 978-80-900450-1-9

Litschmann,T., Rožnovský, J. (2012): Zhodnoecení indexu HUMIDEX na území města Brna. 20th International Poster Day Transport of Water, Chemicals and Energy in the Soil-Plant-Atmosphere Systém, Bratislava, 15.11.2012

Munzar, J. (1994): Gregor Mendel and urban environment. Moravian geographical reports, No. 2, Vol. 2, s. 49 – 51

Pejml, K. (1975): 200 let meteorologické observatoře v pražském Klementinu. HMÚ Praha, 80 s.

SUMMARY

V práci je popsána starší i novodobá historie meteorologických měření v areálu augustiniánského kláštera na Starém Brně. Naměřené hodnoty teplot jsou porovnány s teplotami za stejné období zjištěné v pražském Klementinu. Ukazuje se, že teplotní odchylka v případě měření za oknem je prakticky nulová, po homogenizaci anebo v případě měření v žaluziové budce 2 m nad travnatým povrchem v areálu opatství se teplotní odchylky zvětšují na 0,7 až 1,1 ^{o}C ve prospěch Klementina. Roční chod průměrných měsíčních odchylek ukazuje na rozdílnou termickou kontinentalitu obou lokalit, v chladném půlroce se odchylky zvětšují.

CONTACT

RNDr. Tomáš Litschmann, PhD.

AMET, Žižkovská 1230

691 02 Velké Bílovice

amet@email.cz

THE INFLUENCE OF SPECIFIC LIGHT SPECTRUMS ON ROOTING OF WOODY CUTTINGS OF CONIFEROUS SPECIES IN NURSERY PRACTICE

MARIAN MAIER, PETR SALAŠ, MARTIN JONÁŠ, HANA SASKOVÁ, MAKSAT B. MATRAIMOV

Mendel University in Brno, Faculty of Horticulture in Lednice, Department of Breeding and Propagation of Horticultural Plants, Czech Republic

ABSTRACT

Light is one among the factors, which significantly affect plant development, because it is necessary source of energy. In common nursery practice is vegetative propagation used for propagation of coniferous species. One among the vegetative ways of propagating are woody cuttings. Propagation of coniferous by woody cuttings is released mainly before or after vegetation period, what means during season when quality and quantity of daylight is not enough. This situation could be solved by adding an artificial light. During experiment with adding of artificial light, were used LED systems with specific wavelengths (variant A - 460nm; 670nm and variant B - 440nm; 630nm) with intensity of light around 70 µmol $s^{-1} \cdot m^{-2}$. Spectra were composed in ratio 4:1 ("Red":"Blue") by module mounted LEDs. As an experimental plant material was used *Thuja occidentalis* 'Columna'. Artificial light was added to reach, together with natural daylight, around 12 hours of light. Experiment was released in two periods, first - November to March, second - February to June. Significant differences were found in comparing the term of cutting and also between variants with added artificial lights.

Key words: LEDs, vegetative propagation, supplemental growth light, light spectrums, woody cuttings, greenhouse production, *Thuja occidentalis*

INTRODUCTION

Plants respond to radiation with wavelengths ranged between 400 - 700 nm. These wavelengths are known as Photosynthetically Active Radiation (PAR). For plants are the most important wavelength values located in both ends of range.The so-called "blue" part of the spectrum, located on the left side of the spectrum, affects qualitative growth, reduces elongation growth and influences the formation of chlorophyll. Conversely, the "red" part of the spectrum, which is located on the right side of the spectrum, facilitates quantitative growth. It is particularly very important for the development of the photosynthetic apparatus [1]. However, for plants is not important only the wavelength of the radiation, which are plants subjected, but also its intensity. Plant is not able to sign up too low values and too high are toxic for the plants [2]. For pre-cultivated plants from seeds or vegetative plant propagation are suitable radiation values which ranged from 30 to 100 μmol $s^{-1} \cdot m^{-2}$ [3].

MATERIALS AND METHODS

Two variants of lights composed by LEDs modules with different spectral composition were used in experiment. The composition of the spectra were following: variant A had the highest absorbance at 460 nm for chlorophyll B and 670 nm for chlorophyll A, while variant B had the highest absorbance at 440 nm for chlorophyll A and 630 nm for chlorophyll B.The lights were composed of LED modules in a ratio of 4:1 ("Red":"Blue") means specifically 8 pieces of blue LEDs to 32 pieces of red LEDs. The intensity of radiation was 70 μmol $s^{-1} \cdot m^{-2}$. However, intensity decreases towards the center of the source what is clearly shown in **Fig 1**. Lights were used to reach the extension of day over 12 hours. Simultaneously the effect of natural light was maintained in of both experiments. The intensity of natural light was higher in compare to added light (LED elements), what is evidently visible at **Fig 2** and **Fig 3**.

Plants were assessed using a 6-point scale (no roots, created a callus, created root, rooted, slightly rooted, fully rooted). Plants which are labelled as viable are expressed as % of those labelled as created root, rooted, slightly rooted, fully rooted. Agents for rooting stimulation was not used because of possibility of distorting the results.

Results and Discussion

The results of the experiment showed the percentage of successfully rooted cuttings, as well as quality and quantity of produced roots. According to assumption , the difference between the terms of cutting was proved - term in November showed significant difference between the variants and control, and as the best variant was considered variant A (460 nm, 670 nm) because was observed 19% success rate rooting and the worst results were observed in control variant with 2% success rate, what is described in **Tab 1**.

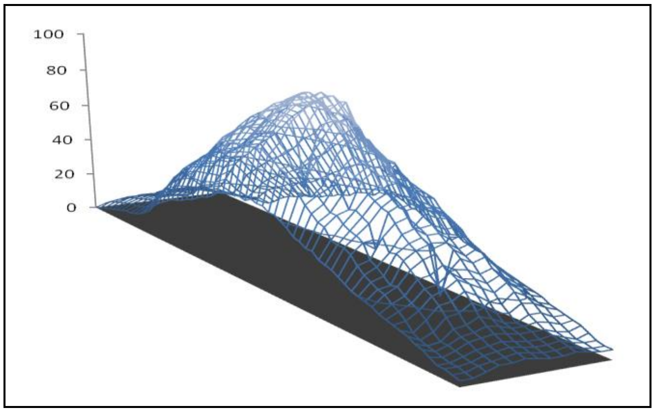


Fig 1 *The light intensity of LED*

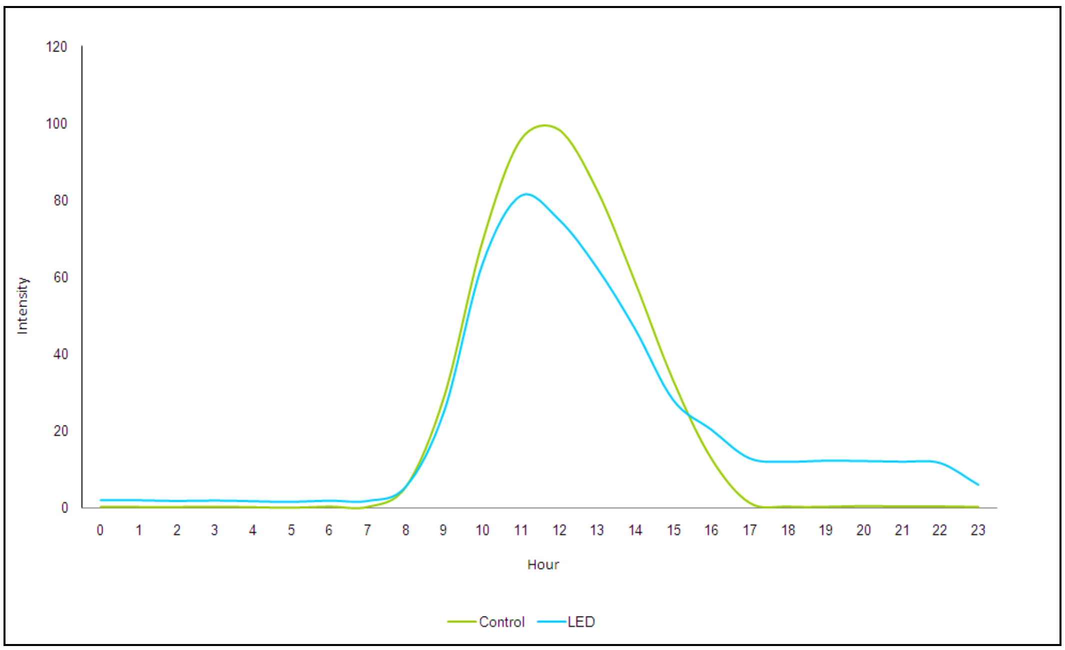


Fig 2 *The average daily course of intensity irradiance from November to March* $(W \cdot h^{-1} m^{-2})$

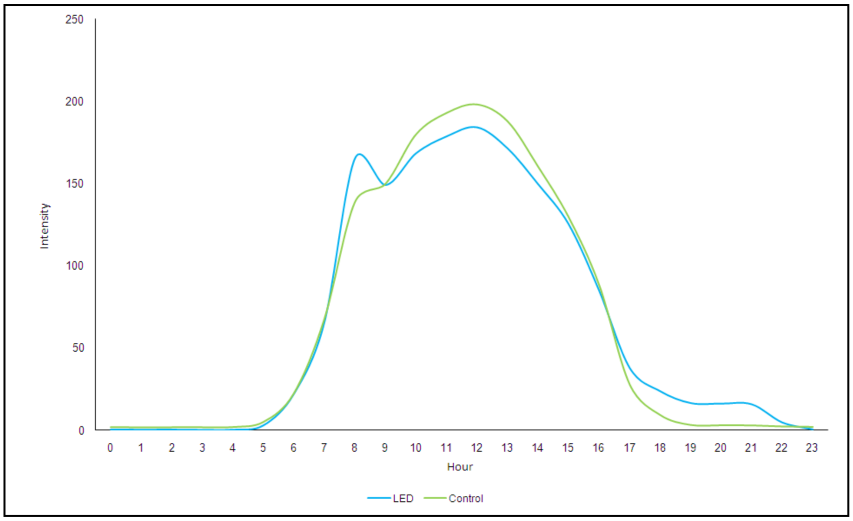


Fig 3 *The The average daily course intensity of irradiance from February to July* $(W \cdot h^{-1} m^{-2})$

Tab. 1 *Success rate of rooting in the period from November to March*

November - March	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
No roots	71	79	67	77	80	89	96	87	96
Created a callus	10	9	8	8	6	5	3	8	4
Created root	4	1	1	3	3	2	1	3	0
Rooted	3	1	2	0	0	0	0	1	0
Slightly rooted	1	2	1	3	1	0	0	1	0
Fully rooted	11	8	20	10	10	4	0	2	0
Viable %	19			12			2		

The second experiment, which lasted from February to June, has already had a significantly higher percentage of rooted cuttings, but it was caused by increased the intensity and also higher number of hours of natural daylight. The difference between the variant and control group is negligible. Variant B was about 10% better than the previous.

Tab. 2 *Success rate of rooting in the period from February to June*

February - June	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
No roots	54	32	25	50	29	30	41	38	31
Created a callus	21	32	5	15	9	12	42	9	14
Created root	13	22	15	13	20	29	13	19	21
Rooted	8	8	14	5	11	16	4	15	16
Slightly rooted	0	2	14	4	7	4	1	4	3
Fully rooted	3	4	28	13	24	10	1	16	15
Viable %		43			52			42	

Conclusion

The present results indicate that rooting of coniferous cuttings have a major impact length and likely intensity of light. Season from November to March is unsuitable because of natural lighting conditions and therefore is necessary to use supplemental grow light.

References

PROCHÁZKA, S., MACHÁČKOVÁ, I., KREKULE, J., ŠEBÁNEK, J.: Fyziologie rostlin. Vyd. 1. Praha: Academia, 1998, 484 s. ISBN 80-200-0586-2.

KUKULIŠ, J., MOKRIČKOVÁ, J.: Vliv intenzity a spektrálního složení umělého světla na kultivaci rostlin. Světlo. 2011, č. 3.

PHILIPS. Growing your profits: Horticultural lighting [online]. 2010. vyd. 2010. Dostupné z: http://www.lighting.philips.nl/application_areas/horticultural/pdf/growing_your_profits.pdf

Aknowledgement

I would like to thank to SVP Components s.r.o for providing light fixtures and to RNDr.Tomáš Litschmann for providing measurements and for help with data processing. This publication was supported by Project No. 6/2014/591 provided by the Internal Grant Agency of MENDELU.

Summary

Světlo je jedním z faktorů, výrazně ovlivňujících vývoj rostlin, je totiž jejich nutným zdrojem energie. Ve školkařské praxi se jehličnaté rostliny rozmnožují převážně vegetativním způsobem. Jedním z těchto způsobů je i dřevité řízkování. Rozmnožování jehličnatých rostlin pomocí dřevitých řízků provádíme zpravidla mimo vegetaci, tedy v období, kdy kvalita a kvantita přirozeného denního světla není příliš vysoká. Tento problém lze vyřešit pomocí přisvětlování. V experimentu byly k přisvětlení použity LED systémy o specifických vlnových délkách (varianta A - 460nm; 670nm a varianta B - 440nm; 630nm) o intenzitě 70 µmol $\cdot s^{-1} \cdot m^{-2}$. Spektra byla sestavena v poměru 4:1 („červená“ : „modrá“) z modulů osazenými led diodami. Jako pokusná rostlina byla využita *Thuja occidentalis* 'Columna', která byla přisvětlována nad 12 hodin spolu s přirozeným světlem. Pokus probíhal ve dvou termínech od listopadu do března a od února do června. Prokázaly se rozdíly jak v termínu řízkování, tak i v přisvětlovaných variantách.

CONTACT

Ing. Marian Maier,

Mendel University in Brno,

Faculty of Horticulture in Lednice,

Department of Breeding and Propagation of Horticultural Plants, Valtická 337, 69144 Lednice,

xmaier1@mendelu.cz

USING PORTABLE DYNAGAGE SAP FLOW LOGGING SYSTEM TO MEASURE SAP FLOW IN THE YOUNG PLANTS ON SOIL CONDITIONER IN NURSERY

MAKSAT B. MATRAIMOV[1], PETR SALAŠ[1], MARTIN JONÁŠ[1], HANA SASKOVÁ[1], MARIAN MAIER[1], TOMÁŠ LITSCHMANN[2], MEDET K.AKHMATOV[3]

1) *Mendel University in Brno, Faculty of Horticulture in Lednice, Department of Breeding and Propagation of Horticultural Plants, Czech Republic*
2) *AMET Corporation, Žižkovská 1230, 691 02 Velké Bílovice*
3) *I.Arabaev Kyrgyz State University, Faculty of Biology and Chemistry, Department of Biodiversity, Kyrgyzstan*

ABSTRACT

The experiment was established in spring 2013 on experimental plots of the Faculty of Horticulture Lednice, Mendel University in Brno. The aim of this work was to evaluate the effect of hydro absorbent (Hydrogel) and growing technology on morphological and physiological parameters of the model plants (*Tilia platyphyllos* L.). For the individual treatments of the experiment a substrate was premixed with an addition of the hydro-absorbent Hydrogel at a rate of 2; 3.5 and 5 grams per cubic meter of the substrate and there was also a control variant. The hydro absorbent Hydrogel retains a lot of water in addition to the humidity of the substrate and it releases the water for the root system, when the moisture content decreases. The plants which were cultivated with a hydro absorbent in the substrate was measured sap flow at the value 14g.h^{-1}, while the sap flow at the value 12 g.h^{-1} for plants from the control variant was observed. Due to our investigation, we can conclude, that Hydrogel doesn't have significant affect to increase sap flow in plants.

Key words: sap flow, transpiration, water stress

INTRODUCTION

The water flow represents the biggest energy flow in vegetation which also causes its magnificent climatic effect. Plants can only survive when their exposed parts are effectively conditioned, i.e. cooled. From all the water taken up by plants, the majority is transpired, leading to leaf cooling and only minor amount of water is consumed to all the other processes. The transpiration can be estimated through measurement of sap flow rates in a tree stem (Čermák and Kučera, 1981; Salaš et al. 2010).

In the last decades, the reaction of the scientific community to this problem has been to invest a substantial amount of research into new irrigation technologies and more efficient scheduling approaches. Plant-based methods are considered to have a greatest potential for irrigation control although, in some cases, there are issues in defining a reference or threshold value and other issues including plant variability within the orchard (Naor and Cohen, 2003). Improved scientific and practical knowledge on plant responses together with advances in electronic sensors and automated equipment for monitoring and data communication, are helping to overcome some of these limitations (Fereres et al. 2003; Naor et al. 2006). In addition, thermal remote sensing methods can be combined with plant-based methods for precise irrigation of heterogeneous commercial orchards using a manageable number of instrumented plants (Sepulcre-Cantó et al. 2006).

MATERIALS AND METHODS

The experiment was established at a multipurpose scientific experimental workplace on plots of the Faculty of Horticulture in Lednice in 2013. *Tilia platyphyllos* L. was selected as the object of the study, which is one of the species with relatively simple technology that is growing with the increasing demand for water and leaf area large enough to accurately measure the parameters. All used garden containers had the same volume – 5 L. In the experiment, each variant used 50 pieces of planting material and the planting technology was traditional. For the individual treatments of the experiment a substrate was premixed with an addition of the hydro-absorbent Hydrogel at a rate of 2; 3.5 and 5 grams per cubic meter of the substrate and control variant (Table1). The substrate used was peat mixture RKS II from manufacturer AGRO CS, a. s., Česká Skalice. Chemical and physical characteristics of the substrate: pH 5.5–7.0; N 250–350 mg.1L^{-1}.; P_2O_5 200–250 mg.1L^{-1}.; K_2O 300–400 mg. 1L^{-1}.

The irrigation system was automatic; containers had sensors for measuring the humidity and temperature of the substrate. Temperature for automatic irrigation was installed and set to 25 ^{0}C.

To study the sap flow, the plants were selected, and the micro sensors were installed. The sap flow was measured three times per month for each variant. Work principle of the micro-sensors in trunk gages is that they have four pairs of differential temperature sensors spaced around the circumference of the trunk. This design ensures that flow rates varying around the circumference are accurately monitored and averaged into one reading. Up to 18 radial heat flux sensing thermocouples are also spaced evenly around the circumference to ensure that radial heat is accurately monitored. Micro-sensors were connected to a datalogger AVRD to take readings every 10s, and to store the data to determine the means at intervals of every 10 min.

Table 1. *Variants of the experiment and the application rate of Hydrogel*

Variants	*Application rate (g.m^{-3})*
1	0.0 – control variant
2	2.0
3	3.5
4	5.0

RESULTS

Figure 1 shows differences in sap flow in the trunks of plants at four variants. Accordingly we can observe that in all cases the highest sap flow was in the afternoon, between about 13:00 and 14:00. This may be due to the fact that during this period there was a higher temperature than in the other daytimes (Fig.4) and the humidity was 68% in average (Fig.5). At the same time, there was observed a small stream of sap at the control variant (var.1), where there was not used any hydro absorbent Hydrogel. The results show that the response of the plants obtained by the stem heat balance method varied dynamically from 5 to 15 min (Trejo-Chandia, 1997).

As shown in Figure 2, in this time period as compared with Figure 1, the sap flow was high, and the percentage was about 80%. Unlike variants 1 and 2, in the variants 3 and 4, the increased sap flow can be observed, resulting in more intense release of vapor into the atmosphere. The atmosphere humidity was 68% in average, the temperature was 22 ^{0}C and the substrate humidity in the container was 25%. With global warming, it is likely, that both daytime and nighttime temperatures will be increasing. If the diurnal temperature range remains constant, the global warming will lead to an increase in transpiration because the saturated vapor pressure curve is steeper at higher than at lower temperatures (Kirschbaum, 2004).

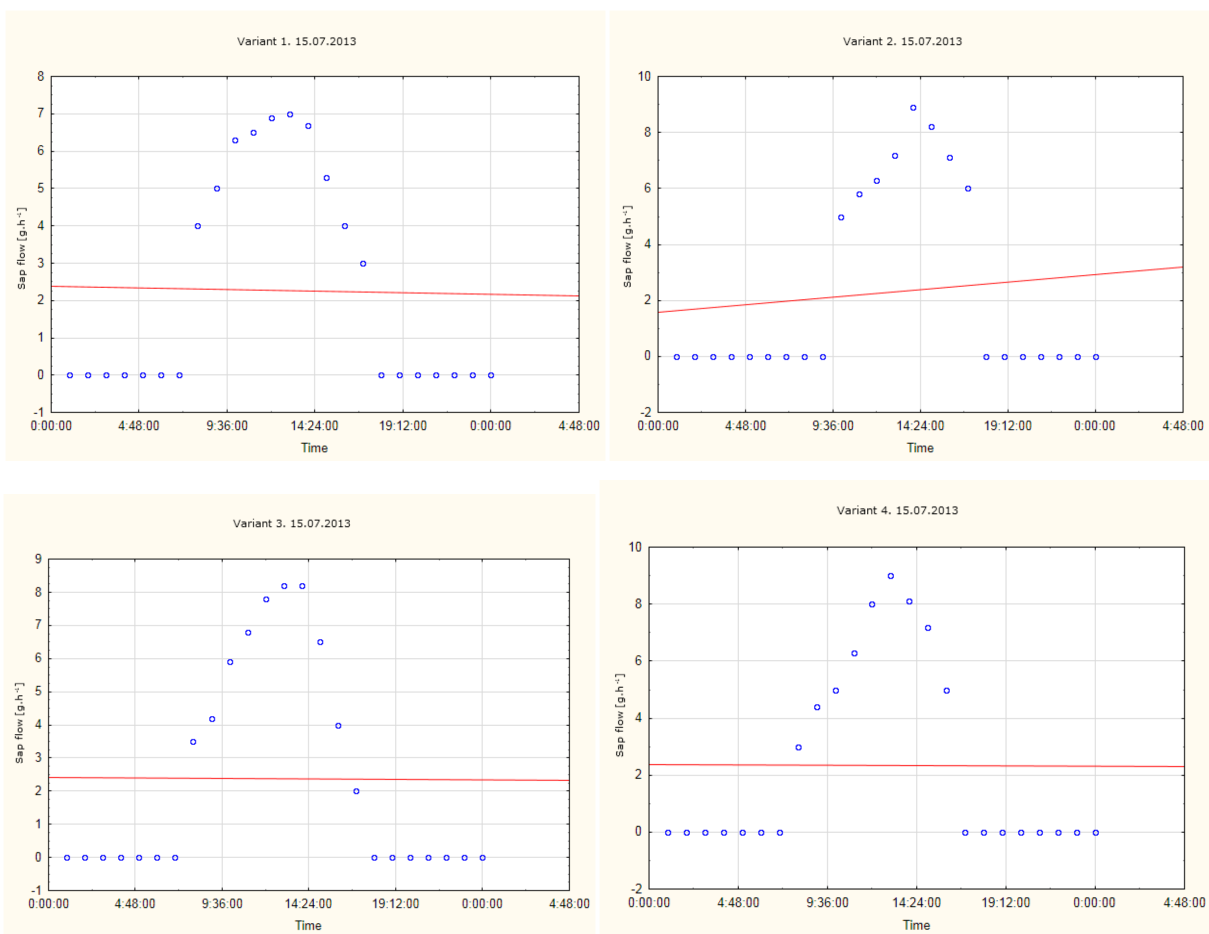


***Fig.1**. Time series of the daily average sap flow density averaged for four variants, 15.07.2013*

Figure 3 shows that at all variants (var.2-4) except the control variant (var.1), the sap flow was substantially the same. Even the definition of the coefficients was identical. This means that for 73% of the cases, the sap flow transpiration rate per hour was about 0.11-0.13. The difference of radial temperature slightly varied during the day due to the cooling of the heater taking place by sap circulation; meaning that when the sap flow increases the difference of radial temperature diminishes (Fig.4). The high stomatal resistance accompanied by low evaporative demands of the wet air caused a strong decrease in transpiration. However, the surface resistance of the moist soil remained low (Fig.5), which created suitable condition for evapotranspiration from soil. In this situation, evapotranspiration from the soil exceeded transpiration. Evapotranspiration and transpiration of different vegetation types are at present well represented in many different SVAT models of different levels of complexity (Čermák and Kučera, 1981).

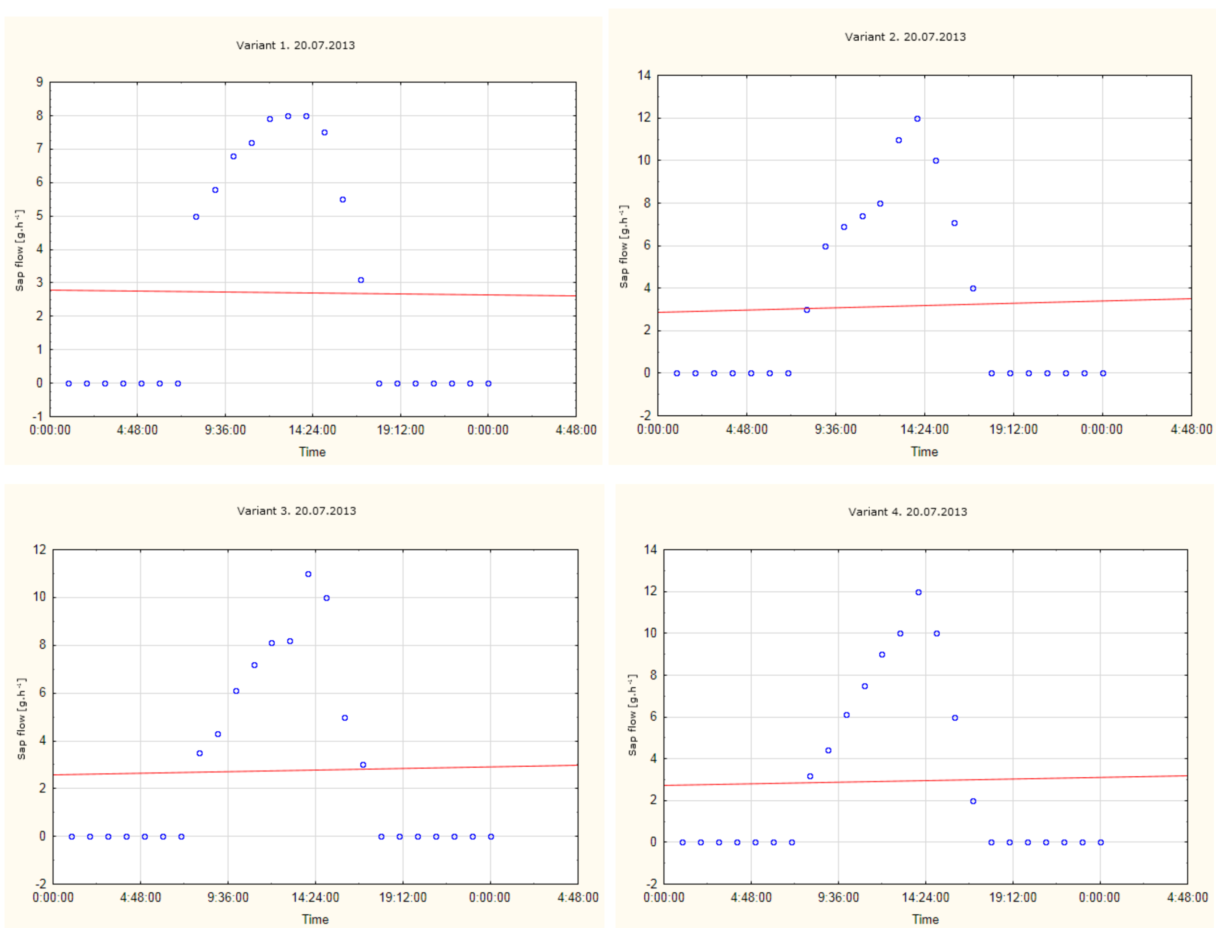


***Fig.2**. Time series of the daily average sap flow density averaged for four variants, 20.07.2013*

DISCUSSION

The experiments show that there is a small difference in sap flow among the variants planted with hydro absorbent and a control variant. As indicated above, the plants planted with Hydrogel performed predominantly high sap flow, which means high transpiration of vapor into the atmosphere. Anyway, other important factors, such as wind, humidity of the substrate, leaf area and plant height, might influence the transpiration besides the hydro absorbent. However, the surface resistance of the moist soil remained low and created suitable conditions for evapotranspiration from the soil. The stem heat balance method appeared to underestimate the values (4.3%) of daily transpiration in plants.

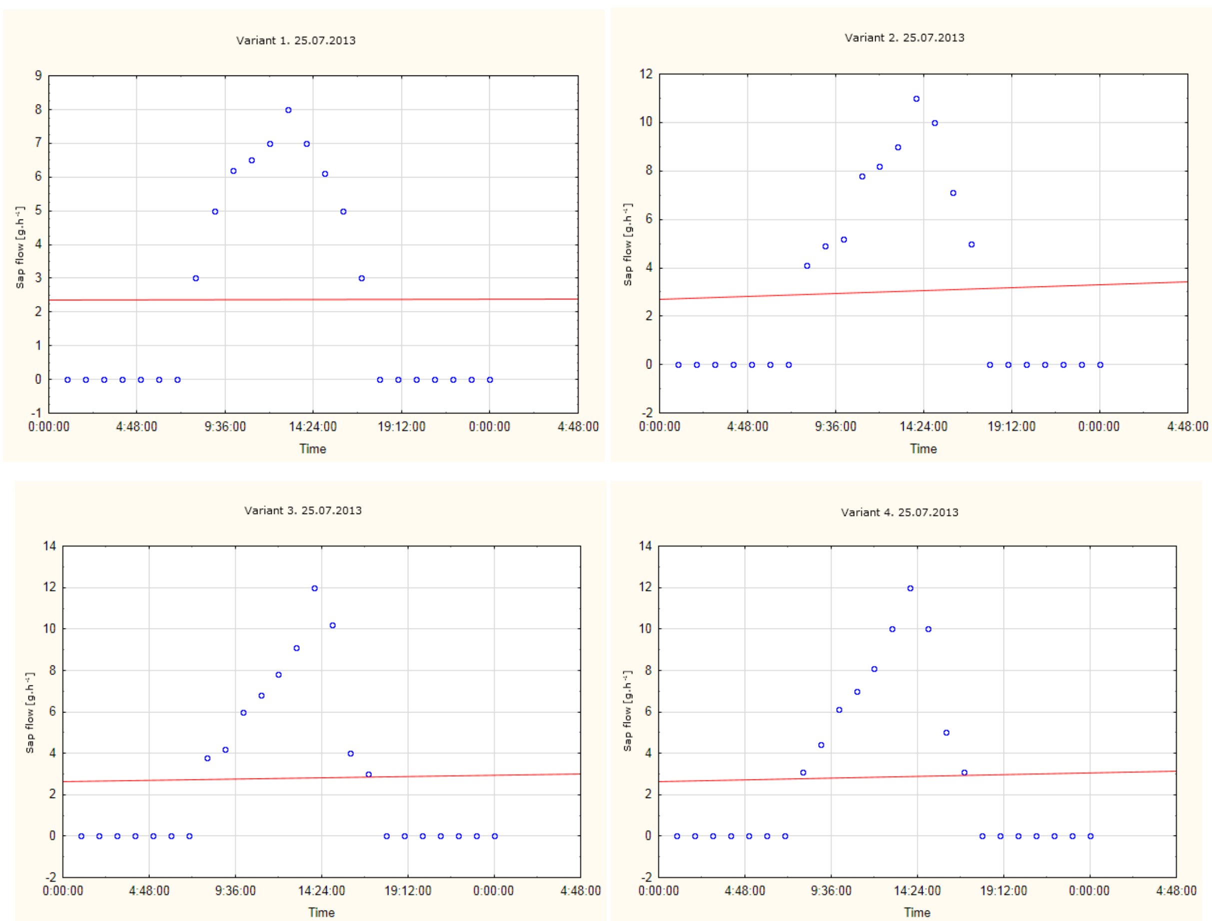


Fig.3. *Time series of the daily average sap flow density averaged for four variants, 25.07.2013*

Conclusions

The hydro absorbent Hydrogel retains a lot of water in addition to the humidity of the substrate and it releases the water for the root system, when the moisture content decreases. This results in constantly high moisture content, which affects the sap flow in the plant. In variants containing high percentage of Hydrogel there was observed a high transpiration rate. It should be noted that in addition to high sap flow and transpiration rate, the morphological parameters of the plants planted with hydro absorbent were much higher than at control variants.

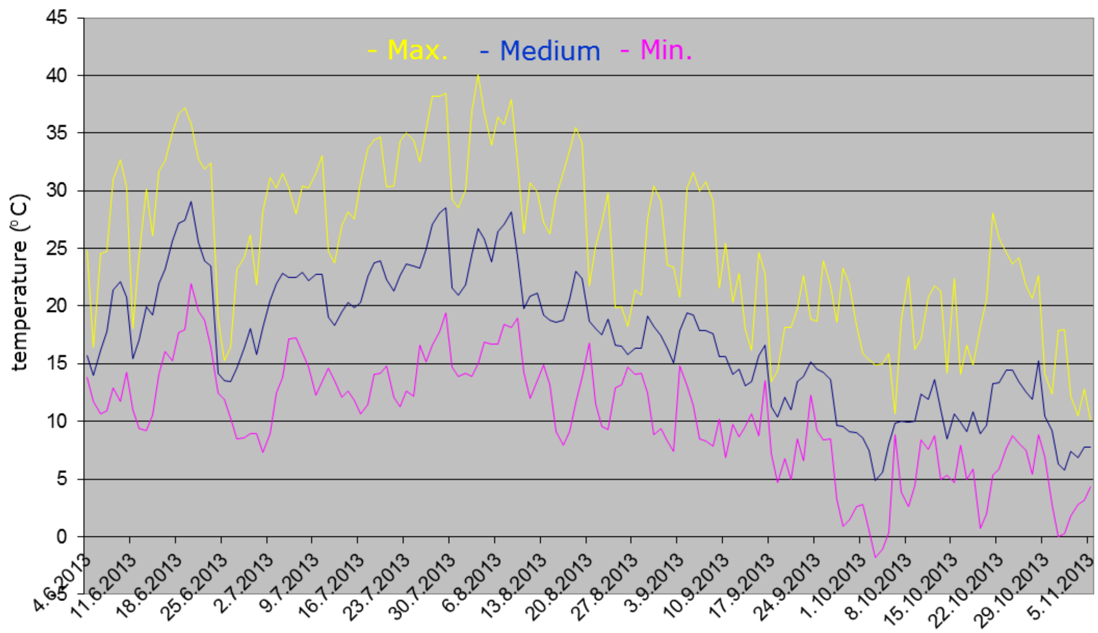


Fig.4. *The average temperature in Lednice, 2013*

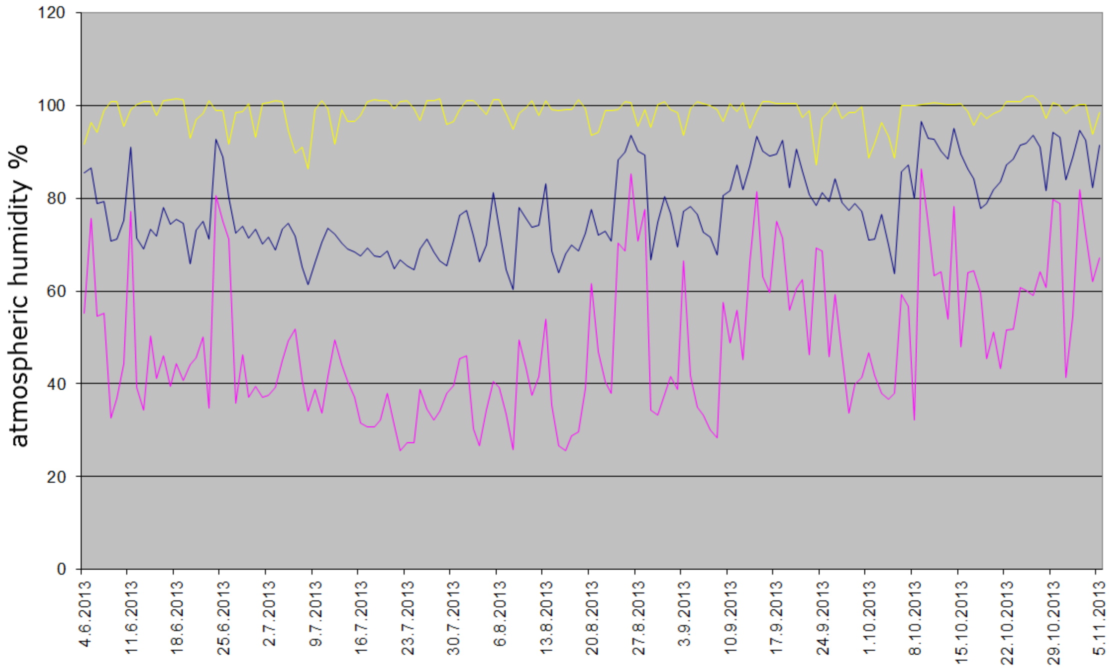


Fig.5. *The atmospheric humidity in Lednice, 2013*

References

Čermák J, Kučera J (1981) The compensation of natural temperature gradient in the measuring point during the sap flow rate determination in trees. Biol. Plant (Praha) 23:469–471.

Salaš, P., Mokričková, J., Litschmann, T., Sasková, H.: Vztah mezi průtokem mízy mladých dřevin a meteorologickými a morfologickými parametry na písčitých půdách. Úroda, vědecká příloha. 2010. sv. 58, č. 12, s. 738–741. ISSN 0139-6013.

Fereres, E., Goldhamer, D.A., Parsons, L.R., 2003. Irrigation water management of Horticultural crops. Hortscience 38 (5), 1036–1042.

Kirschbaum, M.U.F. (2004). Direct and indirect climate-change effects on photosynthesis and transpiration. Plant Biology 6: 242-253.

Naor, A. and S. Cohen. 2003. Sensitivity and variability of maximum trunk shrinkage, midday stem water potential, and transpiration rate in response to withholding irrigation from field grown apple trees. Hortscience. 38(4): 547-551.

Sepulcre-Cantó, G., Zarco-Tejada, P. J., Jiménez-Muñoz, J. C., Sobrino, J. A., de Miguel, E., et al. (2006). Within-field thermal variability detection as function of water stress in Olea Europaea L. orchards with high spatial remote sensing imagery. Agricultural and Forest Meteorology, 136, 31–44.

SUMMARY

Pokus byl založen v Lednici na jaře v roce 2013 na pokusných plochách Zahradnické fakulty Mendelovy univerzity v Brně. Cílem práce bylo zhodnotit vliv aplikace hydroabsorbentu (Hydrogel) a zvolené pěstitelské technologie na morfologické a fyziologické parametry modelových rostlin (*Tilia platyphyllos* L.). Hydrogel byl aplikován ve třech koncentracích: 2 $kg.m^{-3}$, 3.5 $kg.m^{-3}$, 5 $kg.m^{-3}$ pěstebního substrátu, kontrolní varianta byla bez aplikace Hydrogelu. Hydroabsorbent Hydrogel má schopnost absorbovat a uvolňovat vodu a živiny rostlinám a zajišťuje maximální dostupnost vody pro kořeny rostlin v období sucha. U rostlin, které byly pěstovány v substrátu s hydroabsorbentem, byl zjištěn průtok mízy v hodnotě 14 $g.h^{-1}$, zatímco u kontrolní varianty byl zjištěn průtok mízy v hodnotě 12 $g.h^{-1}$. Výsledky ukazují, že Hydrogel neměl vliv na výrazné zvýšení průtoku mízy v rostlinách.

CONTACT

Maksat B. Matraimov, Ph.D.

Mendel University in Brno, Faculty of Horticulture in Lednice, Department of Breeding and Propagation of Horticultural Plants, Valtická 538, 691 44 Lednice, Czech Republic.

maksat.bekboo@gmail.com

FORECAST DANGER OF VEGETATION FIRES IN THE OPEN COUNTRYSIDE IN THE CZECH REPUBLIC

MARTIN MOŽNÝ[1, 2], DANIEL BAREŠ[1]

1) *Czech Hydrometeorological Institute, Doksany Observatory, 41182 Doksany*
2) *Mendel University in Brno, Zemědělská 1, 61300 Brno*

ABSTRACT

Forecast dangers of vegetation fires are used to assess the potential for fire occurrence in the countryside, fire spread and difficulty of fire suppression. Typically, the fire danger forecast systems combine the meteorological information with estimates of the moisture content to produce a simple fire danger index. The Czech Hydrometeorological Institute generates daily maps of 1 to 6 days projected fire danger level in the Czech Republic using weather forecast data. The simple fire danger index *FD* is used for forecasting purposes. Input data are the air temperatures, wind speeds, air humidity and soil moistures. The system is active from 15th of March to 15th of October. Fire danger is mapped in five classes (very low, low, medium, high and very high).

Key words: Forecast; fire danger; fire weather; biometeorology

INTRODUCTION

Chandler et al. (1983) define fire danger as the resultant of some factors that affect the inception, spread and difficulty of control of fires and the damage they cause. These factors include topographic attributes, fuel characteristics and weather variables as well as random factors such as arson. Many of these factors are difficult to quantify numerically.

Simple fire danger indices are used throughout the world. These indices combine information about the current weather and drought. These indices are used, for example, in the United

States, Canada and Australia (Cheney and Sullivan, 1997; Gill et al., 1987; Goodrick, 2002; Van Wagner, 1987).

Within the EU has created the European forest fire information system (EFFIS). This system generates the predictive maps for the whole of Europe using meteorological data from French and German meteorological services (Meteo-France and DWD). For modeling, the risk of forest fires is used the Canadian forest fire weather index (FWI).

Warning against extreme weather conditions is available on the website MeteoAlarm (www.meteoalarm.eu). Information's are provided by the individual national meteorological service for their country. The topic of this paper is a description of the fire danger warnings generate by the Czech Hydrometeorological Institute (CHMI) for territory of Czech Republic.

MATERIALS AND METHODS

Since 2006, the fire danger in the open countryside in the Czech Republic is modeled with the fire danger index *FD* (Možný and Bareš, 2013). FD incorporated the wind speed, soil moisture, air temperature and humidity. The model used equation:

$$FD = (b_1U - b_2F) / (b_3T - b_4H)$$

where T the air temperature in °C, H the air humidity in %, U the wind speed in m/s, F the soil moisture in % of AWC, and b_1, b_2, b_3, b_4 are coefficients to be estimated.

Index *FD* was successfully validated with data on the frequency of fires in the Czech Republic and Germany. The following are the *FD* values used as thresholds of the fire danger classes in the Table 1.

Table 1 *Fire danger classification thresholds for FD*

Fire Danger Classes	***FD* ranges (upper bound excluded)**
Very low	< 0.9
Low	0.9 – 1.7
Moderate	1.7 – 3.0
High	3.0 – 6.0
Very high	≥ 6.0

For analysis were used meteorological data from the database CLIDATA of CHMI and data generated by the system ALADIN. We used in this study the data in the Doksany station (50° 27’ 31” N, 14° 10’ 14” E, 158 m a.s.l.), in the northwestern Czech Republic. This station represents a warm, dry region; during 1961–1990 its average annual air temperature was 8.5 °C and the average annual total precipitation was 456 mm.

RESULTS AND DISCUSSION

To obtain information about changes in fire danger, we analyzed the average daily indices *FD* for the period 2000–2013 at Doksany station. The average daily indices *FD* began to gradually increase immediately after the winter (early March), reaching a peak at the late April and June to August. The daily indices *FD* values declined the late August, and in winter the *FD* stabilized (Fig. 1). Very similar annual course in *FD* values we also recorded on other stations of CHMI.

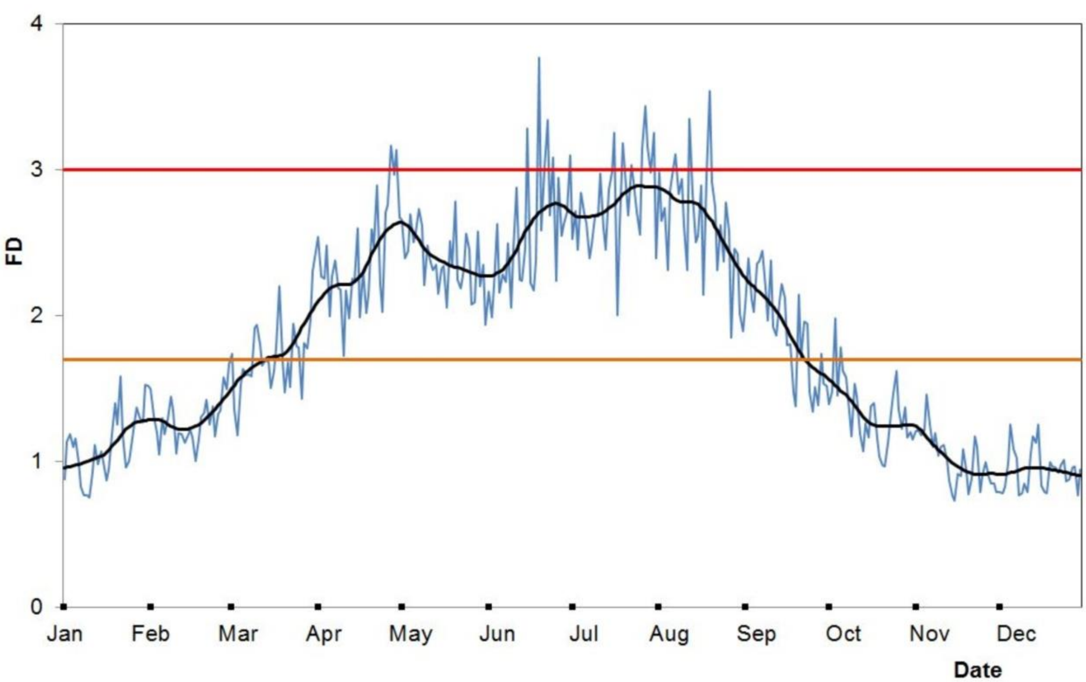


***Fig. 1** Average daily indices FD for the period 2000–2013 at Doksany station.*

Daily indices *FD* ≥ 3 and <6 occurred in the period 2000–2013 quite often. The maximum number of days was recorded at lowland stations. At the Doksany station varied this number of days from 18 (2010) to 97 (2012). Daily indices FD ≥ 6 occurred rarely in the form of individual warm waves of one to several days. At the Doksany station varied this number of days from 0 (2004) to 8 (2012, Fig. 2).

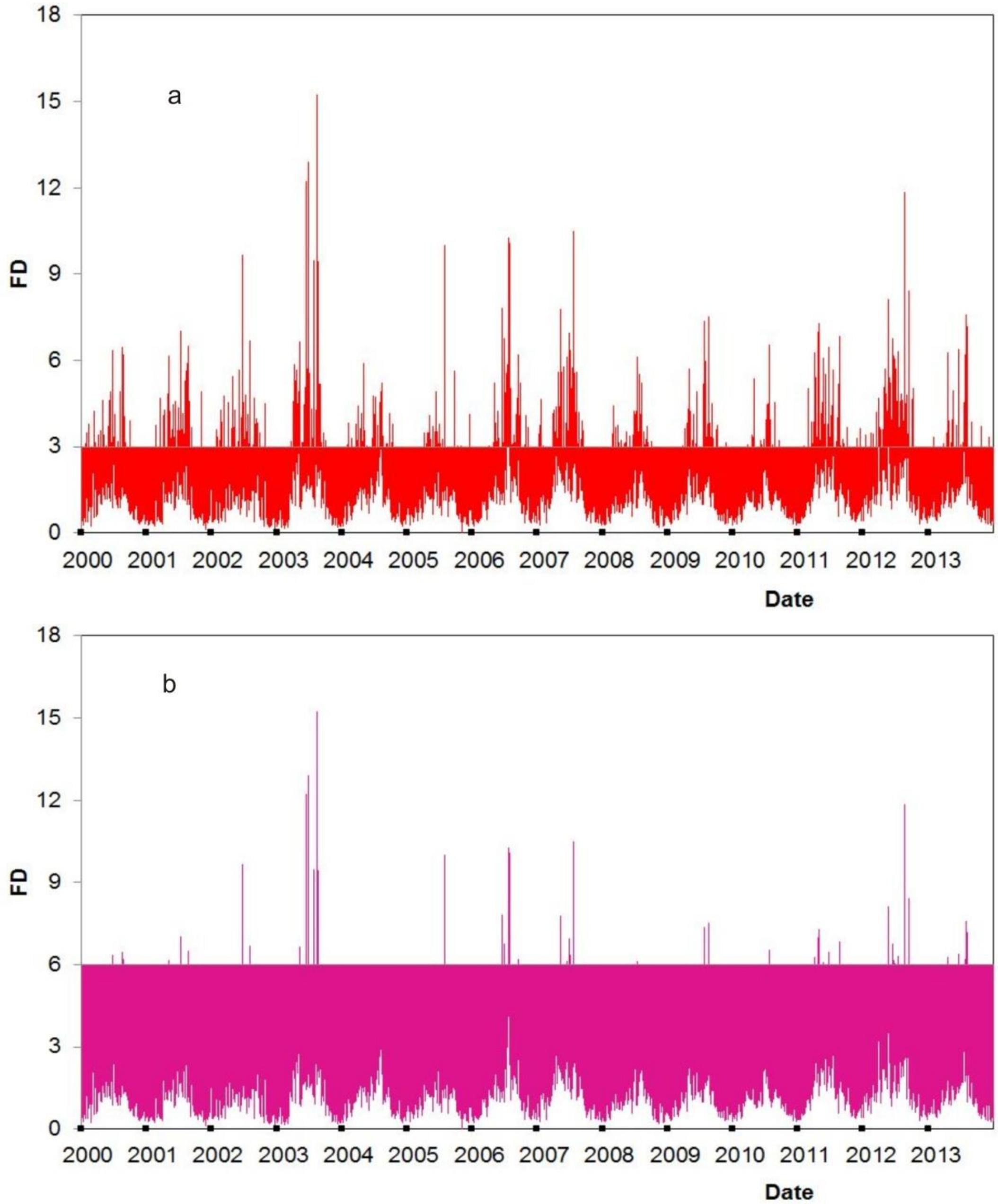


***Fig. 2** Variation of daily indices FD for the period 2000–2013 at Doksany station. Bars indicate deviations from the indices FD ≥ 3 (a) and FD ≥ 6 (b).*

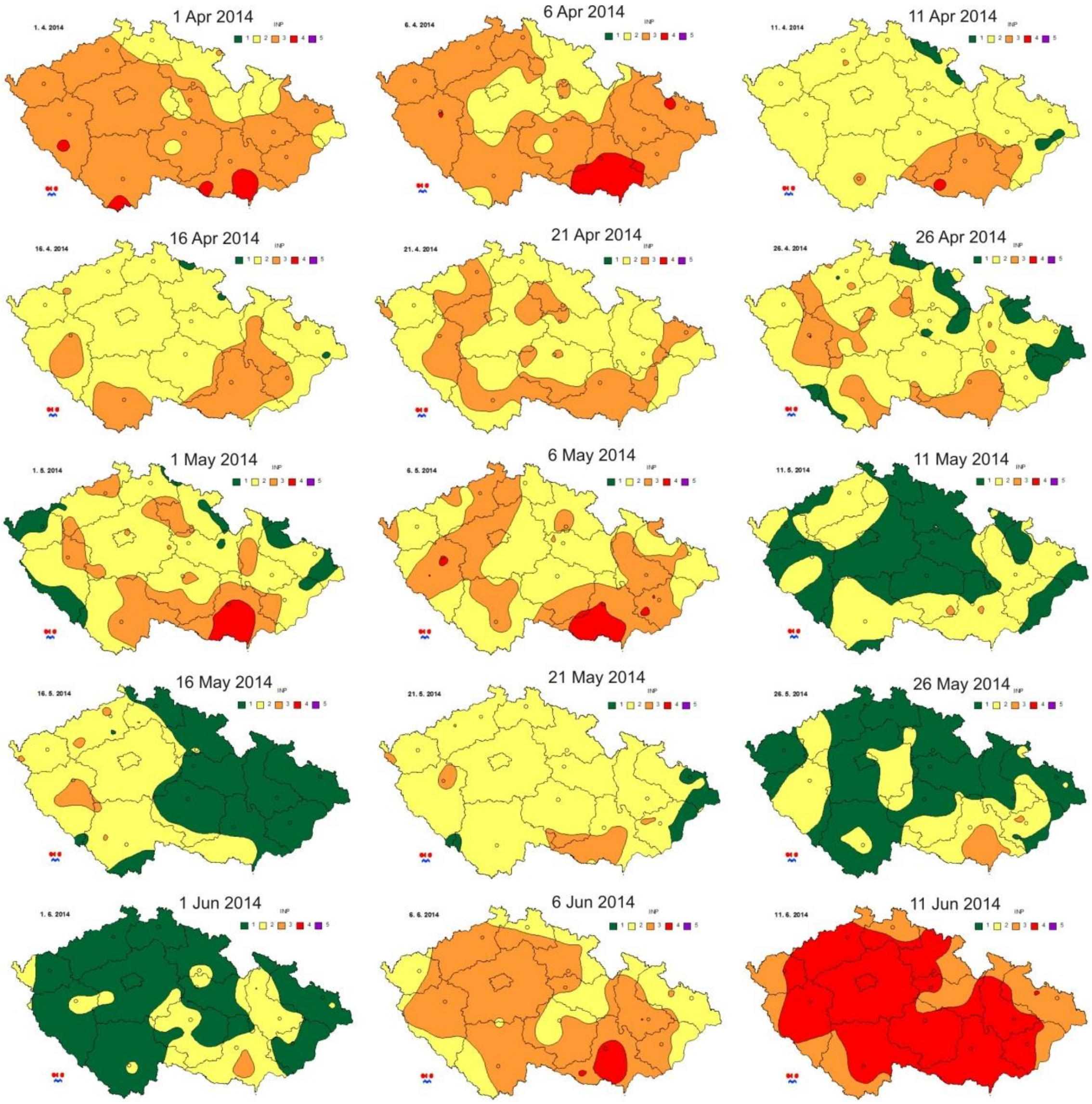


Fig. 3 *Examples of daily maps predicted fire danger level in the Czech Republic. Fire danger is mapped in five classes - very low (green), low (yellow), medium (orange), high (red) and very high (purple).*

We generate daily maps of 1 to 6 days projected fire danger level in the Czech Republic using daily indices *FD*. Maps show a harmonized picture of the spatial distribution of fire danger level throughout the Czech Republic. The system is active from 15th of March to 15th of October (http://www.chmi.cz). Fire danger is mapped in five classes (very low, low, medium, high and very high) defined in Table 1. If it is a forecast that the *FD* will be greater than 3 for the next three days at least half of the regions, we will declare warning of fires.

The largest forest fire in the last 15 years in the Czech Republic was recorded in Bzenec. The fire was reported on 24th May 2012, during the fire burned 160 hectare of forest. The fighting took part in nearly 1,500 firefighters. Figure 4 shows the fluctuations of daily indices *FD* in the period from 20th March to 30th June 2012 in Bzenec. The peak of daily indices FD was reached on 23rd May (FD = 8.1) and 24th May (FD = 6.9).

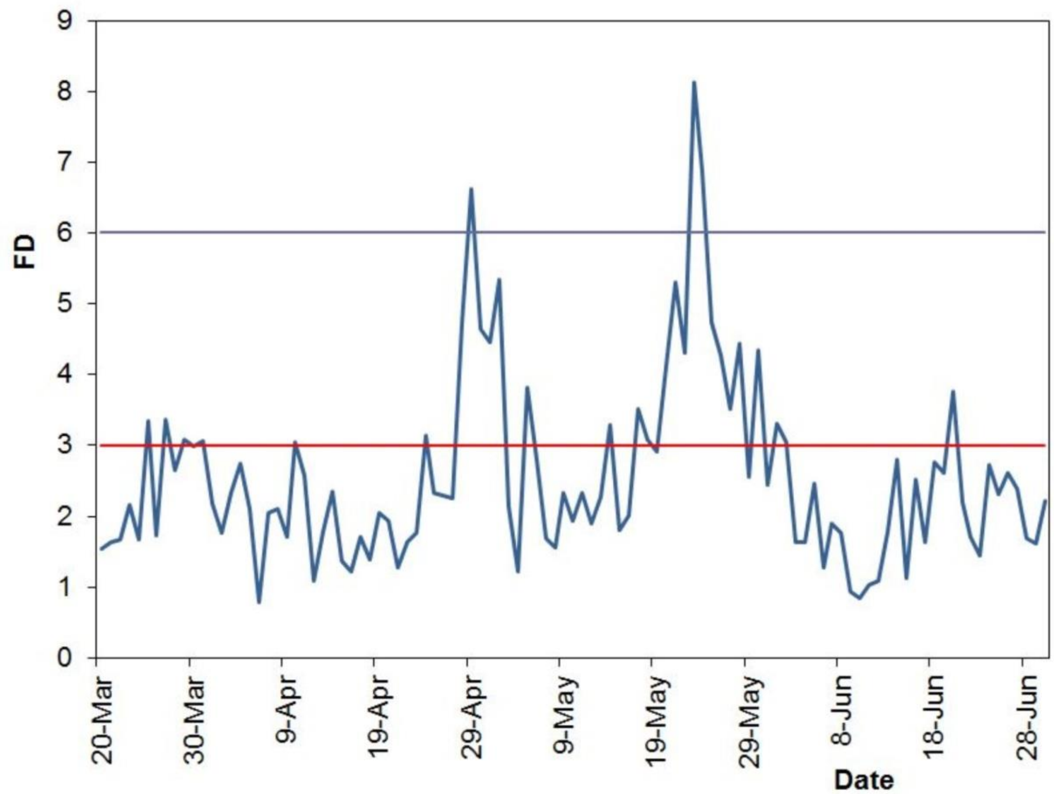


Fig. 4 *Variation of daily indices FD for the period from 20th March to 30th June 2012 in Bzenec.*

In Central Europe the incidence of drought and fire danger as pronounced as in the Mediterranean, but recent studies show the growth rate of these phenomena and that the risk is going to increase dramatically to the future (e.g. Wastl et al., 2012; Venäläinen et al., 2013). Pan-European study (e.g. a project WaterGAP European Commission SEC2007-993) show that Central Europe in the future climatic conditions will have to contend with the increasing water deficit.

CONCLUSION

In this study, we describe the system warning for vegetation fires in the open countryside in the Czech Republic using the index *FD*. A benefit of the proposed simple index *FD* is that it is intuitive and easy to calculate. Every day, we generate maps of 1 to 6 days projected fire danger level in the Czech Republic using the index *FD*. The results are used within the Czech integrated warning service system (http://www.chmi.cz) and the European warning system for extreme weather (http://www.meteoalarm.eu).

REFERENCES

Chandler, C., Cheney, P., Thomas, P., Trabaud, L., Williams, D., 1983. Fire in forestry. In: Forest Fire Behaviour and Effects, Vol. I. John Wiley and Sons, New York.

Cheney, N.P., Sullivan, A., 1997. Grassfires: Fuel, Weather and Fire Behaviour. CSIRO Publishing, Australia.

Wastl, C., Schunk, C., Leuchner, M., Pezzatti, G.B., Menzel, A., 2012. Recent climate change: Long-term trends in meteorological forest fire danger in the Alps. Agricultural and Forest Meteorology, 162–163, 1–13.

Gill, A.M., Christian, K.R., Moore, P.H.R., Forrester, R.I., 1987. Bushfire incidence, fire hazard and fuel reduction burning. Australian Journal of Ecology 12, 299–306.

Goodrick, S.L., 2002. Modification of the Fosberg fire weather index to include drought. International Journal of Wildland Fire 11, 205–211.

Možný, M., Bareš, D., 2013. Czech Fire-Danger Rating System. The Integrated Warning Service System. Czech Hydrometeorological Institute, Praha.

Van Wagner, C.E., 1987. Development and structure of the Canadian forest fire weather index system. Canadian Forestry Service 35 Ottawa, Canada.

Venäläinen, A., Korhonen, N., Koutsias, N., Xystrakis, F., Urbieta, I.R., Moreno, J. M., 2013. Temporal variations and change of forest fire danger in Europe in 1960–2012. Nat. Hazards Earth Syst. Sci. Discuss., 1, 6291–6326.

ACKNOWLEDGEMENT

We gratefully acknowledge the support of the Ministry of Education, Youth and Sports project CZ.1.07/2.3.00/20.0248.

SUMMARY

Předpovědi nebezpečí požárů se používají k varováním před výskytem požárů vegetace ve volné krajině, k posouzení podmínek pro šíření požárů a obtížnosti hašení. Nejčastěji předpovědní systémy požárního nebezpečí využívají jednoduchý index nebezpečí požárů, který kombinuje meteorologické podmínky s odhady vlhkosti půdy. Od roku 2006 využívá Český hydrometeorologický ústav (ČHMÚ) v operativním provozu hodnocení požárního nebezpečí podle indexu FD. Index FD byl úspěšně validován na datech o výskytu požárů v České republice a Německu. Od 15. března do 15. října jsou generovány mapy požárního nebezpečí na 1 až 6 dnů dopředu. Požární nebezpečí je rozděleno do pěti tříd podle velikosti indexu FD. Mapy jsou dostupné na webových stránkách ČHMÚ. Výsledky jsou využívány v rámci Systému integrované výstražné služby ČR a Evropského systému varování před extrémním počasím.

CONTACT

Ing. Martin Možný, Dr.

Czech Hydrometeorological Institute

Doksany Observatory, 41182 Doksany

Phone: 420416861112, e-mail: m.mozny@seznam.cz

ANALYSIS OF THE IMPACT OF METEOROLOGICAL CHARACTERISTICS ON THE TRANSPIRATION SIMULATED IN SIBYLA GROWTH SIMULATOR

LUCIA MACKOVÁ[1], KATARÍNA MERGANIČOVÁ[1], PAULÍNA NALEVANKOVÁ[1], MAREK FABRIKA[1], KATARÍNA STŘELCOVÁ[1], ZUZANA SITKOVÁ[2]

1) *Technická univerzita vo Zvolene, LF, T. G. Masaryka 24, 960 53 Zvolen, Slovakia*
2) *Národné lesnícke centrum – LVÚ Zvolen, T. G. Masaryka 22, 960 92 Zvolen, Slovakia*

ABSTRACT

The research goal was to analyse the impact of meteorological characteristics on transpiration during the growing season of 2013 simulated in SIBYLA growth simulator. The main factors affecting simulated transpiration are global radiation, wind speed, precipitation and air temperature. The analysis of their relationship to the differences between the modelled and measured transpiration showed that the model is able to reflect the impact of precipitation, wind speed, and global radiation on simulated transpiration. The highest correlation was found between the air temperature and the differences of the modelled transpiration to measured values.

Keywords: growth simulator, SIBYLA, transpiration, meteorological characteristics, correlation

INTRODUCTION

Growth models represent important tools that can improve our understanding of growth processes because they attempt to mathematically describe and quantify the system and its behaviour. Hence, they are simplified, purpose-oriented representations of reality. Models are developed on the base of existing knowledge and information about the examined system gathered so far, and their aim is to verify the accuracy of the known facts, to perform the predictions, or to confirm the forecasts (Fabrika and Pretzsch 2011). In Slovakia, the development of SIBYLA forest growth simulator began in 2002. The simulator belongs to semi-empirical individual tree growth simulators of forest ecosystems. Since at present process-based models undergo the most dynamic development, currently the process-based downscale of the model is under the development (Fabrika and Macková 2013). Unlike empirical models that are based on statistical description of the relationships between specific parameters, process-based models try to predict the final growth by describing the background processes driven by external conditions and interactions between the processes (Landsberg 2003). To be able to describe physiological processes in plants, a number of different algorithms need to be defined including absorption of solar radiation, pedotransfer functions, hydrological balance, stomatal conductance, transpiration, leaf energy balance, photosynthesis, respiration, etc. A major advantage of process-based models over empirical ones is their more general validity (Fabrika and Pretzsch 2011). Hence, using of process-based models should lead towards more precise results (Zeide 2003). However, so far not all of the processes are sufficiently understood and have been mathematically described. Therefore, the best solution seems to be the continual transition from empirical through hybrid to process-based models (Mäkelä *et al.* 2000).

The research goal of the presented paper was to analyse the impact of meteorological characteristics on transpiration during the growing season of 2013 simulated in SIBYLA growth simulator. Transpiration as a productive evaporation is the most important physiological process affecting tree growth. Climatic conditions are considered crucial external factors influencing transpiration. Thus, in the presented work we aimed at analysing the impact of meteorological conditions on transpiration simulated in SIBYLA growth simulator.

MATERIAL AND METHODS

The data were obtained from the research plot situated in Bienska valley, forest stand No. 359. The area of the research plot is 80 x 92 m. All trees within the research plot were measured; calliper was used to measure their diameter and Vertex was used to measure their crown height and height to crown base. Field – Map technology was used to measure the position of the trees and their crown projection.

On these six trees we also measured transpiration flow using EMS51A system connected to 16-channel datalogger RailBox V16.

Meteorological data were measured using EMS automatic meteorological station. Air temperature, relative air humidity, and global radiation were recorded at 5 minutes intervals. Precipitation was recorded continuously at 1 m above ground. Wind speed data were obtained from MetOne 034B anemometer installed at the plot.

In addition, from soil probes situated within the plot we took the data about soil volumetric water content, soil depth, and soil structure needed for the calculation of pedotransfer functions. Soil moisture was measured in three depths (15, 30, and 50 cm) and the data were stored at 60 minutes intervals.

A more detailed description of the equipment and the measurement methodology is given in Sitková *et al*. (2014).

The data about the individual trees comprising tree diameter, height, crown projection, and tree position were processed and uploaded in SIBYLA growth simulator. In the module called Physiologist, we simulated hourly values of transpiration during the growing season using the hourly data about global radiation under crown canopy, air temperature, air humidity, precipitation, wind speed and volumetric soil water content following the methods described in Macková (2014). For the simulations we also used the information about soil characteristics, elevation, phenological curve (the beginning and the end of the photosynthetic activity, and the beginning and the end of the full photosynthetic activity).

This paper focuses on the regression analysis between the climatic conditions and the differences of the modelled to measured transpiration values. From six trees we chose two trees (tree 4 and 6), for which the simulated transpiration best reflected the impact of the selected meteorological characteristics: global radiation (GR), wind speed (WS), precipitation (P), and air temperature (AT).

RESULTS AND DISCUSSION

Linear regressions between the differences of the modelled transpiration to measured transpiration flow and climatic characteristics, i.e. global radiation, wind speed, precipitation, and air temperature, are shown in Fig. 1. The blue line represents an ideal state when the modelled and the measured transpiration are equal. The red line is the calculated linear regression between the transpiration differences and the particular climatic characteristic.

From Fig.1 it is clear that the modelled transpiration is overestimated if the values of global radiation, wind speed and air temperatures are small, and when they increase above a certain value the model begins to underestimate transpiration. In case of precipitation we see that the slight and nonsignificant underestimation of transpiration (Table 1) decreases as the amount of precipitation increases. The results of the analyses showed that the correlations between precipitation and the differences of the modellled to measured transpiration were lower in comparison to other climatic characteristics (Table 1). This indicates that the model is able to reflect the effect of precipitation on transpiration. Precipitation significantly affects transpiration, because it influences soil water content as proven by a number of papers, e.g. Bosch *et al.* (2014), Ford *et al.* (2008), Nasr and Mechlia (2007), Čermák and Prax (2001). Clausnitzer *et al.* (2011) found out that the fluctuation of transpiration depends more on the number of rainy days than precipitation totals.

From the results in Tab. 1 we can see that the model of transpiration is able to reflect the impact of precipitation best (R = 0.004 and 0.012 for tree No. 4 and 6, respectively), followed by wind speed (R^2 = 0.092 and 0.191) and global radiation (R^2 = 0.140 and 0.142). The impact of temperature on transpiration seems to be least reflected in the model because the differences between the modelled and measured transpiration are significantly correlated with air temperature (R^2 = 0.365 and 0.411). The importance to include wind speed and wind direction in the transpiration model was proven by Dekker *et al*. (2001), who showed that the results of the transpiration model significantly improved after wind speed and wind direction were incorporated in the model.

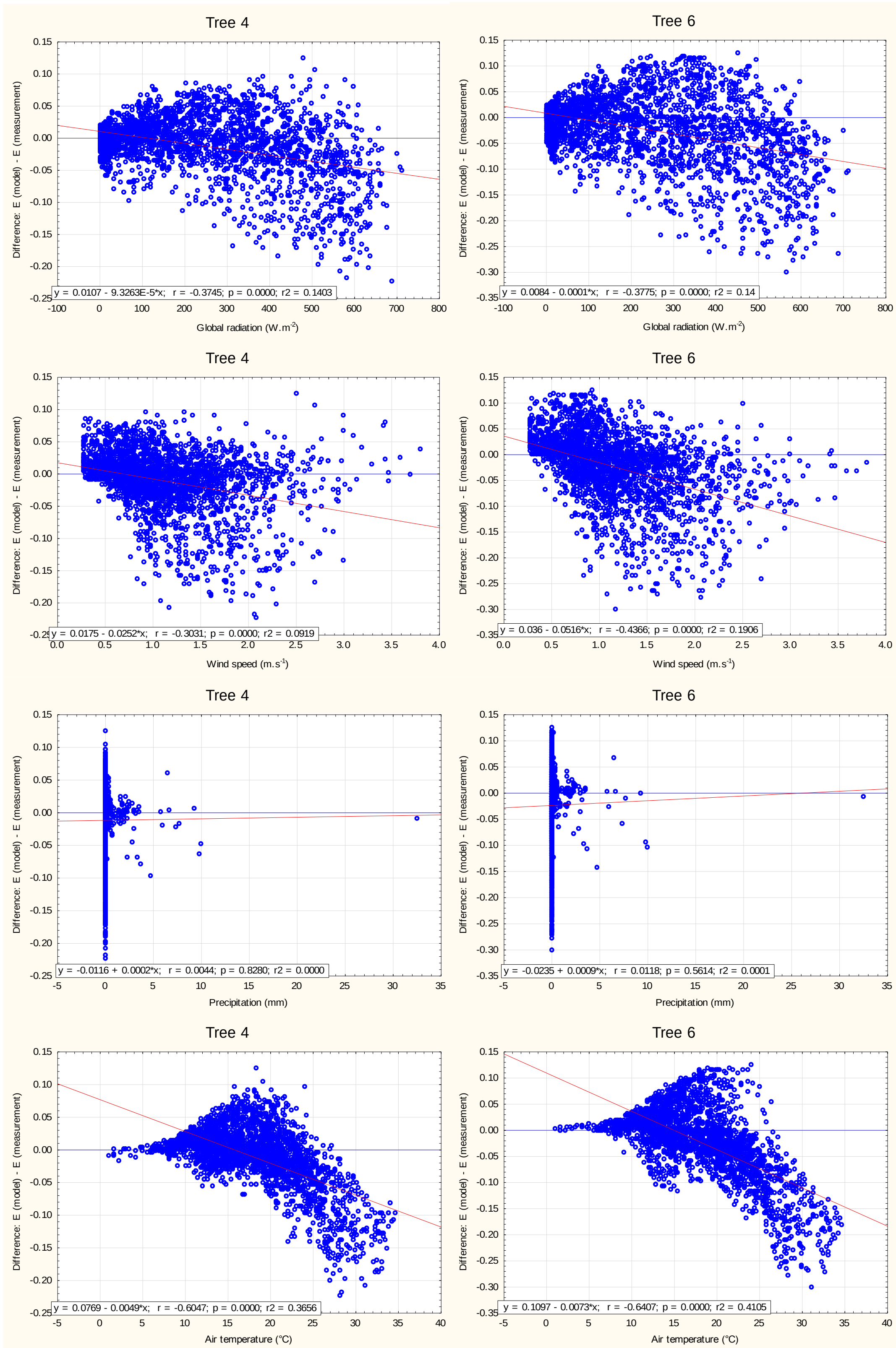


***Fig. 1** Linear regression between the differences of modelled transpiration to measured values and climatic characteristics*

Tab. 1 *Statistical evaluation of linear regression between the climatic characteristics and the differences of modelled transpiration to measured transpiration flow*

Climatic characteristic	**Tree No.**	**R**	**R^2**	**Standard error of estimates**	**F**	**p**	**Significance level ** 99%**
GR	**4**	-0.375	0.140	0.044	396.121	0.000	**
GR	**6**	-0.378	0.143	0.062	403.615	0.000	**
WS	**4**	-0.303	0.092	0.045	245.631	0.000	**
WS	**6**	-0.437	0.191	0.061	571.897	0.000	**
P	**4**	0.004	0.000	0.048	0.047	0.828	
P	**6**	0.012	0.000	0.067	0.337	0.561	
AT	**4**	-0.605	0.366	0.038	1399.404	0.000	**
AT	**6**	-0.641	0.411	0.052	1690.725	0.000	**

CONCLUSION

The assessment of the impact of climatic characteristics incorporated in the transpiration model on the simulated transpiration showed that the model can best reflect the influence of precipitation followed by wind speed and global radiation. The highest correlation was found between air temperature and the differences of modelled transpiration to measured transpiration flow indicating that the impact of temperature on transpiration is not sufficiently addressed in the model. The causes behind this result need to be thoroughly examined in the future. Nevertheless, the results showed that the model is able to elastically react on the changes of climatic conditions that are correctly transformed into modelled transpiration.

REFERENCES

Bosch, D. D., Marshall, L. K., Teskey, R. 2014: Forest transpiration from sap flux density measurements in a Southeastern Coastal Plain riparian buffer system. Agricultural and Forest Meteorology, Volume 187, s. 72–82

Clausnitzer, F., Köstner, B., Schwärzel, B., Bernhofer, Ch. 2011: Relationships between canopy transpiration, atmospheric conditions and soil water availability-Analyses of long-term sap-flow measurements in an old Norway spruce forest at the Ore Mountains/Germany, Agricultural and Forest Meteorology, Volume 151, Issue 8, s. 1023–1034

Čermak, J. and Prax, A. 2001: Water balance of a southern Moravian floodplain forest under natural and modified sol water regimes and its ecological consequences, Annals of Forest Science, 58 (1) (2001), s. 15-29

Dekker, S., C., Bouten, W., Schaap, M. G. 2001: Analysing forest transpiration model errors with artificial neural network, Journal of Hydrology, Volume 246, Issues 1–4, 1 June 2001, s. 197-208

Ford, C. R., Mitchell, R. J., Teskey, R. O. 2008: Water table depth affects productivity, water use, and the response to nitrogen addition in a savanna systém, Canadian Journal of Forest Research, s. 2118-2127

Macková, L. 2014: Metódy procesného modelovania lesa pre zvyšovanie detailu simulácií rastu lesných ekosystémov: dizertačná práca. Zvolen. Technická univerzita vo Zvolene. Lesnícka fakulta. 2014 s.148 2 prílohy

Nasr, X. and Mechlia N. B. 2007: Measurements of sap flow for apple trees in relation to climatic and watering conditions, Mediterranean Options, s. 91-98

Sitková, Z., Nalevanková, P., Střelcová, K., Fleischer, P. Jr., Ježík, M., Sitko, R., Pavlenda, P., Hlásny, T. 2014: How does soil water potential limit the seasonal dynamics of sap flow and circumference changes in European beech? Lesnícky časopis – Forestry Journal, 60(1): s. 15-27

Fabrika, M. and Pretzsch, H. 2011: Analýza a modelovanie lesných ekosystémov. Technická Univerzita vo Zvolene, Zvolen 2011, s. 15 – 599

Fabrika, M. and Macková, L. 2013: Process-based downscale of simulations by empirical model SIBYLA to increase time and space resolution. In Deutscher Verband Forstlicher Forschungsanstalten : Sektion Ertragskunde : Jahrestagung 13.-15.05.2013 Rychnov nad Kneznou in Tschechien / hrsg. Ulrich Kohnle, Joachim Klädtke. - Freiburg im Breisgau : Joachim Klädtke, s. 134-145

Landsberg, J. 2003: Physilogy in forest models: History and the future, FBMIS Volume 1, 2003, 49-63

Mäkelä, A., Landsberg, J.J., Ek, A.E., Burk, T.E., Ter-Mikaelian, M., Ågren, G., Oliver, C.D., Puttonen, P. (2000): Process-based models for forest ecosystem management: current state-of-art and challenges for practical implementation. 2000, Tree Physiology 20: s. 289-298.

Zeide, B. 2003: The U-approach to forest modeling, Canadian Journal of Forest Research; March 2003; 33, 3; 480-489

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency on the base of the contracts No. APVV-0111-10, APVV-0480-12, APVV-0423-10, APVV-0330-11 and VEGA 1/0618/12: Modelling of forest growth processes at high resolution level.

SUMMARY

Príspevok sa zaoberá hodnotením vplyvu vybraných meteorologických charakteristík na transpiračný prúd buka lesného (*Fagus sylvatica* L.) počas vegetačnej sezóny roku 2013. Analýza bola vykonaná v prostredí rastového simulátora SIBYLA. Transpiračný prúd dospelých jedincov buka bol na výskumnej ploche meraný pomocou metódy tepelnej bilancie, zariadením EMS51A. Medzi najdôležitejšie vonkajšie faktory, ktoré ovplyvňujú transpiráciu patria globálna radiácia, rýchlosť vetra, zrážky a teplota vzduchu. Pri posudzovaní vplyvu týchto faktorov na diferencie hodnôt modelovej a meranej transpirácie sme zistili, že model pri simulovaní transpirácie najlepšie odráža vplyv zrážok, rýchlosti vetra a globálnej radiácie. Najmenšia závislosť bola zistená medzi diferenciami odchýlok modelu transpirácie od reality a teplotou vzduchu.

CONTACT

Ing. Macková Lucia

Technická univerzita vo Zvolene, LF

T. G. Masaryka 24

960 53 Zvolen, Slovenská republika

+421 455 206 309

lucia.mackova@tuzvo.sk

USING OF LONG-TERM PHENOLOGICAL OBSERVATIONS OF SHMI AND NFC FOR VALIDATION OF REGIONAL PHENOLOGY MODEL FOR EUROPEAN BEECH

HANA PAVLENDOVÁ[1], ZORA SNOPKOVÁ[2], TIBOR PRIWITZER[1], TOMÁŠ BUCHA [1]

1) *National Forest Centre, T. G. Masaryka 22, 96092 Zvolen, Slovakia*
2) *Slovak Hydrometeorological Institute, Zelená 5, 94701 Banská Bystrica, Slovakia*

ABSTRACT

This study describes the methods and results of the validation of Regional Phenology Model based on NDVI (Normalized Difference Vegetation Index) from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images for European beech (Fagus sylvatica L.). The time series of phenological observation of regional phenological observation sites of SHMI (Slovak Hydrometeorological Institute) for years from 2000 to 2009 and permanent monitoring plots of NFC (National Forest Centre) for 2002 – 2009 was used to validate the date of start of five main spring and autumn phenological events.

The most accurately were derived the phenological events the first leaves, full leafing and the beginning of colouring of leaves. The resulting duration of full foliage was derived with an average error of ± 4.2 days (r = 0.84). Date of onset of phenophases bud break and full colouring of leaves, determining the duration of the entire growing season, were derived with a systematic negative (budbreak), respectively. positive error (full colouring) which increases with increasing altitude. It resulted in an overestimate of the duration of the growing season by an average of 26 days. Possible causes of the differences in the timing of the individual phenophases and their duration are discussed in this paper.

Key words: Regional Phenology Model, MODIS, NDVI, European beech

INTRODUCTION

Phenology examines the timing of important, periodically repeated phases of living plants, so-called phenological phases that depend on the complex environmental conditions, particularly the weather and climate. Phenology as a science is not limited to description and dating of phenological events, but it also study and explain the effects caused by these phenomena (Larcher 1988).

After bud break there is going out a rapid growht of assimilation apparatus of trees. This phenophase is called leaf unfolding. Period of photosynthetic activity of leaves is finished during the next event, which is the colouring of leaves. As the final phase of phenological calendar we can designate the leaf fall.

Phenological observations are also relevant in terms of determining the total length of the growing season of forest trees. After the compleat development of foliage the important period begin; the mature leaves have maximal photosynthetic activity. The duration of phenophase called full foliage, along with other factors, is crucial for the overall production of plants (Hicks and Chabot 1985). The duration of the period of full foliage is important not only in terms of overall growth and production of forest trees, but can affect also the quantity and quality of throughfall precipitation. The duration of vegetation season from bud break to leaf fall for the broadleaved species birch, beech and oak ranges between 5.5 to 6 months (Chalupa 1969).

Satellites based detection of biophysical and structural characteristics of forest stands allows to improve knowledge of the response of forest ecosystems to changing environmental conditions. Launch of satellites Terra and Aqua (NASA Earth Observation Satellites System) with spectroradiometer MODIS (Moderate Resolution Imaging Spectroradiometer) opened up new possibilities for continuous and global monitoring characteristics of forest ecosystems, such as: the normalized vegetation index (NDVI), leaf index (LAI) and the share photosynthetically active radiation absorbed by vegetation (FPAR). The above characteristics are important identifiers of health and ecological conditions of the forest, and are used as inputs to the phenological models (Zhang et al., 2003). Regional Phenological Model is based on evidence that there is a close relationship between the ecophysiological measurements (NDVI, LAI, FPAR) in forest stands and reflectance, measured by satellite sensors (Shabanov 2003 Gobron et al., 2005).

Results from terrestrial measurements are used for validation and parameterisation of outputs of remote sensing data (Cohen et al., 2003).

The aim of this study was to describe the methods and results of the validation of Regional Phenology Model based on NDVI (Normalized Difference Vegetation Index) from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images for European beech (Fagus sylvatica L.). The time series of phenological observation of regional phenological observation sites of Slovak Hydrometeorological Institute for years from 2000 to 2009 and permanent monitoring plots of National Forest Centre for 2002 – 2009 was used to validate the date of start of five main spring and autumn phenological events.

MATERIALS AND METHODS

Construction of phenology model

The modeling phenological development of forests means the prediction of the main phenological events. The annual development of vegetation index was analyzed using the sigmoidal logistic curve (Fisher 2007).

$$v(t) = v_{\min} + v_{amp}\left(\frac{1}{1+e^{m_1+m_2 t}} - \frac{1}{1+e^{m_3+m_4 t}}\right) \qquad [1]$$

Parameters v_{min} and v_{amp} correspond to the minimum value of the vegetation index (NDVI) and amplitude; parameters $m_{1,2,3,4}$ control the shape and slope of the growth (spring) and descending (autumn) phase. Phenological curve was used to derive the date of start of key phenological events. These were derived from the curve by calculating the derivatives of the function and its curvature.

Phenological observations of permanent monitoring plots and spatial transects were used to verify the hypothesis that the extreme values of rate of change of curvature (a local minimum and maximum) are related to the onset of selected phenological event.

Phenological observations

Phenological observations were carried out at 24 regional phenological monitoring stations of SHMI with occurrence of beech and three permanent monitoring plots of NLC (in the following text mentioned as the phenological stations).

Phenophases of broadleaved trees were evaluated according to the scale of the manual for phenological observations of European monitoring system (Preuhsler 1999) and the scale developed by the Slovak Hydrometeorological Institute (Braslavská and Kamenský 1996).

The onset of phenological event is considered as the day when more than 50% of the assessed trees achieved given event. The duration of phenophase was determined by the number of days between the onset of two successive phenological events. Observations were made individually, using binoculars. At each monitoring plot was rated 10 level subjects.

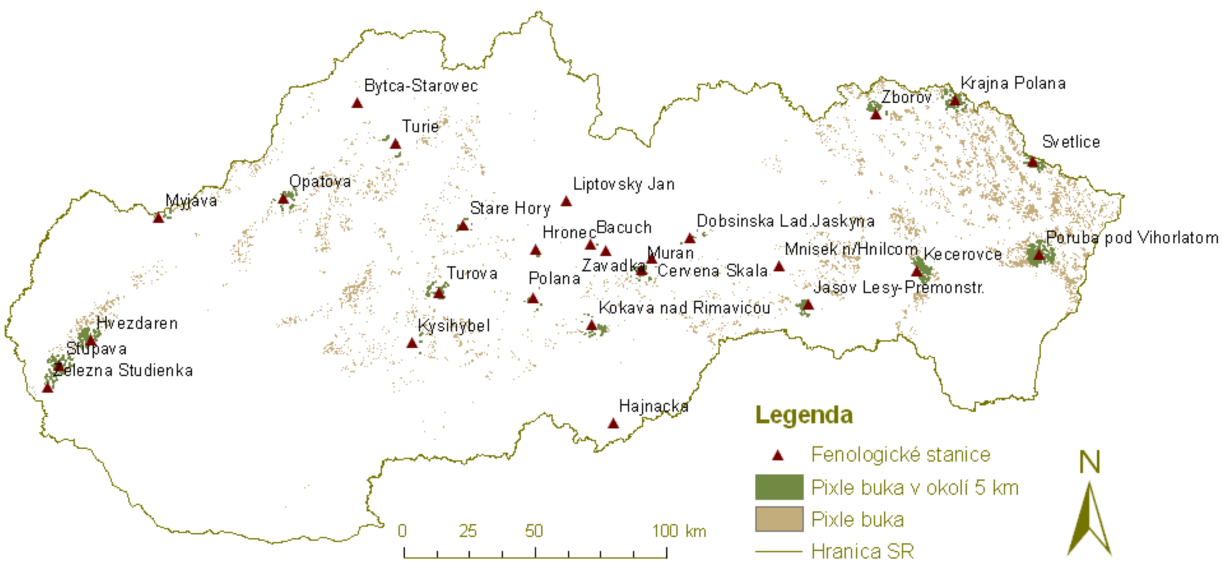


Figure 1 *The spatial distribution of phenological stations and analyzed forest stands with dominant contribution of beech for whole territory of Slovakia and in the vicinity of phenological stations*

Study area and data source

Phenological curve was calculated for beech stands in Slovakia. Pixels of beech (Fig. 1) were selected by combination of two methods - classification of tree species composition from satellite images (Bucha et al. 1999) and the selection according to data of the distribution of beech forest stands in the description JPRL (unit spatial distribution of forest). The boundary pixels and pixels with representation of beech less than 40% were excluded.

The pixels classified as beech within 5 km radius from each phenological stations were selected for analysis. For validation of RFM (Regional Phenology Model) we used the long-term observation of 24 phenological stations of SHMI, 2 permanent monitoring plots of NLC and 3 transects with the occurrence of beech (only for the years 2009-2010). For each selected group of pixels was detected mean altitude and mean values of the onset of assessed phenological events, derived using phenological curve for each year in the period 2000 - 2009 (in the case of permanent monitoring plots NLC period from 2002 to 2009).

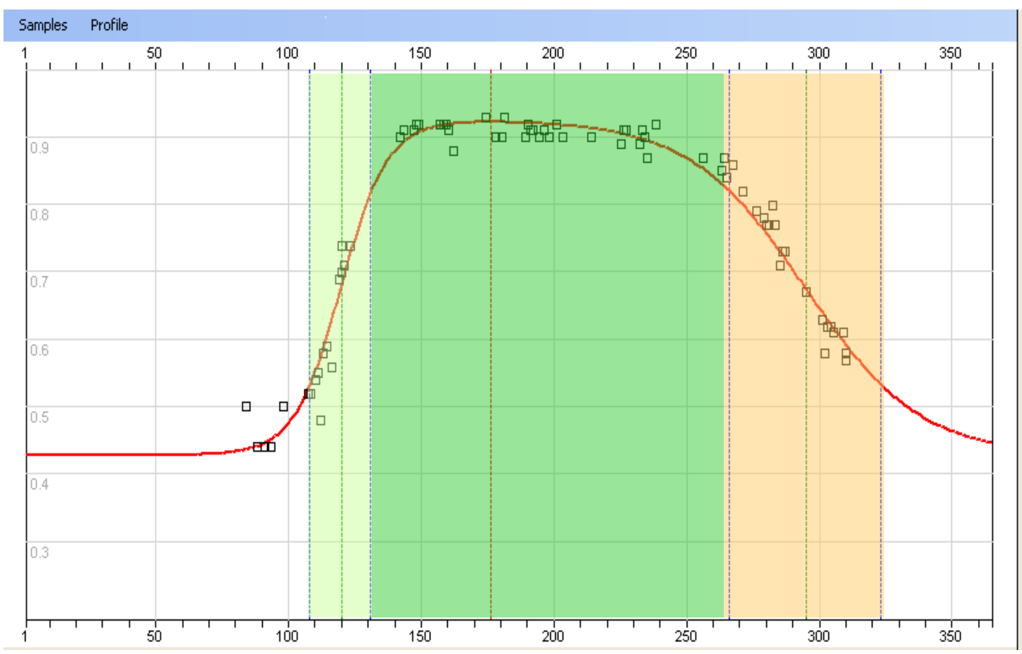


Figure 2 *Logistic sigmoidal function with associated days of phenological events that determined phenological phases i) leaf unfolding (light green), ii) full foliage (dark green), iii) colouring and fall of leaves (orange)*

Results and discussion

Annual course of NDVI for all pixels classified as beech in the period 2000 - 2010 was modeled using a sigmoidal function in the software Phenological Profile ©. This software allows you to calculate extremes in spring and autumn phenological phases, as well as to determine the days when these extremes occur (1st and 2nd derivative). From extreme value interpolation function and their associated date were determined three basic functions of phenological phases: i) leaf unfolding (spring phase, growth period), ii) full foliage (summer phase) and iii) colouring and leaf fall (autumn phase, declination period) (Fig. 2).

Based on long-term phenological observations at permanent monitoring sites NLC and the newly established spatial transect the extreme values of interpolation functions (and the day when they occured) was associated with the onset of each phenological event (Fig. 2):

a) bud break (the beginning of the acceleration in the growth period)
b) the first leaves (maximum acceleration in the growth period)
c) full leafing (the beginning of the decline in the growth period)
d) beginning of colouring of leaves (start of acceleration in the decline period)
e) full colouring of leaves (maximum acceleration in the decline period)

The timing of individual phenophases subject to considerable interannual variation. It is influenced by the meteorological conditions during the current year (air and soil temperature, the occurrence of late frost, moisture availability, etc..).

Between the date of onset of the individual phenological events and altitude there is moderate non-linear relationship. The onset of spring phenophases delays with increasing altitude, the onset of autumn phenophases decreases with altitude, except of the sites with low altitude where the dry conditions at the end of vegetation season probably cause premature yellowing. The length of the growing season of European beech decreases with altitude.

Validation of regional phenology model

Data derived from regional phenology model (RFM) were validated using data from long-term observations on the permanent monitoring plots and regional phenological stations. For validation, we used data obtained from multiple projects and programs of Slovak

Hydrometeorological Institute and National Forestry Centre (Climatological Service of SHMI, ICP Forests, Forest Focus, FutMon).

For each pixels group within the 5 km radius from each phenological station, the median of the date of onset of five phenological events was calculated (derived from NDVI curve). We excluded stations without any pixel classified as beech in vicinity (Hajnáčka, Liptovský Ján, Bytča). Using higher number of pixels around each phenological station can eliminate the high spatial variability at the onset of each phenological phases in a relatively small area, which could have a negative impact on the comparison of data from ground-based observations and data derived from regional phenological model and consequential interpretation of results (Fischer et al. 2006).

Basic set (all pixels classified as beech) and the sample set (pixels within a radius of 5 km from the phenological stations) have normal distribution of frequencies according to altitude. Based on the frequency distribution the sample set can be considered sufficiently representative for the territory of Slovakia. Frequency distribution according to altitude in the sample set in the vicinity of phenological stations does not exactly match distribution of phenological stations; that could be one of the sources of uncertainty during validation (Fig. 3).

During the validation we evaluated i) the accuracy of the onset of each phenological event, ii) the duration of phenological phases and iii) the duration of full foliage and the growing season.

We have identified several potential sources of uncertainty derivation regional phenological model.

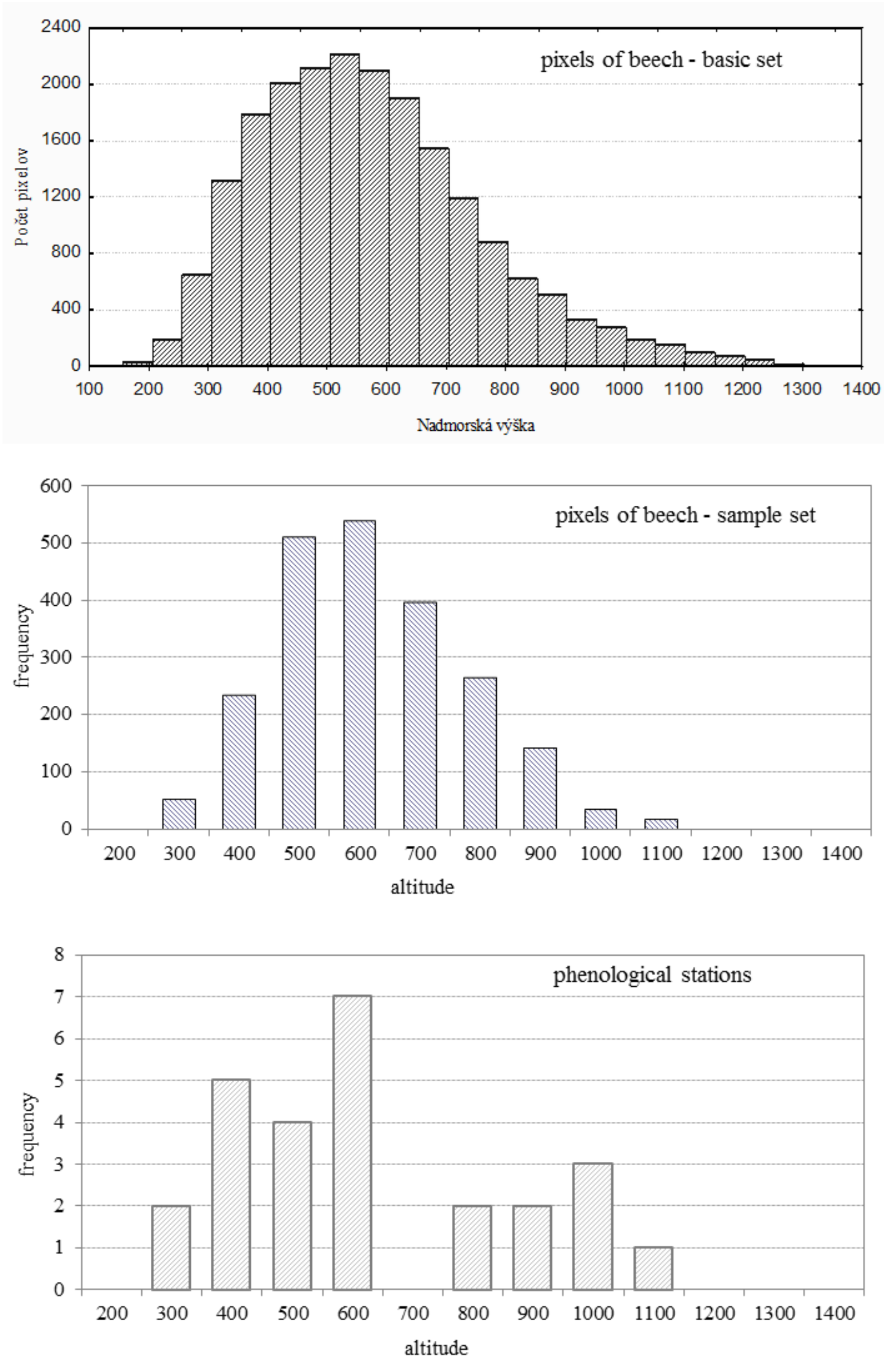


Figure 3 *The distribution of frequencies according to altitude for all pixels classified as beech, pixels within 5 km radius from phenological stations and for phenological stations*

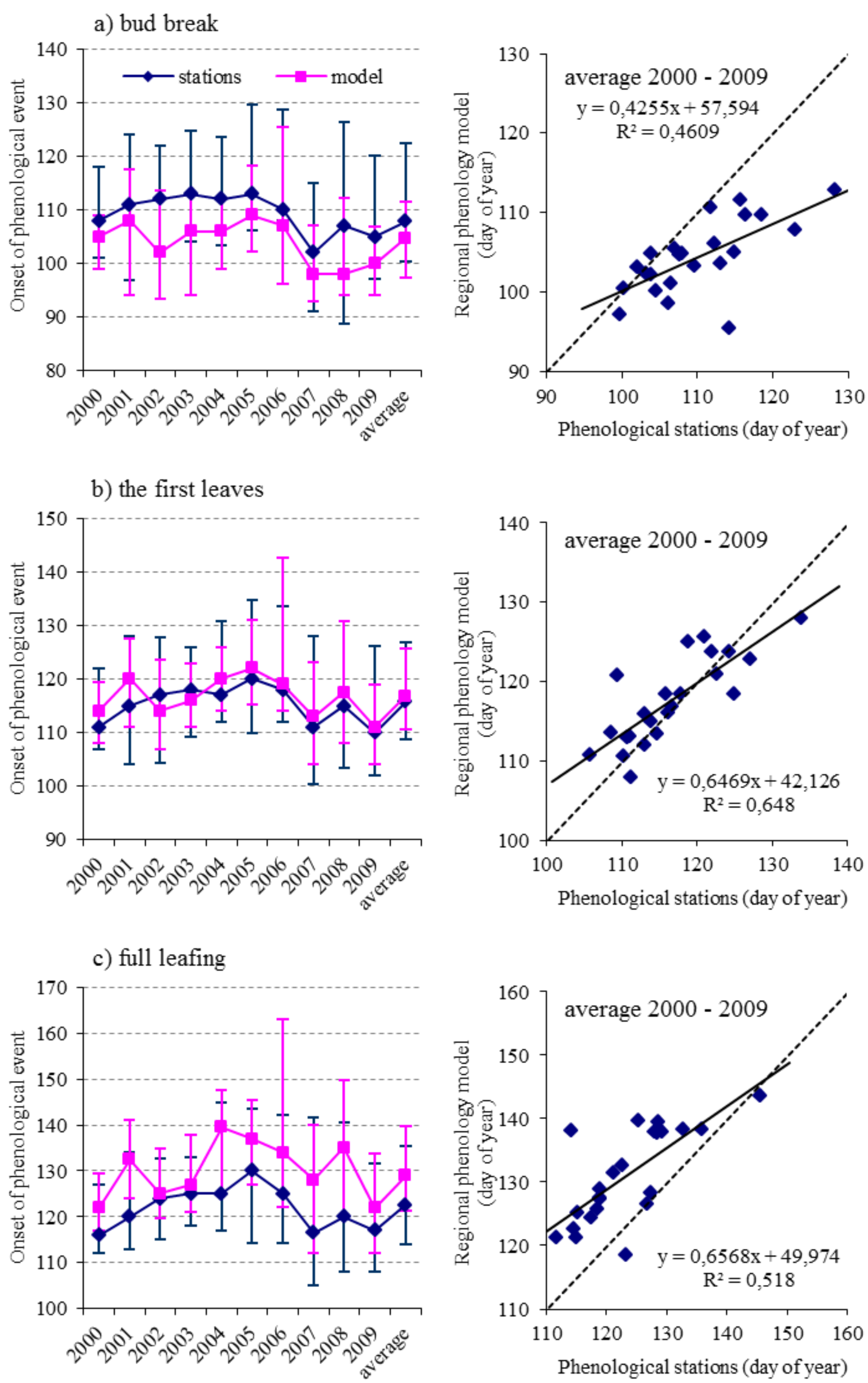


***Figure 4** Average day of onset of spring phenological events (bud break, the first leaves, full leafing) during 2000 - 2009 and their correlation between phenological observation and data derived from RFM (error bars represent 5-95 percentile of values)*

Bud break

Bud break derived from RFM occurs, on average, 5.6 days earlier than the observed bud break (Fig. 4a). The absolute difference between observed and derived values increases with altitude.

There are more possible reasons of the observed differences. One of possible reason is the occurrence of understory trees and bushes and their earlier onset of leaves unfolding comparing to the observed trees in canopy. For beech forest stands there is typical the occurrence of spring herbs, so-called spring heliophytes. Like in the case of understory trees, a slight shift of terms in comparison with MODIS data may be due to earlier onset of ground vegetation compared to the tree level, a strategy known as phenological escape (Brandýsová and Bucha 2012).

The first leaves

The first leaves is the most accurate derived phenological event, with an average error of 0.9 days, compared with the ground-based observations in phenological stations (Fig. 4b). It is also the phenological event that is in some phenology models considered to be the onset of the growing season (Fisher et al., 2007).

Full leafing

This phenological event was derived with a systematic error, in the average delay of 7.6 days (Fig. 4c).

Phenological event full leafing of deciduous trees is defined as a state where already all individuals in the group have leaves, leaves are light green, but still smaller than mature leaves (Braslavská and Kamenský 1996). After leaf unfolding, the assimilation apparatus continues to growth rapidly, changing its quality, which affects the reflectance. Enlarging of leaves occurs (while the increase of leaf area) even after the phenological event full leafing. According to observations of seasonal changes in leaf area index (Pavlendová 2009) we can consider this derived phenological event as a state when the main growth of assimilation apparatus was finished.

Course and duration of leaves unfolding (spring phase, growth period)

According to the results derived from MODIS RFM the length of this phenophase have increased with altitude, this increas does noc result from observations of phenological stations.

The duration of the spring phenophase leaves unfolding was overestimated as a result of earlier determination of bud break and later determination of full leafing in RFM. On average, in absolute values the overestimation was 13.3 days (12.6 vs. 25.9 days), that is over 100%.

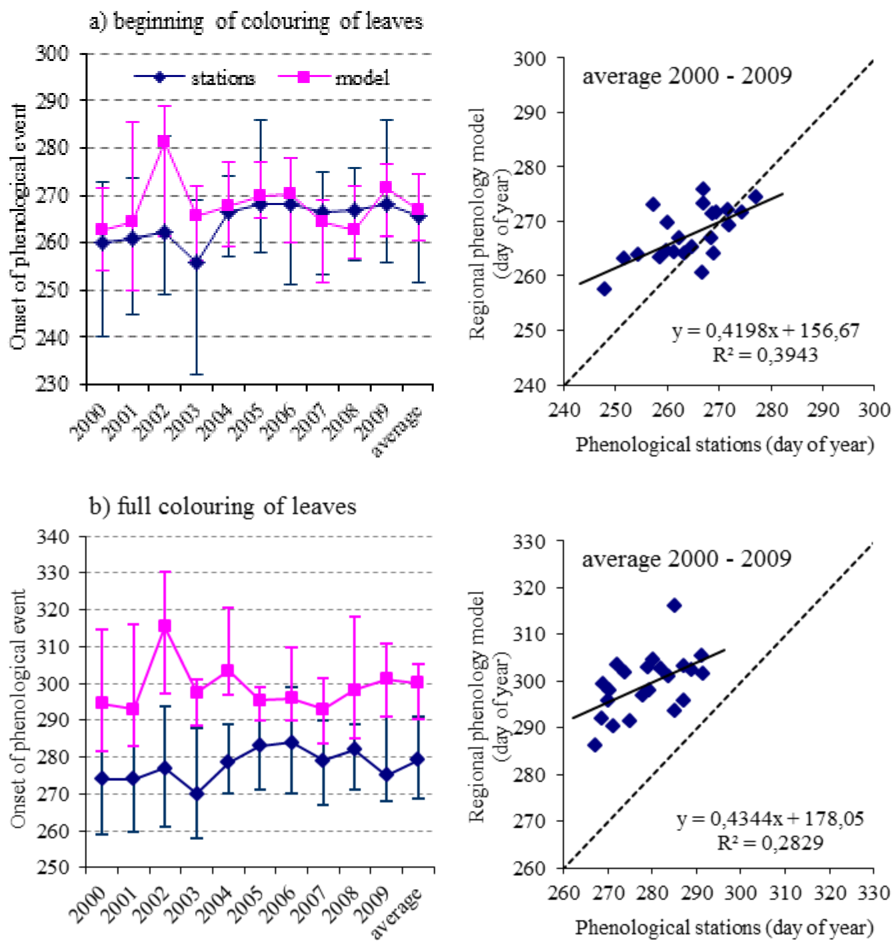


***Figure 5** Average day of onset of autumn phenological events (the beginning of colouring of leaves and full colouring of leaves) during 2000 - 2009 and their correlation between phenological observation and data derived from RFM (error bars represent 5-95 percentile of values)*

Beginning of colouring of leaves

Phenological event the beginning of colouring of leaves has been derived with a random error, on average with a delay of 3.3 days (Fig. 5a).

Onset of this event decreases with altitude (beginning earlier), with the exception of the sites with low altitude that probably manifest the impact of drought on premature yellowing. The onset of leaves colouring derived from RFM lasts significantly shorter period, compared to the observations of phenological stations (Fig. 5a).

Full colouring of leaves

Full colouring of leaves is the least accurately derived phenological event. It was derived with a systematic error, 20.2 days in average (Fig. 5b).

Major cause of inaccurate derivation of full colouring of leaves, as well as other autumn phenophases (start and end of leaf fall) can be considered the way there are changes in the reflectivity autumn: reflectance gradually declines over the colouring, leaf fall and later, to a value before starting growing season. Yellow and dead leaves still on the trees is not possible to distinguish using satellite images from fallen leaves, where their gradual decomposition is influenced by several factors, especially moisture.

The course and duration of leaves colouring (autumn phase, declination period)

According to the results derived from MODIS RFM the length of the phenophase leaves colouring increases with altitude, this increas does noc result from observations of phenological stations. Significant delay of phenological event full colouring of leaves derived from RFM resulted in overestimate of the duration of the first part of autumn phenophase – leaves colouring.

The difference between the length of the events derived from RFM and the observed values at phenological stations averaged in absolute terms 15.6 days (30.5 vs. 14.9 days), in relative terms it is again more than 100%.

The duration of the growing season

Currently, several approaches are used in the calculation of the duration of the growing season, a uniform definition of the growing season does not exist (White et al. 1997).

Part of phenological models defined beginning and end of growing season (onset and offset) as a half maximum at the sigmoidal curve for NDVI (Fisher 2007) or LAI (Kang et al. 2003, Hanes & Schwartz 2010), the others identify the onset and offset of growing season as the point of greatest changes at the logistic curve (Zhang et al. 2003). Some models that use phenological data define the vegetation season as the period from bud break to full colouring of leaves, however, thay require the data about the duration of the ascending (spring) and descending (autumn) phenophase (eg. DO3SE).

The definition of the duration of the growing season differs according to requirement of the models, balances and evaluations with input of the phenological data (hydrological, production model, gas flux, nutrient balance, etc..).

The main advantage of RFM is that it allows to derive timing of all phenological events and can calculate the length of growing season according to the required definition.

In the first phase, we calculated the length of growing season as the period between budbreak and full colouring of leaves (Fig. 6). The length of the growing season derived from RFM was systematically overestimated by 26.1 days in average (standard error 27.9 days).

The duration of full foliage is part of the growing season crucial for the overall production. It was derived from RFM with the random error in comparison with terrestrial phenological stations, 4.2 days shorter in average (standard error 7.6 days) (Fig. 6).

The results show that the regional phenology model can quite accurately derive the timing of spring phenological phases, as well as the duration of full foliage. We detected higher errors for determination of autumn phenophases, especially the full colouring of leaves. Similar results reported Stöckli et al. (2008), who used phenology prediction model with high accuracy in derivation of onset of the growing season, but the model was weak during determination of offset of growing season. Problems with modelling of offset of growing season for beech treesw reported also Richardson et al. (2006).

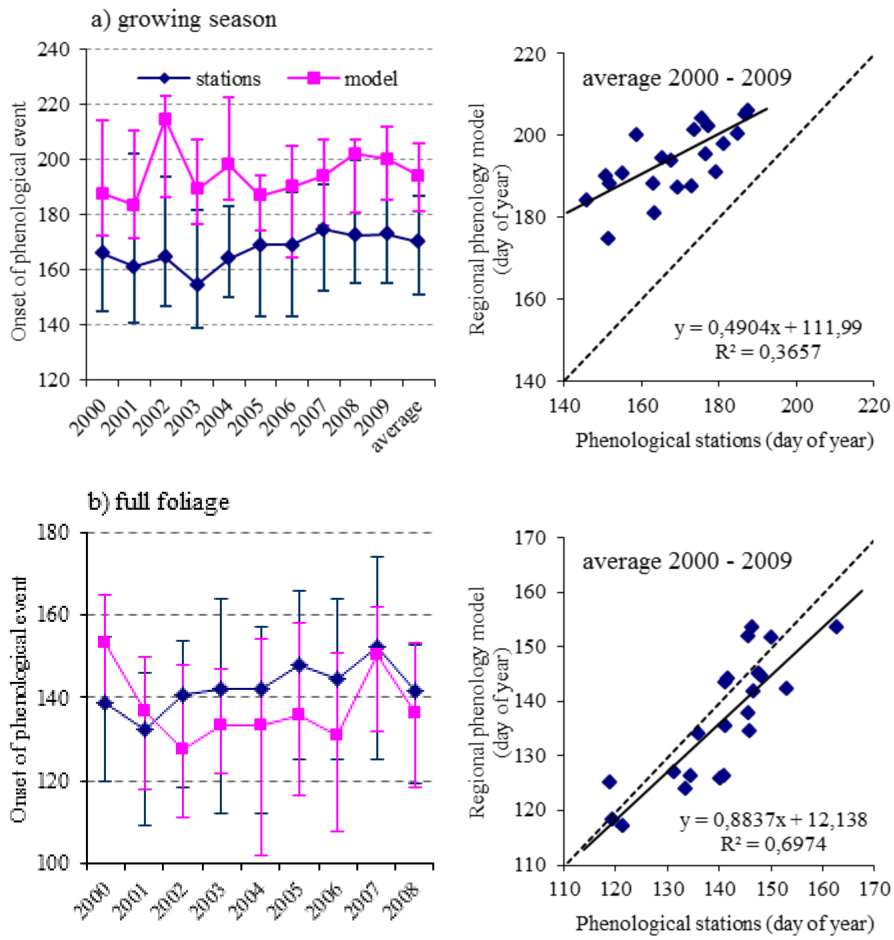


Figure 6 *Average duration of the observed and derived growing season (growing season and full foliage) during 2000 - 2009 and their correlation between phenological observation and data derived from RFM (error bars represent 5-95 percentile of values)*

Conclusion

The timing of five phenological events based on NDVI curves derived from MODIS data were idenfied for the territory of beech forest stands in Slovakia in the period 2000 – 2010. Between the date of onset of the individual phenological events and altitude there is moderate non-linear relationship. The onset of spring phenophases delays with increasing altitude, the onset of autumn phenophases decreases with altitude, except of the sites with low altitude where the dry conditions at the end of vegetation season probably cause premature yellowing. The length of the growing season of European beech decreases with altitude.

Regional phenology model for European beech (Fagus sylvatica L.) has been validated on an extensive range of phenological observations. The time series of phenological observation of regional phenological observation sites of Slovak Hydrometeorological Institute for years from 2000 to 2009 and permanent monitoring plots of National Forest Centre for 2002 – 2009 was used to validate the timing of five main spring and autumn phenological events.

The most accurately were derived the phenological events the first leaves, full leafing and the beginning of colouring of leaves. The resulting duration of full foliage was derived with an average error of ± 4.2 days (r = 0.84). Date of onset of phenophases bud break and full colouring of leaves, determining the duration of the entire growing season, were derived with a systematic negative (budbreak), respectively. positive error (full colouring) which increases with increasing altitude. It resulted in an overestimate of the duration of the growing season by an average of 26 days. Modeling is a useful tool that provides us information about (not only) forest ecosystems with high temporal and spatial resolution, but it can be used to predict changes in the phenology of forest tree species due to climate change. Validation using ground-based measurements, respectively. observation allows the model results to be correctly interpreted.

References

Brandýsová, V., Bucha, T., 2013: Vplyv prízemnej vegetácie a podrastu na priebeh fenologickej krivky bukových porastov odvodenej z údajov MODIS. Lesnícky časopis - Forestry Journal, Bratislava, 15. 3. 2013, 58(4), 231-242.

Braslavská, O., Kamenský, L., 1996: Fenologické pozorovanie lesných rastlín. Metodický predpis, Slovenský hydrometeorologický ústav, Bratislava, 1996, 22 s., 2 tab.

Bucha, T., 1999: Classification of tree species composition in Slovakia from satellite images as a part of monitoring of forest ecosystem biodiversity. Acta Instituti Forestalis., 9, 1999, pp. 65-84

Cohen, W. B., Maiersperger, T.K., Yang, Z.Q., Gower, S.T., Turner, D.P., Ritts, W.D., Berterretche, M., Running, S.W., 2003: Comparisons of land cover and LAI estimates derived from ETM+ and MODIS for four sites in North America: a quality assessment of 2000/2001 provisional MODIS products. Remote Sensing of Environment, 88, 233 –255.

Fisher, J. I., Richardson, A. D., Mustard, J. F., 2007: Phenology model from surface meteorology does not capture satellite-based greenup estimations. *Global Change Biology*, *13*(3), 707-721. doi:10.1111/j.1365-2486.2006.01311.x

Fisher, J., Mustard, J., Vadeboncoeur, M., 2006: Green leaf phenology at Landsat resolution: Scaling from the field to the satellite. *Remote Sensing of Environment*, *100*(2), 265-279. doi:10.1016/j.rse.2005.10.022

Gobron, N., Pinty, B., Taberner, M., Mélin, F., Verstraete, M. M. Widlowski, J.-L., 2005: Monitoring the Photosynthetic Activity of Vegetation from Remote Sensing Data. Advances in Space Research, doi:10.1016/j.asr.2003.07.079.

Hanes, J. M., Schwartz, M. D., 2010: Modeling land surface phenology in a mixed temperate forest using MODIS measurements of leaf area index and land surface temperature. *Theoretical and Applied Climatology*. doi:10.1007/s00704-010-0374-8

Hicks, D.J., Chabot, B.F., 1985: Decidous forest. In: Chabot, B.F. and Mooney, H.A. (eds.), Physiological Ecology of North American Plant Communities, Chapman and Hall, NY., p. 257- 277

Chalupa, V., 1969: Počátek, trvání a ukončení vegetační činnosti u lesních dřevin. In: Práce VÚLHM, zv. 37, Zbraslav - Strnady, VÚLHM, s. 41-68

Kang, S., 2003: A regional phenology model for detecting onset of greenness in temperate mixed forests, Korea: an application of MODIS leaf area index. *Remote Sensing of Environment*, *86*(2), 232-242. doi:10.1016/S0034-4257(03)00103-2

Larcher, W., 1988: Fyziologická ekologie rostlin. Vydání 1., Academia Praha, 368 s.

Preushler, T., 1999: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forest. Part IX, Phenological observation. UN-ECE, 35 p.

Richardson, A. D., Bailey, A. S., Denny, E. G., Martin, C. W., O'Keefe, J., 2006: Phenology of a northern hardwood forest canopy. *Global Change Biology*, *12*(7), 1174-1188. doi:10.1111/j.1365-2486.2006.01164.x

Shabanov, N.V., Wang, Y., Buermann, W., Dong, J., Hoffman, S., Smith, G.R., Tian, Y., Knyazikhin, Y., Myneni, R.B., 2003: Effect of foliage spatial heterogeneity in the MODIS LAI and FPAR algorithm over broadleaf forests. Remote Sensing of Environment, 85, 410–423.

Stöckli, R., Rutishauser, T., Dragoni, D., O'Keefe, J., Thornton, P. E., Jolly, M., Lu, L., Denning, A. S., 2008: Remote sensing data assimilation for a prognostic phenology model. *Journal of Geophysical Research*, *113*(G4), G04021. doi:10.1029/2008JG000781

White, A., & Thomton, P. E., 1997: A continental responses phenology model climatic for monitoring variability vegetation to interannual. *Area*, *11*(2), 217-234.

Zhang, X., Friedl, M.A., Schaaf, C.B., Strahler, A.H., Hodges, J.C.F., Gao, F., Reed, B.C., Huete, A., 2003: Monitoring vegetation phenology using MODIS. Remote Sensing of Environment, 84, 471–475

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0608-10.

SUMMARY

V príspevku popisujeme metódy a výsledky validácie regionálneho fenologického modelu odvodeného z NDVI (Normalized Difference Vegetation Index, normalizovaný vegetačný index) zo satelitných snímok MODIS (Moderate Resolution Imaging Spectroradiometer) pre drevinu buk lesný (*Fagus sylvatica* L.). Na validáciu dňa nástupu piatich hlavných jarných a jesenných fenologických udalostí bol použitý rad pozorovaní regionálnych fenologických staníc SHMÚ (Slovenský hydrometeorologický ústav) z rokov 2000 - 2009 a rad fenologických pozorovaní na trvalých monitorovacích plochách NLC (Národné lesnícke centrum) z rokov 2002 - 2009.

Najpresnejšie boli odvodené dni nástupu fenofáz začiatok zalisťovania, všeobecné zalisťovanie a začiatok žltnutia. Z nich vyplývajúca dĺžka trvania plného olistenia, rozhodujúca pre celkovú produkciu, bola odvodená s priemernou chybou ±4,2 dni (r=0,84). Dni nástupu fenofáz rašenie pupeňov a všeobecné žltnutie listov, určujúce dĺžku trvania celého vegetačného obdobia, boli odvodené so systematickou zápornou (rašenie pupeňov), resp. kladnou chybou (všeobecné žltnutie listov), ktorá sa zvyšovala s nadmorskou výškou, čím došlo k nadhodnoteniu dĺžky trvania vegetačnej sezóny v priemere až o 26 dní. Možné príčiny zistených rozdielov v čase nástupu jednotlivých fenofáz a dĺžke ich trvania sú diskutované v príspevku.

CONTACT

Ing. Hana Pavlendová, PhD.

Nationa Forest Centre – Forest Research Institute

T. G. Masaryka 22, 96092 Zvolen, Slovakia

pavlendova@nlcsk.org

EFFECT OF BARN AIRSPACE TEMPERATURE ON COMPOSITION AND TECHNOLOGICAL PARAMETERS OF BULK MILK PRODUCED BY DAIRY COWS OF CZECH FLECKVIEH AND HOLSTEIN BREEDS

O. POLÁK[1], D. FALTA[2], O. HANUŠ[3], G. CHLÁDEK[2]

1) *Department of Crop Science, Breeding and Plant Medicine Mendel University in Brno, Czech Republic*
2) *Department of Animal Breeding, Mendel University in Brno, Czech Republic*
3) *Dairy Research Institute, Ltd., Czech Republic*

ABSTRACT

On two farms (A and B), samples of bulk milk produced by dairy cows of the Holstein (H) and Czech Fleckvieh (CF) breeds were collected every week on the same day within the time interval of 32 weeks. The aim of this sampling was to determine the effect of barn airspace temperature on milk composition and its technological parameters. The following average values of all bulk milk samples (n = 64) were recorded: barn airspace temperature (BAT) 12.29 °C; rennet coagulation time (RCT) 211 sec.; curd quality class (CQC) 1.55; titratable acidity (TA) 7.16 °SH; protein content (P) 3.46 %; fat content (F) 4.09 %; lactose content (L) 4.78 %; and solids non fat (SNF) 8.85 %. As compared with H, dairy cows of CF breed produced milk with statistically significantly higher (P < 0.01) contents of P (+0.28 %), SNF (+0.27 %) and statistically significant (P < 0.05) of TA. The remaining differences were statistically insignificant (P > 0.05): BAT; RCT; CQC; F and L. As far as the effect of temperature was concerned, calculated correlation coefficients and plotted graphs indicated a marked effect of BAT on RCT; F and P. This effect was in all cases markedly negative: at lower BAT, F and P values were higher and RCT longer while at higher temperatures they were lower and shorter. These trends were similar in both breeds regardless to differences in average values of aforementioned parameters.

Key words: barn airspace temperature, composition of milk, technological parameters of milk, heat stress

INTRODUCTION

Although the milk cattle shows a high adaptability to a wide scale of climatic conditions, its performance can be influenced by great temperature fluctuations occurring within the year. Nowadays, effects of the heat stress represents a tropical problem also in Eastern and Central Europe. Summer climate causes the heat stress of dairy cows and the heat stress results in am depression in milk production. The heat stress occurs in situations when the ambient temperature is higher than that of the animal´s thermal neutral zone (Novák *et al*., 2009). According to Vokřálková and Novák (2005), the thermoneutral zone of dairy cows ranges from −5 to +24 °C. Other authors reminded that in high-yielding (i.e. > 6,500 kg) and, especially, older cows, the thermal stress developed at temperatures > 21°C (Novák *et al*., 2009; Vokřálková and Novák, 2005). The heat stress problem is getting worse as production levels continue to rise (Mitlöhner *et al*., 2002; Beatty *et al*., 2006). The summer depression in production of milk causes significant economical losses in the dairy industry. The basic condition of dairy farm management depends on the knowledge of and understanding to factors affecting milk production at most, i.e. not only nutrition and health status of dairy cows but also the parity and calving season, technological systems, and, above all, microclimatic conditions (Maust *et al*., 1972; Gader *et al*., 2007). Livestock performance is affected by heat stress mainly due to the fact that animals having problems with high temperatures and heat try to control their thermoregulation and heat production by reduced feed intake (Davis *et al*., 2003; Mader *et al*., 2004).

Within a species, the variation in milk composition and yield is dependent on many factors. Some of them are of genetic nature while others concern stage of lactation, daily variation, parity, type of feeding, udder health, and season (Haenlein, 2003). Climatic conditions are known as seasonal changes which influence the milk composition. There is a negative correlation between the environmental temperature on the one hand and amounts of milk fat and protein on the other. When the temperature is increasing the solids non fat tends to decrease (Ozrenk and Inci, 2008). Ng-Kwai-Hang *et al*. (1984) and Lacroix *et al*. (1996) reported that the percentage of fat, protein and casein was influenced by the seasonal variations. Hanuš *et al*. (2008) observed influence of summer period on milk composition particularly on protein and solids non fat which decreased. Also Dolejš *et al*. (1996) mentioned a decrease in protein and solid non fat content in milk with increase of air temperature. It is clear that influence of dairy cow milk yield level on fat content (Hanuš *et al*., 2007) is more intensive in Czech Fleckvieh but less intensive in Holstein (Janů *et al*., 2007) which is comparable to influence of environmental temperature variation on fat. Dolejš *et al*. (1996) found also the milk fat content depression with air temperature increase. Sevi *et al*. (2001) found high ambient temperatures to adversely affect the yield and cheese-making parameters of milk by the clotting time and the rate of clot formation and decreasing clot firmness. The photoperiod (i.e. light-to-dark ratio) can also induce marked changes in milk yield and composition (Casati *et al*., 1998). In fact, a high light-to-dark ratio leads to a reduction in fat and protein contents of milk, probably as a consequence of a greater secretion of prolactin whose concentration in plasma is higher in the summer than in the winter (Tucker, 1989). Lactation period moved forward progressing and when the environmental heat degree increased, the fat content decreased (Sekerden, 1999; Yetismeyen, 2000). Jõudu *et al*. (2008) concluded that an increase of protein content of milk has resulted in reducing rennet coagulation time of milk.

Marked environmental effects on milk composition and technological quality of milk also cannot be negligible. These effects are usually involved into such models as effect of breed, year or season. For example De Marchi *et al*. (2007) mentioned that in their experiments, milk producing by dairy cows of Holstein-Friesian breed showed the worst coagulation (including RCT) among all other breeds under study. In addition Hanuš *et al*. (2011) observed that herd, year, and season showed a significant effect on milk composition and its technological parameters (including RCT) of milk produced by dairy cows of the Czech Fleckvieh breed. Daviau *et al*. (2000) mentioned that shorter RCT was associated with a decrease in the content of protein, which usually associated also with a decrease in the content of casein. A significant effect of season and herd on rennet coagulation time and other parameters of milk technological quality in Holstein cows was observed also by Chládek *et al*. (2011).

The aim of this study was to determine the effect of barn airspace temperature on composition (i.e. contents of protein, fat, lactose and non fat solids) and technological parameters (titratable acidity, rennetability and curd quality) of bulk milk samples collected in herds of Czech Fleckvieh and Holstein breeds of cattle.

MATERIAL AND METHODS

The study was performed on two farms (A and B) in the South Moravian Region of the Czech Republic within the period from June 17th 2010 to January 19th 2011.

The herd on the first farm (A) consisted only from purebred Holstein (H) dairy cows (in average 350 head). In this herd, the average milk performance was 9,500 kg per lactation. The farm is situated in the village of Žabčice in a lowland area (GPS 49°0'51.786"N, 16°36'14.809"E) at the altitude of 179 m. All cows were kept together under identical conditions in a loose housing system with bedding and received a complete feeding ration *ad libitum*. Cows were milked twice a day at 4.00 and 16.00 h. This was the same barn as that used in experiments performed by Walterová *et al*. (2009).

On the other farm (B), only purebred dairy cows (in average 600 head) of the Czech Fleckvieh (CF) breed were raised. The average milk performance was 7,500 kg per lactation. The farm is situated in a lowland region in the village of Říčany, Moravia, Czech Republic (GPS 49°12'32.319"N, 16°23'42.666"E) in the altitude of 349 m. All animals were kept under identical conditions in a loose housing system with bedding and received also a complete feeding ration *ad libitum*. They were milked twice daily also at 4.00 and 16.00 h. This experiment took place in the same barn as that used by Erbez *et al*. (2010). On both farms were optimized diet according to Petrikovič and Sommer (2002). Feeding ration consisted from common used feeds in this region (corn silage, cereal meals, solvent oil meals, minerals and vitamins supplements).

Within a period of 32 weeks, bulk milk samples were collected in both herds once a week always on the same day. The samples represented a mixture of morning and evening milk. The average barn airspace temperature (BAT in °C) was measured on the day before milk sampling. Temperature measurements were performed every 15 minutes using three HOBO data loggers (H08-007-02, Onset Computer Corporation®), which were located approx. 1.40 m above the floor level in three different locations inside the barn to eliminate the effect of only one place of measuring.

On the next day, the average percentages of fat content (F), protein (P), lactate monohydrate (L), and solids non fat (SNF) were estimated in collected bulk milk samples together with values of titratable acidity (TA), rennetability (RCT), and curd quality (CQC). Milk rennetability was estimated using a „Nephelometric-turbidimetric test of milk coagulation (Chládek and Čejna, 2005). The test was performed using the preparation Laktochym 1:5000 (Milcom Tábor) in the dose of 1 ml per 50 ml of milk (after the dilution of the renneting agent in the ratio 1:4). Curd quality (CQC) was evaluated after 60 minutes of incubation of 50 ml of renneted milk at 35 °C and compared with tabular values (Gajdůšek, 1999) using the scale from (1 = the best to 5 = the worst). TA was measured in a milk sample of 100 ml using an alkaline solution up to light pink colour of the mixture (in ml of the 0.25 $molx1^{-1}$ $NaOHx100ml^{-1}$). The method was performed pursuant provisions of the standard CSN57 0530. Contents of P and F were estimated using the apparatus Milkoscope C5 (see the standard ČSN 57 0536).

For statistical analysis (by means of bi-factorial analysis of variance), programmes MS Excel and UNISTAT Version 5.1 were used.

The analyses carried on, including abbreviations and units of measurement were as follows:

H = Holstein

CF = Czech Fleckvieh

P = protein content (%), $g.100g^{-1}$

F = fat content (%), $g.100g^{-1}$

L = lactose (%), $g.100g^{-1}$

SNF = solid non fat (%), $g.100g^{-1}$

BAT = barn airspace temperature (°C)

RCT = rennet coagulation time (in seconds)

CQC = curd quality class

TA = titratable acidity (°SH).

Results and discussion

Values of mean, minimum, maximum and standard deviation (SD) of data from analysis of cow's milk composition, technological parameters and barn airspace temperature are shown in Table I. On both farms (n = 64), the average value of BAT was 12.29 °C and the standard deviation was 9.32 °C. On the farm A, the average BATs ranged from a minimum of −3.96 °C to the maximum of 28.51°C; for the whole period under study, the average value of BAT was 13.25 °C. On the farm B, the corresponding values of BATs ranged from –7.41 °C to +26.24 °C; for the whole period under study, the average value of BAT was 11.34 °C. This means that in some periods the monitored dairy cows were exposed to a heat stress (above all if BATs approached to the limit of 26 °C). Many authors (e.g.Berman *et al*., 1985; Hahn, 1999 and West, 2003) reported that BATs above 23-26 °C were for dairy cattle critical and that caused a decrease in milk production. Some other authors, however, (e.g. Falta *et al*., 2008; Vokřálová and Novák, 2005) demonstrated that for high-yielding dairy cows BATs of only 21 °C were critical and triggered the heat stress.

Table I: *Mean, minimum, maximum and standard deviation of milk composition, technological properties and barn airspace temperature on both farms (A and B)*

Parameter	Total				Farm A			Farm B			Signifi-cation
	$\bar{x}$	SD	min.	max.	$\bar{x}$	min.	max.	$\bar{x}$	min.	max.	
RCT (second)	211	16.5	160	240	213	185	240	209	160	240	N.S.
CQC (class)	1.55	0.50	1.00	2.00	1.56	1.00	2.00	1.53	1.00	2.00	N.S.
TA (°SH)	7.16	0.24	6.42	7.64	7.10	6.64	7.50	7.22	6.42	7.64	*
P (%)	3.46	0.20	3.14	3.83	3.32	3.14	3.56	3.60	3.33	3.83	**
F (%)	4.09	0.21	3.64	4.48	4.08	3.64	4.48	4.11	3.67	4.41	N.S.
L (%)	4.78	0.06	4.61	4.86	4.79	4.62	4.86	4.77	4.61	4.86	N.S.
SNF (%)	8.85	0.20	8.44	9.24	8.72	8.44	8.91	8.99	8.77	9.24	**
BAT (C°)	12.29	9.32	−7.41	28.51	13.25	−3.96	28.51	11.34	−7.41	26.24	N.S.

*Signification: N.S. – non significant (P > 0.05); ** (P < 0.01); * (P < 0.05)*

RCT – rennet coagulation time; CQC – curd quality class; TA – titratable acidity; P – protein content; F – fat content; L – lactose content; SNF – solids non fat; BAT – barn airspace temperature, SD – standard deviation

In both herds, the average values of P and its standard deviation were 3.46 % and ± 0.20 %, respectively. On the farm A, the average value of P was 3.32 % (with the minimum and the maximum of 3.14 % and 3.56 %, respectively) while on the farm B it was 3.60 % (with the minimum and the maximum of 3.33 % and 3.83 %, respectively). The difference between farms A and B was statistically highly significant ($P < 0.01$). The average values of F and its standard deviation for the whole period under study and both herds were 4.09 % and ± 0.21 %, respectively). On the farm A, the average F value was 4.08 % (with the minimum and the maximum of 3.64 % and 4.48 %, respectively) while on the farm B it was 4.11 % (with the minimum and the maximum of 3.67 % and 4.41 %, respectively). The difference between both farms was statistically non-significant ($P > 0.05$). From our observed values F and P, we can say that milk yield both breeds were higher than average in conditions of Czech Republic in comparison to data from the Milk Recording Scheme for the year 2010 according to Kvapilík et al. (2011). In the whole set of dairy cows and for the whole period under study, the average values of L and its standard deviation were 4.78 % and ± 0.06 %, respectively. On the farm A, the average value of L was 4.79 % (with the minimum and the maximum of 4.62 % and 4.86 %, respectively). On the farm B, the corresponding value was 4.77 % (with the minimum and the maximum of 4.61 % and 4.86 %, respectively). Also this difference between both farms was statistically non-significant ($P > 0.05$). In both herds and for the whole period under study, the average values of SNF and its standard deviation were 8.85 % and ± 0.20 %, respectively. On the farm A, the average value of SNF was 8.72 % (with the minimum and the maximum of 8.44 % and 8.91 %, respectively). On the farm B, the corresponding value was 8.99 % (with the minimum and the maximum of 8.77 % and 9.24 %, respectively). This difference between both farms statistically highly significant ($P < 0.01$).

For the whole period under study and both herds, the average values of RCT and its standard deviation were 211 sec and ± 16.5 sec. On farm A, the average value was 213 sec. (with the minimum and the maximum of 185 sec and 240 sec, respectively), while on the farm B it was 209 sec. (with the minimum and the maximum of 160 sec. and 240 sec, respectively). The difference between both farms was statistically non-significant (P > 0.05). As far as the values of CQC and its standard deviation for the whole study period were concerned, these were 1.55 ± 0.50, respectively. On the farm A, the average value of CQC was 1.56 class and on the farm B the corresponding value was 1.53 class. The minimum and the maximum values of QCQ (i.e. Class 1 and Class 2, respectively) were recorded in both herds. On the farm A, the average value of TA was 7.10 °SH and ranged from 6.64 to 7.50 °SH; on the farm B, the corresponding values were 7.22 and 6.42−7.64 °SH, respectively. In both herds, the average values of TA and its standard deviation were 7.16 °SH and ± 0.24, respectively. The difference between both farms was statistically significant (P < 0.05).

The correlation between milk content, technological parameters and barn airspace temperature on farms A and B are shown in Tab. II.

Table II: *Correlation between milk content, technological properties and barn airspace temperature on farm A and farm B*

Farm A									
		RCT	**CQC**	**TA**	**P**	**F**	**L**	**SNF**	**BAT**
Farm B	**RCT**	**1**	-0.1597	0.1763	0.4187	0.5027	0.0539	0.4167	-0.4654
	CQC	-0.1977	**1**	-0.1697	-0.4003	-0.4279	0.0494	-0.3408	0.3790
	TA	0.0874	-0.2418	**1**	0.3363	0.0355	-0.5153	0.0950	-0.3953
	P	0.6610	-0.3447	0.4663	**1**	0.8071	-0.0937	0.9112	-0.8832
	F	0.5852	-0.3062	0.3282	0.8660	**1**	0.1596	0.8390	-0.7866
	L	-0.4985	0.1450	-0.2384	-0.6691	-0.5605	**1**	0.2863	0.0749
	SNF	0.6882	-0.3629	0.4403	0.9562	0.8509	-0.4586	**1**	-0.8013
	BAT	-0.5875	0.2820	-0.3838	-0.8886	-0.8889	0.6057	-0.8542	**1**

RCT – rennet coagulation time; CQC – quality of curd; TA – titratable acidity; P – protein content; F – fat content; L – lactose content; SNF – solids non fat; BAT – barn airspace temperature

These data indicate a marked effect of BAT on all parameters of milk composition and technological quality on both farms; non-significant was only the effect of BAT on L content on the farm A. RCT was negatively correlated with BAT on both farms ($r = -0.46$ and $r = -0.59$, respectively; $P < 0.01$). This means that the higher the value of BAT, the shorter that of RCT. Average values of summer BAT indicated that during this season, the limit of heat stress could be trespassed on some days (Falta *et al*., 2008; Hanuš *et al*., 2008). As mentioned by Daviau *et al*. (2008), the shorter RCT was associated with a decrease in P content and also of casein. It was found out in this study that lower values of RCT were associated with a lower content of protein above all in the summer season; however, our results do not correspond with data published by Jõudu *et al*. (2008); Ikonnen *et al*. (2004) and Sevi *et al*. (2001) who obtained opposite results. This could be partly explained on the base of high summer temperatures recorded in our study. This observation also corresponded with results published by Nájera *et al*. (2003). Regardless to differences existing between both farms, the value of CQC was positively correlated with BAT on both farms ($r = 0.38$ and $r = 0.28$ on farms A and B, respectively; $P < 0.01$) while that of TA was correlated negatively ($r = -0.39$ and $r = -0.38$ on farms A and B, respectively; $P < 0.01$). This effect of BAT on RTC on farms A and B is shown also in Fig. 1.

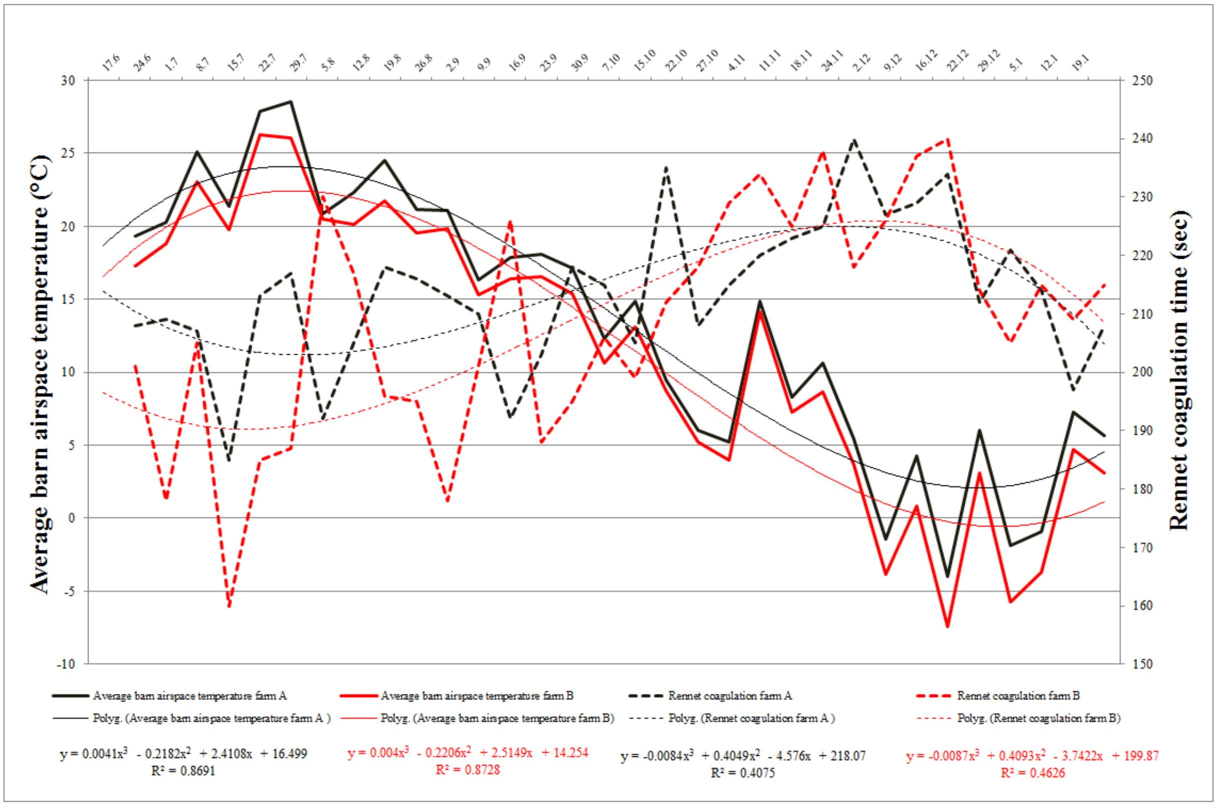


Figure 1: *Effect of barn airspace temperature on rennet coagulation time on farm A and B*

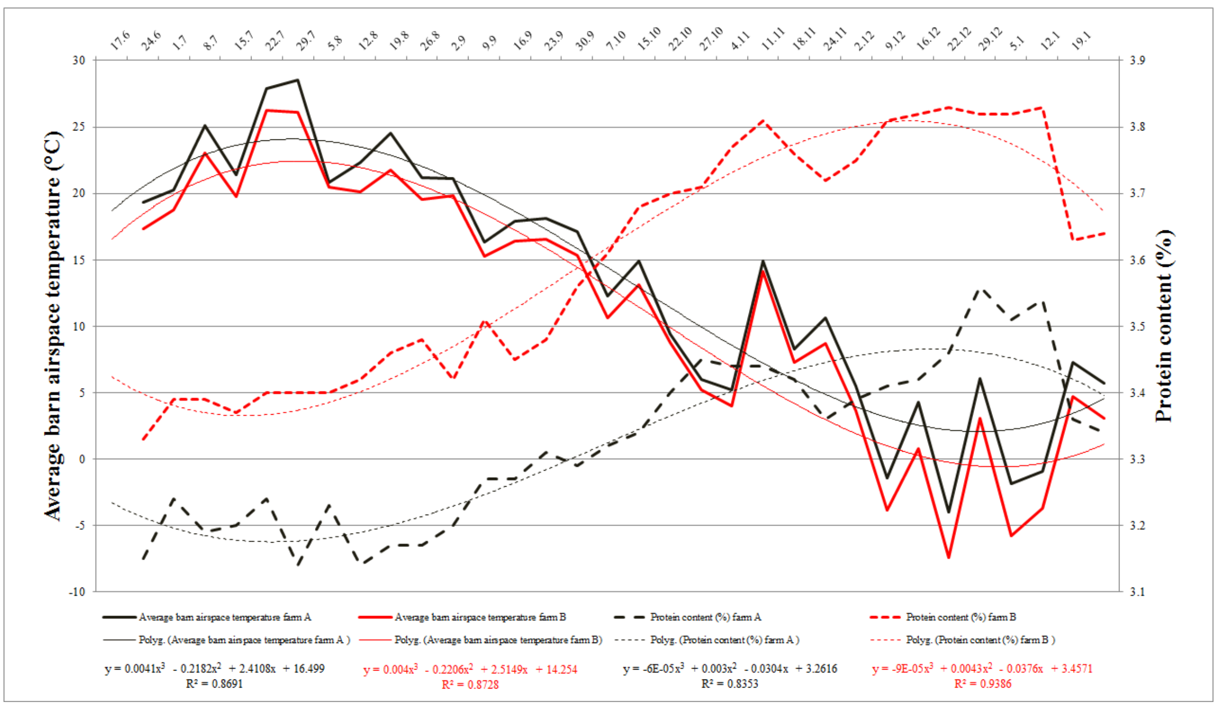


Figure 2: *Effect of barn airspace temperature on protein content on farm A and B*

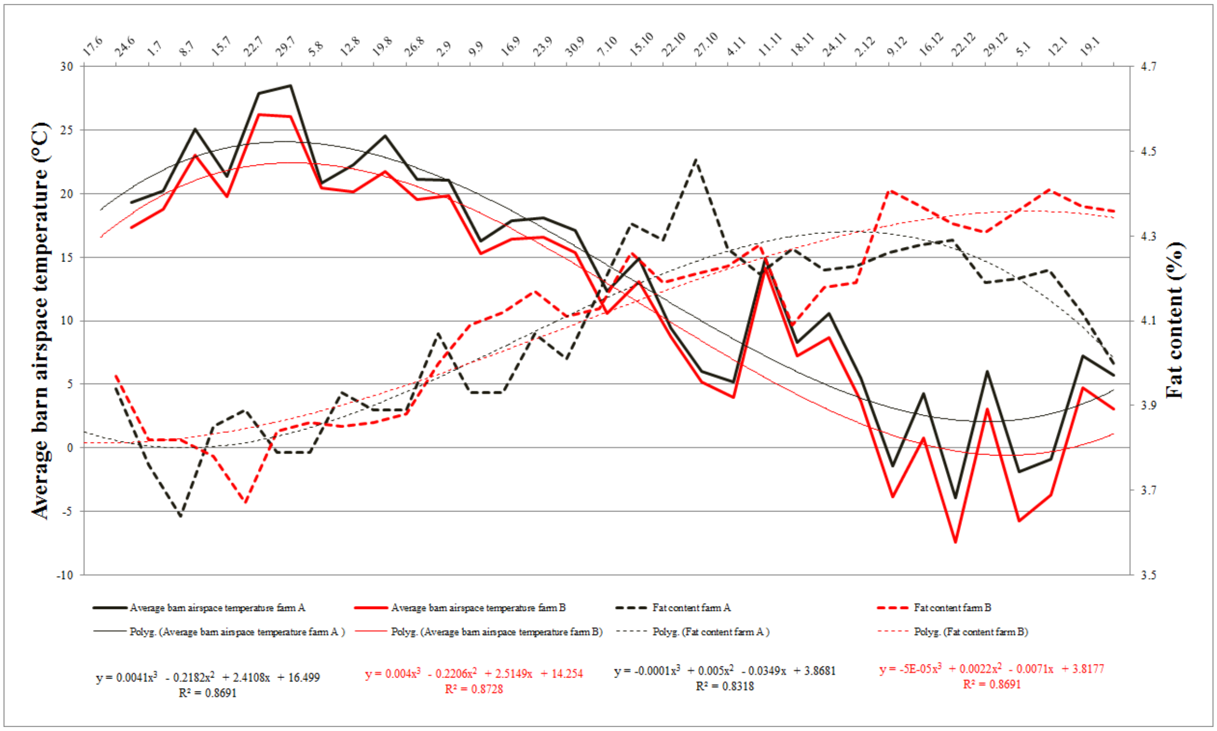


***Figure 3:** Effect of barn airspace temperature on fat content on farm A and B*

As far as the effect of BAT on values of P was concerned, the highest negative correlation coefficient was found out on both farms (r = −0.88 and r = −0.88 on farm A and B, respectively; P < 0.01). This effect of BAT on P content is obvious also in Fig. 2.

Further, a negative coefficient of correlation was found out also between BAT and F content on both farms (r = −0.79 and r = −0.89 on farm A and B, respectively; P < 0.01). This effect of BAT on F content on farms A and B is illustrated also in Fig. 3. This trend in growth of P under conditions of decreasing temperatures was published by several authors (Hanuš *et al.*, 2008; Dolejš *et al.*, 1996; Ng-Kwai-Hang *et al.*, 1984; Lacroix *et al.*, 1996). Kadzere *et al.* (2001) confirmed that during periods of warm weather, the percentage of milk protein decreased in all dairy cows. Moreover, McDowell *et al.* (1976) mentioned that if lactating dairy cows were transferred from a barn with air temperature of 18 to another with 30 °C, production of milk fat, solids non fat and milk protein decreased by 39.7; 18.9 and 16.9%, respectively. Ozrenk and Inci (2008) also observed that contents of protein and fat of milk change along the year and that the percent of milk protein was positively correlated with that of milk fat. This observation was corroborated also in this study: it was found out that there was a positive correlation between contents of F and P (values of correlation coefficients on farms A and B were r = 0.81 and r = 0.87. respectively; P < 0.01). Further it was found out that there was a positive correlation between BAT and L content on farms and B (r = 0.07; P > 0.05 and r = 0.61; P < 0.01, respectively). The result recorded on farm B differs from data published by Kadzere et al. (2001) who wrote that temperature did not affect the lactose percentage. This marked difference can be partly explained by the fact that the breed of cattle was different. On both farms, the correlation between BAT and SNF was also very high (r = −0.8 and r = −0.85 on farms A and B, respectively).

It can be therefore concluded that differences in RCT, as observed in our study (i.e. 13.5 %), were not the same as those recorded by Hanuš *et al*. (2010), respectively. Chládek *et al*. (2011) under different conditions and in different breeds (34.00 %, resp. 22.7 %). The existence of significant differences among individual breeds support the opinion that the parameter „breed“ should be taken into account as one of factors that influence results of experiments focused on milk technological quality. An insignificant effect of breed on parameters of technological quality of milk observed in this study does not corresponds with data published by Hanuš *et al*. (2011) who recorded them in a study with a different breed of cattle.

It is obvious that similar trends in the growth and decrease of temperatures were observed in the course of this study on both farms. However, it can be concluded that average daily temperatures were nearly identical on both farms and that the average difference was approximately 2 °C. This resulted above all from different localities, in which both farms were situated in the region of South Moravia. Thus, the differences in composition and technological parameters of milk resulted above all from different breeds: as compared with H dairy cows, those of CF breed produced statistically significantly (P < 0.01) higher percentages of P (by +0.28 %), SNF (by +0.27 %) and statistically significant difference (P < 0.05) of TA (by – 0.12 °SH). The other differences were statistically non-significant (P > 0.05): BAT (−1.91 °C), RCT (−4 sec.), CQC (-0.03 class), F (+0.03 %) and L (−0.02 %).

CONCLUSION

As far as the effect of temperature is concerned, the calculated values of correlation coefficients (and also the plotted graphs) indicate a marked effect of BAT on RCT, F and P. At lower temperatures, this effect was always markedly negative (i.e. higher in case of F, P and longer in case of RCT) while at high temperatures it was less pronounced (i.e. lower and shorter). It is also necessary to remember that, within the period under study, milk composition and its technological parameters were markedly influenced by the temperature (BAT), which could further deepen differences existing between individual breeds. Regardless to differences in average values of parameters under study, these trends were similar in both breeds.

REFERENCES

BEATTY, D. T., BARNES, A., TAYLOR, E., PETHICK, D., MCCARTHY, M., MALONEY, S. K., 2006: Physiological response sof Bos taurus indicus cattle to prolonged, continuous heat an10., PIERRE, A., GOUDÉDRANCHE, H., MAUBOIS, J. L., 2000: Rennet coagulation of skim milk and curd drainage: Effect of pH, casein concentration, ionic strength and heat treatment. Lait 80, 4: 397−415. ISSN 1958-5586.

DAVIS, M. S., MADER, T. L., HOLT, S. M., PARKHUST, A. M., 2003: Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature. Journal of Animal Science, 81: 649−661. ISSN 0021-8812.

De MARCHI, M., DAL ZOTTO, R., CASSANDRO, M., BITTANTE, G., 2007: Milk coagulation ability of five dairy cattle breeds. Journal of Dairy Science, 90, 8: 3986−3992. ISSN 0022-0302.

DOLEJŠ, J., TOUFAR, O., KNÍŽEK, J., 1996: The temperature of rearing enviroment affects on milk chemical composition. (In Czech), Náš Chov, 7: 20. ISSN 0027-8068.

ERBEZ, M., FALTA, D., CHLÁDEK, G., 2010: The relationship between temperature and humidity outside and inside the permanently open-sided cow's barn. Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis. LVIII, 5: 91−96. ISSN 1211-8516.

F10A,,0L0T000A D., WALTEROVÁ L., SKÝPALA M., CHLÁDEK G., 2008: Effect of stable microclimate on milk production of Holstein cows on the 2nd and 3rd lactation. Animal welfare, etológia és tartástechnológia. [online] 7, URL:http://www.animalwelfare.szie.hu/Cikkek/200802/Szarvasmarha/AWETH2008104110.pdf.

GADER, AZA, AHMED M-KA, MUSA LM-A, PETERS KJ, 2007: Milk yield and reproductive performance of Friesian cows under Sudan tropical conditions. Archiv Tierzucht. 50, 155−64. ISSN 0003-9438.

GAJDŮŠEK, S., 1999: Milk processing II – practise. Mendel University in Brno, (in czech), p 92.

HAENLEIN, G., 2003: Nutritional value of dairy products of ewe and goat milk. Retrieved January 28, from http://ag.udel.edu/extension/information/goatmgt/gm-10.htm.

HAHN, G. L., 1999: Dynamic response of cattle to thermal heat loads. Journal of Animal Science, 77: 10−20. ISSN 0021-8812.

HANUŠ, O., FRELICH, J., JANŮ, L., MACEK, A., ZAJÍČKOVÁ, I., GENČUROVÁ, V., JEDELSKÁ, R., 2007: Impact of different milk yields of cows on milk quality in Bohemian spotted cattle. Acta Veterinaria Brno, 76: 563−571. ISSN 1801-7576.

HANUŠ, O., FRELICH, J., TOMÁŠKA, M., VYLETĚLOVÁ, M., GENČUROVÁ, V., KUČERA, J., TŘINÁCTÝ, J., 2010: The analysis of relationships between chemical composition, physical, technological and health indicators and freezing point in raw cow milk. Czech Journal of Animal Science. 55, 1: 11−29. ISSN 1212-1819.

HANUŠ, O., KUČERA, J., YONG, T., CHLÁDEK, G., HOLÁSEK, R., TŘINÁCTÝ, J., GENČUROVÁ, V., SOJKOVÁ, K., 2011: Effects of sires on wide scale of milk indicators if first calving Czech Fleckvieh cows. Archiv Tierzücht, 54, 1: 36−50. ISSN 0003-9438.

HANUŠ, O., VYLETĚLOVÁ, M., GENČUROVÁ, V., JEDELSKÁ, R., KOPECKÝ, J., NEZVAL, O., 2008: Hot stress of Holstein dairy cows as substantiv factor of milk composition. Scientia Agriculturae Bohemica, 39 (4): 310−317. ISSN 0582 - 2343.

CHLÁDEK, G., ČEJNA, V., 2005: Measuring of rennet coagulation time by Nephelo-turbidimetric sensor of milk coagulation. Mléko a sýry 2005, (In Czech), Prague, 127−130. ISBN 80-8623-8-48-2.

CHLÁDEK, G., ČEJNA, FALTA. D., MÁCHAL., 2011: Effect of season and herd on rennet coagulation time and other parametres of milk technological quality in Holstein dairy cows. Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis. LIX, 5: 00−00. ISSN 1211-8516.

IKONNEN, T., MORRI, S., TYRISEVÄ, A. M., ROUTTINEN, O., OJALA, M., 2004: Genetic and phenotypic correlations between milk coagulation properties, milk production traits, somatic cell count, cassein content and pH of milk. Journal of Dairy Science., 87: 458−467. ISSN 0022-0302.

JANŮ, L., HANUŠ, O., FRELICH, J., MACEK, A., ZAJÍČKOVÁ, I., GENČUROVÁ, V., JEDELSKÁ, R., 2007: Influence sof different milk yields of Holstein cows on milk quality indicators in the Czech Republic. Acta Veterinaria Brno, 76, 4: 553−561. ISSN 1801-7576.

JÕUDU, I., HENNO, M., KAART, T., PÜSSA, T., KÄRT, O., 2008: The effect of milk protein on the rennet coagulation properties of milk from individual dairy cows. International Dairy Journal, 18, 9: 964−967. ISSN 0958-6946.

KADZERE, C. T., MURPHY, M. R., SILANIKOVE, N., MALTZ, E., 2001: Heat stress in lactating dairy cows: a review. Livestock Production Science, 77: 59−91. ISSN: 0301-6226.

KVAPILÍK, J., RŮŽIČKA, Z., BUCEK, P., 2011: Ročenka. Chov skotu v České Republice. 36−37. ISBN 978-80-904131-6-0.

LACROIX, C., VERRET, P., PAQUIN, P., 1996: Regional and seasonal variations of nitrogen fraction in commingled milk. International Dairy Journal, 6: 947−961. ISSN: 0958-6946.

MADER, T. L., DAVIS, M. S., 2004: Effect of management strategies on reducing heat stress of feedlot cattle: Feed water intake. Journal of Animal Science, 82: 3077−3087. ISSN 0021-8812.

MAUST, L. E., MCDOWELL, R. E., HOOVEN, N. W., 1972: Effects of summer weather on performance of Holstein cows in three stages of lactation. Journal of Dairy Science, 55: 1133−1139. ISSN 0022-0302.

McDOWELL, R. E., HOOVEN, N. W., CAMOENS, J. K., 1976: Effects of climate on performance of Holstein in first lactation. Journal of Dairy Science., 59: 965−973. ISSN 0022-0302.

MITLÖHNER, F. M., GALYEAN, M. L., MCLOGN, J. J., 2002: Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers. Journal of Animal Science, 80: 2043−2050. ISSN 0021-8812.

NÁJERA, A. I., DE RENOBALES, M., BARRON, L. J. R., 2003: Effects of pH, temperature, CaCl2 and enzyme concetrations on the rennet-clotting properte of milk: a multifactorial study. Food Chemistry, 80, 3: 345−352. ISSN 0308-8146.

NG-KWAI-HANG, K. F., HAYES, J. F., MOXLEY, J. E., MONARDES, H. G., 1984: Variability of test.day milk production and composition and relation of somatic cell counts with yield and compositional ganges of bovine milk. Journal of Dairy Science, 67: 361−366. ISSN 0022-0302.

NOVÁK, P., VOKŘÁLKOVÁ, J., BROUČEK, J., 2009: Effects of the stage and number of lactation on milk yield of dairy cows kept in open barn during high temperatures in summer months. Archiv Tierzucht. 52, 6: 574−586. ISSN 0003-9438.

OZRENK, E., INCI., S. S., 2008: The effect of seasonal variation on the composition of cow milk in Van Province. Pakistan Journal of Nutrition, 7 (1): 161−164. ISSN 1680-5194.

PETRIKOVIČ, P., SOMMER, A., 2002: Potreba živín pre hovězí dobytok. Výskumný ústav živočišnej výroby Nitra, 6: 3−60. ISBN 80-88872-21-9.

SEKERDEN, O., 1999: Effects of calving season and lactation order on milk yield and milk components in Simmental cows. Turkish Journal of Veterinary and Animal Sciences, 23: 79−86. ISSN 1300-0128.

SEVI, A., ANNICCHIARICO, G., ALBENZIO, M., TAIBI, L., MUSCIO, A., DELL´AQUILA, S., 2001: Effects of solar radiation and feeding time on behavior, immune responses and production of lactating ewes under high ambient temperature. Journal of Dairy Science, 84: 629−640. ISSN 0022-0302.

TUCKER, H. A., 1989: Photoperiod affects intake, growth and milk production of cattle. Feedstuffs, 61: 15−16.

VOKŘÁLKOVÁ, J., NOVÁK, P., 2005: Climatic extrems and lactation. (In Czech), Náš chov, 9: 40−42. ISSN 0027-8068.

WALTEROVÁ, L., ŠAROVSKÁ, L., FALTA, D., CHLÁDEK, G., 2009: Relation between some climate parametres inside and outside the stable in the course of the year. Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis. LVII, 4: 125−132. ISSN 0165-7380.

WEST, J. W., 2003: Effects of Heat-Stress on production in Dairy Cattle. Journal of Dairy Sciences, 86: 2131−2144. ISSN 0022-0302.

YETISMEYEN, A., 2000: Milk technology. Ankara, Ankara University Agriculture Faculty Press No: 1511.

SUMMARY

Tato studie probíhala na dvou farmách (A, B) u dvou stád chovaných na území Jihomoravského kraje (Česká republika). Na farmě A bylo chováno stádo holštýnského skotu, na farmě B byly dojnice českého strakatého plemene. Celkem bylo odebráno 64 vzorků syrového kravského mléka v období od 17.června 2010 do 19.ledna 2011. Průměrné hodnoty technologických parametrů mléka byly zjištěny následovně: čas srážení 211 sekund, titrační kyselost 7,6 °SH, kvalita sýřeniny 1,55, obsah tuku 4,09%, obsah bílkovin 3,46%, obsah laktózy 4,78% a tukuprostá sušina 8,85%. Průměrná denní teplota byla 12,29 °C. Vliv sezóny byl statisticky průkazný u téměř všech sledovaných parametrů, jedinou výjimkou byl obsah laktózy na farmě A. Při porovnání výsledků získaných v průběhu roku byla zaznamenána nejnižší hodnota času srážení v letním období, zatímco v zimě byla naměřena nejvyšší hodnota. V letním období byly zaznamenány nejnižší hodnoty u obsahu: tuku, bílkovin a tukuprosté sušiny. Na podzim byla naměřena nejnižší hodnota u obsahu laktózy, zatímco u obsahu tuku a bílkovin byla nejvyšší. Vliv plemene téměř ve všech případech byl statisticky neprůkazný, jedinou výjimkou byl obsah tuku a tukuprosté sušiny.

Maximální rozdíly mezi oběma plemeny byly následující: čas srážení 80 sekund, titrační kyselost 1,22 °SH, kvalita sýřeniny 1, obsah tuku 0,84 g.100g-1, obsah bílkovin 0,69 g.100g-1, obsah laktózy 0,34 g.100g-1, obsah tukuprosté sušiny 0,8 SNF g.100g -1. Porovnáme-li průběh teplot v obou lokalitách, je možné konstatovat, že trend v růstu a poklesu teplot byl téměř stejný v průběhu sledovaného období, a že průměrný rozdíl teplot mezi chovy činil 2 °C. Tento rozdíl teplot byl dán jiným umístěním farem v regionu jižní Moravy. Je možné konstatovat, že nejnižší hodnoty času srážení byly shodně zaznamenány na obou farmách v průběhu letní sezóny.

CONTACT

Ing. Ondřej Polák

Mendel University in Brno

Zemědělská 1

613 00 Brno

Czech Republic

Phone number: +420 702 201 146

e-mail: xpolak@mendelu.cz

The impact of dry and wet events on the quality and yield of Saaz hops in the Czech hop growing regions

V. Potop

Czech University of Life Sciences Prague, Department of Agroecology and Biometeorology, Prague, Czech Republic, potop@af.czu.cz

Abstract

This study deals to investigate the impact of dry and wet conditions on the inter-annual variability of yield and quality parameters of hops (*Humulus lupulus* L.) in the Czech hop cultivation regions. The Standardized Precipitation Evapotranspiration Index (SPEI) was used to quantify the dry and wet conditions for each month of the year and 6 accumulated lags from 1961 to 2012. The statistical analysis of hop production was conducted using the cultivation area (ha) and yield of Saaz semi-early red bine hop (t/ha) over the Czech Republic as a whole (1920–2012) and for three Czech hop growing regions (1992-2012). Datasets of alpha-acids content (%) of Saaz semi-early red bine hop between 1967 and 2012 for Žatec and from 1992 to 2012 for Úštěk and Tršice regions were processed. Additionally, data of alpha-acids content (%) of Bór and Sládek hybrid varieties growing in Žatec region (1979-2012) was obtained from Hop Research Institute Saaz.

Key words: SPEI, alpha-acids content, hybrid varieties, Bór, Sládek

Introduction

The hop growing in the Czech Republic is concentrated in three hop cultivation regions (Žatec, Úštěk, Tršice) out of which the largest and most important is the Žatec area. At present hops cultivation areas are significantly less represented at 2%. The growing season of hops (from bud burst to cone development) takes 102 days on average with the sum of air temperatures 1537

°C, the duration of sunshine is 731 hours, the rainfall amount is 176 mm and with 28.5 days with precipitation total of at least 1 mm (Hájková L. et al. 2012).

The growth and development of hops plants is adversely influenced by droughts, moreover, an essential part of Žatec hop-growing region is situated in the rain shadow. The lowland regions of the Czech Republic experienced a general drying trend in the spring months at short-term lags, whilst at the end of the 20th century, drought during the April-June period became a factor explaining a considerable proportion of the yield variability (Potop et al., 2014). Moisture deficit during the hop growing season was found to cause reductions in hop cone yield (e.g. Hnilickova et al. 2009).

In this study deals to investigate the impact of drought (wet) on the inter-annual variability of yield and quality parameters of hops using the Standardized Precipitation Evapotranspiration Index (SPEI).

MATERIALS AND METHODS

The statistical analysis of hop production was conducted using the growing area (ha) and the yield of Saaz semi-early red bine hop (t/ha) over the Czech Republic as a whole (1920–2012) and for Žatec, Úštěk and Tršice growing regions (1992-2012). Dataset of the content of alpha-bitter acids (%) of Saaz semi-early red bine hop from 1967 to 2012 for Žatec and from 1992 to 2012 for Úštěc and Tršice regions was processed. In addition, content of alpha-bitter acids (%) of Bór and Sládek hybrid varieties growing in Žatec region in the period 1979-2012 was obtained from Hop Research Institute Saaz.

To identify the impact of the SPEI inter-annual variability of yield and quality parameters of hops, the evolution of cumulative moisture conditions from 1 to 6-month lags from 1961 to 2012 was applied. In the current study, recently improvement methods to calculate the SPEI was used (Beguería et al., 2013). The SPEI dataset used in this paper was downscaled from the SPEI Global Drought Monitor (http://sac.csic.es/spei.htm) at Žatec, Doksany and Olomouc climatological stations coordinates.

The indicator of agricultural drought impact may be represented by the residuals of the de-trended yield. To eliminate bias due to non-climatic factors, the trend was removed using linear regression when calculating yield variability. The residual variation reflects the effects of weather on yield, and the residuals amplify the yield departures from normal weather conditions. To compare α-acids contents variability among varieties and regions with different mean values and standard deviations, the α-acids contents residuals were standardized for each hop series using the Z-score transformation, quantifying the original score in terms of the number of standard deviations that the score is from the mean of the distribution. Subsequent analyses were done on the standardized content of alpha-bitter acids residuals series. The impact of the SPEI inter-annual variability on the yield and quality parameters of hops was evaluated by correlations of the non-parametric Spearman's Rho coefficient.

RESULTS

Statistical analysis of productivity parameters of hop varieties

A more detailed analysis of the average Saaz yields (tha^{-1}) and cultivated areas (ha) over the Czech Republic as a whole (1920–2012) and for three Czech hop growing regions (1992-2012) was conducted (Table 1). At the national level, the Saaz yield series show significant inter-annual variation and their average value for the 1920-2012 period was 0.9 tha^{-1} with a large values of the variation coefficient (Cv=0.28). The highest historically yields was achieved in 2010 (1.9 tha^{-1}), while the lowest harvested yields in 1952 (0.3 tha^{-1}).

As shown in tab. 1, the extent of Saaz hop land area has been reduced. The highest cultivation area was recorded in 1929 (17264 ha), and the lowest in 2012 (only 4366 ha). The year 1929 was significantly for the Czech Republic and undoubtedly was the largest producer of hops in the world, both in terms of production areas and export. The reduction cultivation areas are most pronounced in the 2000s over Úštěk and Tršice hop-growing regions.

In the tab. 1 is also statistically processed quality parameters such as average α-acids content (%) of Saaz hops in the three growing areas. The longest time series of α-acids content are available between 1967 and 2012 at Žatec, while at Úštěk and Tršice for the period 1994-2012. The alpha-acid contents varied from year to year and from region to region. In Žatec the lowest α-acid was achieved in 1999, and the highest in 1968. Whilst in Úštěk and Tršice regions, the minimum α-acids content was recorded in 1994, and reached a peak in 1996.

Tab. 1 The quality and yield parameters of Saaz semi-early red bine hop at the country and region levels

		Žatec	**Uštěk**	**Tršice**
	1920-2012	1992-2012		
yield tha^{-1}				
mean	0.9	1.0	1.1	1.3
min	0.3 (**1952**)	0.8 (**2000**)	0.9 (**1994**)	0.8 (**1993**)
max	1.9 (**2010**)	1.5 (**2010**)	1.5 (**2005**)	1.8 (**2005**)
Cv	0.28	0.18	0.15	0.23
cultivation areas (ha)				
mean	9181.3	4988.2	920.9	778.4
min	4366.0 (**2012)**	3400.0 (**2012**)	466.0 (**2012**)	500.0 (**2012**)
max	17264.0 (**1929**)	7672.0 (**1993**)	1884.0 (**1993**)	1153.0 (**1992**)
Cv	0.28	0.28	0.46	0.26
alpha-acids content (%)				
	-	1967-2012	1994-2012	
mean	-	3.9	3.5	3.4
min	-	1.9 (**1999**)	2.0 (**1994**)	2.3 (**1994**)
max	-	6.8 (**1968**)	4.4 (**1996**)	4.8 (**1996**)
Cv	-	0.28	0.19	0.23

Tab. 2 The alpha-acids content (%) in hybrid varieties growing in Žatec area (1979- 2012)

	hybrid varieties	
	Bor	Sládek
mean	8.9	8.0
min	5.5 (**1998**)	5.4 (**1983**)
max	13.0 (**1987**)	11.2 (**1988**)
Cv	0.20	0.20

Table 2 shows the descriptive statistics of α-acids content in hybrid varieties for Žatec area over the period 1979-2012. The hybrid varieties are more productive than Saaz hops, and yields are also more stable. The minimum values of α-acids content were in the years 1998 (Bor) and 1983 (Sladek), the maximum values were in the years 1987 (Bor) and 1988 (Sladek). The low temperatures in the first ten-days of August and the lack of soil moisture (SPEI≤-1) in 1998 adversely affected the development of Bor hop cones. The extreme high summer temperature in 1983 adversely affected the α-acids content of Sladek.

Evolution of the hops yield residuals series

Variability of the yield residuals (t/ha) from linear trend of Saaz semi-early red bine hop at the country and region levels are shown in fig. 1. For the entire country, according to the values of yield residuals series from 1920 to 2012, the 39 years are qualified as normal (mean); 28 years correspond to high yield losses and 26 years to high yield increment. The majority of low-yielding years of Saaz hope were concentrated in the periods of 1921-1930, 1941-1950, 1951-1960 and 1990-2000. The 75 % of these years have been identified as severe and extreme drought years by the SPEI (e.g., 1961, 1964, 1974, 1990, 1992, 1994, 2000, 2003 and 2012). The highest-yielding years were in the following years: 1937, 1939, 1963, 1969, 1970, 1988, 2005, 2010, and 2011. The years 1992, 1998, 2000, 2003, 2006, 2007, and 2012 appear to have the highest yield losses over Žatec region. The analysis of the temporal evolution of the yield hop residuals series indicates similar crop failures at Úštěk and Tršice regions (2012, 2003, 2000, 2007, 1994, and 2006). Thus, 2012 ranked at the top with respect to hop yield losses since 1992.

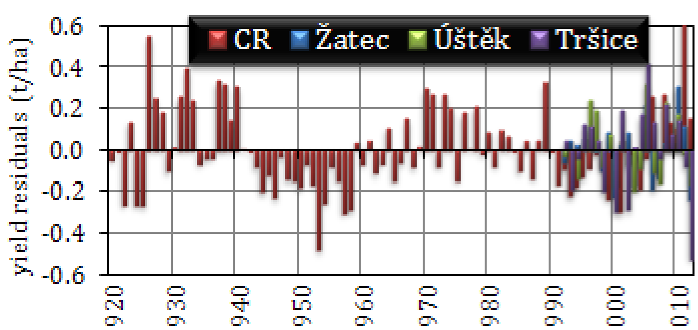


Fig. 1 *Variability of the yield residuals (t/ha) from linear trend of Saaz semi-early red bine hop at the country and region levels*

Evolution of standardized of α - acids content series

Standardized of alpha-acids content of Saaz semi-early red bine hop for 1967-2012 period at Žatec and 1992-2012 period at Úštěk and Tršice regions are shown in fig. 2. For Saaz hop, quality reduces in the Žatec cultivation area were detected by the standardized of alpha-acids content series for the years 1976 (-2.2), 1983 (-1.9), 1994 (-1.5), 1989 (-1.1) and 2006 (-1.0), and for the Úštěk area during the years 1994 (-1.5) and 2006 (-1.4). Over Tršice region, the highest alpha-acids content reduces were in 1994 (-1.2), 2002 (-1.2), 2006 (-1.1), and 2007 (-1.0).

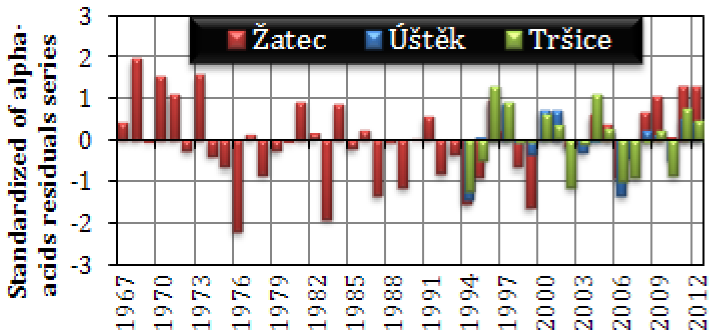


Fig. 2 *Standardized of alpha-acids content of Saaz semi-early red bine hop for 1967-2012 period (Žatec) and 1992-2012 period (Úštěk and Tršice regions)*

Figure 3 depicts temporal evolution of standardized of alpha-acids content of Bór and Sládek varieties growing in Žatec region for 1979-2012. The number of years with a standardized of alpha-acids content of Bór lower (higher) than -1.0 (+1.0) was 10 (12), whereas for Sládek was 12 (10). The standardized of alpha-acids content of Sládek detected reduces in the following years: 1999, 1983, 1998, 1982, 1990, 1994, 1986, 1992, 2011, 2004, 1989 and 2002 (scored by the highest losses), while for the Bór the highest losses occurred in 1998, 1983, 1994, 1991, 2002, 1992, 2008, 2006, 1979, and 1982.

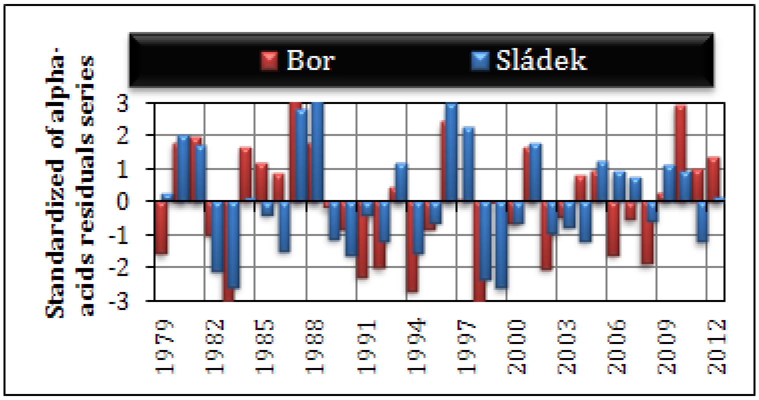
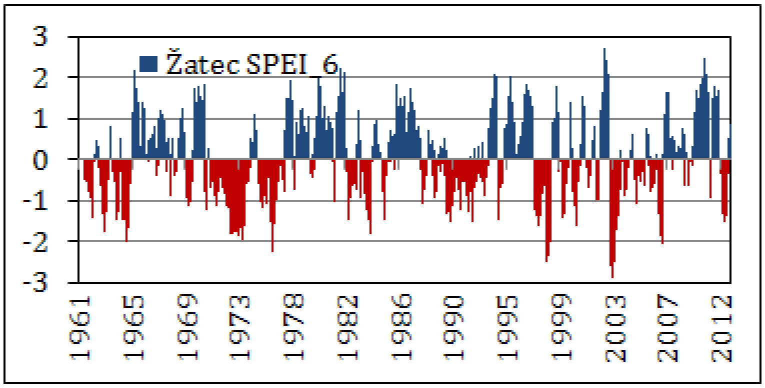
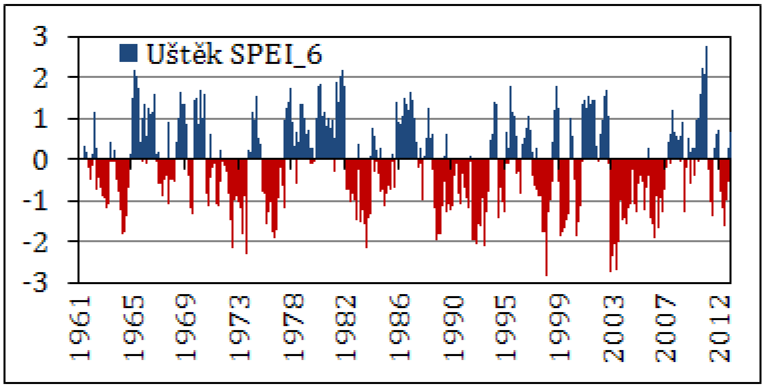


Fig. 3 *Standardized of content of alpha-bitter acids (%) of Bór and Sládek varieties for 1979-2012 period (Žatec region)*

Evolution of moisture conditions in the Czech hop cultivation areas

Moisture conditions in the Czech hop cultivation areas between 1961 and 2012 are illustrated by SPEI variation. Temporal evolution of dry and wet events quantified by the SPEI at 6-month lags (upper panel) and frequency distribution





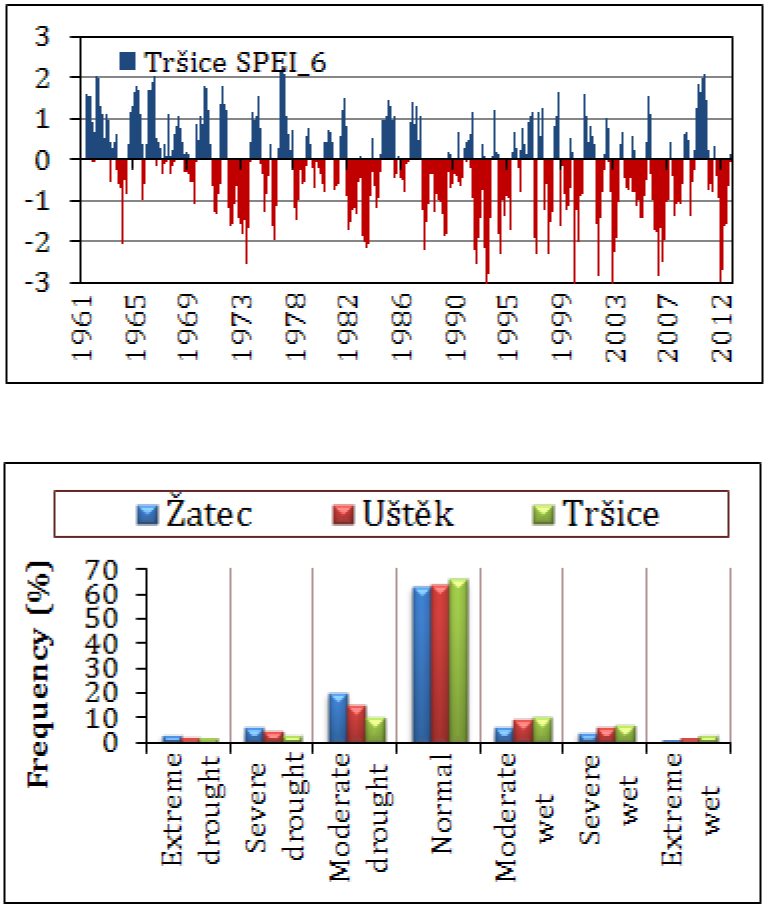


Fig. 4 *Temporal evolution of dry and wet events quantified by the SPEI at 6-month lags (upper panel) and frequency distribution (%) of the SPEI values during the growing season (April-September) in 7 classes of moisture categories (bottom panel) for the period 1961-2012*

of the SPEI values during the growing season (April-September) in 7 classes of moisture categories (bottom panel) from 1961-2012 are shown in fig. 4.

The 6-month lag contains moisture conditions from the current month and the past five months, and was used for computing the SPEI value for a given month. The normal moisture condition (SPEI values > -0.99 or < 0.99) among the three cultivation areas varies between 63 and 66 %. Moderate drought (ranges from 10 to 20 %) prevailed over moderate wet conditions (from 6 to 10 %). Severe drought (SPEI values from -1.50 to -1.99) and severe wet (SPEI values from 1.50 to 1.99) are almost equally distributed. However, the occurrence of extreme moisture conditions has a tendency toward dry conditions (SPEI≤-2.), especially for the Žatec area.

In the case of the Žatec region, the main and most severe drought episodes occurred in 1961-1964, 1971-1976, 1982-1983, 1989-1994, and 2003-2007, as indicated by the SPEI at 6-mo lags. In Uštěk growing area the main drought episodes were identified by the SPEI-6 in 1961-1964, 1975-1976, and 1988-1994, 1998-2000, 2003-2007, and 2011-2012. In accordance with the SPEI at 6-month lags, the persistence and extent of the droughts were recorded in Tršice in 1982-1983, 1989-1994, and 2003-2009.

The impact of dry (wet) events on the quality and yield parameters

Table 3 summarised the correlation coefficients between the monthly SPEI at 1-, 2-, 3- and 6-month lags, temperatures, precipitation and standardized of α - acids content (yield). The relation between the SPEI and the yield of Saaz hops explained from 20 to 53% of the regional yield variability.

For instance, fig. 5 shows the relationship between the monthly SPEI at 1-month lag during April-August and the annual yield, and alpha-acids of Sazz hops in the period 1992-2012 over Žatec cultivation area. The correlations indicate that year-to-year variations in both yield and α - acids content series are related to the year-to-year variation in the SPEI series. That is, higher yields (α - acids content) are observed in moderately wet and normal years, and lower yields (α - acids content) occurred under severely and extremely dry/wet conditions. The correlation analysis over the last two decades showed that the yield-responses to drought (wet) conditions increased from the beginning of hop growing season to the month of August. One key result is that, for Žatec region, the appearance of moisture deficit (SPEI≤-1) was more frequent at the very beginning of the growing season (April, r = -0.20, p = 0.05). The strongest correlation of the SPEI was demonstrated for May (r = 0.53, p = 0.01). In June, the correlation weakened (r = 0.21, p = 0.01), while slightly higher but still significant influences were seen in July (r = 0.33, p = 0.05) and August (r = 0.45, p = 0.05).

Tab. 3 Correlation coefficients between the monthly SPEI at 1-, 2-, 3- and 6-month lags, air temperature (t° C), precipitation (p, mm) and yield residuals/ standardized of α – acids

	t °C	**p, mm**	**SPEI-1**	**SPEI-2**	**SPEI-3**	**SPEI-6**
yield residuals (t/ha)						
April	-0.44**	-0.13	-0.15	-0.14	-0.19	-0.12
May	-0.30*	0.01	0.10	-0.01	-0.01	-0.10
June	-0.29*	0.11	0.15	0.18	0.10	0.10
July	-0.54**	-0.07	0.31*	0.25*	0.33*	0.24*
August	-0.14	0.10	-0.26*	-0.41	-0.35	-0.23
standardized of α - acids						
April	0.10	0.01	-0.10	-0.27	-0.22	0.00
May	-0.43	0.50**	0.53*	0.43*	0.22	0.34
June	-0.26	0.10	0.21*	0.49**	0.43**	0.32
July	0.15	0.46**	0.33	0.31	0.56**	0.49**
August	-0.41	0.34*	0.45	0.57	0.51	0.57**

$^*p < 0.05$; $^{**}p < 0.01$

For quality parameters, as shown by fig. 5, correlation between the SPEI and α-acids contents is not noticeable. However, the positive and negative correlation between the SPEI and α - acids content becomes significant in July (r = 0.53, p = 0.01) and August (r = -0.30, p = 0.05), respectively. The impact of drought (wet) events detected by the SPEI from April to June on the alpha-acid content was not statistically significant at the level of risk $p < 0.05$.

Discussion

The obtained results in this study, as well as results of previous studies (Možny et al., 2009; Kucera and Krofta 2009; Pavlovic et al., 2012) show that temperature and rainfall temperature patterns and drought (wet) conditions, during the hop vegetation have a stronger influence on accumulation of alpha-acids in technological maturity of hop cones.

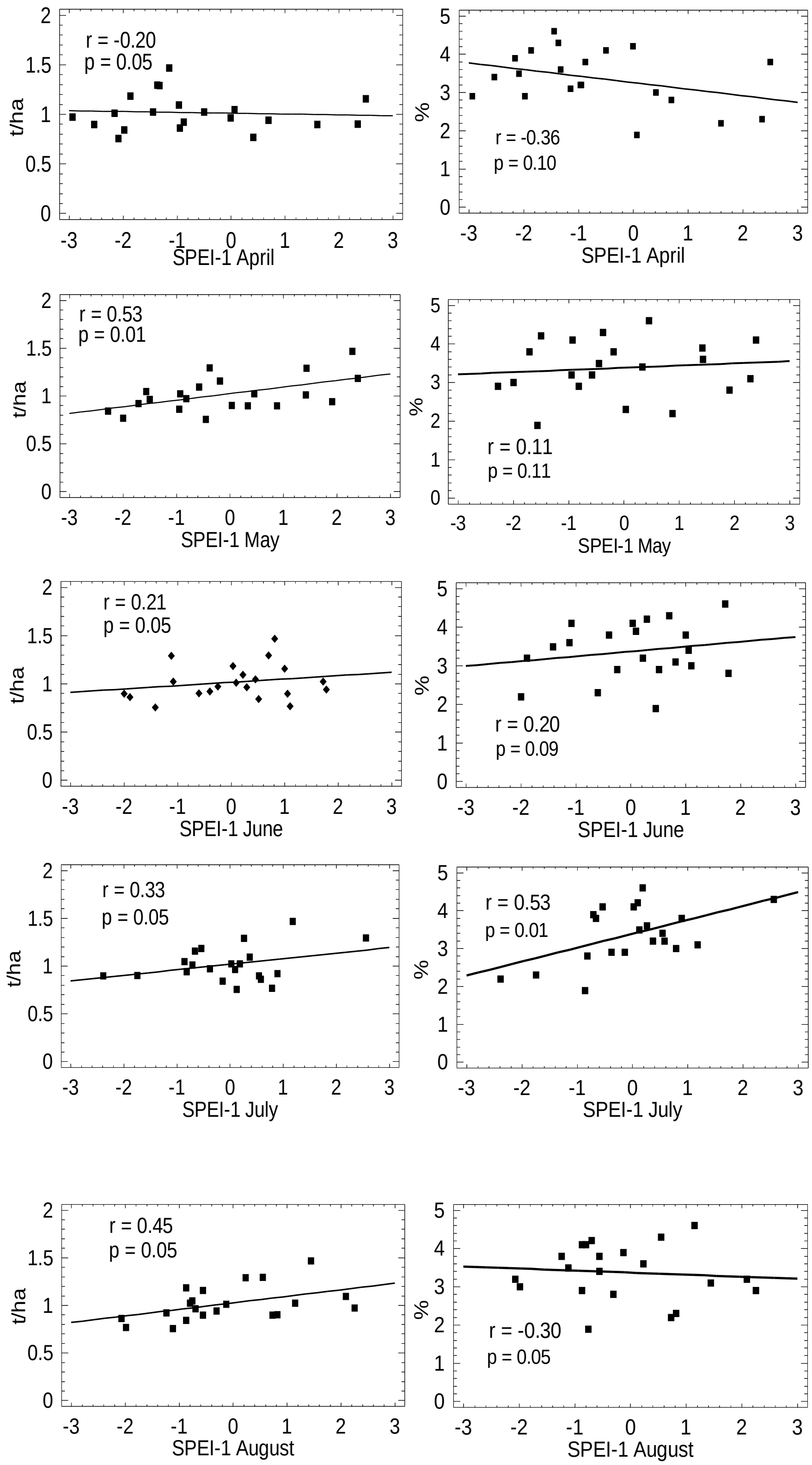


Fig. 5 *Relationship between the monthly SPEI at 1-month lag during April-August and the yield (t/ha), and alpha-acids content (%) of Sazz hops in the period 1992-2012 (Žatec)*

Several previous observation and modelling studies support this view, demonstrating that the dynamics of hop growth, generative development and the accumulation of α – acids have a very strong impact on yield and quality of hope cones. Mozny et al. (2009) found a positive impact of rainfall and a negative effect of temperature on alpha-acid contents for the period 1954-2006 over Žatec cultivation region. Kucera and Krofta (2009) found that the strongest influence on the alpha-acid content was exerted by air temperatures in July. Rainfall had significant effects during the period from May to July. The results of this study confirm the statements discussed above.

CONCLUSION

This study can be considered an initial step towards assessing the potential impacts of the dry and wet events detected by the SPEI on the yield and quality of hops varieties in the Czech hop cultivation regions. The evolution of wet, dry and normal episodes during hops growing season and their correlation with variability of the yield and quality parameters of hop varieties have been identified. This study also statistically analysis of the yield and quality of hops datasets in three hop-growing areas and the Czech Republic, as whole for Saaz semi-early red bine hop and selected hybrid varieties such as Bór and Sládek. The temporal evolution of production areas for individual growing region and at the country level was also evaluated. The preliminary obtained results show that the quality parameters of hops do not illustrate strong associations between the α-acids content and the SPEI; only a positive moderate correlation was observed in July.

REFERENCES

Beguería, S., Vicente-Serrano, S.M., Reig, F., Latorre, B. (2013): Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int. J. Climatol. DOI: 10.1002/joc.3887.

Kucera, J., Krofta, K. (2009): Mathematical model for prediction of yield and alpha acid contents from meteorological data for Saaz aroma variety. Acta Horticulturae, 848: 131–139.

Hájková, L. et al. (2012): Atlas of the phenological conditions in Czechia. ČHMÚ Praha, Univerzita Palackého v Olomouci, Praha-Olomouc, 311 p.

Hnilickova, H., Hnilicka, F., Svoboda, P., Koren, J. (2009): The impact of water deficit on selected physiological characteristics of juvenile hop plants (Humulus lupulus L.). Cereal Research Communications, 37: 301–304

Možný, M.,Tolasz, R., Nekovař, J., Sparks, T., Trnka M., Žalud, Z. (2009). The impact of climate change on the yield and quality of Saaz hops in the Czech Republic. Agricultural and Forest Meteorology. 149. 6-7, 913-919.

Pavlovic, V., Pavlovic, M., Cerenak, A., Kosir, I.J., Ceh, B., Rozman, C., Turk, J., Pazek, K., Krofta, K, Gregoric, G. (2012): Environment and weather influence on quality and market value of hops. Plant soil environ, 58, (4): 155–160

Potop et al. 2014. Performance of the standardized precipitation evapotranspiration index at various lags for agricultural drought risk assessment in the Czech Republic. Agricultural and Forest Meteorology. (under review).

ACKNOWLEDGEMENT

Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

SUMMARY

V této práci byla vyhodnocena závislost výnosu a kvality chmele na vláhových poměrech v průběhu vegetačního období chmele. Byl určen vývoj vlhkých, suchých a normálních měsíců vegetačního období v letech 1961-2012. Pro kvantifikaci sucha byl z řady různých charakteristik zvolen Standardizovaný srážkový evapotranspirační index (SPEI). V této práci byl pro hodnocení vláhových poměrů v průběhu vegetačního období chmele zpracován datový soubor z mezinárodního portálu monitoring sucha dle SPEI (http://sac.csic.es/spei/). Data byla stažena dle zeměpisných souřadnic klimatologických stanic Žatec, Doksany a Olomouc za období 1961-2012. SPEI byl počítán pro různé časové intervaly – 1, 2, 3 a 6 měsíců. Intervaly byly vybrány s ohledem na vegetační cyklus chmele a na nerovnoměrnou distribuci srážek a kolísání teplot v kratším intervalu než 6 měsíců.

Podrobněji byla analyzována a provedena korelace proměnlivosti výnosů chmele a obsahu α – hořkých kyselin u Žateckého poloraného červeňáku (ŽPČ) na kumulaci vláhového deficitu v průběhu vegetačního období. Veškerá data byla použita z lokalit Žatecké, Tršické a Úštěcké chmelařské oblasti. Pro každou chmelařskou oblast byla vypočtena četnost výskytu jednotlivých

kategorií sucha vymezených podle SPEI: extrémní vlhko, silné vlhko, mírné vlhko, normální, mírné sucho, silné sucho a extrémní sucho. Zároveň byla vyhodnocena dynamika růstu chmele a obsah α - hořkých kyselin jak v ŽPČ pro celou Českou republiku od roku 1920 – 2012 a pro jednotlivé pěstitelské oblasti od roku 1992 do 2012, tak u hybridních odrůd v období 1979 – 2012 pro Bór a Sládek.

Korelaci mezi SPEI a výnosem ŽPČ vysvětluje 20 až 53 % z fluktuace regionálního výnosů. Obsah α – hořkých kyselin ve chmelu je ročníkově značně proměnlivý, je závislý na průběhu povětrnostních podmínek v průběhu vegetační sezóny. Je zřejmé, že chmel v průběhu hlavních růstových fází, vyžaduje vyšší teploty, jež podporují tvorbu alfa hořkých kyselin, avšak i dlouhotrvající vysoké teploty v období počátku tvorby osýpky a počátku hlávkování, mají negativní dopad na výnos a obsah α – hořkých kyselin. Výsledky dále poukazují, že dosahovaný výnos a kvalita chmele v jednotlivých letech jsou ovlivněny průběhem počasí ve vegetačním období, a to především rozložením množstvím srážek a teplotami. Je velice obtížné hodnotit vliv povětrnostních podmínek na kvalitu a výnos chmele. Každý ročník je jiný a chmel pokaždé reaguje jinak, jak na teplotu, tak na srážky. I vysoký úhrn srážek v měsíci srpnu způsobuje pokles tvorby α – hořkých kyselin. Kritický byl rok 2012, jak pro celou ČR, tak pro jednotlivé produkční oblasti. Vlivem povětrnostních podmínek, kdy únorové holomrazy poškodily část porostů a následné sucho, umocněné vysokými teplotami v měsíci srpnu, v nejcitlivějším období tvorby výnosu, měly za následek snížení celkové produkce. Kritický rokem byl rok 2003, za posledních 52 let nejsušší, a i z pohledu alfa hořkých kyselin se ukazuje, že hybridní odrůdy reagují na povětrnostní podmínky odlišně, díky delší vegetační době.

CONTACT

Dr. Vera Potop

Česká zemědělská univerzita v Praze

Fakulta agrobiologie, potravinových a přírodních zdrojů

Katedra agroekologie a biometeorologie

Kamýcká 129

165 21 Praha 6 - Suchdol

potop@af.czu.cz

ASSESSMENT OF POTENTIAL EVAPOTRANSPIRATION AT CHISINAU STATION

V. POTOP[1], C. BORONEANT[2]

1) Czech University of Life Sciences Prague, Department of Agroecology and Biometeorology, Prague, Czech Republic, potop@af.czu.cz,

2) Center for Climate Change, Geography Department, University Rovira I Virgili, Tortosa, Spain, constanta.boroneant@urv.cat,

ABSTRACT

A comparison between two empirical methods for calculating potential evapotranspiration (PET), namely Hargreaves and Penman-Monteith is presented using the downscaled time series from CRU TS3.21 observation dataset at the closest grid point to Chisinau station coordinates, and observation series at Chisinau climatological station in the Republic of Moldova for the period 1951-2012. The Hargreaves PET model is based on minimum and maximum air temperature and extra-terrestrial radiation, while the Penman-Monteith method is based on minimum, maximum and mean air temperature, vapour pressure and cloud cover. The following diagnostic statistical quantities are analysed: (1) correlation coefficient (r) and (2) coefficient of determination (R in %).

Key words: potential evapotranspiration**,** Hargreaves method, Penman-Monteith metod

INTRODUCTION

Potential evapotranspiration (PET) is an important variable in drought identification to determine evaporative demand of the atmosphere. The PET concept was first introduced in the late 1940s and beginning of 1950s by Penman. It is defined as "the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile". Recent drought studies (e.g. Dai, 2011; Begueria et al., 2013) have enhanced the debate on the effect of actual evapotranspiration (ETa), reference evapotranspiration (ETo) and/or potential evapotranspiration (PET) on drought quantification. ETa is the water lost under real conditions. The ETo is defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, bulk surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, and no moisture stress " (Allen et al., 1994). Estimates of ETo are largely applied in irrigation schemes to define crop water requirements.

Since the 1940s a number of methods have been developed for calculating evapotranspiration. Based on the principal climatic element or physical process involved in the formula of its calculation these methods can be grouped into five categories: (1) water budget (Guitjens, 1982), (2) mass-transfer (Harbeck, 1962), (3) combination (Penman, 1948), (4) radiation (Priestley and Taylor, 1972), and (5) temperature-based (Thornthwaite, 1948). The Food and Agriculture Organization of the United Nations (FAO) and American Society of Civil Engineers (ASCE) have adopted the Penman-Monteith (PM) method as the standard for computing the PET from climate data (Allen et al., 1998; Penman, 1948). The PM equation requires extensive meteorological data and long-term records of these variables which are not always available. Hargreaves and Allen (2003) have demonstrated that the Hargreaves (Hg) method is the best alternative for quantifying evapotranspiration when accurate meteorological data are missing. The Hargreaves formula to calculate PET is a function of maximum and minimum temperature, and extraterrestrial radiation calculated as a function of latitude and the day of the year. Studies have demonstrated that PET estimates from the Hg and PM equations are very similar, with differences less than 2 mm per day (Droogers and Allen, 2002). Hargreaves and Allen (2003) showed that the monthly PET calculated with the Hg equation was within 97–101% of PET measured by a lysimeter for semi-arid and sub-humid regions of the United States.

The main objectives of this study are: 1) to compare the PET series calculated with Hargreaves method using CRU TS3.21 data downscaled at the closest grid point to Chisinau station coordinates and, using observation at station, and 2) to compare the CRU PET series calculate with a variant of Penman Monteith method with the PET calculated with Hargreaves method in the closest grid point to Chisinau station coordinates.

MATERIALS AND METHODS

This study was carried based on observational data recorded at a secular climatological station Chisinau available from Moldova's State Hydrometeorological Service for the period 1951-2012. The geographical coordinates of the station are 46°58'03''N; 28°51'23''E, and the altitude is 173 m above sea level. Due to the availability of quality controlled long and continuous series, we chose the Chisinau station as representative for Moldova domain to compare the time series of monthly averages of daily minimum (Tmin), daily maximum (Tmax) and daily mean (Tmean) of CRU TS3.21 at the closest grid point to the station coordinates, and station observations. These data were further used to calculate PET with Hargreaves method (Hargreaves and Allen, 2003) and to compare it with the PET CRU TS3.21 time series calculated with a variant of Penman Monteith method (Ekstrom at al. 2007). The Hargreaves method used in this study to calculate PET (Hargreaves and Samni, 1985) is:

$$PET = 0.0023 \cdot Ra \cdot TD^{0.5} \cdot (Tm + 17.8) \qquad (1)$$

where

Ra - extraterrestrial radiation (MJ $m^{-2}day^{-1}$)

TD - the difference between the maximum and minimum temperatures in °C

Tm - the average monthly temperature (t_{max}+ t_{min}/2).

The variant of Penman Monteith method used by CRU to calculate PET in TS3.21 is based on minimum, maximum and mean air temperature, vapour pressure and cloud cover (Harris et al., 2014).

The following statistical quantities were analysed: (1) correlation coefficient (r) and (2) coefficient of determination (R^2). The R^2 of the best-fit regression line, which is the ratio of the explained variance to total variance, is used to determine the quality of the fit between the Hg and PM estimates for PET.

RESULTS

At the first stage, the CRU TS3.2 time series of monthly averages of daily minimum, maximum and mean air temperature at the closest grid point to Chisinau station coordinates have been compared with the corresponding series of observations. The left panels of Figure 1 present the comparison between the multiannual means of Tmean, Tmax and Tmin calculated for the closest grid point to station coordinates from CRU TS3.21 and the corresponding series of observations. The results show that the CRU data does quite well in representing the multiannual means of daily extremes (t_{max} and t_{min}) and mean air temperature (t_{mean}). Slightly differences are observed in the right-hand panels of Figure 1 where the frequency distribution of temperature CRU TS3.21 series and station series are represented on a single graph axially-symmetric.

The values of CRU series t_{mean} range between -11.5 and 24.9 °C while at station the t_{mean} values range between -11.9 and 26.0 °C, respectively. The t_{max} (t_{min}) values of CRU series range between 7.9 and 31.4 °C (-15.2 to 19.1 °C) while at station the values range between -8.7 and 32.6 °C (-15.4 and 20.2 °C), respectively

The differences in the frequency distribution of CRU TS3.21 series and observation series at station can be explained by the CRU metadata corresponding to the cell centred at 47.25ºN; 28.75ºE. The values in that grid point depend on the number of stations that could have influenced the data value for that cell for each time step. The sphere of influence is the correlation decay distance, which is 750 km for diurnal temperature range, and 1200 km for mean temperature (New et al,2000). The averaged number of stations that have influenced the values in the closest CRU TS3.21 grid point to station coordinates is 92.

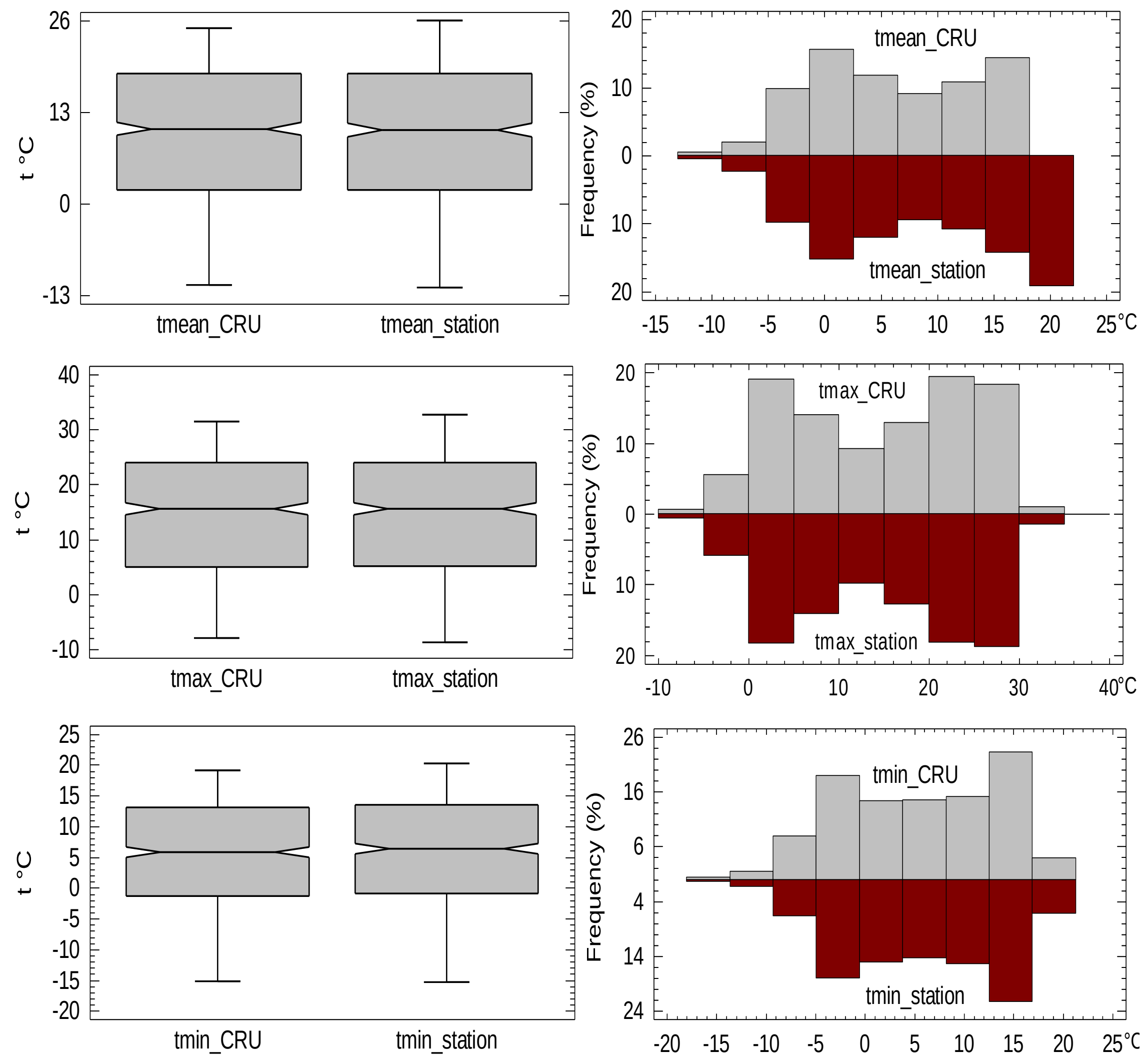


Fig. 1 Comparison between the multiannual means of monthly averages of daily means, daily maximum and daily minimum of CRU TS3.21 series at the closest grid point to Chisinau station coordinates and the corresponding series of station observations (1951-2012). The height of the box portion shows the interquartile range of the dataset, and range between the 25th and the 75th percentiles. The horizontal bar within the box represents the median value. The margins of the whiskers indicate the 10th and 90th percentile values, respectively

At the second stage of the study, we calculated PET with Hargreaves method using as input data the series of Tmax and Tmin both for CRU TS3.21 series downloaded at the closest grid point to Chisinau station coordinates, and for series of observations at station. The estimates of PET with Hg method using CRU data is almost similar to PET with Hg method using observations at Chisinau station (Fig. 2a). This result is supported by the CRU TS3.21 metadata which shows that the actual number of all station observations in the cell centred at 47.20ºN; 28.75ºE is 1 which actually is the Chisinau station.

Next, the differences between estimates of PET with two empirical methods - Penman-Monteith and Hargreaves – based on CRU data at the closest grid point to Chisinau station and based of observations at station were analysed. Fig. 2a shows the comparison between the multiannual mean of monthly PET of CRU_PM series at the closest grid point to station coordinate, and PET_Hg series calculated with CRU and station data for the period 1951-2012. The estimates of PET_Hg range between 0.0 and 5.9 mm/day, while the estimates of PET_PM range between 0.0 and 6.6 mm/day. The scatter plot of the differences between the time series PET_Hg and PET_PM based on CRU data at the closest grid point to station coordinates is shown in Fig. 2b. The correlation coefficient between these time series of PET is very high (r = 0.99) while the coefficient of determination indicates that the regression line perfectly fits the PET series (97.38%). These results show that PET_Hg is a reliable method to estimate PET_PM at Chisinau station with limited input meteorological data.

(a) (b)

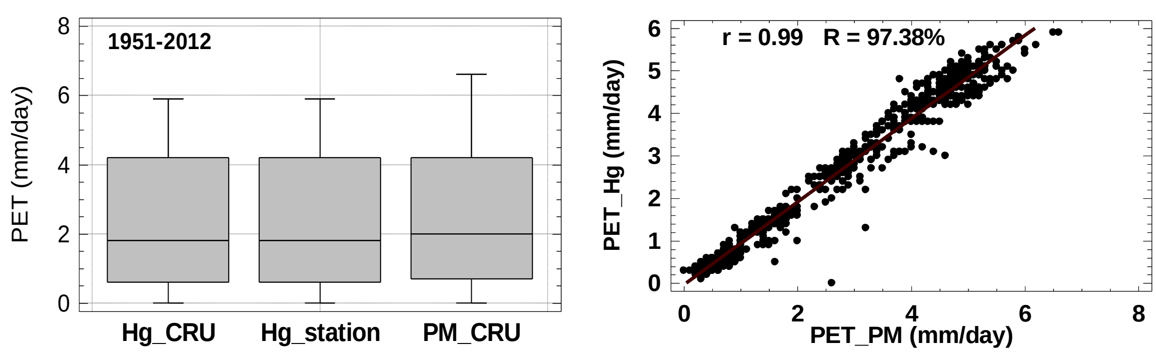


Fig. 2 (a) Box plot of multiannual mean of monthly potential evapotranspiration (PET, mm/day) estimates with Hargreaves method based on CRU TS3.21 data at the closest grid point to Chisinau station coordinates (Hg_CRU), and based on station observations (Hg_station) and, CRU TS3.21 series of PET estimates with Penman-Monteith (PM_CRU) for the period 1951-2012 ; (b) Scater plots of monthly PET series calculated with Hg and PM methods based on CRU TS3.21 data, and the correlation coefficient between these two series of PET

Detailed results on the correlation and various statistics of monthly PET_Hg and PET_PM based on CRU TS3.21 series at the closest grid point to Chisinau station coordinates for the period 1951-2012 are summarized in Table 1.

Table 1 *Statistics of monthly potential evapotranspiration (mm/day) estimates with Hargreaves (Hg) and Penman-Monteith (PM) methods using CRU TS3.21 dataset*

	mean		STDev		Min		Max		r	R^2 (%)	MAE
	Hg	PM	Hg	PM	Hg	PM	Hg	PM			
Jan	0.4	0.4	0.1	0.2	0.2	0.0	0.6	1.0	0.65	41.9	0.1
Feb	0.6	0.7	0.2	0.3	0.3	0.4	1.0	1.6	0.74	54.1	0.1
Mar	1.4	1.4	0.3	0.4	0.9	0.7	2.0	2.6	0.94	88.7	0.1
Apr	2.7	2.8	0.3	0.4	2.0	1.8	3.5	3.9	0.88	77.4	0.1
May	4.1	4.1	0.3	0.5	3.3	3.0	4.9	5.5	0.92	84.3	0.1
Jun	4.9	4.7	0.4	0.5	4.2	3.7	5.6	6.2	0.89	79.8	0.1
July	5.0	5.1	0.3	0.5	4.3	4.1	5.8	6.6	0.92	85.1	0.1
Aug	4.3	4.6	0.3	0.4	3.6	3.5	5.0	5.6	0.90	81.6	0.1
Sep	2.9	3.0	0.3	0.2	2.1	2.0	3.3	4.0	0.86	74.0	0.1
Oct	1.5	1.6	0.2	0.3	1.2	1.0	1.9	2.0	0.73	53.4	0.1
Nov	0.6	0.7	0.1	0.2	0.5	0.3	1.0	1.6	0.79	62.1	0.1
Dec	0.4	0.4	0.1	0.1	0.3	0.1	0.5	0.8	0.45	20.6	0.1

The Table 1 presents the monthly means (mean) and the standard deviations (STDev) of PET_Hg and PET_PM series, the lowest (Min) and the highest (Max) values of these series, the correlation coefficient (r), the coefficient of determination (R^2) which indicates how well the regression line approximates the distribution of real data and, the mean absolute error (MAE) which is the average value of the residuals.

According to the correlation coefficients and the coefficient of determination for each month, it is obvious that the lowest likelihood between Hg and PM was found in January (r = 0.65; R^2 = 41.9%) and December (r = 0.45; R^2 = 20.6%). On the other hand, the highest likelihood between the monthly series of PET_Hg and PET_PM was identify in the following months: March (r = 0.94; R^2 = 88.7%), May (r = 0.92; R^2 = 84.3%), July (r = 0.92; R^2 = 85.1%) and August (r = 0.90; R^2 = 81.6%).

The next step of the comparison between monthly estimates of PET_PM and PET_Hg using the CRU data refers to the differences between the monthly multiannual means of these two series of PET estimates. The results are shown in Figure 3a. Relative high difference between the PET estimates with PM and Hg is shown in May (PET_Hg are slightly lower than PET_PM) and in June (PET_Hg are slightly higher than PET_PM). The lowest difference between the two estimates was found during winter and autumn months. The annual cycle of monthly PET calculated with

PM and Hg methods is presented in Figure 3b. The picture shows that July is the month with the highest water surface evapotranspiration in the Republic of Moldova, with a multiannual average of PET_Hg equal to 151.7 mm and of PET_PM equal to 157.1 mm, respectively. During the month of July the highest PET_Hg was 183.1 mm while PET_PM was 205.0 mm, and the lowest PET_Hg was 99.4 mm while PET_PM was 127 mm. The multiannual means of PET_Hg and PET_PM during summer were 428.9 mm and 441.0 mm, respectively for the period 1951-2012. The multiannual means of the annual PET_Hg and PET_PM range between 607.0 mm and 800.0 mm, and 748.0 mm and 1073.0 mm, respectively.

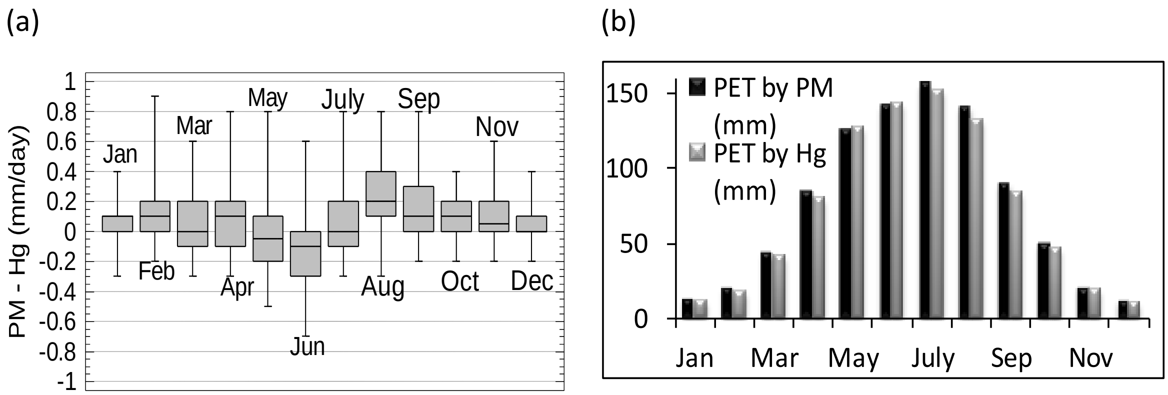


Fig. 3 (a) Box-and-whisker plot of the differences (mm/day) between PET estimates using PM and Hg methods. (b) Annual cycle of monthly PET calculated with PM and Hg methods

DISCUSSION

In the recent decades many authors have adopted the Penman-Monteith method as the standard way to estimate PET. The main drawback associated with this method is the relatively high data demand. An alternative approach where only mean maximum and mean minimum air temperature and extraterrestrial radiation are required is the Hargreaves method (Hargreaves and Allen, 2003). The Hg method has been intensively used because it produces very acceptable results under various climates. Though the most accurate method is the one that is physically based on the PM equation (Popova et al., 2006, Vicente-Serrano et al., 2007, Shahidian et at., 2013), the large number of parameters required for its calculation made it difficult to obtain due spatial coverage of data for PET calculations needed to assess the drought conditions at country level. A number of studies have demonstrated that PET estimates with Hargreaves for periods longer than 1 week (Hargreaves and Allen, 2003) provide similar results to those obtained using the Penman-Monteith equation. In the present study, we have also obtained similar results with both methods. In addition, previous studies (Potop, 2011) confirm that the role of temperature is evident in summer drought episodes, which depend on temperature anomalies that contribute to the increasing of PET. The extremely dry summer of 2007 in the Republic of Moldova is illustrative in regard of temperature roll for PET estimates As the results of the present study show, PET estimates with Hargreaves method can be considered as reasonable quantities to detect drought, under Moldova's currently warming climate.

Jensen et al. (1997) compared the PET_Hg estimates with PET calculated with other empirical methods and concluded that the differences in PET values computed with other methods were not larger than those introduced by measuring. Lopez-Urrea et al. (2006) compared seven PET equations in semiarid area in the southern Spain with lysimeter data and concluded that the Hargreaves method was the second best after the PM method. The use of Hargreaves method to calculate PET in various climates has helped researchers to search ways to improve precision of PET estimates at local scale where no previous data exist (Shahidian et at., 2013).

Conclusion

The CRU TS3.21 series of PET calculated with the Penman-Monteith method downscaled at the closest grid point to Chisinau station coordinates has been compared with the PET series calculated with Hargreaves method using CRU data and observation data at Chisinau station. The range of correlation coefficient between the PET series calculated with Hargreaves and Penman-Monteith methods range between 0.45 and 0.94 for all months. The results confirm, that Hargreaves method can be used as an acceptable alternative to Penman-Monteith method to estimate PET in the Republic of Moldova.

References

Allen, R.G., Smith, M., Pereira, L.S., Perrier, A. (1994): An update for the calculation of reference evapotranspiration. *ICID Bulletin* 43: 35–92.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998): Crop evapotranspiration: guidelines for computing crop requeriments. *Irrigation and drainage, paper 56*. FAO. Roma. Italia

Beguería, S., Vicente-Serrano, S.M., Reig, F., Latorre, B. (2013): Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *Int. J. Climatol*. DOI: 10.1002/joc.3887.

Dai, A. (2011): Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. *Journal of Geophysical Research* 116, D12115, doi:10.1029/2010JD015541

Droogers, P., Allen, R.G. (2002): Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst*. 16: 33–45.

Ekström, M., Jones,P.D., Fowler,H.J., Lenderink,G., Buishand,T.A., and Conway,D.: Regional climate model data used within the SWURVE project – 1: projected changes in seasonal patterns and estimation of PET, *Hydrol. Earth Syst. Sci.*, 11, 1069-1083, doi:10.5194/hess-11-1069-2007, 2007.

Guitjens, J. C. (1982): Models of Alfalfa Yield and Evapotranspiration. *Journal of the Irrigation and Drainage Division.* Proceedings of the American Society of Civil Engineers, 108(IR3): 212–222.

Harris, I., Jones, P.D., Osborn T.J., Lister, D.H. (2014): Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *Int. J. Climatol.* 34: 623–642

Harbeck, Jr., G. E. (1962): A Practical Field Technique for Measuring Reservoir Evaporation Utilizing Mass-transfer Theory, *U.S. Geol. Surv.,* Paper 272-E, pp. 101–105.

Hargreaves, G.L., Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. *Appl. Eng. Agric*. 1: 96–99.

Hargreaves, G.L., Allen, R.G. (2003). History and evaluation of Hargreaves evapotranspiration equation. *J. Irrigat. Drain. Eng.* 129: 53–63.

Jensen, D., Hargreaves, G., Temesgen, B., Allen, R. (1997): Computation of ETo under non ideal conditions. *Journal of Irrigation and Drainage Engineering ASCE.* 123(5): 394–400.

Lopez-Urrea, R., Martín de Santa, Olalla, F., Fabeiro, C., Moratalla, A. (2006): Testing evapotranspiration equations using lysimeter observations in a semiarid climate. *Agricultural Water Management.* 85: 15–26.

Martınez-Cob, A., Tejero-Juste, M. (2004): A wind-based qualitative calibration of the Hargreaves ET_o estimation equation in semiarid regions. *Agric Water Manage*. 64: 251–264.

New, M., Hulme, M. and Jones, P.D., 2000: Representing twentieth century space-time climate variability. Part 2: development of 1901-96 monthly grids of terrestrial surface climate. *Journal of Climate* **13**, 2217-2238

Penman, H. L. (1948): Natural Evaporation from Open Water. *Bare Soil and Grass', Proc.*, Royal Soc., London 193, 120–145.

Popova, Z., Kercheva, M., Pereira, L.S. (2006): Validation of the FAO methodology for computing ET_o with missing climatic data application to South Bulgaria. *Irrig. Drain.* 55: 201–215

Potop, V., (2011): Evolution of drought severity and its impact of corn in the Republic of Moldova. *Theoretical and Applied Climatology* 105, 468-483.

Priestley, C.H.B., Taylor, R.J. (1972): On the assessment of the surface heat flux and Evaporation using Large-scale Parameters. *Monthly Weather Review.* 100: 81–92.

Shahidian, S., Serralheiro, R. P., Serrano J.,Teixeira J. L. (2013): Parametric calibration of the Hargreaves–Samani equation for use at new locations. *Hydrol. Process*. 27: 605–616.

Thornthwaite, C. W. (1948): An approach toward a rational classification of climate. *Geog. Review*. 38: 55–94.

Vicente-Serrano, S.M., Lanjeri, S., López-Moreno, J.I. (2007): Comparison of different procedures to map reference evapotranspiration using geographical information systems and regression-based techniques. *Int J Climatol*. 27: 1103-1118.

Acknowledgement

Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

Summary

Tato práce se zabývá srovnáním dvou empirických metod pro stanovení potenciální evapotranspirace (PET), a to Hargreaves a Penman-Monteith na sekulární klimatologické stanici Kišiněv. Vzhledem k dostupnosti kvalitní, dlouhé a nepřetržité řady meteorologických měření, byl zvolen Kišiněv jako reprezentativní stanice pro porovnávání vstupních datových souborů CRU a naměřených staničních dat, které byly dále využity k výpočtu PET v Moldavské republice. Pro

analýzu využitelnosti zkoumaných metod byla použita za období 1951-2012 klimatologická databáze sítě s vysokým rozlišením CRU verze TS3.2 a datový soubor z klimatologické stanice Kišiněv. Výpočet PET Hargreaves modelem (Hg) je založen na minimální a maximální teplotě vzduchu a na úhrnu globální radiace vztažné k zeměpisné šířce klimatologické stanice, zatímco metoda Penman-Monteith (PM) je založena na minimální, maximální a průměrné teplotě vzduchu, tlaku vodní páry a oblačnosti. Ke statistickému vyhodnocení vztahu mezi PET vypočtenou těmito metodami byly použity korelační koeficient (r), koeficient determinace (R^2) a ukazatel průměrné systematické chyby (MBE).

Podle koeficientů korelace byla zjištěna nízká korelace mezi PM a Hg v lednu (r = 0,65; R^2 = 41,9 %) a v prosinci (r = 0,45; R^2 = 20,6 %), naopak nejvyšší v měsících březnu (r = 0,94; R^2 = 88,7 %), květnu (r = 0,92; R^2 = 84,3 %), červenci (r = 0,92; R^2 = 85,1 %) a srpnu (r = 0,90; R^2 = 81,6 %). Řada studií ukázala, že PET vypočtená Hargreaves modelem na dobu delší než 1 týden, poskytuje podobné výsledky jako při použití Penman-Monteith rovnice. V této studii byly získány podobné výsledky.

CONTACT

Dr. Vera Potop

Česká zemědělská univerzita v Praze

Fakulta agrobiologie, potravinových a přírodních zdrojů

Katedra agroekologie a biometeorologie

Kamýcká 129

165 21 Praha 6 - Suchdol

potop@af.czu.cz

APPLICATION OF DSSAT MODEL TO SIMULATED THERMOPHILIC CROPS IN CENTRAL AND SOUTHERN EUROPE

V. POTOP[1], E. MATEESCU[2], L. TÜRKOTT[1], P. ZAHRADNÍČEK[3, 6], C. BORONEANȚ[4], F. CONSTANTINESCU[5], M. IAMANDEI[5]

[1]*Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Agroecology and Biometeorology, Prague, Czech Republic, potop@af.czu.cz*

[2]*National Meteorological Administration of Romania,*

[3]*Global Change Research Centre AS CR, Czech Republic*

[4]*Center for Climate Change, Geography Department, University Rovira I Virgili, Tortosa, Spain*

[5]*Research - Development Institute for Plant Protection, Romania*

[6]*Czech Hydrometeorological Institute, Brno, Czech Republic*

ABSTRACT

This study presents applications of DSSAT version 4.5 software package to simulate thermophilic crops. The results are used to identified adaptation options to reduce impacts of climate changes, pest and diseases in thermophilic crops in the central and south-eastern Europe, specifically in Elbe River lowland and Romania. For the Czech Republic, experimental research at farm level includes: (1) testing thermophilic assortment of vegetables in Elbe lowland conditions; (2) monitoring the meteorological data, phenological phases, soil characteristics, leaf area and the amount of aboveground biomass on farmer vegetable fields. For Romania, the focus is put on crop water use efficiency under current and future climate scenarios for thermophilic species (maize) in different agricultural sites from south and south-eastern regions. CERES Maize and CROPGRO-vegetables modules embedded in DSSAT were used.

Key words: CERES Maize, CROPGRO-tomato, plant protection, climate change

INTRODUCTION

Due to climate change, the breeding of new and improved vegetable crop varieties can lead to an extension of areas suitable for the profitable cultivation of vegetables. Some thermophilic vegetables that currently grow mostly in the southern Europe (e.g., melons, eggplants, tomatoes and peppers) can become more suitable for cultivation in lowland areas in central Europe (Potop et al. 2013, 2014a-d). Determine prospective areas for growing thermophilic vegetables in the lowlands in the Czech Republic using regional climate models and crop models can be useful tools. The crop growth models may provide information on plant production based on projected climate conditions, and also how management practices may be used to maximize the crop yield optimizing the application quantities and the time of application during the crop cycle. The principle of crop growth models is to incorporate in the basic algorithms the results of measurable biotic processes and their linkages with the abiotic conditions. The water use efficiency (WUE) also, is a measure of cropping system performance in the use of available water for reproductive growth (the ratio of the net gain in dry matter over a given period, divided by the water loss).

Among the crop simulation models that have been used for assessing the impact of climate change on agricultural crops, the Decision Support System for Agrotechnology Transfer (DSSAT) model has been largely used worldwide (Hoogenboom et al., 2010).

There were three main objectives in this study: (1) parameterisation of CROPGRO-tomato model and simulation of crop growth cycle of Thomas cultivar in filed conditions in the Elbe River lowland; (2) application of the CERES-Maize in combination with the climatic predictions RegCMs/SRES A1B at high resolution (10 km) to assessing the impact of climate change upon maize crop in southern Romania, and (3) monitoring of the biotic factors, as pests and diseases on the yield of maize hybrids in field conditions in southern Romania.

MATERIALS AND METHODS

Filed experiment

For the Czech Republic, experimental research at farm level includes: (1) testing thermophilic assortment of vegetables in Elbe lowland conditions; (2) monitoring the meteorological data, phenological phases, soil characteristics, leaf area and the amount of aboveground biomass on farmer vegetable fields. The main field experiment tasks were followed: the establishment of field trial, installation of meteorological sensors in crop canopy to monitor microclimate of fields (relative air humidity, soil moisture, air and soil temperatures, rainfall) service of instrumentation and data download, service of field trials (cultivation, weeding, irrigation, fertilization, standard protection against diseases and pests) with high growth areas of market vegetables, such as celery, cucumber, tomato, eggplants, pepper and green bean vegetables) (Fig. 1a). Czech study area is located in the warmest areas of the middle Elbe lowland, a region specialising in the growing and marketing of vegetables. Here the studied field was cropped with Thomas F1 tomato (*Solanum lycopersicum* L.) (Fig. 1a, bottom). This new variety is an early season tomato with a large red fruit (57-67 mm; weight of fruit ~ 120 grams) which is quickly ripens (Table 1). Fruit does not crack even on the adverse weather conditions and is widely preferred by growers. It has a disease tolerance at Mosaic Virus-ll and Yellow Leaf Curl Virus.

Table 1 *Overview on the length of growing period of tomato (Solanum lycopersicum L.)*

Growth period	Planting or sowing period (month)	Harvest period (month)
P – H *3 – 5* months*	-half of March – sowing in greenhouse - outplanting second half of May (without cowering)	<u>*cultivars of bush tomatoes for fresh market*</u> (by hands) -beginning of July (2 x weekly) -final (end of September – beginning of October)

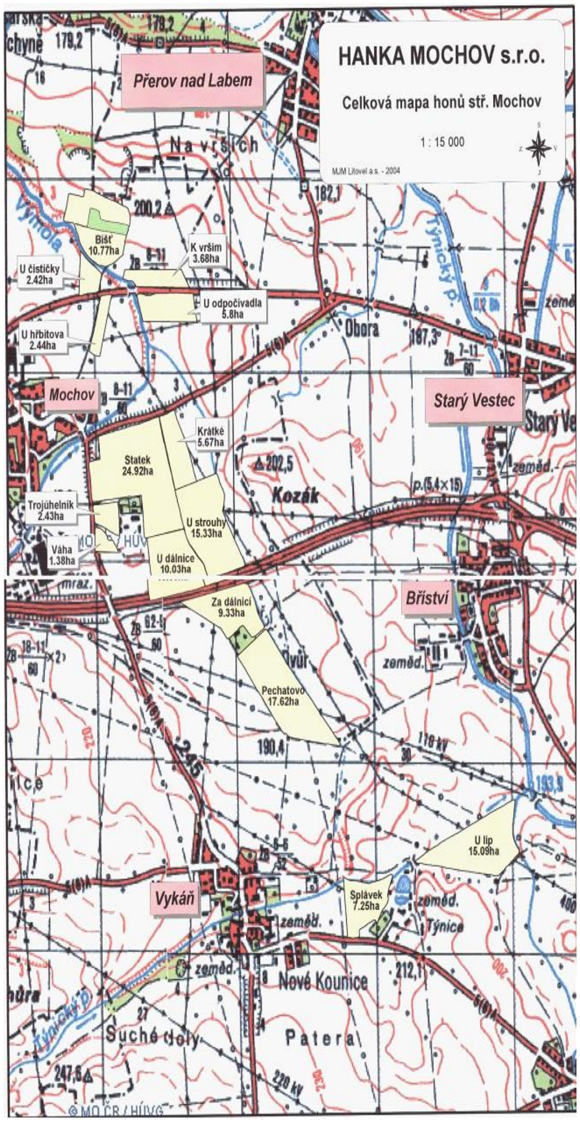
*Growing periods are distinguished as being the time from planting until harvest (P-H). *3 – 5 months means from planting to first harvest – last harvest*

Culture measures were all according to commercial practice. Leaves were picked weekly from bottom up to 3 to 4 leaves above the coloring truss. The main reasons for leaf removal are prevention of diseases and obtaining faster fruit ripening. The number of fruit per truss was set to 9 and more. Fruit production (fresh weight harvested fruits) was continuously registered. Phenology observation was done weakly. Leaf area index (LAI), Leaf area ratio (LAR), dry matter (i.e. above-ground crop mass partitioning in stem, leaves and generative organs: flower and trusses of fruits) and soil sampling were measured periodically. The first soil sampling was done before planting, which is allow to determine the initial condition, content of mineral nitrogen in the soil layers. Plant density was 2.3 plants m^{-2}. Irrigation was applied according to the soil moisture once or twice per week with a dose of 15 mm. Crop management options adopted in this study were to those practiced by the local farmers in the study area.

For Romania, the focus is put on crop water use efficiency under current and future climate scenarios for maize crop in different agricultural sites from south region, respectively Caracal agricultural area which is located in the south part of the Oltenia region, in a vulnerable area to drought conditions. The researches in the experimental field plots included: 1) testing of some maize hybrids in specific conditions (PR36V74, LG 34.75) from southern Romania 2) monitoring the meteorological data, phenological phases and biotic factors. The experiments were conducted on a mold clay-iluvial soil with 2.8% humus and a pH of 6.8 (Fig. 1b)

Input data in crop model

The CERES Maize and CROPGRO vegetables models, both included in the DSSAT version 4.5 software program (Hoogenboom et al., 2010), were used in this study to perform crop yield simulations of maize (Romania) and tomato (Czechia), respectively. The Czech study has connected daily weather data recorded at Poděbrady station (ϕ=50°08´N, λ=15°08´E, at 189 m) from the Czech Hydrometeorological Institute and fields experimental data at farm Hanka Mochov s.r.o. (ϕ=50º08´N, λ=14º47´E, at 193 m) measured by Czech University of Life Sciences Prague. The area around farm represents irrigated arable lands mostly cultivated with vegetables, where the model will be calibrated and validated. To run CROPGRO model, minimum inputs was used and these include weather, soil properties, plant characteristics and experimental data. We used the daily weather dataset requirements of the model, such as rainfall (mm), solar radiation (MJ m^{-2} d^{-1}), t_{min} and t_{max} (°C). According to this dataset, the CROPGRO was further calculated daily potential evapotranspiration (PET) by Priestley and Taylor (1972) method.



geographical position: φ=50.246 N, λ=14.606 E, h=192 m

geographical position: φ=50.146 N, λ=14.806 E, h=187 m.

Fig. 1a *Map of fields location at the Czech farm and geographical position of experimental fields*

Fig. 1b *Some aspects from maize experimental fields (0.2 ha) from geographical position: 44.11398 N; 24.39982 E, (Left –overview of experimental plot; Right: Ostrinia nubilalis attack on maize)*

The daily solar radiation (R_G) at Poděbrady station (1961-2013) is calculated by Ångström-Prescott formula (Ångström, 1924, Prescott 1940) based on the fraction of daily total atmospheric transmittance of the extraterrestrial solar radiation (R_A), a fraction of actual (n) and potential sunshine duration (N) during the day:

$$R_G = R_A * (A + B * (n/N)) \quad \text{(Eq. 1)}$$

where A and B are empirical coefficients determined for the particular site. The Ångström-Prescott coefficients at Poděbrady were A=0.21 and B=0.54.

Soil properties, used as input for CROPGRO-tomato at Mochov farm (Czechia), are provided in Table 2.

Table 2 *Soil properties used as input for CROPGRO at Mochov farm (Czechia)*

Soil layer (cm)	SLHV	CEC	SLOC	SLNI	SLCL	SLSI	SLSA
0-20	7.7	23.6	2.27	0.12	34.6	50.4	15.0
20-60	7.6	23.4	2.41	0.13	35.7	49.1	15.2
> 60	7.6	23.4	2.41	0.13	35.7	49.1	15.2

SLHV - soil pH in water, CEC - cation exchange capacity (mmol/100g), SLOC - soil organic carbon (%), SLNI - total soil nitrogen (%), SLCL- clay (%), SLSI - silt (%), SLSA - sand (%)

Initial input dry mass was set to 2.25, 1.71 and 0.01g for leaves, stem and generative organs, respectively. Initial LAI and LAR were 0.0578 m^2 m^{-2} and 0.0185 $m^2.g^{-1}$, respectively. Starting date for the simulation corresponds with outplanting date of the crop in the field, which was set at day 141 (21 May in BBCH 501 phenological stage). The simulation period ended at day 273 (30 September), a reasonable estimate for the date when plants are stopped in practice.

For Romania, the simulation model CERES-Maize as well as the Seasonal Analysis Program, integrated in the DSSAT, were used in assessing the impact of climate change upon maize crop. The model was run for current climate conditions (1961-1990) as well as for the 2021-2050 and 2071-2100 regional climate scenario-anticipated conditions, considering the direct effect of increased CO_2 concentrations (from 330 to 450 ppm) upon the photosynthesis processes. The results simulated under climate change conditions were compared to those obtained for the current climate. In order to analyse the historical meteorological data (air temperature, rainfall, wind, sunshine duration for the period 1961-2013) and agrometeorological information (soil moisture, maize phenology data and yields crop maize) has been used considered as representative for agricultural areas Caracal weather station (ϕ=46º6'0"N, λ=24º21'26", at 106 m). Used as inputs, the management variables of maize crops resulted from calibrating and validating the model and they take different values according to the agro-climatic area analyzed: mean seeding date ranges between 15-22 April, average seed density 45.000-60.000 pl/ha, distance between rows 12-12.5 cm and seeding depth 7.8 cm.

RESULTS

Tomato responses

Monthly and daily series of temperatures (minimum and maximum), rainfall and solar radiation for the period 1961–2013 were analysed. Mean monthly maximum and minimum temperatures, solar radiation and rainfall for the period 1961-2013 at Czech experimental site are shown in the Fig. 2. During growing season (GS) of tomato, daily totals of R_G values across the experimental site varied from 16.7 to 30.8 MJ $m^{-2}d^{-1}$. The average t_{max} and t_{min} during the GS are 20.8 (the highest t_{max} = 38.8 °C; 1.08.1994) and 10.4 °C, respectively. The mean precipitation total in the GS is 328 mm, while the highest daily amount reached in 2.06.2013 (88 mm). The summer GS (tmean≥15°C) corresponds to the beginning of the transplanting of thermophilic vegetables. The mean dates of the start and end of the GS for tmean≥15°C are May 21 to September 7, and the mean length of the GS is 109 days. For field thermophilic vegetables, a shift in the beginning date of the GS in the spring months is more advantageous than a change in the growing season length. The risk of spring frost after May 15 is low (Potop et al 2013, 2014d).

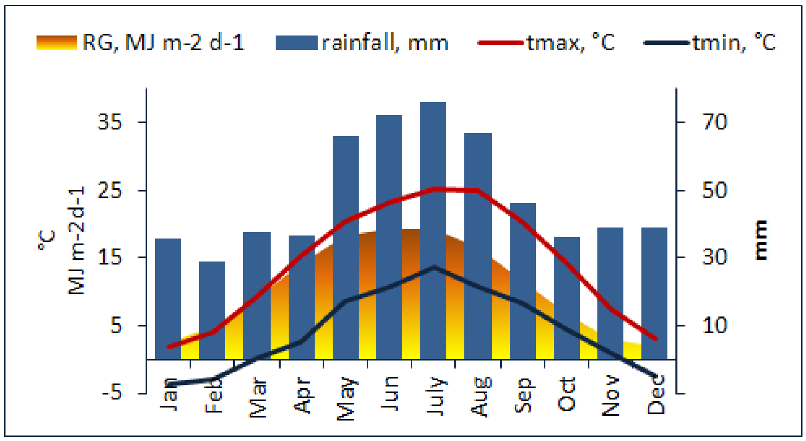


Fig. 2 *Monthly averages of air temperatures (maximum and minimum), solar radiation and rainfall for the period 1961-2013*

Additionally, the ALADIN-Climate/CZ and RegCM regional climate models were adopted to calculate possible shifts in the start, end and length of the climatological growing season under the SRES A1B scenario for two future periods (2021–2050 and 2071–2100) over the Elbe lowland (Potop et al. 2014b). The growing season is projected to lengthen considerably by the end of the 21st century compared with the mid-21st century and the reference period 1971–2000. Projected future climate conditions could result in significant shifts in the median of start and end of the growing season to earlier and later dates, respectively, relative to the current climate.

The length of both vegetative and reproductive tomato phenological cycles was rather strongly affected by adverse weather events during experimental period.

The field experiment was carried out in 2012 and 2013. The year 2012 was characterized by dry and hot weather, and 2013 was wet with large temperature fluctuations. When comparing the years 2012 and 2013, the decisive risk factor for yield formation of tomato was a thermal stress caused by the large differences between night and day air temperature in the flowering stage in

2012, and the low night temperatures and heavy torrential rains during June in 2013 (Fig. 3). Moreover, in 2013 at the stage of early flowering and fruit formation was observed up to 20 cases when the night air temperature dropped below 15 ° C.

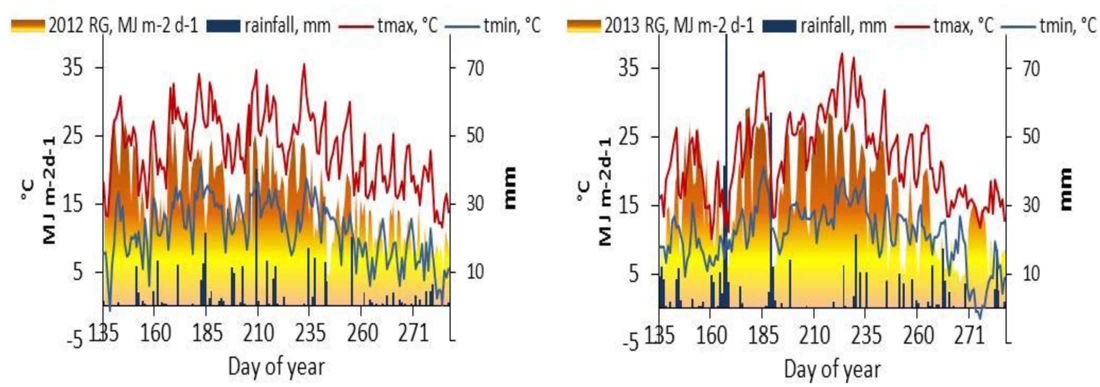


Fig. 3 *Daily air temperatures (maximum and minimum), solar radiation and rainfall during experimental years (2012-2013)*

We can note that the developmental stage of a vegetative unit at which the leaves are removed influenced LAI strongly and therefore crop growth rate. Early leaf pruning decreased LAI as well as biomass. Plant density influences LAI and dry mass. Fruit pruning increases assimilate allocation to the vegetative plant parts and would influence LAI. A reduced fruit load will increase dry mass per unit of ground area, due to higher weights of the vegetative plant parts. An increase in the number of fruits per truss decreased crop growth rate, as LAI was negatively influenced. CROPGRO-tomato in both years overestimated LAI for Thomas cultivar. Possible reason for overestimation of LAI is extreme meteorological conditions during experimental years, which creates large differences between observed and simulated LAI.

Maize responses

In Caracal area, the mean annual air temperature rose by 0.5 °C in the 1981-2013 period in comparison with climatic period of reference (1961-1990). In terms of monthly data the highest values were recorded in winter and summer months (Table 4). As regards precipitation, a trend of decreasing in the annual precipitation amounts could be observed. The mean monthly values register in general a decrease in ten months out of the twelve month (Table 4).

Fig. 4 provides the soil moisture trend for maize crop at Caracal station during the highest water demands of the plants (July- August) over 1971-2013 period. It highlights that the prevailing droughty years (≤50% AWC- available water content of the soil) in both months.

Table. 4 *Mean monthly air temperature and monthly rainfall amounts in Caracal over 1981-2013 period, compared with baseline climate period (1961-1990)*

Interval	Monthly air temperature (ºC)											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961-1990	-2.3	0.1	5.2	11.7	17.1	20.5	22.5	21.8	17.8	11.4	5.3	0.2
1981-2013	-1.2	0.7	5.8	11.7	17.5	21.4	23.5	22.9	17.8	11.7	5.0	0.0
Deviation	1.1	0.5	0.6	0.0	0.5	0.9	1.0	1.2	0.0	0.3	-0.3	-0.2
Monthly rainfall amounts (mm)												
1961-1990	38.7	38.9	40.0	47.9	63.1	73.2	60.4	46.3	32.1	32.4	47.7	45.2
1981-2013	31.9	29.6	36.9	43.9	51.6	60.2	51.8	41.0	38.5	39.3	41.0	40.5
Deviation	-6.8	-9.3	-3.1	-4.0	-11.5	-13.0	-8.6	-5.3	6.3	6.9	-6.7	-4.7

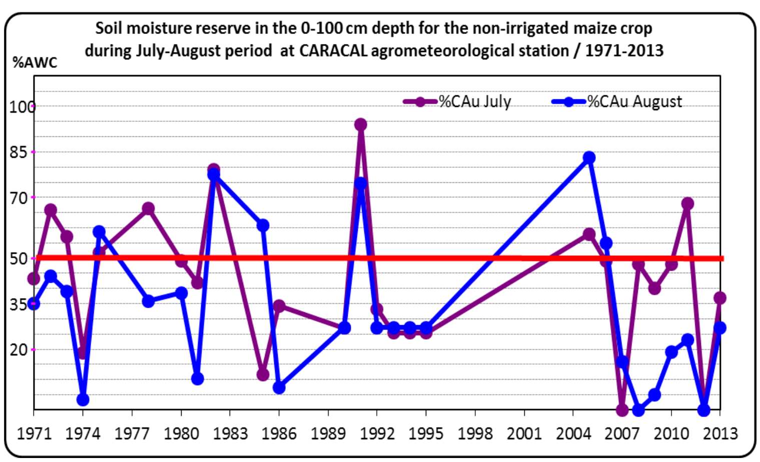


Fig. 4 *Soil moisture trend for the maize crop during July-August period at Caracal (1971-2013)*

Changes in yield levels and the length of vegetation period, as well as in cumulated precipitation and evapotranspiration during the vegetation season were quantified. In current clime conditions, the average maize yield is 5094 kg/ha at Caracal. Analysing the simulated results highlighted that for maize average grain yields tend to decrease by 14.4% over 2021-2050, and by 36.5% over 2071-2100 (Fig. 5, left). Also, according to the climate predictions, a shortening by 15-25 days of the vegetation period in maize crops is possible over both periods due to increasing of air temperatures, as well as due to water stress during grain filling (July-August). Being also a C4 plant, maize benefits less from the effect of increased CO_2 concentrations upon photosynthesis (Fig. 5, right).

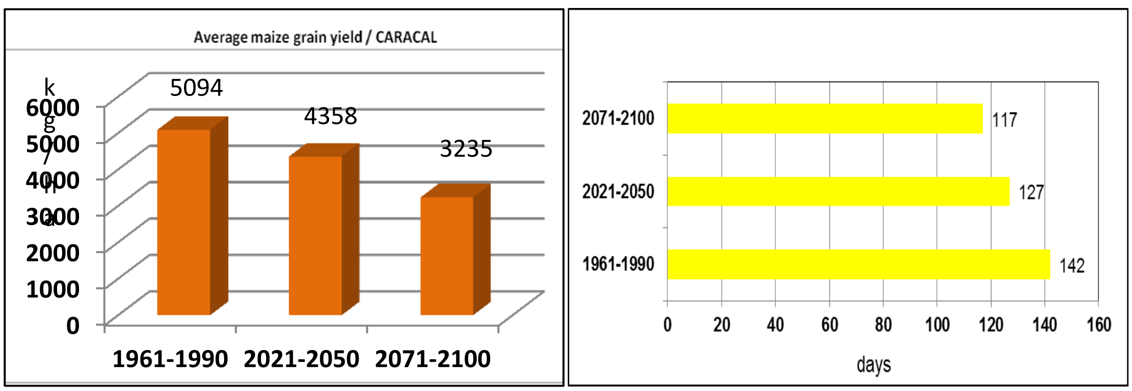


Fig. 5 *Maize grain yields and changes of the growing season duration of maize crops in the current and future climate (RegCMs/ 2021-2050 and 2071-2100/ SRES A1B scenario).*

The predicted WUE of maize crop increased by 9.9…12.5%, with an earlier sowing date (April 1 and 11) in comparison with current dates (April 10).

Monitoring biotic factors in maize canopy

For maize pest control is neccessary a strict monitorization of the target pests and the aplication of preventive control measures. During April-August 2013 were systematically monitorized the main pest development in corn crop (Fig.1b) as *Tanymecus dilaticollis*, *Ostrinia nubilalis*, black cutworm, *Agrotis segtum, Autographa gamma* and the invasive species *Diabrotica virgifera virgifera*. In the first case study, were the hybrid LG 34.75 was studied, the dicotyledonous weeds were dominant and their control was performed only in vegetation (Table 5).

Table 5 *Production results of different variants in the first study case*

Variant	Product and dose	Yield (kg ha^{-1})	TKM (g)	HM (kg)
1	Zeagran 2 l/ha Crew 1 l/ha Sprayguard 0.1 l/ha	8345	230.3	67.8
2	Zeagran 1.5 l/ha Dicopur Top 0.8 l/ha CREW 1 l/ha Sprayguard 0,1 l/ha	8512	232	68.7
3 (untreated)	-	6855	217	67.2

TKM - thousand-grain mass, HM - Hectoliter mass

Both herbicides Zeagran and Dicopur top had a good activity in controlling the annual and perennial dicotyledonous weeds, and their mixture increased the perennial weeds control efficacy (variant 2), especially the *Convolvulus arvensis*. Crew herbicide had a good activity against annual and perennial monocotyledonuous weeds. Significant increases yield values of 1657 kg/ha in the variant 2 and of 1469 kg/ha in the variant 1 highlighted the importance of weed control in the maize crop.

In the second study with maize hybrid PR36V74, weeds control scheme was achieved in 3 variants (Table 6). The best results were obtained in the first variant, were treatments were applied pre emergent (after sowing) and post emergent. Adengo herbicide consist of two active substances with a large spectrum of annual weeds control and with high residual activity, beeing able to preserve it's activity after rain. The presence of perennial weeds, both dicotyledonous (*Cirsium arvense, Convolvulus arvensis*) and monocots (*Sorghum halepense*) required the use of two herbicides, Bromoxinil and Equip. The weeds control efficacy was very good and the yield increased with 3486kg/ha.

Table 6 *Production results of different variants in the second study case*

Variant	1	2	3	Untreated
Preemergent Weed control treatment	ADENGO 0,4 l/ha		MERLIN DUO 2.0 l/ha	-
Postemergent weed control treatment	1) Buctril Universal 0.8 l/ha 2) EQUIP 2.5 l/ha 3) -	1) - 2)- 3) LAUDIS 2.25 l/ha	1) Buctril Universal 0.8 l/ha 2) EQUIP 2.5 l/ha 3) -	-
Foliar fertilization	Boron 2.0 l/ha+ Wuxal macromix 3.0 l/ha	Boron 2.0 l/ha+ Wuxal macromix 3.0 l/ha	Boron 2.0 l/ha+ Wuxal macromix 3.0 l/ha	-
Yield (kg ha^{-1})	8341	7855	8173	4855
TKM (g)	283.3	262.2	271.8	253.4
HM (kg)	71.0	69.5	70.5	69.2

The variant 2 had just vegetation treatments with 2.25 l/ha LAUDIS herbicide. This herbicide disturbs the photosynthesis process and has a double systemic action. Also, control very well the annual weeds species. The perennial species, especially the dicotyledonous can regenerate, and therefore, in our experiments the yield was lower in this variant. In the third variant were the treatments were made with the herbicide MERLIN DUO the results were similar with the ones from the variant 1 but it was noticed after the application a reinfestation with annual weeds. The yield increased in this variant with 3318 kg/ha. Besides high efficacy in weeds control, in this study was noticed the importance of fertilization in obtaining significant yield increases.

DISCUSSION

Studies on the response of tomato to climate change are very limited. For instance, in the studie of Ventrella et al. (2012) reported that tomato appears to be more sensitive to climate change than the winter durum wheat in southern Italy. Moreover, the results showed that under future climate scenarios tomato yields will be limited more by high temperature than by water availability. In this context, water scarcity and pedological droughts in south and south-east Romania can cause drastic yields decreases, particularly during the excessively droughty agricultural years such as: 2006-2007 and 2011-2012, and the higher/lower than optimum temperatures are reflected by metabolically reactions in plants, causing thermal stress especially in summer and winter, while every modification in the trend of their lows can easily aggravate frost injury in sensitive plants. For this reason the adaptation of crop species to climate change can be mainly based on the experience obtained from their reactions to extreme climate events by implementing climate change risk adaptation and management plans as well as on the new researches approaching the regional and local effects related to the behavior of genotypes in current and predictable climate change conditions (Sandu et al., 2010; Mateescu and Stancalie, 2010, 2012; Mitrica et all, 2013).

CONCLUSION

This simulation study provided details relating to the responses of thermophilic crops to weather extreme events under current and future climate and also how management practise may be used to maximize the crop productions in the central and south-eastern Europe, specifically in Romania and Elbe River lowland and. In our future work, we plan to calibrate a field vegetable crop growth model in Elbe River lowland.

The results of CERES-Maize simulation showed that the future climate evolutions may have important effect upon maize crop and these are conditioned by an interaction between the following factors: current climate changes on a local scale, severity of climate scenario-forecasted parameters, how the increased CO_2 concentrations influence photosynthesis, and the genetic nature of plant types. Maize crop being a C4 plant is vulnerable to climate change, mainly in the case of a scenario predicting hot and droughty conditions.

The very significant influences of the weed suppression on maize grain yield in comparison with untreated variants emphasize the importance of treatments to control weeds in maize crop. Depending on the actual conditions on the field (weed spectrum of maize crop and climatic conditions) one of the proposed variants for weed control can be selected. Climatic conditions in 2013 were unfavorable for the evolution of pest and diseases (especially cold period between emergence of maize and the stage of 4 leaf that influenced the evolution of thermophilic insect *Tanymecus dilaticollis* and subsequent drought during the period of laying eggs by the european corn borer) in maize crop and therefore the attack degree and implicitely the stress generated by pests and diseases did not influenced the yield.

REFERENCES

Ångström, A. Solar and terrestrial radiation. QJR Meteorol. Soc. 1924, 50, 121-125.

Hoogenboom G., Jones J.W., Wilkens P.W., Porter C.H., Boote K.J., Hunt L.A., Singh U., Lizaso J.L., White J.W., Uryasev O., Royce F.S., Ogoshi R., Gijsman A.J., Tsuji G.Y. (2010). Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5 [CD-ROM]. University of Hawaii, Honolulu, Hawaii.

Mateescu E, Alexandru D. (2010). Management recommendations and options to improve the crop systems and yields on South-East Romania in the context of regional climate change scenarios over 2020-2050. In: *Series A LIII - Agronomy, University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Agriculture*. 328-334.

Mateescu E., Stancalie G. at all (2012). Drought Monitoring in Romania. In: *JRC/DMCSEE/Biotechnical faculty/ "Different approaches to drought monitoring – towards EuroGEOSS interoperability model*", Ljubljana, *23rd – 25th November 2011, "*Towards EuroGEOSS interoperability model in drought monitoring in SEE region", 16-27.

Mitrica B, Mateescu E, Dragota C. S. , Busuioc A., Grigorescu I.E., Popovici A. (2013). Climate change impacts on agricultural crops in the Oltenia Plain (Romania). In: *13th SGEM GeoConference on Energy And Clean Technologies, SGEM2013 Conference Proceedings*, June 16-22, 2013, 573 – 584. DOI:10.5593/SGEM2013/BD4/S19.009;

Potop V, Türkott L, Zahradníček P, Štěpánek P (2013). Temporal variability of late spring and early autumn frosts during growing season of vegetable crops in Elbe River lowland (Polabí). *Meteorological Bulletin*, 66, 135–142.

Potop V, Zahradníček P, Türkott L, Štěpánek P., Soukup J (2014a). Risk occurrences of damaging frosts during the growing season of vegetables in the Elbe River lowland, the Czech Republic. *Nat Hazards*, 71, 1-19.

Potop V, Zahraniček P, Türkott L, Štěpánek P, Soukup J. (2014b). Potential impacts of climate change on damaging frost during growing season of vegetables. *Scientia Agriculturae Bohemica, 45, 26-35.*

Potop V, Boroneat C, Možný M, Štěpánek P, Skalak P. (2014c). Observed spatio-temporal characteristics of drought on various time scales over the Czech Republic. *Theor Appl Climatol.* 115 (3). 563-581.

Potop V, Zahradníček P, Türkott L, Štěpánek P (2014d). Changes in the timing of growing season parameters over the Elbe River lowland (Polabí). *Meteorological Bulletin*, (in printing).

Priestley, C.H.B., Taylor, R.J. (1972): On the assessment of the surface heat flux and Evaporation using Large-scale Parameters. *Monthly Weather Review.* 100: 81–92.

Prescott, J.A. Evaporation from a water surface in relation to solar radiation. Trans. R. Soc. South Australia 1940, 64, 114-118

Sandu I**,** Mateescu E, Vatamanu V.V. (2010) Climate change impact on agriculture in Romania. Editura SITECH Craiova, 392.

Ventrella D, Charfeddine M, Moriondo M, Rinaldi M, Bindi M. (2012). Agronomic adaptation strategies under climate change for winter durum wheat and tomato in southern Italy: irrigation and nitrogen fertilization. Reg. Environ. Change. 12:407–419

ACKNOWLEDGEMENT

We thank to dr. Vilau Nicolae and dr. Vilau Florica from SCDA Caracal for providing us with some important data and advices for the paper preparation. This work had benefited from financial support through the ADER 1.1.1. Project "Geo-referential indicators system at different spatial and temporal scales to assess the vulnerability and adaptation of agro ecosystems to global changes”, 2011 – 2014, the Sectoral Plan ADER 2020 of the MARDR. Institutional Support Program for Long Term Conceptual Development of Research Institution provided by MSMT CR and project CZ.1.07/2.3.00/20.0248. The Czech team is grateful to the P. Hlavinka (Institute of Agrosystems and Bioclimatology, Mendel University in Brno) for preparing meteo input data in DSSAT.

SUMMARY

Tato studie představuje využití aplikace DSSAT programu verze 4.5 pro simulaci růstu a vývoje teplomilných plodin. Výstupy modelu budou využity pro snížení negativních dopadů klimatické změny na produkci teplomilných plodin a rozvoj fytopatogenů ve střední a jihovýchodní Evropě, konkrétně pak v Polabské nížině a v Rumunsku. Současně bude řešena problematika možného přizpůsobení se této klimatické změně a jejího využití v zemědělské produkci. V České republice probíhá experimentální výzkum na úrovni zemědělských podniků a zahrnuje: (1) testování sortimentu teplomilných zelenin v klimatických podmínkách Polabské nížiny; (2) sledování agrometeorologických prvků, půdních vlastností, růstových fází a fyziologických parametrů (LAI, LAR, relativní rychlost růstu, suchá biomasa) rostlin v průběhu vegetace v polních podmínkách. V případě Rumunska je kladen důraz na využití vody teplomilnými plodinami (kukuřice) v podmínkách současného a budoucího klimatu v různých zemědělských regionech jižního a jihovýchodního Rumunska. Pro simulaci jsou v programu DSSAT použity moduly kukuřice CERES a zeleniny CROPGRO. Pro studii v České republice jsou využívána denní meteorologická data stanice Poděbrady (ϕ = 50° 08' N, λ = 15° 08' E, 189 m n. m.) spravované Českým hydrometeorologickým ústavem a data ze stanic spravovaných Českou zemědělskou univerzitou v Praze umístěných v porostech na experimentálních pozemcích farmy Hanka Mochov s. r. o. (ϕ = 50° 08' N, λ = 14° 47' E, 193 m n. m.). Experimentální plochy, kde je model ověřován a kalibrován, jsou součástí pozemků s vybudovanými závlahami a využívanými převážně k pěstování zeleniny. Vstupní meteorologická data do modelu jsou denní úhrn srážek (mm), globální záření ($MJ.m^{-2}.d^{-1}$), t_{min} a t_{max} (°C). Z těchto dat je následně modelem vypočtena metodou Priestley a Taylor denní potenciální evapotranspirace (PET). Denní globální záření (R_g) je vypočteno dle vzorce Ångström-Prescotta. Půdní parametry využité v modelu jsou sledovány ve třech hloubkách 0 - 20 cm, 20 – 60 cm a >60 cm. Jsou to SLHV - pH půdního roztoku, CEC - kationtová výměnná kapacita ($mmol.100g^{-1}$), SLOC - celkový obsah organického uhlíku (%), SLNI - celkový obsah dusíku (%), SLCL – jíl (%), SLSI – prach (%), SLSA – písek (%). Počáteční datum simulace bylo stanoveno na den výsadby rostlin 21. května (141 den Juliánského kalendáře) a konec simulace na termín odpovídající průměrnému počátku prvních mrazů 30. září (273. Juliánský den), tedy poslední sklizni s vysokou tržní jakostí plodů. V době výsadby byly rostliny

rajčat odrůdy Thomas ve vývojové fázi BBCH 501, hmotnost suché biomasy listů 2,25 g, stonku 1,71 g a generativních orgánů 0,01 g a vypočtená hodnota LAI byla 0,0578 m^2 m^{-2}, LAR (Leaf Area Ratio) 0,0185 $m^2.g^{-1}$.

CONTACT

Dr. Vera Potop

Department Agroecology and Biometeorology

Faculty of Agrobiology, Food and Natural Resources

Czech University of Life Sciences Prague

Kamycka 129; 165 21 Prague 6 – Suchdol;

potop@af.czu.cz

G.J. Mendel´s meteorological observations

Jaroslav Rožnovský

Czech Hydrometeorological Institute, Brno branch office

Abstract

G. J. Mendel is an important figure in the history of Czech meteorology. He was responsible for the expansion of the weather observation network in Moravia. His measurements are part of the Brno series, one of the longest in the region of the Czech Republic. On the list of his publications, ones about meteorology prevail, which are not just the result of analysis of his measurements, but also works that give detailed description of the physical basis of meteorological phenomena and come with some new findings. Looking at Mendel´s list of scientific works as a whole, one can see that he was a scientist with exceptionally broad specialization, who was able to analyze individual phenomenon as well as be aware of the natural processes on a global level. At this point it is also necessary to point out his great observational talent, accuracy, diligence and precision, all of which he proved in his meteorological activities.

Key words: G. J. Mendel, meteorological observations, agriculture, Brno

Introduction

Gregor Johann Mendel left a significant mark in history of science as a brilliant geneticist and so it comes as a surprise to many that while being the abbot at the Augustinian monastery during the period of his major discoveries, he saw himself as a meteorologist (Figure 1).

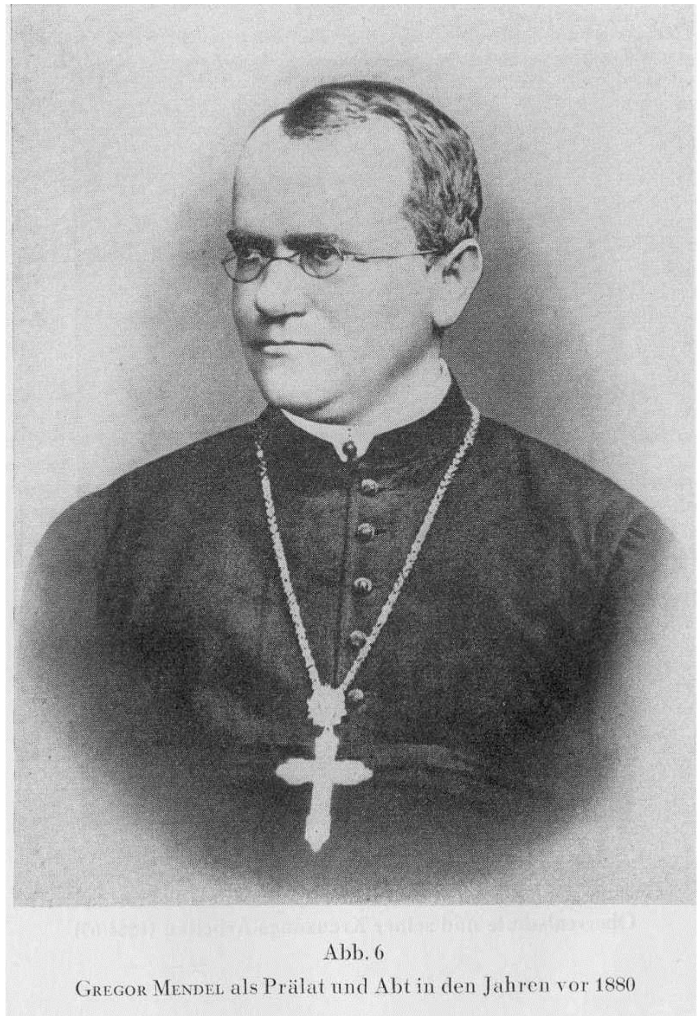


Figure 1 – Gregor Johann Mendel, a portrait from 1880 (Křížený, 1965)

This fact is supported by records from his meteorological observations, which he not only hand written himself, but also analyzed. It is proved that on a petition of the Natural Science Society from 1870 regarding foundation of Moravian university, Mendel has meteorologist as his profession. It is of course obvious that the significance of Mendel's observations of the weather in Brno is far from the significance of his genetic laws. It is, however, absolutely reasonable to say that during his life he devoted at least as much time to meteorology as he did to his other scientific activities. This is also seen from the list of his publications, where ones concerning meteorology prevail by far (Appendix A). Unlike the significance of his genetic discoveries, which was only realized after his death, his meteorological works were well-known and his opinion sought and valued.

Mendel's meteorological measurements in Brno

Based on evidences, continuous meteorological measurements were started by Dr. Paul Olexík on 1st January 1848 in the area of faculty hospital and finished on 30th June 1878 due to his severe illness. G. Mendel was Dr. Olexík's close friend and helped him with measurements at his station. An evidence for this is also Mendel´s description of Olexík's station. Based on Mendel´s records, measurements were performed at the second floor of the house No.100 on Pekařská street, where a barometer (a device for measuring pressure) and a psychrometer (a device composed of two thermometers, one of which had a sock on its mercury flask, which on the other end was submerged in distilled water. The thermometer without this sock, the so-called dry-bulb thermometer, was used to measure the air temperature. The one with the sock, called the wet-bulb thermometer, measured temperature influenced by water evaporation, the so-called wet-bulb temperature. Both temperatures were then plugged into a psychrometric equation to calculate air humidity, in particular to calculate the water vapor pressure). Using these devices, pressure, temperature and humidity values were obtained. Dr. Olexík's minimal thermometer and rain gauge was placed in the garden of the hospital. The amount of precipitation was determined by weighing. It is quite probable that Mendel already performed parallel measurements in the monastery, some say already from 1857. Mendel´s own records of meteorological observations from 1st July 1878 up to July 1883 are archived in the archive of the Brno branch of the Czech Hydrometeorological Institute. An example of very detailed and neatly organized records are shown in Figure 2.

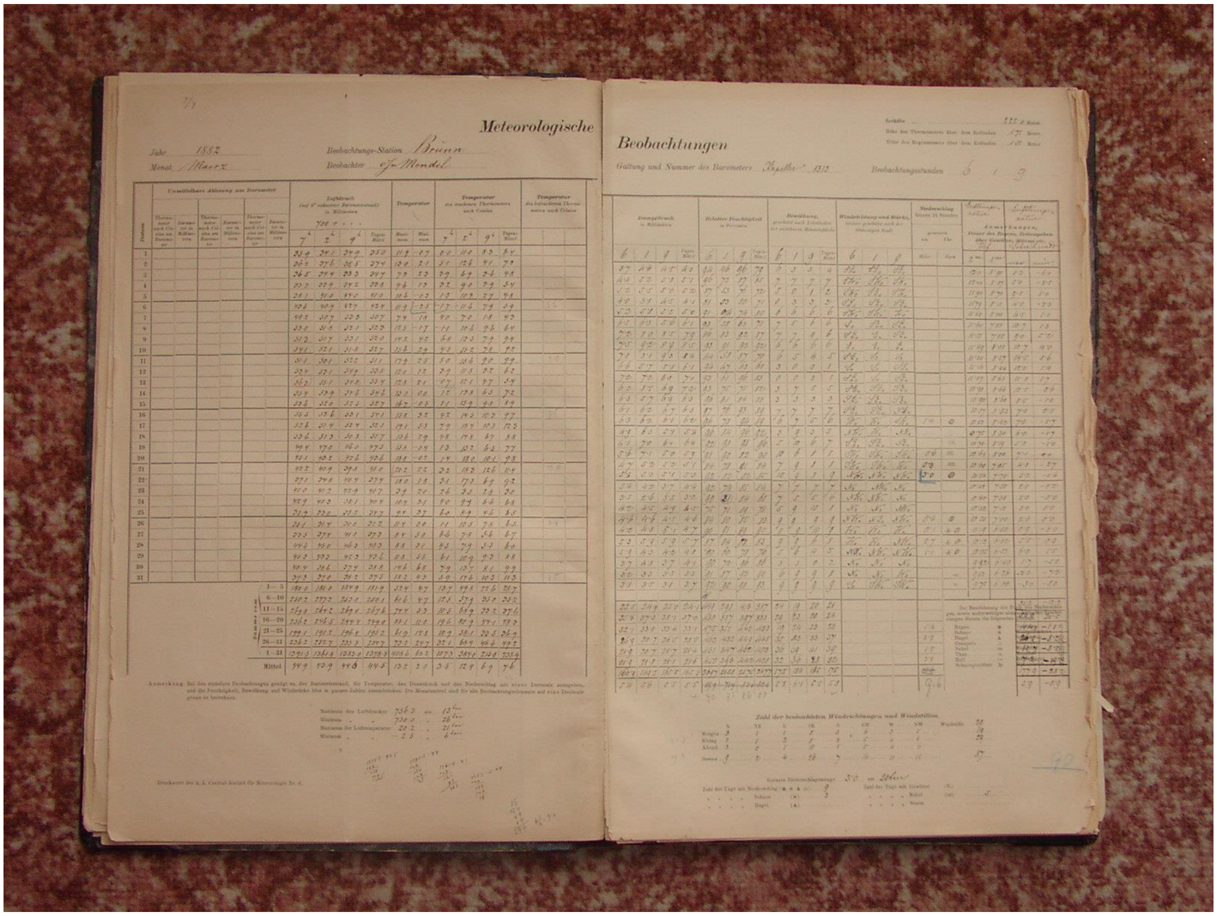


Figure 2 – An example of Mendel´s records of meteorological observations

There is not a consensus about this, but based on evidence Mendel moved his observations to the area of the current monastery on Mendel´s square. Psychrometer with a barometer was placed on the first floor, where he probably used a metal Stevenson screen for the psychrometer, the extreme thermometers were in the garden next to the bee house and the rain gauge in the so-called “prelate” garden. We could say that Mendel in fact recorded the weather right until his death, because his own hand written records come even from July 1883.

In 2002, a metal Stevenson screen in a very bad condition was found in the depository. At first it seemed more like just some piece of crooked metal. After renovation, however, it became one of the exhibits as a proof of Mendel´s meteorological activity (fig. 1). To our great surprise, after careful cleaning we found inside mercury thermometers, which were undamaged and the mercury column very clear, in other words the capillary was not dirty, which is typical for meteorological thermometers used for a longer period of time. These thermometers became even more interesting once we found out that they were manufactured by the Kappeller company, which also manufactured the psychrometer used by Dr. Olexík, and that they used the Réaumur scale (these days hardly ever used scale introduced by Réaumur in 1730, where the water boiling point was assigned a value of 80°R. The conversion between the Celsius scale can be performed using the equation t(°R) = 4/5 t (°C) and t(°C) = 5/4 t (°R).

Although it is not possible to fully prove these thermometers come from Mendel´s measurements, but at least in case of one of them it is highly probable. This is also proved by an expert opinion from a professional technician of the Technical museum in Brno Jaroslav Pipota, who apart from others states, that one of the analyzed thermometers was manufactured by the Kappeller company, based in Vienna, already in 1854. He then estimates that this thermometer comes from the second half of the 19^{th} century (Figure 3).

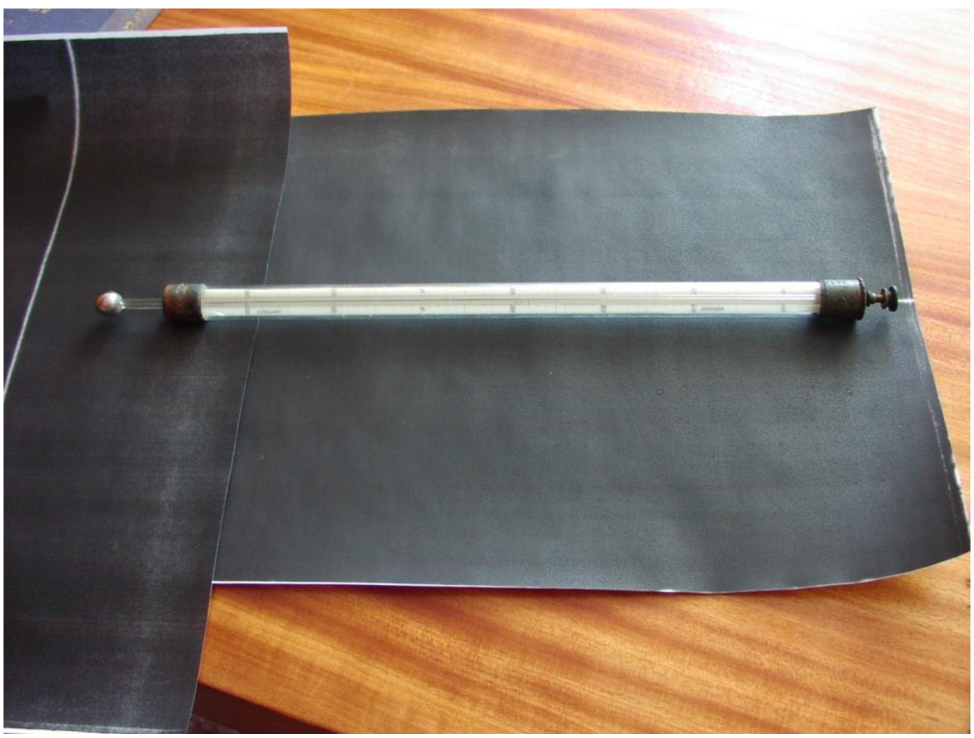


Figure 3 – The original thermometer from the Kappeller Company

Publications

The Brno Nature Society is created on 21^{st} December 1861 and G. Mendel was one of its founders. In this society he has the role of a meteorologist. The section for natural sciences assigned him to perform and analyze meteorological observations in Brno. The results of the analysis of Brno climate were published in 1863 in the form of a graphs and tables under the name Bemerkungen zu der graphisch-tabellarischen Uebersicht der meteorologischen Verhältnisse von Brünn. The course of annual air temperature is shown in Figure 2. He also mentions that air temperatures in city centers are higher than those at the suburbs. This fact was only published more than 20 years later by Hann, even though it was in fact Mendel who first proposed the idea of a phenomenon today known as "Urban Heat Island".

From 1863 he publishes results of processed annual meteorological measurements as Meteorological observations from Moravia and Silesia for years 1863, 1864, 1865, 1866, 1869 (Meteorologische Beobachtungen aus Mähren und Schlesien für das Jahr 1863 etc.). He supported foundation of other meteorological stations and there is evidence that he was also responsible for the creation of several of them in 1865, for example in the cities of Těšín, Hukvaldy, Hranice, Kroměříž etc.

One of significant Mendel´s meteorological publications was physically most well worked out publication from 1871 called Die Windhose vom 13th October 1870. Its written publication was preceded by a presentation about a storm, presented by Mendel on 9th November 1870 on a meeting of the Natural Science Society. In his work he evaluates his own findings and also findings of other witnesses who observed the storm. He described the course of this storm, which was unusual not just by the time of the year when it appeared and the location where it appeared, but also the extent of damages it caused. The article gives detailed physical analysis including electrical phenomena and it is proven that Mendel had very good knowledge of meteorological findings of that period. He also mentions the fact that those who considered the storm as a phenomenon of devil have poor knowledge of physics.

When evaluating Mendel´s activity, also his support of spreading meteorological forecasts for agriculture is mentioned. Being a wise farmer, Mendel was aware of the importance of weather and climate for agriculture. He therefore fully supported when the Central Institution for Meteorology and Geodynamics in Vienna started issuing short-term weather forecasts on 1st January 1877, which were distributed via telegraph. Subscribers then often passed it further to surrounding towns using simple signalization, for example by hanging baskets or raising flags. Mendel himself tried to produce a 3-day weather forecast, but wasn't very successful. He was aware of the fact that the knowledge back then was insufficient for being able to issue longer forecasts.

He published the results of the analysis of his weather observations in a form of graphs and tables evaluating the Brno climate in 1883. In this work he points out that the temperatures in the city center are higher than those in the city outskirts, today a common phenomenon known as the "urban heat island".

Mendel´s activities as a meteorologist supported the spread of meteorological forecasts for farmers. He himself was a wise farmer familiar with the significance of weather and climate for agriculture.

Conclusion

G. J. Mendel is an important figure in the history of Czech meteorology. He was responsible for the expansion of the weather observation network in Moravia. His measurements are part of the Brno series, one of the longest in the region of the Czech Republic. In the list of his publications, ones about meteorology prevail, which are not just the result of analysis of his measurements, but also works that give detailed description of the physical basis of meteorological phenomena and come with some new findings. It is, however, obvious that these works did not become as significant as his works from the field of biology, in particular genetics.

There is currently a trend towards applying findings from fundamental research in practice and in this context one must not forget Mendel as well. An example of this is his effort towards using weather forecasts by farmers. Looking at Mendel´s list of scientific works as a whole, one can see that he was a scientist with exceptionally broad specialization, who was able to analyze individual phenomenon as well as be aware of the natural processes on a global level. At this point it is also necessary to point out his great observational talent, accuracy, diligence and precision, all of which he proved in his meteorological activities.

Appendix A – Chronological overview of significant G. J. Mendel´s works

- *Über Verwüstung am Gartenrettig durch Raupen*. Verhandlungen des zoologisch-botanischen Vereins in Wien (Wien), 3, 1853, p. 116 - 118.
- *Bemerkungen zu der graphisch-tabellarischen Übersicht der meteorologischen Verhältnisse von Brünn*. Verhandlungen des naturforschenden Vereines in Brünn (Brno) 1, 1862, Abhandlungen, p. 246-249 – 1 tb. (2).
- *Bemerkungen zu der graphisch-tabellarischen Übersicht der meteorologischen Verhältnisse von Brünn.* Brünn, typ. Gastl 1862, 4 p., tb.
- Jahresberichte pro 1862 des naturforschenden Vereines in Brünn (Brno), 1, 1862.
- *Meteorologische Beobachtungen aus Mähren und Schlesien für das Jahr 1863.*
- Verhandlungen des naturforschenden Vereines in Brünn (Brno), 2, 1863, Abhandlungen, p. 99-121.
- *Meteorologische Beobachtungen aus Mähren und Schlesien für das Jahr 1864.* (Vorgelegt in der Sitzung vom 8. März 1865.)
- Verhandlungen des naturforschenden Vereines in Brünn(Brno), 3, 1864, Abhandlungen, p. 209-220.
- *Versuche über Pflanzen-Hybriden*. (Vorgelegt in den Sitzungen vom 8. Februar und 8. März 1865.) Verhandlungen des naturforschenden Vereines in Brünn (Brno), 4, 1865, Abhandlungen, p. 3-47.
- Verhandlungen des naturforschenden Vereines in Brünn (Brno), 4, 1865.
- *Versuche über Pflanzenhybriden*. Brünn, typ. Gastl 1866. 47 p.

References

Kříženecký J. (1965), Gregor Johann Mendel 1822-1884, Texte und Quellen zu seinem Wirken und Leben, Johan Ambrosius Barth Verlag, Leipzig 1965. 198 p.

Liznar J. (1886): Ueber das Klima von Brünn. Sonder – Abdruck aus dem XXIV. Bande der Verhandlungen des naturforschenden Vereines in Brünn, Brno, 70 p.

Štěpánek, P., 1998: Metody analýzy kolísání teploty vzduchu a srážek na příkladu Brna. Diplomová práce. Katedra geografie, PřF MU, Brno, 120 p.

SUMMARY

G. J. Mendel se významně zapsal do dějin české meteorologie. Zasloužil se o rozšíření sítě meteorologických pozorování na Moravě. Jeho měření jsou součástí brněnské řady, jedné z nejdelších na území České republiky. V jeho publikační činnosti počtem převládají práce meteorologické, které nejsou jen výsledkem zpracování naměřených údajů, ale také práce s podrobnou analýzou fyzikální podstaty meteorologických jevů, přinášející nové poznatky. Jisté však je, že tyto práce nedosáhly významu prací biologických, či přesněji řečeno genetických. Jestliže dnes hovoříme o potřebě co nejvíce využívat poznatků základního výzkumu, musíme tento pohled zdůraznit u G. J. Mendela. Dokladem je jeho snaha o využití předpovědi počasí pro zemědělce. Vezmeme-li v úvahu celé vědecké dílo G. J. Mendela, vidíme, že šlo o vědce s mimořádně širokým zaměřením, který dokázal analyzovat dílčí jevy, ale současně je vnímal v celkovém komplexu přírodních procesů. Zde jen nutné zdůraznit též jeho vynikající pozorovatelský talent, přesnost v práci, píli a pečlivost, toto vše uplatnil i ve své meteorologické činnosti.

CONTACT

RNDr. Ing. Jaroslav Rožnovský, CSc.

Czech Hydrometeorological Institute, Brno

Kroftova 43, 616 67 Brno

Telephone: 541 421 011

Email: roznovsky@chmi.cz

Minimum Temperatures above Different Surfaces in Strawberry Cultivation

Petr Salaš[1], Tomáš Litschmann[2], Hana Sasková[1]

1) *Department of Breeding and Propagation of Horticultural Plants, Mendel University in Brno, Mendel University in Brno, Faculty of Horticulture ,Valtická 337, 691 44 Lednice*
2) *AMET Corporation, Žižkovská 1230, 691 02 Velké Bílovice*

Abstract

The paper focuses on the evaluation of temperature data from close-to-ground readings above different surfaces used in cultivation of strawberries (open soil, straw mulch, mulching cloth), with grass as a standard surface used in meteorological readings. It is apparent that straw mulch significantly limits inputs and outputs of heat to and from soil, and therefore, under specific weather conditions, temperatures above straw are lower than above other surfaces. These variations are the highest in spring months when low temperatures at ground level are common, and if straw is layered too early it may lead to an increased risk of frost damage to strawberry buds and flowers.

Key words: frost, strawberry, mulch, ground temperature

Introduction

Growing of strawberries has a hundreds of years old tradition in our climatic zone. To protect the ripening fruit from moist soil and consequent fungal diseases, the traditional method has always been to cover the beds with straw (Fig. 1). This also reflects in the English name of the fruit, which refers to straw directly. In the past few years there have been numerous cases of early onset of vegetation upon which the buds, flowers or fruitlets were damaged by ground frost. Greater damage was observed in those parts of plantations where straw was already piled up in between the beds; less severe damage or no damage occurred where the straw was not laid yet. As the information on the influence of different types of mulch on ground temperatures is very sparse, we decided to set up an experiment aimed at studying the differences between minimum temperatures above various surfaces used in strawberry cultivation.

Plíšek, 2002, Dušková and Kopřiva, 2005 state different possibilities of using mulching materials in strawberry production. The most commonly used materials include black PVC, unwoven and woven mulching cloths, biodegradable foils, straw, wood shavings, organic waste mixes (wood chips, peat, sawdust) or mowed grass. Each of the materials has its pros and cons. The colour of the mulching material significantly influences the permeability of photosynthetically active radiation, and therefore the development of weeds. Good warming of the soil and weed control is ensured if brown and green mulch is used, while blue and reddish brown foils are used to cover the soil (Johnson and Fennimore, 2005). Black unwoven or black woven cloths absorb sunlight and accelerate ripening (Matuškovič, 2004, Sing et al. 2007). The disadvantage is a risk of higher frost damage to early-flowering varieties and overheating in summer. Another option could be the use of blue and white foil for postponing harvest (Pokorný, 2006). Kasperbauer and Loughrin (2002) expressed a hypothesis that red colour or mulch influences the FR/R ratio – phytochrome activity – which leads to increased allocation of assimilates in the strawberry fruit and consequent improving of quantitative (size, weight) and qualitative (aroma, content of organic acids and sugars) parameters of the fruit. Kikas and Luik (2002) proved a positive influence of organic mulch (straw, wood pulp) and black foil, which both supported the occurrence of beneficial insects.

The effect of mulch, either made of plant material or foil, influences temperature and humidity in the soil underneath. As Andrade et al (2010) say, a layer of straw on soil surface, with its heat-insulating properties, reduces the average temperature of soil underneath and the temperature amplitudes. In night hours it reduces heat loss through longwave radiation and during the day the soil is protected from direct sunlight, which reduces the heat input.

Mulch layer contributes to reducing evaporation from the surface of open soil. The research of Taparauskiemé and Miseckaité (2014) showed that humidity of top soil layer is higher under straw mulch than under exposed soil. It is therefore assumed that straw mulch, insulating plants above it from heat longwave heat input from the soil, would have a greater influence on reducing temperature of objects present in this layer compared to other surfaces, which do not protect from the soil heat output so effectively. Besides straw, strawberry cultivation practice uses various foils and mulching textiles, therefore our experiment focused on minimum temperatures above black woven mulching cloth. Practical meteorology uses shortly-mown lawn as a standard surface for measuring ground temperature, which is why we also included this type of surface in the comparative measuring.

Fig. 1 Straw layering still belongs to traditional technologies of strawberry cultivation in our environment

MATERIALS AND METHODS

The experiment took place between May 2013 and May 2014 at the premises of Mendeleum, Faculty of Horticulture of Mendel University, Lednice. Surfaces with grass, open soil, wheat straw mulch and black woven mulching cloth were prepared and maintained within a relatively small distance of several metres. Temperature sensor (DS18B20, Dallas Semiconductor) in copper nickel-coated casing on a special stand was placed 5 cm above each of these surfaces

(Fig 2), in accordance with ČHMÚ regulations (Žídek, Lipina 2003). Thermometers are not protected by any radiation cover, which aims to ensure the resulting energy balance, influencing their temperature, which should be approximately the same as on the surface of the surrounding plants. Data provided by a thermometer installed in this way represents not only the ambient air temperature, but also the effect of longwave radiation balance, and of heat loss through evaporation in case of dew, or its gain from condensation of vapour on the thermometer’s surface. The readings from thermometers were recorded in regular 15-minute intervals using Meteo-UNI datalogger (AMET, Velké Bílovice). The lowest values for each day (0 – 24 hours) were selected from the measured data, and were further evaluated using standard statistic methods presented below.

Fig. 2 Position of sensors above the different surfaces

RESULTS AND DISCUSSION

Fig. 3 captures the differences between minimum temperatures above open soil and three other alternatives. It is clear that lower minimum temperatures occur throughout the entire monitored period above straw-covered surface than above open soil. Differences are smaller above cloth: both negative (i.e. lower temperature above cloth than above open soil) and positive (higher temperature above cloth surface). The grass patch yielded similar results – differences are both positive and negative.

This is clearly visible on the curves of variation excess for individual surfaces on Fig. 4, which shows that in 90 % of cases the temperatures above straw-mulched surface were lower than above bare soil; the two other alternatives show almost zero inclination. In 10 % of the cases a temperature lower by more than 1.8°C can be expected above straw than above open soil, while in the same number of cases it is only by more than 0.7°C lower above grass and cloth.

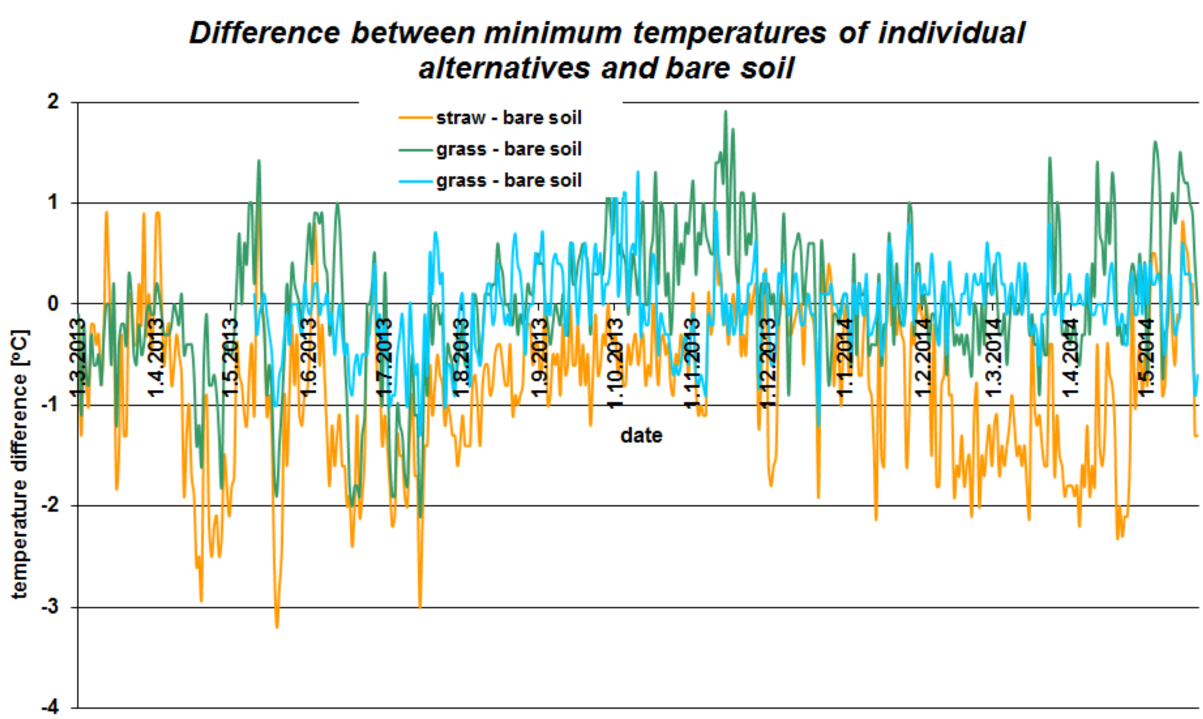


Fig. 3 Difference between minimum temperatures of individual alternatives and bare soil

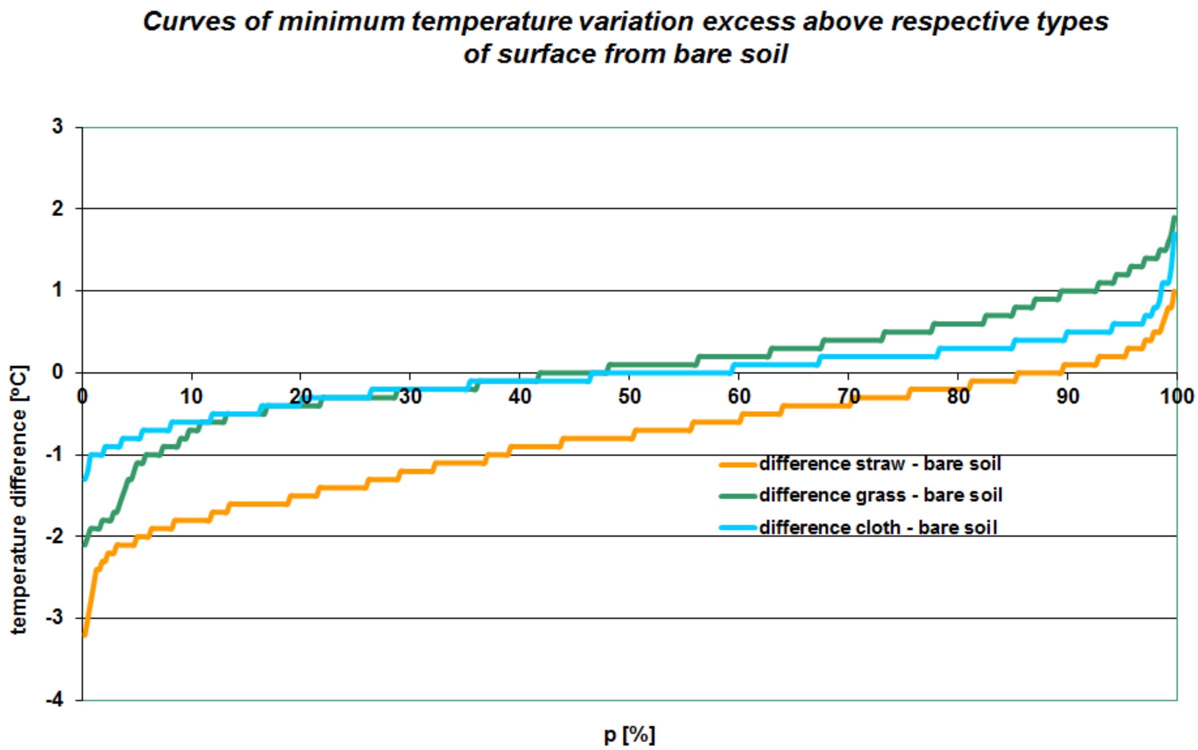


Fig. 4 Curves of minimum temperature variation excess above respective types of surface from bare soil

Fig. 3 suggests that minimum temperature variations do not remain the same throughout the year; their year-round progress can be seen on Fig. 5, which shows average monthly negative variations of the individual alternatives. In case of straw it is clear that negative variations occur practically throughout the entire first half of the year from February to July, while towards the autumn months they gradually drop, achieving their minimum in October and November. The grass patch showed maximum negative variations in June and flat minimum in the autumn months, which is probably related to the growth of the grass patch. The lowest negative variations were noted with the cloth – these temperatures peak in July.

For potential frost damage to strawberry plants the ground temperatures in spring are crucial, especially in April and May. The lowest temperatures in these months were recorded above straw mulch, approximately by 1.0 – 1.4°C lower than above open soil. Use of woven mulching cloth leads to substantial reduction of these variations, on average to 0.2 – 0.4°C.

An example of typical course of temperatures in a period of negative energy balance with radiation weather regime is shown on Fig. 6, documenting the course of temperatures in 5 cm above the respective surfaces. A relatively fast drop of temperature above straw occurred shortly after sunset, while above other surfaces it decreased more slowly. This difference was maintained until dawn, but while above straw the temperatures reached negative values after midnight, they stayed above freezing point above the remaining surfaces. This proves the insulation capability of straw, which reduces heat penetration into the soil during the day, and at night it prevents heat loss through longwave radiation.

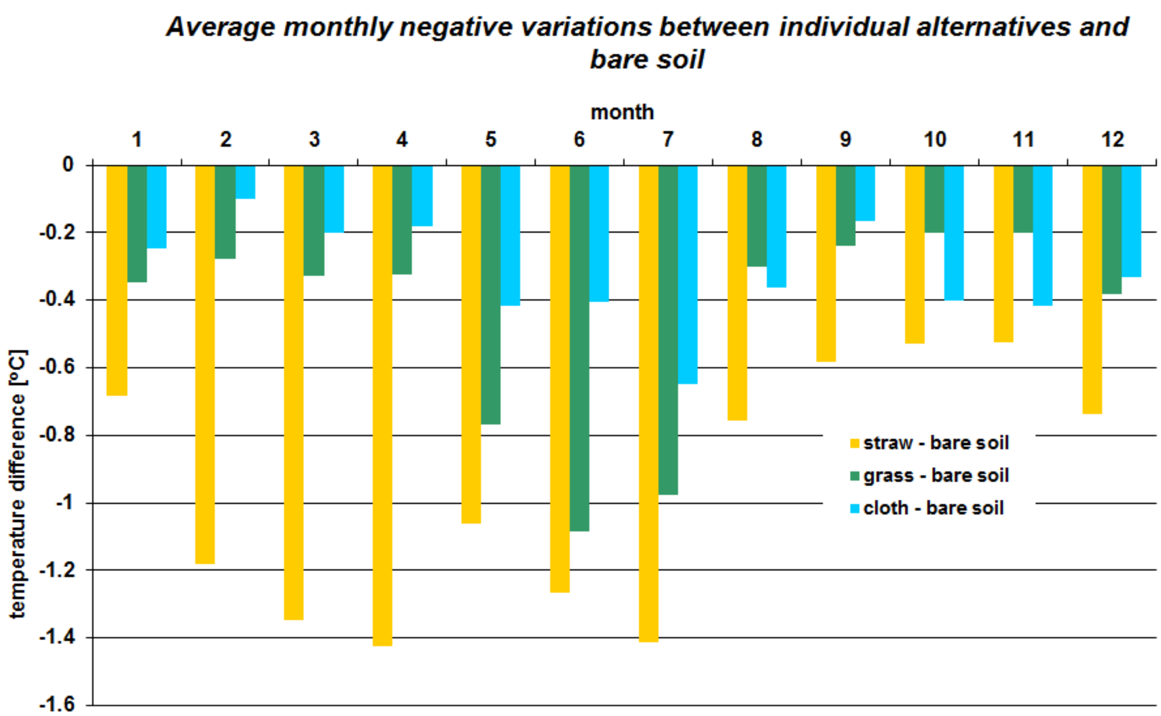


Fig. 5 Average monthly negative variations between individual alternatives and bare soil

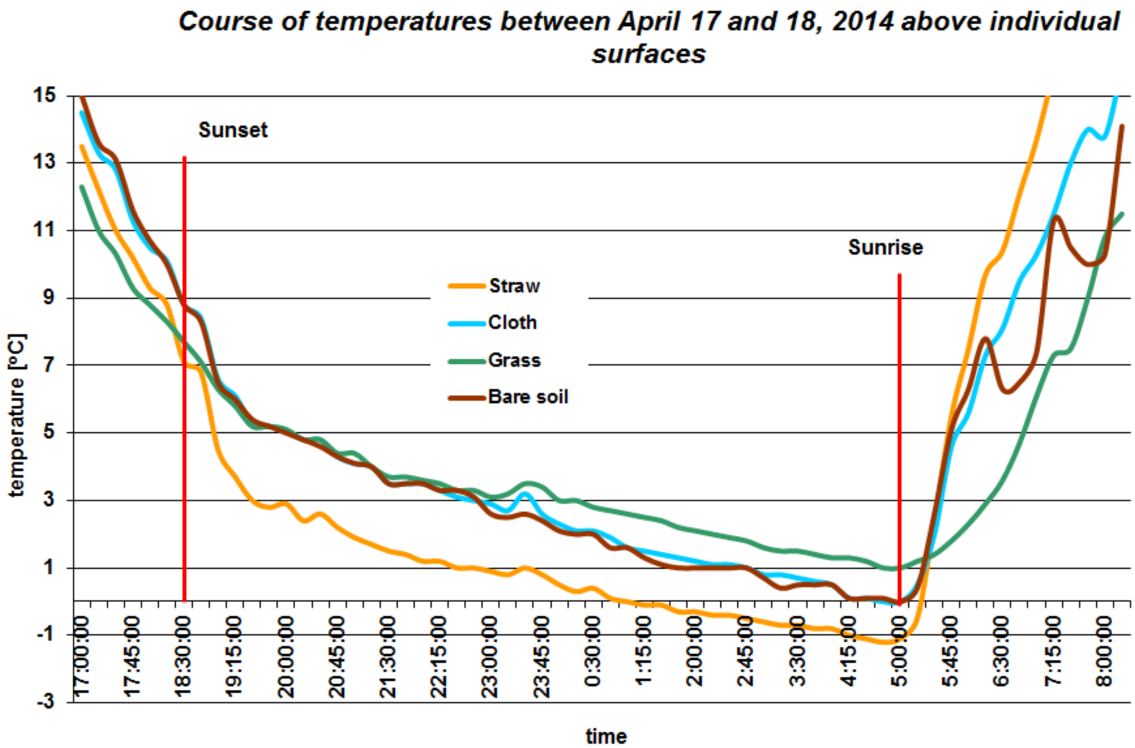


Fig. 6 Course of temperatures between April 17 and 18, 2014 above individual surfaces

CONCLUSION

The presented analysis shows a significant effect of the straw mulch on the minimum temperatures 5 cm above its surface. In extreme cases the differences may reach up to 3°C compared to bare soil. At nights with radiation regime of weather and in temperatures near the freezing point, plants above straw are much more prone to freezing than above tested surfaces. It was noted that the temperature difference occurs shortly after sunset, and that lower temperatures persist until sunrise. Temperatures are slightly higher above the cloth, and the difference from open soil is not as high as with straw. In some cases, higher minima were recorded above cloth than above open soil, but the difference is not a great one and in most cases it represents just several decimal points of Celsius, especially in the critical spring period.

The conclusion for growers of strawberries: if applying straw mulch, you can wait until the risk of ground frost has passed, i.e. until the second half of May. If applying mulching cloth, the probability of frost damage is the same as above open soil.

REFERENCES

Andrade, J.A. a kol. (2010): Effects of soil tillage and mulching on thermal performance of a luvisol topsoil layer. Folia Oecologica, vol. 37, No. 1, p. 1-7, ISSN 1336-5266

Taparauskiené, L.,Miseckaité, O. (2014): Effect of mulch on soil moisture depletion and strawbwerry yield in sub-humid area. Pol. J. Environ. Stud., Vol. 23, No. 2, p. 475-482

Žídek, D., Lipina, P. (2003): Návod pro pozorovatele meteorologických stanic. Metodický předpis č. 13.,ČHMÚ Ostrava, 90 s.

Dušková, L.; Kopřiva, J. (2005): Pěstujeme jahody. 2., aktualiz. vyd. Praha: Grada, 78 s. ISBN 80-247-1263-6.

Johnson, M.S.; Fennimore, S.A (2005):.Weed and crop response to colored plastic mulches in strawberry production. HortScience, 2005. Vol. 40, iss. 5, s.1371–1375, ISSN 0018-5345.

Kasperbauer, M.J.; Loughrin, J.H; Wang S.Y (2001): Light reflected from red mulch to ripening strawberries affects aroma, sugar and organic acid concentrations. Photochem Photobiol. Jul;74(1):103-7.

Kikas, A.; Luik, A. The influence of different mulches on strawberry yield and entomofauna. Acta Horticulturae, 2002, 567, 2,701–704

Matuškovič, J. (2002): Strawberry culture in the Slovak Republick. Acta Horticulturae 567, ISHS. Vol. 2, s. 543-545, ISBN 90-6605-775-0

Plíšek, B. (2001): Ekologické pěstování jabloní a tržní produkce bio jablek. Šumperk: PRO-BIO, 66 s. MK ČR E 11007.

Pokorný, L. (2000): Jahody pěstované na vyvýšených hrůbcích. Sborník: Jahodářství na prahu XXI. století. Odborný seminář, Lednice. s. 37-39. ISBN 80-7157-480-5.

Singh, R.; Sharma, R.R.; Goyal, R.G. (2007): Interactive effects of planting time and mulching of Chandler strawberry (Fragaria x ananassa Duch.). Scientia Horticulturae, Vol. 111, iss. 4, s. 344-351, ISSN 0304-4238.

SUMMARY

Příspěvek se zabývá vyhodnocením naměřených přízemních teplot nad různými povrchy, vyskytujícími se při pěstování jahod (holá půda, slámový mulč a textilie), travní porost byl zvolen jako standardní povrch používaný v našich podmínkách při meteorologických měřeních. Ukazuje se, že slámový mulč výrazně omezuje toky tepla do a z půdy a proto i teploty nad ním jsou za příhodných povětrnostních podmínek nižší než nad ostatními povrchy. Tyto odchylky jsou největší v jarních měsících, kdy se ještě vyskytují nízké přízemní teploty a v případě předčasného nastlání slámy se zvyšuje riziko mrazového poškození květů.

CONTACT

RNDr. Tomáš Litschmann, PhD.

AMET Corporation

Žižkovská 1230

691 02 Velké Bílovice

Tel. +420 731702744, E-mail: amet@email.cz

EXTREME POOR SNOWFALL CONDITION IN WINTER 2013/2014 IN COMPARISON TO PREVIOUS DECADE OF WINTERS IN THE CATCHMENT AREA OF HUČAVY

TOMÁŠ ŠATALA, MATÚŠ HRIBIK, JAROSLAV ŠKVARENINA

Department of Natural Environment, Faculty of Forestry, TUZVO, Ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

ABSTRACT

The paper is focused on an overall assessment of water supply in snow cover from data gathered by field measurements of winter seasons between 2004 – 2014 in a small mountain catchment Hučava (caldera of Poľana) especially at last winter season 2013/2014.Calculation of water reserves in snow cover also reflects the impact of forest cover. Temporal and spatial distribution of snow cover has been processed in ArcGIS software environment and the results show that the distribution and duration of snow cover is very variable, from lack of water supply in the snow (winter 2014) to maximum snow water equivalent of 525.4 mm (April 2013), which represents half the average annual rainfall on top of Poľana mountains.

Key words: water supply in snow cover, Hučava

INTRODUCTION

Snow in the global energy and water budget plays an important role, due to its high albedo and the ability to store water (Tabari *et al*. 2009). Scenarios of climate change (IPCC, 2013), expected changes in quantity, temporal and spatial distribution of snow on the surface and thus the impact on water resources dependent on snowmelt. Retreat enlargement permanent snow cover deteriorating hydrological regime (in particular water availability during the year), not only for Slovakia but also in many areas of the world. Temporal and spatial distribution of snow cover is important information from multiple points of view. Snow cover is an important hydrological basin, climate and biological agents. Significantly on the distribution of snow cover affects forest cover by influencing the accumulation and melting snow under the canopy compared to open area. This difference is dependent on specific habitat conditions and weather conditions of the winter (Gelfan et al., 2004). From a hydrological point of view, it is important to know the laws that govern as well as the total amount of snow cover in winter, snow accumulated in the basin. Snow cover closely depends on the air temperature and rainfall, and thus of changing climatic conditions. As the environmental factor is not the only reservoir of water for the spring season, but snow also protects the soil and vegetation from strong frosts. (Kadlec & Kovář 2008).

Snow, however, also acts as the negative. Especially in the winter with the presence of abundant snow cover may damage crops. A large amount of snow cover in mountainous areas restricts the movement of people and the risk of avalanches, which may hit the low-lying contiguous areas of forest. The other negative effect of snow cover is rich spring-winter floods, occurring especially in the steep warming accompanied by rain precipitation. Conversely, the absence of a minimum amount of snow cover lead to drying of the country to warmer and drier spring period and also has a link with the occurrence.

MATERIAL AND METHODS

For Slovak conditions and, in particular, for the calculation of the water supplies in small mountain catchments are the most credible the results of the measurements, whereas a network of meteorological stations of the projection is not thick enough, especially at higher altitudes. Monitoring of the characteristics of the snow cover from the winter season 2003/04 is up to the present, in the Poľana in the Hučavy basin (fig. 1). The monitoring methodology developed by the Department of personnel of the natural environment at the Technical University in Zvolen and conforms to the industry standard: 3109:02 OTN and in this work it further use. Hydrophysical characteristics of the snow cover are found the mass weighting method with use of snowtube. Snowtube has a cross section of 50 cm^2 weight.

Monitoring of the basic properties of snow has been carried out on a monthly basis. We conducted 5 measurements of snow water equivalent and the density. In open areas, such as in plantations, we carried out with the aid of a portable carrier 20 findings of the heights of the snow. Characteristics of snow cover on the height tranzekt we have found from 600 to 1280 meter above sea level in height intervals of approximately 100 meters -free area and the area for forest. We used measuring standard by the SHMÚ. After previous experience, that more donations would be sustainable and statistically unimportant. Less donations, however, could prove to be the accuracy of the results now (Hríbik & Škvarenina 2005).

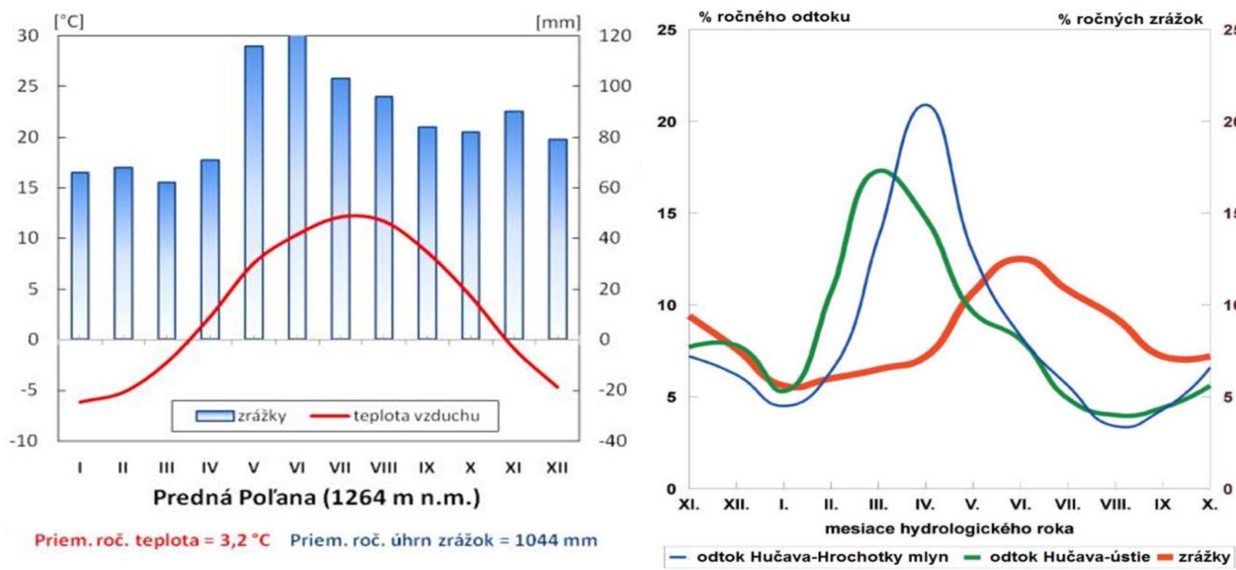


Fig.1 *Climate - graph a hydro - graph for Hučava basin (Hríbik et al., 2007)*

The whole process is carried out in the computer processing of the results of the field monitoring of the environment. Analysis of water in snow cover and its temporal and spatial distribution on the surface of the basin we carried out the tools and resources offered by the GIS environment, ArcGIS 10. The whole process is carried out over a digital model of the terrain of the third generation of the DMR 3 (grid cell size 10 x 10 meters). After getting the input data, the first step was in defining the catchment area, which we have identified on the basis of the DMR and the closing of the flow profile (limnigraphic station Hrochotský mlyn). With the following specified parameters generated by the catchment area of the module: *Spatial Analyst Tools /Watershed/ Hydrology.* For the next course of action, it was necessary to divide the area of the forest and the area of the basin and create a digital model of the terrain for the forest and the free surface. To the end, we provide the model of Spatial Analyst Tools/Mask, where the mask was vector Extraction/Extract by a layer of forest economic recovery plan of the 2011 crop. A similar process was used for forest and also a separate DMR for free area.

The next step was determining the dependence between the altitude (independent variable) and then changing the value of the water and the amount of snow and the height of snow (dependent variables), we decided to make a linear regression of dependency (average coefficients of determination 0.75-0.79). This dependency is used by SHMÚ and hydrophysical characteristics of the snow cover detected also in the interpretation of our expeditionary measurements. On the basis of computed altitude values as an independent variable, based on the regression between values and the amount of snow cover and water-dependent transformations, such as the data transferred into the program through snap-in map algebra Spatial Analyst Tools/Map Algebra/Raster Calculator. The underlying layers of the digital models of terrain analysis are for free area and the area of the forest basin. This procedure created maps of the distribution of water and the amount of snow cover. Derived maps decremented the amount of snow cover and water value of statistical indicators for the snow cover (in mm). We extracted the value specifically for the free area and the area of forest. Supply of water in snow cover catchment area (in million m^3) of water was detected as the sum of the values of snow cover on the desktop, open area and together. For ease of interpretation and to check the accuracy of the maps have been created transparent map outputs for each winter season, which arise by the classification image using Spatial Analyst Tools / Reclass / Reclassify. A similar procedure was used in the work of Hríbik *et al.*2008: Zimné zásoby snehu v malom horskom povodí Studeného potoka v orografickom celku Západné Tatry.

RESULTS

Snow water equivalent is the most concise characteristics from the perspective of hydro-physical properties of snow. It is the most important information obtained within the framework of information on snow cover. It is closely dependent on the amount (in our case, the coefficient of determination, R^2 = 0.85 for the GOP and R^2 = 0.80 for forest) and the density of the snow cover, and is defined as the amount of water that would be a thawing of snow cover. Given in millimeters and applies as: 1 mm of water per 1 m^2 is 1 liter of water.

It has seen that culmination occurs mainly in the months of February and March, as the amount of snow, which provesthe relationship between these characteristics. Interesting is the fact that the maximum snow water equivalent at the time of its culmination value is the value of 525,4 mm (April 13), representing almost half of the average annual rainfall, rainfall on top of Poľana (1145 mm) bound in the form of snow. In contrast, last winter (2013/2014) we note the lack of snow on most of the area.

Considering the diversity of both the weather and the natural environment is the amount, distribution and duration of snow cover is very variable. Calculation of the water supply in snowpack was million. m^3 (Fig. 2), we note that the values are within the ten-year data variable to the extent that the difference between maximum and minimum water supply catchments in time is the culmination of more than 20 - fold. Maximum water supply (March 2006), was at 8,295 million m^3 while the minimum (February 2014) the water supply of snow cover accounted for only 0.352 million m^3 of water (February 2014). When expressed under the two winter seasons can be simplified in the assessment highlights winters in terms of water availability in snow cover in the basin held: 2006> 2005> 2013> 2012> 2004> 2007> 2009> 2008> 2010> 2011> 2014.

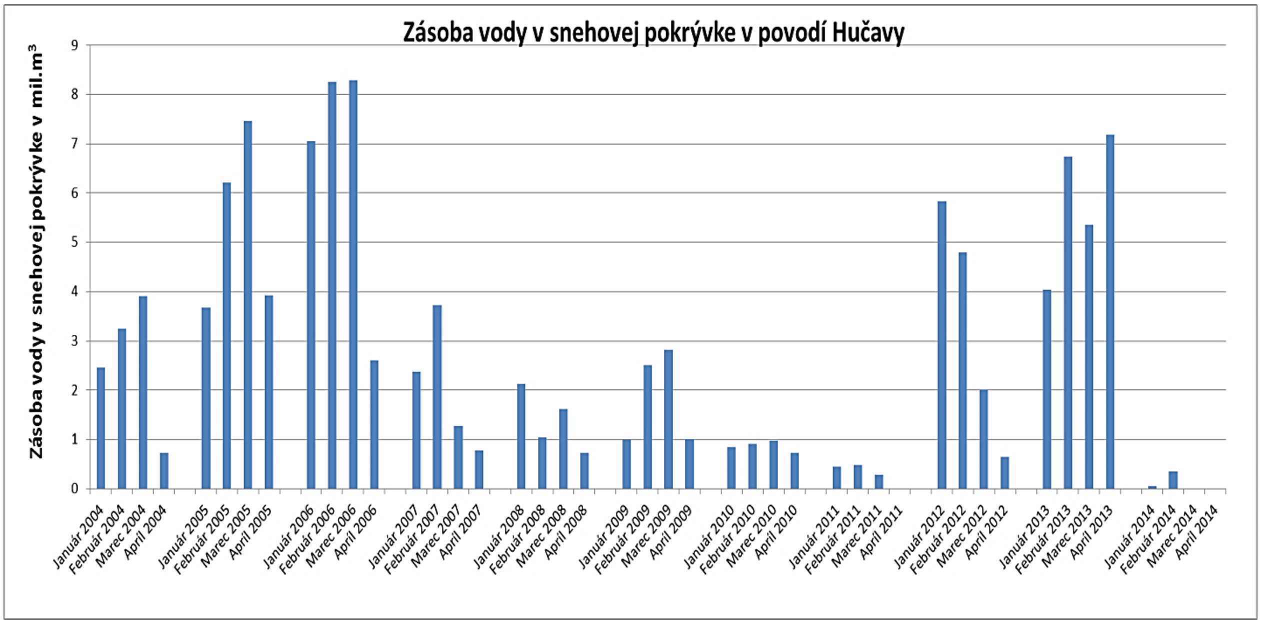


Fig.2. *Supply of water (in million m^3) bound in snow cover in the watershed Hučava (2004-2014)*

Graphic evaluation of snow water equivalent (Fig. 3) also captures the spatial variation of the catchment area. The colour range is selected from white (absence of snow) colours to deep red colour (maximum water depth values). Boundary of the basin boundary maps are most altitudes. Well it is therefore observable rising water value snowpack in altitude basin. In forest stands watching the generally lower water depth values over the free surface (best seen in March 2004).

CONCLUSIONS

The paper aimed to take stock and mutually compare water supplies in the basin Hučava in the years 2004-2014. Calculation of water reserves in snow cover is considering the impact of forest cover as in Slovakia is the most mountainous and foothill catchment, especially at higher altitudes forested. From the hydrological point of view can be considered snowpack water reservoir, which is variable and highly dependent on climatic conditions of environment. This variability of water resources and demonstrate our results within 11 - years monitoring. The snow cover is therefore accumulated significant reserves of water. This spring depends on the weather or sudden continuously released into surface and subsurface runoff. In the case of a severe warming associated with abundant rainfall, these water supplies, flooding potential danger of melting snow. Conversely earlier spring retreat, or even complete absence of permanent water and abundant snow cover is a major cause of faster and stronger spring air temperature rise. If there is no moisture deficit, caused by a lack of snow, spring rains sufficient coverage, this condition may lead to the formation of prolonged droughts and stronger with adverse, sometimes disastrous consequences for agricultural production and water management.

On the other hand, has a certain scale influence on climate conditions alone snowpack. Views on global climate change, its speed, impact and degree of fault may often vary, sometimes they are quite contradictory. However, it is undeniable that it has become a reality. General climatological analyzes confirm the change in the duration of snow cover, as well as the decline in the proportion of precipitation falling on the earth's surface in the form of solid state (except the highest mountain positions).

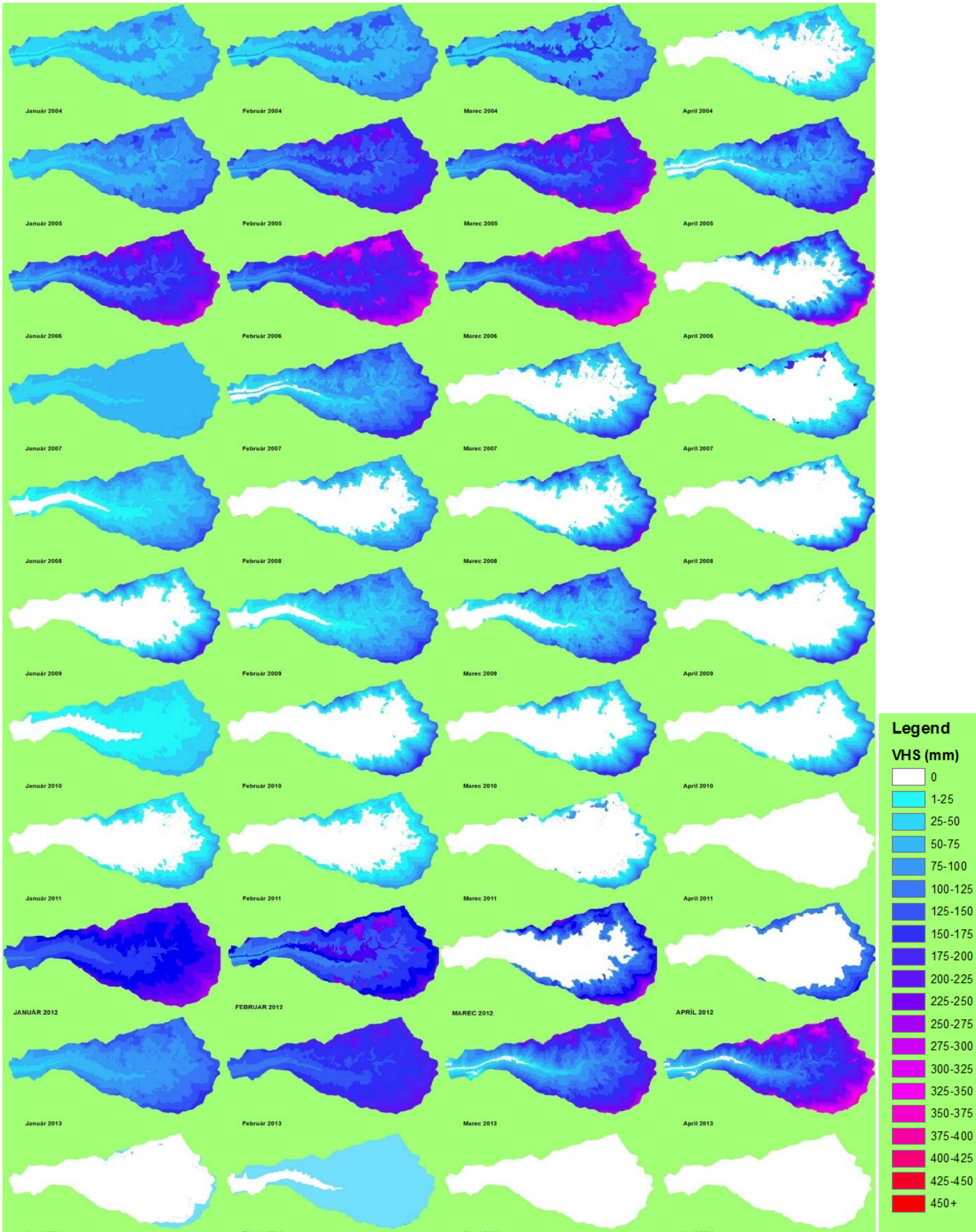


Fig. 3 *Temporal and spatial distribution of water depth values in the basin Hučava (2004-2014)*

The most significant loss of solid precipitation was recorded at altitudes 1,000 to 1,500 m (may be included here and basins of central Slovakia). Areas below 1000 m n. m. begin to significantly dominate liquid precipitation, especially at the beginning and end of winter. Synergistic effect of changes in precipitation and temperature rise disrupts the natural water cycle, since its end effect snow melting. Therefore, research snow conditions and water resources tied up in snow cover has legitimate meaning.

REFERENCES

Gelfan, A.N., Pomeroy, J.W., Kuchment,L.S.,2004: Modeling Forest Cover Influences on Snow Accumulation, Sublimation, and Melt, Journal of Hydrometeorology Special Section, 2004 (5), p.785-803.

Hríbik, M., 2007: Modelovanie zmien hydrofyzikálnych vlastnosti snehovej pokrývky ako zdroja imisnej záťaže vo vybraných pohoriach Slovenska v podmienkach rastúcich koncentrácii oxidu uhličitého. Dizertačná práca, p. 155.

Hríbik, M., Majlingová, A., Škvarenina, J., 2008: Zimné zásoby snehu v malom horskom povodí Studeného potoka v orografickom celku Západné Tatry. „Bioklimatologické aspekty hodnocení procesů v krajině“, Rožnovský, J., Litschmann, T. (eds.), 2008, p.10.

Hríbik, M., Škvarenina, J., 2005: Príspevok k štúdiu mikroklímy snehovej pokrývky v bukovom a smrekovom lesnom poraste BR Poľana. In: Rožnovský, J., Litschmann, T. (eds.): „Bioklimatologie současnosti a budoucnosti“, Křtiny 12. – 14.9.2005, CD nosič a zborník abstraktov 4 s

Intergovernmental Panel on Climate Change (IPCC) 2013: Fifth Assasment Report: Climate Change (AR5), Working Group I. Report „The Physical Science Basin“. 2013. p. 318-382.

Kadlec, V., Kovář, P.,2008: Využitie zrážkovo- odtokového modelu KINFIL na povodí Hučavy. Správy lesníckeho výskumu, 2008,(3).
OTNŽP SR 3109:02. Meranie a vyhodnocovanie snehových zásob v povodí

Tabari, H., Marofi, D., Abyaneh, H. Z., Sharifi, M.R., 2009: Comparison of artificial neural network and combined models in estimating spatial distribution of snow depth and snow water equivalent in Samsami Basin of Iran, Neural Computing&Applications Springer-Verlag London Limited, 2009,19,(4), p.625-635,

ACKNOWLEDGEMENTS

This post is the result of the implementation of the project: a centre of excellence for decision support in the Woods and from ITMS: 26220120120, supported by research and development, operational programmes financed by the ERDF (20%).

We support research activities in Slovakia/project is co-financed by EU funds/. This post is also supported by research grants for the VEGA 1/1130/12 (40%), in VEGA 1/0281/11 (10%), in VEGA 1/0257/11 (10%) of the Slovak grant Agency for science and the Agency for the promotion of research and development within the framework of the Treaty no APVV 0423-10 (20%).

SUMMARY

Predkladané výsledky poukazujú na veľkú variabilitu snehových zrážok malého horského povodia. A to od absencie snehovej pokrývky (zima 2014) až po polovicu priemerných ročných zrážok (525,4 mm) na vrchole Poľany viazaných vo forme snehu (apríl 2013). Táto variabilita snehových zrážok sa prejavuje aj vo výsledkoch v rámci 11 – ročného monitoringu. V lesných porastoch sledujeme všeobecne menšie hodnoty výšky snehovej pokrývky aj vodnej hodnoty snehu ako na voľnej ploche. Výpočtom zásob vody viazanej v snehovej pokrývke v povodí Hučavy (v miliónoch m^3) konštatujeme, že hodnoty sú v rámci sledovaného obdobia rokov 2004-2014 premenlivé až do tej miery, že rozdiel medzi maximálnou a minimálnou hodnotou vo vrchole zimy je viac ako 20 – násobný. Maximálna v snehu viazaná zásoba v povodí bola 8,295 miliónov m^3 vody (marec 2006), zatiaľ čo minimálna zásoba vody v snehovej pokrývke predstavovala iba 0,352 m^3 vody (február 2014). Rozdielne čísla každej zimy ukazujú, že sledovanie snehových pomerov v malých horských povodiach je dôležité či už pre predpoveď povodní s topiaceho sa snehu alebo naopak následnej suchej periódy s jeho absencie aj vo vyšších nadmorských výškach.

CONTACT

Ing. Šatala Tomáš

Department of Natural Environment, Faculty of Forestry, TUZVO

Ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

0902 066 192, ssatalatomass@gmail.com

DETECTION OF DROUGHT EVENTS USING COMBINATION OF SATELLITE DATA AND SOIL MOISTURE MODELLING

DANIELA SEMERÁDOVÁ [1,2]***, MIROSLAV TRNKA*** [1,2]***, PETR HLAVINKA*** [1,2]***, JAN BALEK*** [1,2]***, ROMAN BOHOVIC*** [2]***, TSEGAY TADESSE*** [3]***, MICHAEL HAYES*** [3]***, BRIAN WARDLOW*** [4]***, ZDENĚK ŽALUD*** [1,2]

1) *Institute of Agrosystems and Bioclimatology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic*
2) *Global Change Research Center AS CR, v.v.i., Bělidla 986/4a, 603 00 Brno, Czech Republic*
3) *National Drought Mitigation Center, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA*
4) *Center for Advanced Land Management Information Technologies (CALMIT) School of Natural Resources, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA*

ABSTRACT

The use of satellite data offers a potentially well usable tool to accurate drought monitoring. The study examines the space-time possibility of agricultural drought detection using freely available data from the MODIS instrument onboard Terra and Aqua satellites that reflects vegetation condition. Vegetation greenness metrics used in this study are based on the spectral reflectance curves in the visible red and near-infrared part of the spectrum and are expressed in relation to the average for the period of 2000-2014. The results are presented in weekly time step for the whole area of the Czech Republic, and are compared to the drought monitor system, based on the SoilClim dynamic model for soil water content estimates. These data, as well as other parameters, such as soil properties and land use, are integrated at 500 meters spatial resolution.

Key words

Drought monitor, remote sensing, MODIS, NDVI, seasonal greenness

INTRODUCTION

Remote sensing (RS) technology (observations of the earth surface from sensor systems mounted on air borne, space borne or land-based platforms) is increasingly used for monitoring crops and to detect the impacts of stress on vegetation. The cause of this stress may lie in various biotic (pests, diseases) and abiotic factors. Agricultural drought (and its impacts on vegetation) was analyzed in this study. The efficiency of RS techniques can be seen in the vegetation state metrics calculation, referred as vegetation/drought indices, as well as in large amount of data availability at a time with extensive geographic coverage and high repetition rate. Furthermore satellite images from active sensor MODIS (Moderate Resolution Imaging Spectroradiometer), which is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites, acquiring data in 36 spectral bands, or groups of wavelengths are available for free.

Various vegetation indices (VI) are commonly used for monitoring the vitality and photosynthetic activity of the vegetation, e. g. the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), the Vegetation Condition Index (VCI), the Normalized Difference Water Index (NDWI). They are used to identify the health status of vegetation, to depict phenological changes, to estimate green biomass and also to assess the impact of drought. Drought indices are being used to characterize drought operatively and they vary by the use of disciplinary data. Combining them with remote sensing derived land surface information is typical for the latest generation of drought indices, such as the recently developed Vegetation Drought Response Index (VegDRI; Brown et al., 2008).

The most often deployed vegetation index in many applications is NDVI because of its simplicity in both calculation and interpretation. It has been extensively used for drought monitoring (e.g. Yuhas, Scuderi 2009, Geng et al. 2014), drought detection related to crop yield estimation or forecast (i.e. Liang, 2004, Doraiswamy et al., 2004; Li et al., 2007; Huang et al., 2013; Kowalik et al., 2014). Time series of NDVI allows monitoring not only drought but the natural dynamic of vegetation phenology too (Hmimina et al., 2013).

The vegetation reflects high in the near infrared (NIR = 0.7-1.1 µm) due to its canopy geometry, the health of the standing vegetation and absorbs more in the red (RED, around 0.66 µm) radiation range due to its biomass and photosynthetic activity. Stressed vegetation has a higher reflectance than a healthy vegetation in RED and lower reflectance in NIR radiation range of the electromagnetic spectrum. Vegetation indices take the advantage of this differential response in the visible and the infrared range of the spectrum and indicate both changes in cellular structure of the leaves and the amount of chlorophyll present in the plants.

The main objective of this paper is to evaluate detected drought events using remotely sensed NDVI. It is hard to differentiate between vegetation anomalies caused by drought and changes caused by other stress factors without further information. The close relationship between vegetation vigour and available soil moisture means that the MODIS-acquired NDVI could be used to evaluate drought events by comparing it to outputs of Integrated Drought Monitoring System (IDMS, Trnka et al, 2014). This IDMS is based on the actual meteorological measurements in addition with another input data, such as soil types, land cover, slope and amount, extent and duration of snow cover, and is capable to assess the drought occurrence and its severity in a daily step.

MATERIALS AND METHODS

1) Satellite-based vegetation stress monitoring

For the satellite data set, measurements collected by MODIS instrument aboard Terra satellite for almost 15 years (from Feb. 2000 to Jul. 2014) were used. As indicator of vegetation health condition NDVI (eqv.1) was used. It is a function of green leaf area and biomass and it consists of a normalized ratio of the NIR and red bands (RED):

$$NDVI = (NIR - RED) / (NIR + RED) \qquad (1)$$

The MODIS Surface Reflectance daily product at 250-meter resolution for the period 2000-2014 was obtained through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota. This tool provides Bands 1 and 2 (centered at 648 nm, and 858 nm, respectively) that were used to calculate NDVI. Using associated data quality layer pixels of lower quality mainly due to clouds were masked. The cause of variations or noise in radiometric data can be either by instrument calibration, scan angle, sun angle or atmospheric conditions. The effect of noise can be reduced by data composition using the greenest pixel method or via data smoothing with curve fitting of filtering techniques. In order to eliminate high-frequency noise of channel values, the NDVI was calculated and smoothened using filtering procedure developed by Mendel University in Brno and Global Change Research Center AS CR, v. v. i. in cooperation with National Drought Mitigation Center and Center for Advanced Land Management Information Technologies, both University of Nebraska-Lincoln.

Due to variation in NDVI time series, caused by utilization of crop rotation schemes and changing crop patterns between seasons, the NDVI values were aggregated into a rectangular grid with cells of size 5 x 5 km; i. e. the average value of all pixels inside a cell represents the cell value. For each cell, the prevailing type of land cover was determined using Corine Land Cover 2006 data set – Version 16 (04/2012). Then reclassification of all vegetation categories into 7 main categories on the dataset was carried out with exclusion of artificial surfaces, water bodies and wetlands: (1) arable land, (2) heterogeneous agricultural areas, (3) grassland and pastures, (4) broad-leaved forest, (5) coniferous forest, (6) mixed forest, (7) scrub and/or herbaceous vegetation associations and/or bare areas.

The severity of drought situation could be assessed by the extent of NDVI deviation from its historical mean. The concept of relative greenness was used in next steps starting with the calculation of average NDVI values in a weekly step for the period 2000-2014. The difference of the average value from the long term mean for a particular week is referred as Percent of Average Actual Greenness (PAAG, Fig. 1). In order to depict drought impacts especially on field crops, two variations of this parameter were obtained by taken different landuse category range into account.

2) Ground based drought monitoring tool

The SoilClim model (Hlavinka et al. 2011) based on approach by Allen et all. (1998), was used as a tool for estimation of reference and actual evapotranspiration, presence of snow cover, soil temperature at 0.5 m depth and soil moisture course within two defined layers. SoilClim works in a daily time steps and needs maximum and minimum air temperature, global solar radiation, precipitation, vapor pressure and wind speed as meteorological inputs. Further datasets for simulation are required, such as the basic soil properties (soil water holding capacity) and information about vegetation cover that is defined by coefficients of crop identification, referred as Kc parameters.

This tool was used for the whole area of the Czech Republic divided into regular grids with spatial resolution 500 m. The rendered maps of drought intensity compares the actual value of soil moisture in each grid for a particular day with the distribution of soil moisture values during the period 1961 – 2010 with time window of ± 10 days from current date. The value is subsequently expressed as a percentile of soil moisture in a specific day and is used to assign the corresponding category of drought intensity (S0 – S5) to it.

RESULTS

NDVI as a function of green leaf area and biomass is successfully used index for operational drought assessment. Mainly the relative greenness approach, i.e. the ration of current NDVI to the historic mean NDVI for the same region and period give us the information about impacts of stress on vegetation. The greenness parameter PAAG is visualized in Fig 1 for the week 28 in 2014 for the Czech Republic at 5 km spatial resolution reflecting the vegetation condition after prolonged low rainfall time period: the bigger map depicts relative greenness by averaging NDVI values for cropland and grassland pixels exclusively; the change compared to the situation of the previous week is mapped on the left bottom side; vegetation greenness using NDVI values for all land cover types is illustrated on the left top map.

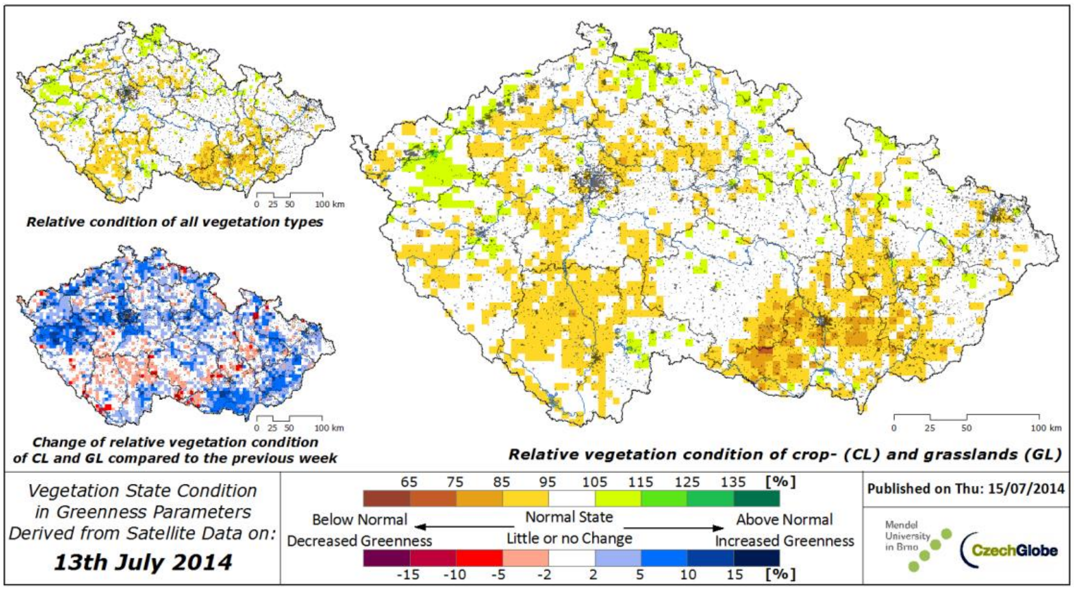


***Fig. 1**: Percent of average actual greenness (PAAG), the NDVI-derived landuse specific greenness parameter that reflects relative vegetation condition for a particular week from Sunday, 06th July to Sunday, 13th July 2014.*

Consequently the results assessing the relative vegetation condition and the intensity of drought for the time period between weeks 12 and 26 in 2012 have been compared using GIS technique. Prolonged and intense drought event in the southern and central Moravian region (partially apparent in the Bohemian region) is evident in maps of drought intensity (Fig. 2a) based on outputs from IDMS. This situation had a negative impact on vegetation especially at a time of intense spring growth (between weeks 21 - 23). This could be observed from satellite images as well, namely from the greenness parameters, that are being derived from satellite data and reflect the relative condition of vegetation (Fig 2b). The strongest negative response of the vegetation in week 22 can be associated with the decreased water availability within the root-zone soil layer in the course of the actual and the previous week.

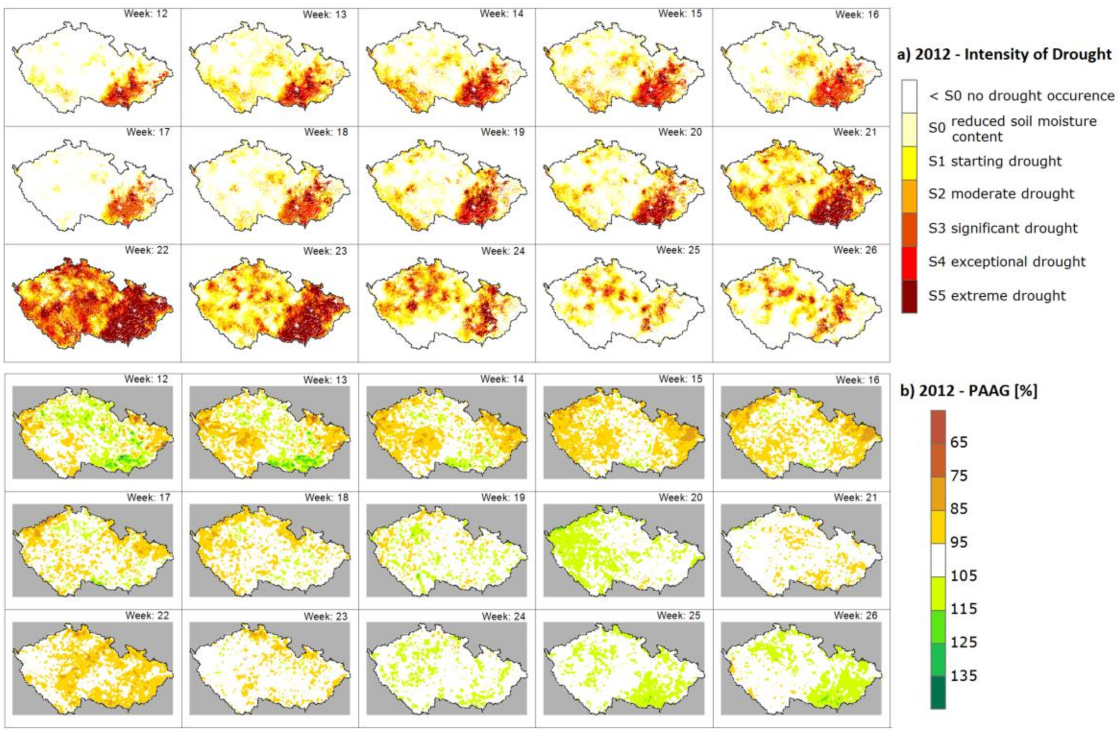


***Fig. 2**: The visualization of a) the intensity of drought within the root-zone soil layer for the period between weeks 12 and 26 in 2012, b) percent of average actual greenness (PAAG), the NDVI-derived greenness parameter that reflects relative condition of all vegetation types, for the same period.*

The sensitivity of the method was verified in the study by evaluating the relative vegetation condition based on NDVI in the whole area of the Czech Republic. The weekly data accessibility is a big advantage highlighted by the independence of this method on ground measurements and observations. The obtained results confirm that this satellite approach is valuable additional tool for basic ground method assessing the agricultural drought.

Conclusion

The change in absorption and reflection characteristics could the underlying idea for a tool monitoring various cause stressed vegetation. NDVI is one of VIs indicating given changes of spectral characteristics. Its original values or derived parameters give us the information if and how much stress the plants are under. In case of drought events detected using meteorological data and further information (about soil, exposition, snow cover etc.) NDVI can be used for vegetation water stress confirmation. The example of the year 2012 with significant episode of spring drought, indicated by drought monitoring based on SoilClim, justifies the use of this method for the determination of drought and its impacts on vegetation.

References

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Guidelines for computingcrop water requirements. FAO Irrigation and Drainage Paper No. 56.

Brown, J.F., Wardlow, B.D., Tadesse, T., Hayes, M.J., & Reed, B.C. 2008. The Vegetation Drought Response Index (VegDRI): A new integrated approach for monitoring drought stress in vegetation. GIScience and Remote Sensing, 45, 16-46

Doraiswamy, P.C., J.L. Hatfield, T.J. Jackson, J.H. Prueger, B. Akhmedov, Stern, A.J. 2004. Crop condition and yield simulations using Landsat and MODIS, Remote Sensing of Environment , 92:548–559

Geng, L., Ma, M., Yu, W.,Wang, X., Jia, S.2014. Validation of the MODIS NDVI Products in Different Land-Use Types Using In Situ Measurements in the Heihe River Basin, Ieee Geoscience And Remote Sensing Letters, 11, Issue: 9: 1649-1653, DOI: 10.1109/LGRS.2014.2314134

Hlavinka, P., Trnka, M., Balek, J., Semerádovám D., Hayes, M., Svoboda, M., Eitzinger, J., Možný, M., Fischer, M., Hunt, E., Žalud, Z. 2011. Development and evaluation of the SoilClim model for water balance and soil climate estimates. Agriculture and Water Management 98: 1249–1261

Hmimina, G., Dufrêne, E., Pontailler, J.-Y., Delpierre, N., Aubinet, M., Caquet, B., de Grandcourt, A., Burban, B., Flechard, C., Granier, A., Gross, P., Heinesch, B., Longdoz, B., Moureaux, C., Ourcival, J.-M., Rambal, S., Saint André, L., Soudani, K. 2013. Evaluation of the potential of MODIS satellite data to predict vegetation phenology in different biomes: An investigation using ground-based NDVI measurements Remote Sensing Of Environment 132, 145–158,

Kowalik, W., Dabrowska-Zielinska, K., Meroni, M., Raczka, T.U., de Wit, A. 2014. Yield estimation using SPOT-VEGETATION products: A case study of wheat in European countries, International Journal of Applied Earth Observation And Geoinformation, 32 : 228-239 DOI: 10.1016/j.jag.2014.03.011

Li, A., Liang, S., Wang, A., Qin, J. 2007. Estimating crop yield from multi-temporal satellite data using multivariate regression and neural network techniques, Photogrammetric Engineering and Remote Sensing 1, 73-1149

Liang, S. H., Fang, J., Teasdale, M., Cavigelli., Hoogenboom, G. 2004. Estimation of crop yield at the regional scale from MODIS observations, Proceedings of the IGARSS, 3:1625–1628.

Trnka, M., Hlavinka, P., Semerádová, D., Hayes, M., Štěpánek, P., Možný, M., Zahradníček, P., Balek, J., Eitzinger,, J., Žalud, Z., 2014. Monitor sucha pro Českou republiku – www.intersucho.cz, sborník konference Mendel a Bioklimatologie, v tisku

Yuhas, A. N., Scuderi, L.A. 2009. MODIS-derived NDVI Characterisation of Drought-Induced Evergreen Die-off in Western North America Geographical Research 47 Issue: 1: 34-45

ACKNOWLEDGEMENT

This contribution was supported by COST CZ program of Ministry of Education, Youth and Sports of the Czech Republic "The possibilities of using remote sensing to determine actual evapotranspiration of selected field crops" project No. LD14121 and the Operational Program of Education for Competitiveness of Ministry of Education, Youth and Sports of the Czech Republic project "Building up a multidisciplinary scientific team focused on drought" project No. CZ.1.07/2.3.00/20.0248.

SUMMARY

Článek je příspěvkem k problematice monitoringu zemědělského (půdního) sucha využívající technologie dálkového průzkumu Země pomocí satelitů. Senzorem MODIS (Moderate Resolution Imaging Spectroradiometer) umístěným na družici Terra byla v týdenním kroku sledována kondice vegetace prostřednictvím parametrů, odvozených z vegetačního indexu NDVI (Normalized Difference Vegetation Index). Data byla agregována pro celé území České republiky v gridu 5x5 km, aby byl získán reprezentativně homogenní obraz krajiny a jejího landuse. Změny a anomálie v hodnotách indexu směrem ke zhoršení kondice vegetace naznačují působení stresu. V případě časové shody takto pozorovaného stresu s vyšší intenzitou sucha, kterou ukazuje ISSS (Integrovaný Systém Sledování Sucha) založený na pozemních datech, lze s vysokou mírou pravděpodobnosti vysvětlit změnu NDVI jako odezvu vegetace na probíhající sucho. V rámci výsledků je popsána reakce porostů na epizodu sucha v jarním období roku 2012.

CONTACT

Ing. Daniela Semerádová, Ph.D.

Institute of Agrosystems and Bioclimatology

Faculty of Agronomy

Mendel University in Brno

Zemědělská 1, Brno, 613 00 Czech Republic

E-mail: dany357@yahoo.com

LONG-TERM TEMPORAL CHANGES OF PRECIPITATION QUALITY IN THE MOUNTAINOUS REGION OF CHOPOK (LOW TATRAS, SLOVAKIA)

MAREK SITÁR[1], MIRIAM HANZELOVÁ[1], JOZEF MINĎÁŠ[2], JAROSLAV ŠKVARENINA[1]

1) *Department of Natural Environment, Forestry Faculty, Technical University in Zvolen*
2) *Institute of Ecology and Environmental Sciences, University of Central Europe in Skalica*

ABSTRACT

The paper has analysed the data about chemical composition of precipitation at Chopok EMEP station. The database comprised the information about the concentrations of sulphates, nitrates, ammonia ions, base cations and heavy metals (Cd, As, Al, Zn). The results are presented in a graphical form showing long-term temporal trends in the chemical composition of precipitation. The statistical characteristics of temporal trends were tested with Student method analysing the significance of the sampling coefficient of correlation. We revealed that the majority of concentrations of selected elements in precipitation significantly decreased in time.

Key words: precipitation chemistry, atmospheric deposition, temporal trends, acidification

INTRODUCTION

Continuous development of industrial and agricultural activities, transport, and the change in natural landscape and its individual components to anthropogenic components contribute to systematic distortion of balance in environment. The atmosphere, that does not recognise borders among countries, is most affected by human activities. Pollutants are transported over long distances of hundreds of kilometres from the pollution sources depending on the time they persist in the atmosphere. Pollutant emissions from stationary and mobile sources undergo chemical changes in the atmosphere, and have direct and indirect effects on human health and environment (SAŽP, 1997). Monitoring of chemical elements and compounds that cause acidification, eutrophication and other chemical processes in environment is still up to date. Acidification and eutrophication can contribute to climate change by influencing the gas exchange between the soil and the atmosphere. The impact of increased emissions of NOx is most discussed (Bartoňová, 2009).

The area of the Slovak Republic is situated at the south-eastern edge of the area with the highest regional air pollution and acidity of precipitation in Europe (SHMÚ, 2009). The problems with acid rains occurred several times in the last century. The first significant decrease of pH in precipitation was recorded in the 60s of the last century due to continually increasing concentration of SO_2, and NO_x in the atmosphere (Barančok & Varšavová, 1998). The residence time of SO_2 in the air is 1-3 days, while the residence time of nitrogen oxides is 1-10 days.

Several papers have dealt with the changes in precipitation chemistry in relationship to elevation and season (e.g. Bublinec & Dubová 1994). The results from the observations point out at significant acidification of through-fall in mountainous spruce forests, with the gradient of pH decrease equal to 0.32 units per 100 elevation metres. The authors found that the acidity was the highest in spring and winter, while pH slightly increased as autumn was approaching. Similar results were also presented by Škvarenina (1994).

The summary report on the environment in Europe (EEA, 1998) published by the European Environment Agency (EEA) with the headquarters in Copenhagen presents that the emissions of acidifying pollutants have significantly decreased since 1990, particularly in Central and Eastern Europe as a result of economic restructuring and gradual introduction of modern technologies. The reduction in Western Europe is primarily connected with the changes in the use of fuels, desulphurisation and denitrification of combustion gases, and the introduction of three-way catalysts in cars. Due to significant reduction of emissions, no further acidification occurs in the majority of European ecosystems, although several risk areas still exist situated mainly in Central Europe (Hůnová et al., 2009).

In connection with the significant reduction of SO_2 emissions in Slovakia as well as in the whole Europe and with far more moderate decrease of NO_x emissions, in the last decade we have observed a change in the ratio between sulphates and nitrates, and hence, also a change in their impact on precipitation acidification. While before the sulphates dominated, nowadays nitrates have become more important. This change can also modify the impact of acidic atmospheric deposition on vegetation. Some studies point out that the precipitation containing more sulphates is more toxic than the precipitation comprising more nitrates although their pH is equal (Ashenden, 2002).

MATERIALS AND METHODS

Study area

The meteorological observatory of the Slovak Hydrometeorological Institute (SHMÚ) on Chopok is situated at the ridge of the Low Tatras at an elevation of 2,008 m a.s.l., longitude 19°35'32", and latitude 48°56'38". The measurements started in 1977. Since 1978, this observatory has been a member of the EMEP (Environment Monitoring and Evaluation Programme) and GAW/ BAPMoN/WMO networks.

Chopok station belongs to a cold climatic region. Long-term mean of precipitation totals (1951-1980) is 1,142 mm, from which 667 mm falls in the summer half-year. A more detailed climatic description is shown in Figure 1.

Emission situation

According to NEIS (National Emission Inventory System), the main polluters in the district of Liptovský Mikuláš are 4 big and 100 medium sources of air pollution concentrated into two industrial centres of two towns – Liptovský Mikuláš and Liptovský Hrádok. In 2003, these sources produced in total 45.562 tons of particulate matter,756.205 t SO_2, 211.959 t NOx, 85.372 t CO and 24.181 t TOC to the atmosphere. In the study area, no significant sources of pollution exist, only small sources from the category of fuel-energy industry. The local air pollution comes from line sources, particularly road II/584 between Liptovský Mikuláš and Demänovská Dolina. CO, NOx, volatile non-methane hydrocarbons are mainly emitted to the atmosphere from these line sources. To a lesser extent, the combustion gases of cars also comprise the compounds of SO_2, CH_4, N_2O, Pb, HN_3, CO_2.

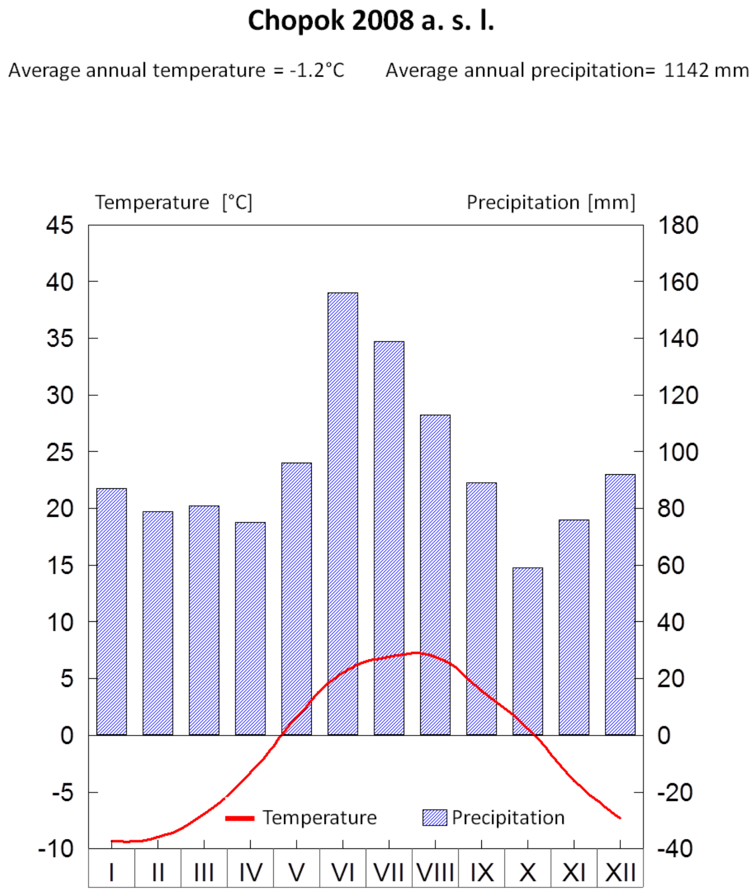


Figure 1 Climate data for Chopok

Pollution situation

The immission load of the area can be characterised only at places where the state of the atmosphere is monitored. For this reason, an automatic monitoring station is installed on Chopok. It is a regional station that belongs to a network of EMEP (European monitoring evaluation programme – programme for monitoring and evaluation of long-range transmission of air pollutants in Europe).

According to the results of EMEP measurements, the Slovak Republic (SR) is situated at the south-eastern edge of the area with the highest regional air pollution and precipitation acidity in Europe. The acidity of precipitation at this station represented by pH was 4.5 in 2000, which indicates the most acid precipitation from all regional stations in Slovakia (SHMÚ, 2010).

Sampling and analytical methods

Sampling and analytical methods used for the precipitation sampling and chemical analytical methods are presented in Tab.1

Tab 1 Method of sampling and analytical methods, Chopok (EMEP, 2010)

	Sampling	Sampling frequency	Analysis method
Precipitation			
Precipitation amount	SK02: Bulk,	Daily	
Sulphate	SK02: Bulk	Daily	Ion chromatography
Nitrate	SK02: Bulk	Daily	Ion chromatography
Ammonium	SK02: Bulk	Daily	Ion chromatography
Magnesium	SK02: Bulk	Daily	Ion chromatography
Sodium	SK02: Bulk	Daily	Ion chromatography
Chloride	SK02: Bulk	Daily	Ion chromatography
Calcium	SK02: Bulk	Daily	Ion chromatography
Potassium	SK02: Bulk	Daily	Ion chromatography
pH	SK02: Bulk	Daily	pH meter

Statistical characteristics were calculated in Microsoft Excel 2007. From the basic tabular values of weighted concentrations of pollutants in precipitation we first calculated deposition using the following formula (1)

Deposition (N) = RR x CON (N) (1)

Deposition of a pollutant N [kg.ha^{-1}.year^{-1}]

RR – precipitation amount (mm);

CON – concentration of a pollutant: mg.l^{-1}, of heavy metals in µg.l^{-1};

N – pollutant;

The analysed characteristics were visualised in Microsoft Excel 2007 as a time series described by a regression line. Statistical characteristics of temporal trends were tested with Student test of significance of sampling coefficient of correlation with *f=n-2* degrees of freedom.

RESULTS

The graphs presented below are based on the tabular values from EMEP, which include the values of pH, activity of H+, concentrations of sulphates converted to sulphur, and nitrates and ammonia ions converted to nitrogen. Afterwards, deposition of individual chemical elements was calculated from these values, and time series were evaluated as presented in tables.

From the graphical representation of the values and the trend regression line (Fig.2, Fig.3) it is obvious that from the long-term point of view, precipitation totals slightly increased by 6.4 mm of atmospheric precipitation per year. The correlation in the analysed time series is significant at 95% significance level, which means that the temporal trend is significant.

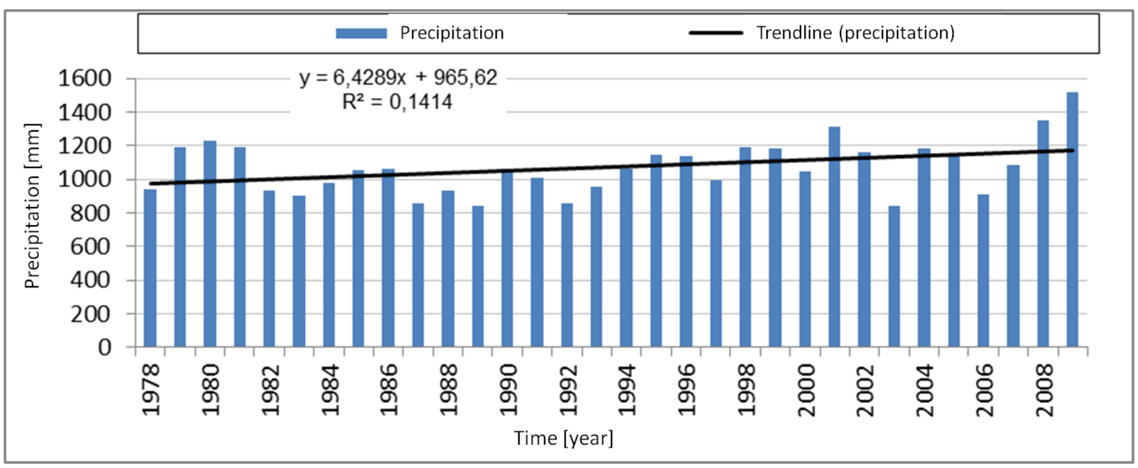


Figure 2 Annual precipitation totals during 1978-2009

The acidity of atmospheric precipitation significantly decreased during the analysed period. This trend is mainly caused by the reduction of primary acidifying ions, such as sulphate and nitrate ions. The reduction in the concentration of these ions is evident from the following graphs (Fig.4, 5) and Tab 2.

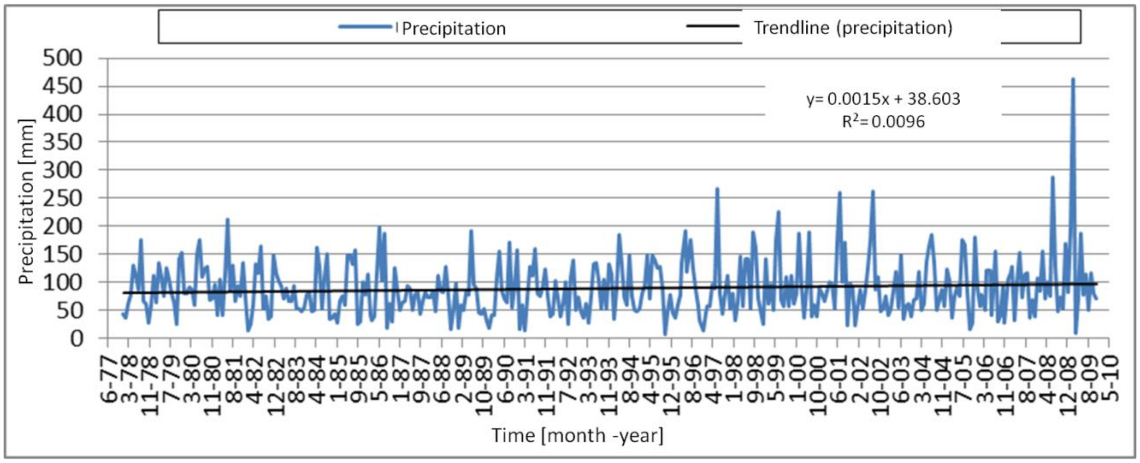


Figure 3 *Monthly precipitation totals during 1978-2009*

Table 2 *Characteristics of the acidifying substances, annual values*

Chopok	**acidifying substances**								
Statistic value	**Precipitation**			**N-NH_4^+**		**S-SO_4^{2+}**		**N-NO_3^-**	
				concentration	deposition	concentration	deposition	concentration	deposition
	mm	pH	H^+	mg.l^{-1}	kgN.ha^{-1}.year^{-1}	mg.l^{-1}	kgS.ha^{-1}.year^{-1}	mg.l^{-1}	kgN.ha^{-1}.year^{-1}
Rate of change mm; mg.rok^{-1}; kg.ha^{-1}.rok^{-1}	6.4289	0.0224	-2.00E-06	-0.0341	-0.3443	-0.0669	-0.6557	-0.117	-0.0756
tendency	increasing	increasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing
P=1-α%.level of significance	95.00%	99.90%	99.90%	99.90%	99.90%	99.90%	99.90%	99.90%	99.90%
max	1519.8	4.95	0.0001	1.37	15.7405	2.59	30.9202	0.61	6.4341
min	840.27	3.93	0.00001122	0.37	4.234169	0.41	4.3584	0.25	2.860925

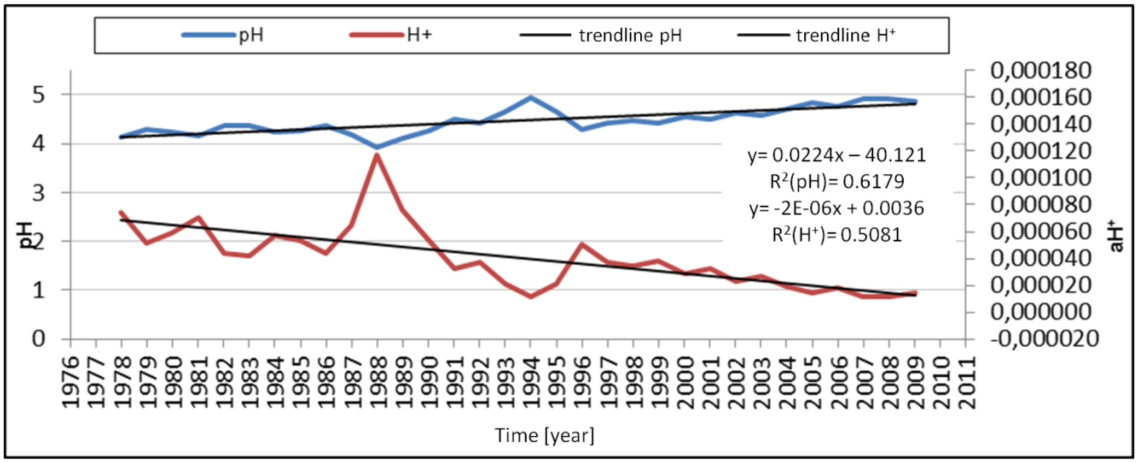


Figure 4 *Annual weighted means of pH and aH*$^+$ *in precipitation during 1978-2009*

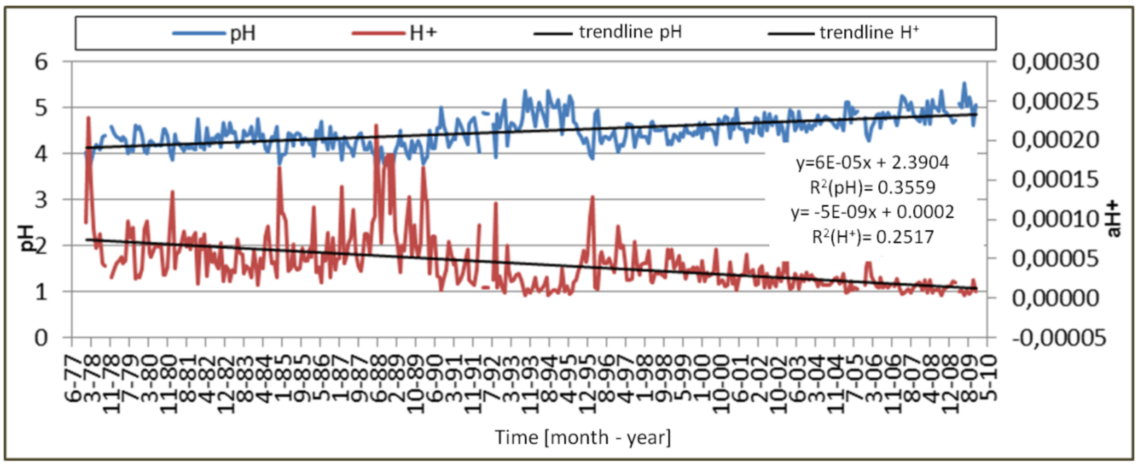


Figure 5 *Monthly weighted means of pH values and activity of H*$^+$ *in precipitation during 1978-2009*

Sulphate ions were dominant in precipitation, and contributed to the acidity of precipitation most. Their concentration was decreasing at a rate of -0.0669 mg.l^{-1} per year and -0.0002 mg.l^{-1} per month over the whole period from 1978 to 2009 as shown in Fig 6. This decreasing trend correlates with the time series at 99.90% significance level. The overall reduction in the concentration of sulphates coincided with the long-term reduction of SO_2 emissions since 1980 (SHMÚ, 2008). The monthly weighted means of sulphate concentrations converted to sulphur fluctuated from 0.23 to 7.07 mg.l^{-1}, which indicates that the values of sulphate concentrations are very variable, although their variance gradually decreased (Fig.7).

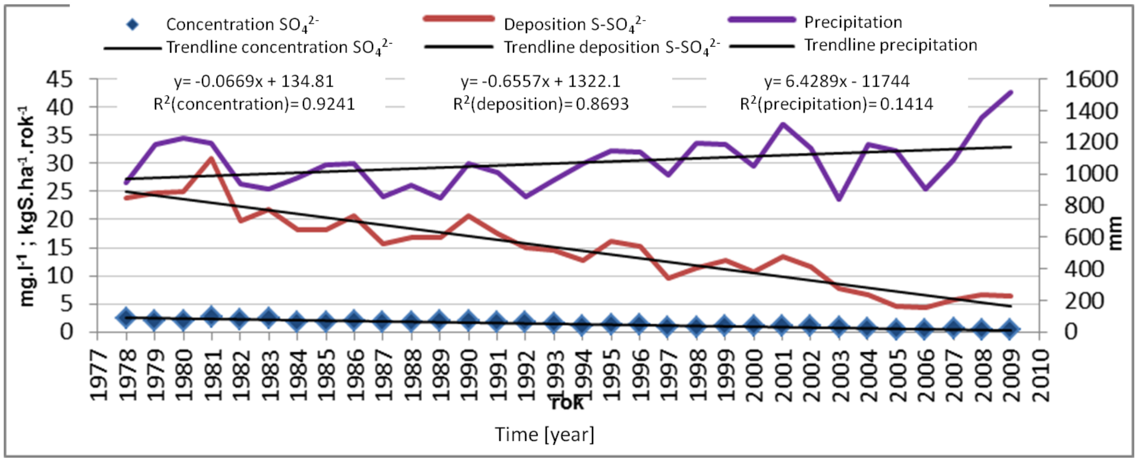


Figure 6 *Deposition of S-SO_4^{2-}, precipitation totals, concentration of S-SO_4^{2-} from annual weighted means during 1978-2009*

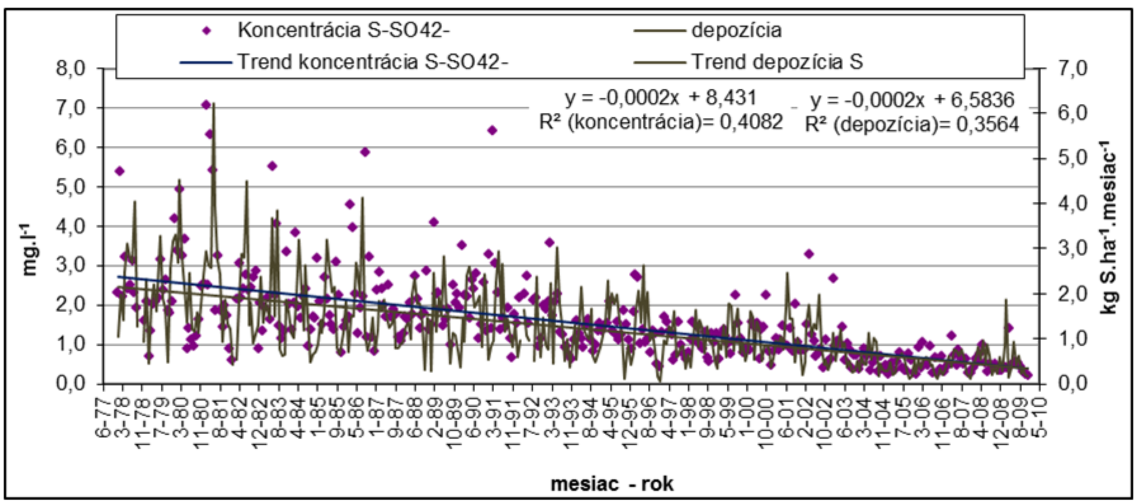


Figure 7 *Monthly weighted means of concentration of S -SO_4^{2-}, deposition of S-SO_4^{2-}, and precipitation during 1987-2009*

At Chopok EMEP station, the concentration of nitrates started to be measured and assessed in October 1985. The results of the analyses showed a decreasing trend in the concentration of nitrates in precipitation presented in Fig. 8 and 9, which was also statistically confirmed at 99.90% level. The concentration was decreasing at a rateof -0.117 mg.l^{-1} per year. The amount of nitrates in precipitation did not change as fast as the amount of sulphates. Considering the factors and the sources of elements affecting chemical composition of precipitation, the emissions from fossil fuels and car traffic are the main source of nitrates in precipitation.

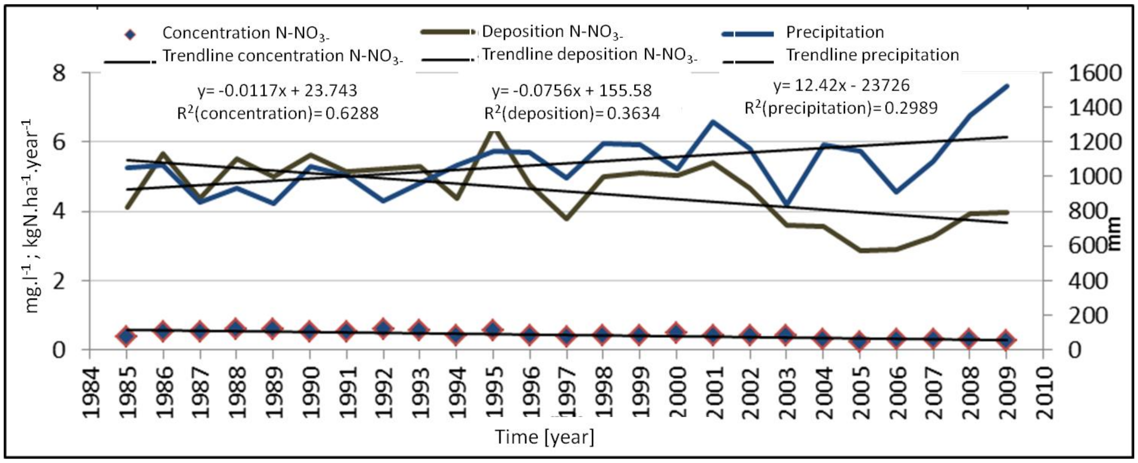


***Figure** 8 Deposition of N-NO$_3^-$, precipitation totals, concentration of N-NO$_3^-$ from annual weighted means during 1985-2009*

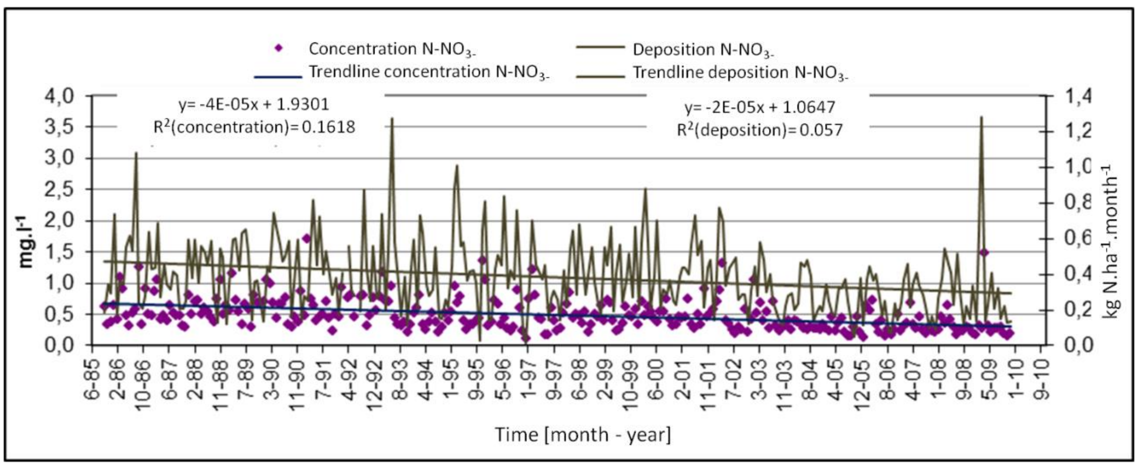


***Figure 9** Monthly weighted means of N-NO$_3^-$ concentrations and N depositions in precipitation during 1985-2009*

The measurements of ammonia ions started at Chopok EMEP station in 1994. The values of the annual weighted means of NH_4^+ cations converted to nitrogen were almost two-fold of the values of nitrate nitrogen in precipitation. The analysis of the temporal changes in concentrations of ammonia nitrogen revealed a decreasing trend in the time series at a rate of -0.0341 mg.l^{-1} of nitrogen per year. The decreasing trend is evident from Fig. 10 and 11 and was confirmed at 99.90% significance level. In spite of the decreasing tendency of the time series, high concentrations were also recorded, e.g. in April 2009, which was, however, caused by low precipitation total. The results indicate that the higher concentration was not coupled with the higher deposition of ammonia nitrogen.

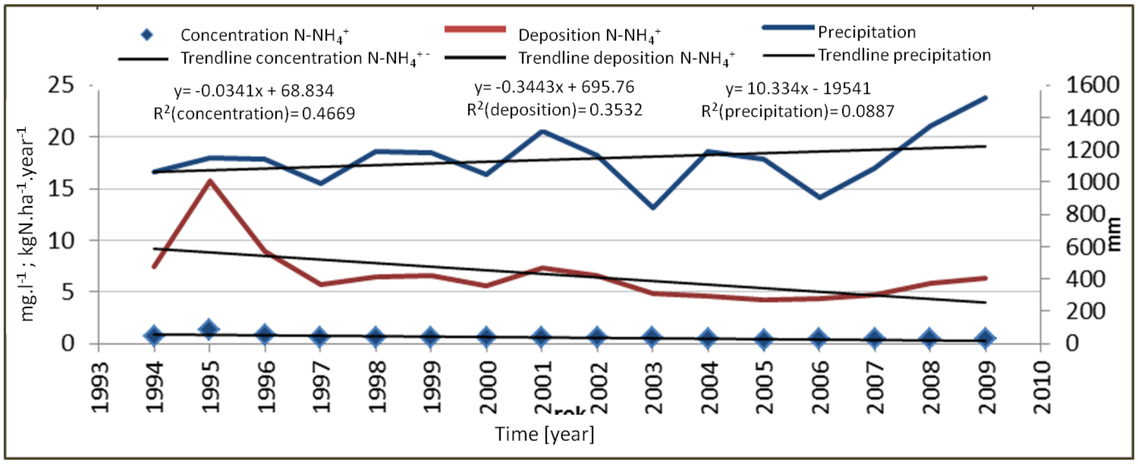


Figure 10 *Deposition of $N\text{-}NH_4^+$, precipitation totals, concentration of $N\text{-}NH_4^+$ from annual weighted means during 1994-2009*

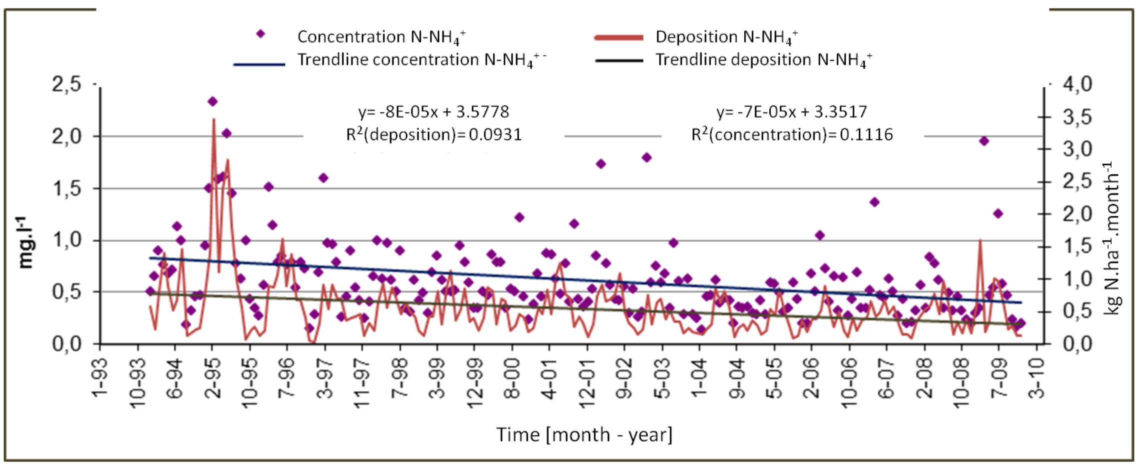


Figure 11 *Monthly means of $N\text{-}NH_4^+$ concentrations and $N\text{-}NH_4^+$ depositions in precipitation during 1994-2009*

Tab.3 presents the concentrations and depositions of alkaline cations from the tabular values obtained from EMEP and their statistical characteristics.

***Table 3** Characteristics of alkaline cations, annual values*

Chopok	**basic cations**								
Statistic value	**Precipitation**	**Calcium**		**Magnesium**		**Potassium**		**Sodium**	
		concentration	deposition	concentration	deposition	concentration	deposition	concentration	deposition
	mm	$mg.l^{-1}$	$kgCa.ha^{-1}.year^{-1}$	$mg.l^{-1}$	$kgMg.ha^{-1}.year^{-1}$	$mg.l^{-1}$	$kgK.ha^{-1}.year^{-1}$	$mg.l^{-1}$	$kgNa.ha^{-1}.year^{-1}$
Rate of change mm; $mg.rok^{-1}$; $kg.ha^{-1}.rok^{-1}$	15.112	-0.0583	-0.5845	-0.009	-0.0891	-0.017	-0.1707	-0.0154	-0.1411
tendency	increasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing
P=1-α%. level of significance	90.00%	99.90%	99.00%	99.00%	95.00%	99.00%	95.00%	99.00%	95.00%
max	1519.8	1.85	21.2554	0.34	3.9064	0.7	8.0426	0.65	7.4681
min	840.27	0.1	0.908	0.02	0.1816	0.06	0.5448	0.068	0.7264

The concentrations of alkaline cations in precipitation were relatively stable. Annual weighted means of concentrations of individual base cations fluctuated as follows: Na^+: 0.068 – 0.65 $mg.l^{-1}$, Mg^{2+}: 0.02 – 0.34 $mg.l^{-1}$, Ca^{2+}: 0.1 – 1.85 $mg.l^{-1}$, K^+: 0.06-0.7 $mg.l^{-1}$. Fig.12 presents the decreasing temporal development in the concentration of base cations and also we can see an extreme value in 1995 and the variation of Ca^{2+} and Na^+ concentrations. In the last period, the concentrations of K^+ and Mg^{2+} were balanced. Fig.13 presents the relative portion of individual base cations in precipitation where calcium is the dominat base cation with relative portion higher than 50%.

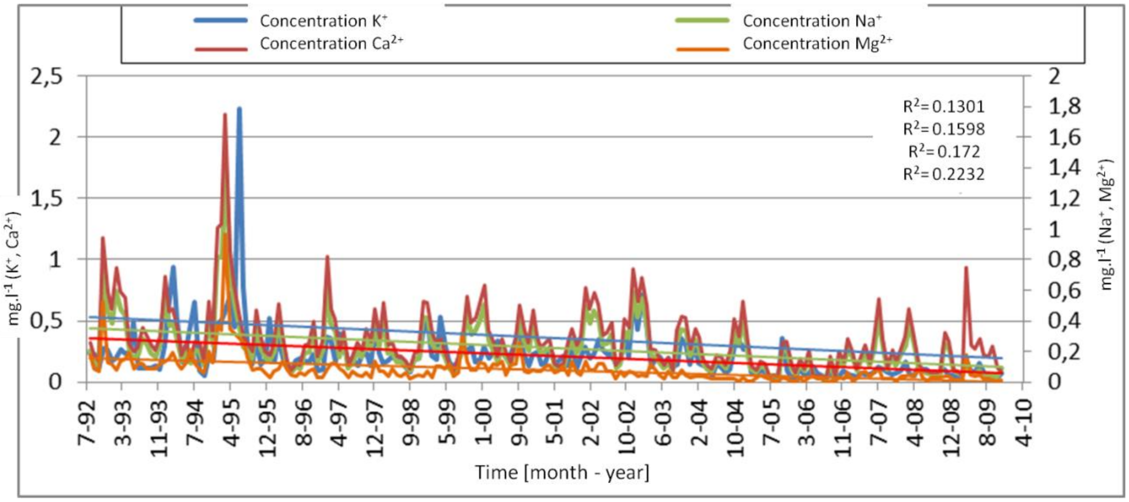


Figure 12 *Monthly weighted means of alkaline cations in precipitation during 1992-2009*

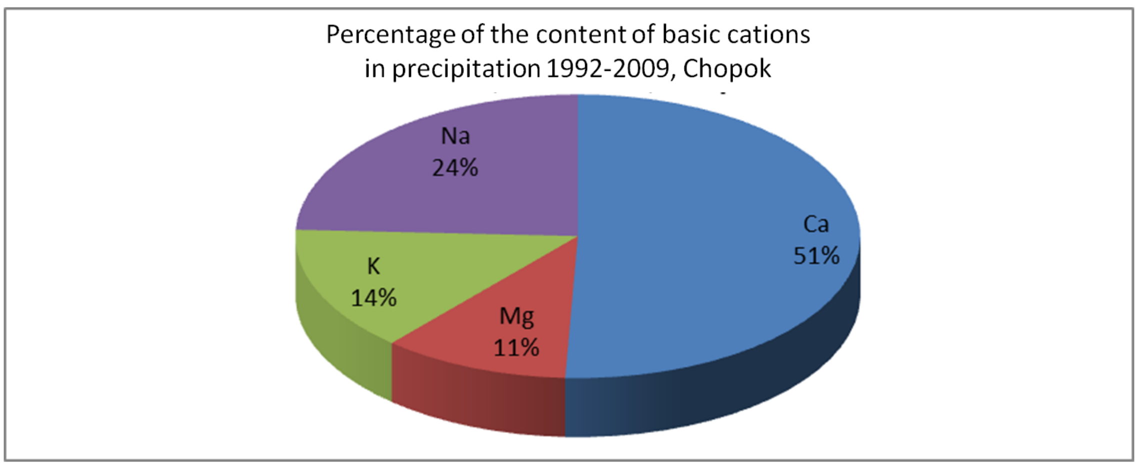


Figure 13 *Percentual proportion of alkaline cations in precipitation*

Graphical visualisation of long-term temporal trends in concentration of heavy metals in precipitation and their wet atmospheric deposition are presented in Tab.4

We can see great variation in monthly values of aluminium concentrations (see Fig.14) as well as the deposition values (Fig.15). Overall, the concentration decreased, which was statistically confirmed at 99.00%.

Table 4 *Characteristics of heavy metals, annual values*

Chopok	Heavy metals								
Statistic value	Precipitation	Zinc		Aluminum		Cadmium		Arsenic	
		concentration	deposition	concentration	deposition	concentration	deposition	concentration	deposition
	mm	$\mu g.l^{-1}$	$gZn.ha^{-1}.year^{-1}$	$\mu g.l^{-1}$	$gAl.ha^{-1}.year^{-1}$	$\mu g.l^{-1}$	$gCd.ha^{-1}.year^{-1}$	$\mu g.l^{-1}$	$gAs.ha^{-1}.year^{-1}$
Rate of chase mm; $mg.rok^{-1}$; $kg.ha^{-1}.rok^{-1}$	15.502	-2.3898	-20.788	-5.3076	-41.57	-0.0788	-0.8117	-0.0181	-0.1002
tendency	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing	decreasing
P=1-α%. level of significance	99.00%	99.90%	99.00%	99.00%	95.00%	99.00%	99.00%	80.00%	**
max	1519.8	99.416	1004.5788	107.136	1031.5687	0.946	9.8936	0.603	5.4752
min	840.27	16.118	221.3044	22.138	237.9472	0.062	0.6736	0.146	1.5863

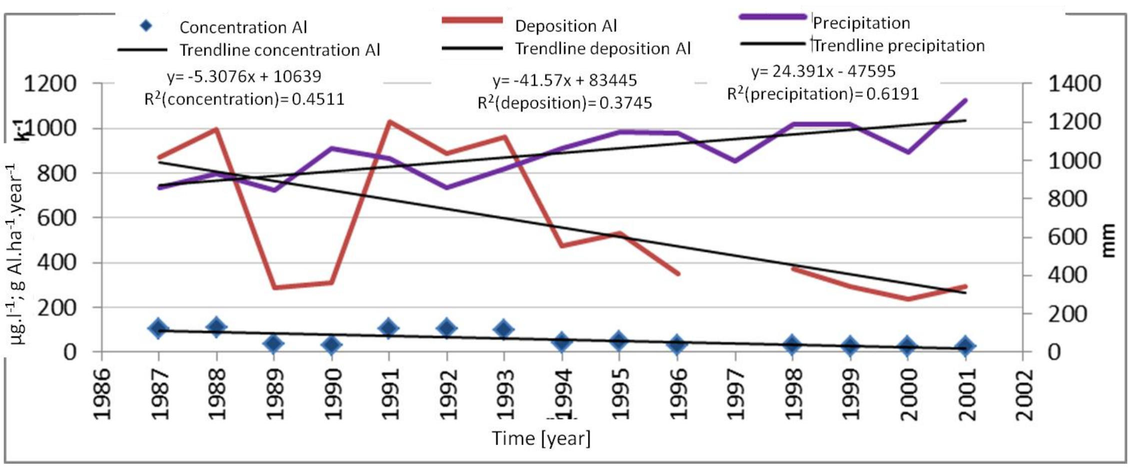


Figure 14 *Deposition of Al, precipitation totals, concentration of Al from annual weighted means during 1987-2009*

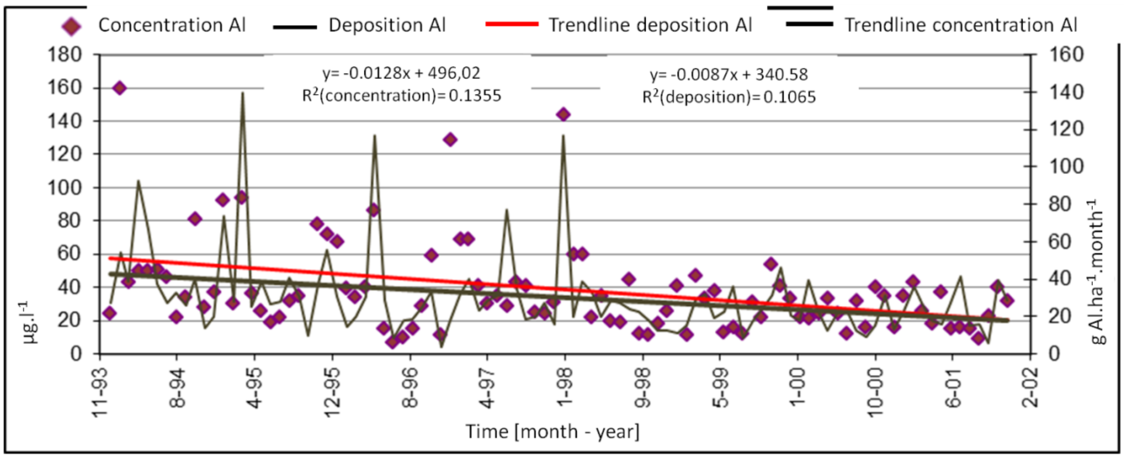


***Figure 15** Monthly weighted means of Al concentration and deposition in precipitation during 1994-2001*

The concentration of zinc in precipitation has been observed in Chopok EMEP station since 1987. The analysis of temporal change in the zinc concentration in precipitation revealed a significant decreasing trend (Fig.16, 17) confirmed by a statistical test at 99.00%. Monthly values of weighted means of zinc concentration in precipitation were very variable as shown in Fig.17. From this figure we can also see increased concentrations in 2009 due to low precipitation totals in some months.

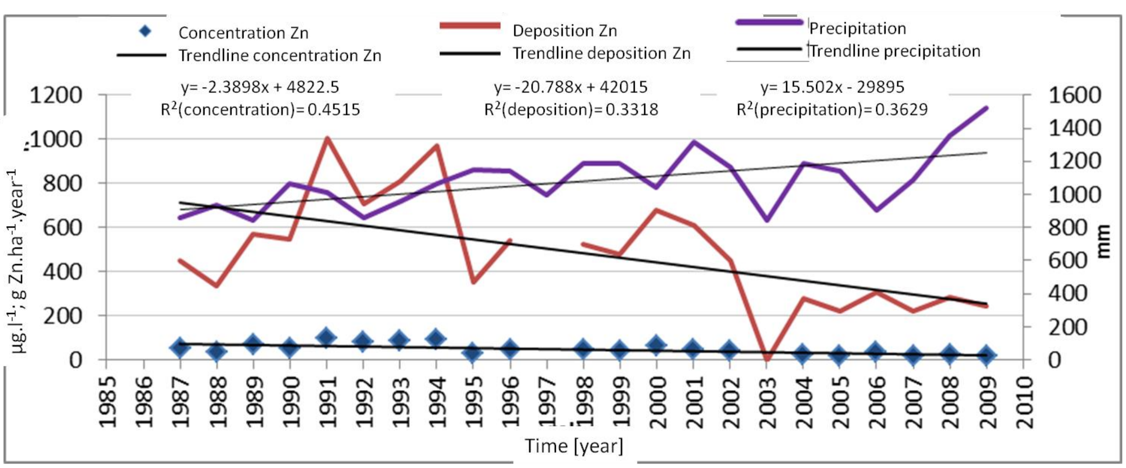


***Figure 16** Deposition of Zn, precipitation totals, concentration of Zn from annual weighted means during 1987-2009*

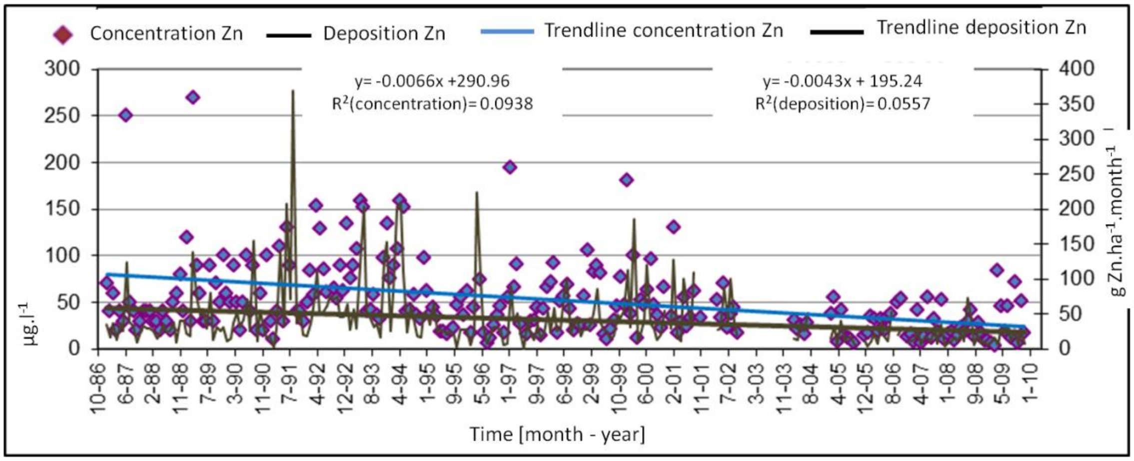


Figure 17 *Monthly weighted means of Zn concentration and deposition in precipitation during 1987-2009*

The concentrations of Cd did not vary greatly during the ten-year-long measurements. However, the temporal changes in concentrations of Cd had a decreasing trend that was statistically confirmed at 99.00%. Higher concentrations were rare. At the end of the year 2008 and during 2009 we can see an increase in Cd concentrations in precipitation, as well as in its deposition (Fig.18, 19). This is caused by the increased emissions of Cd due to the increased production of copper.

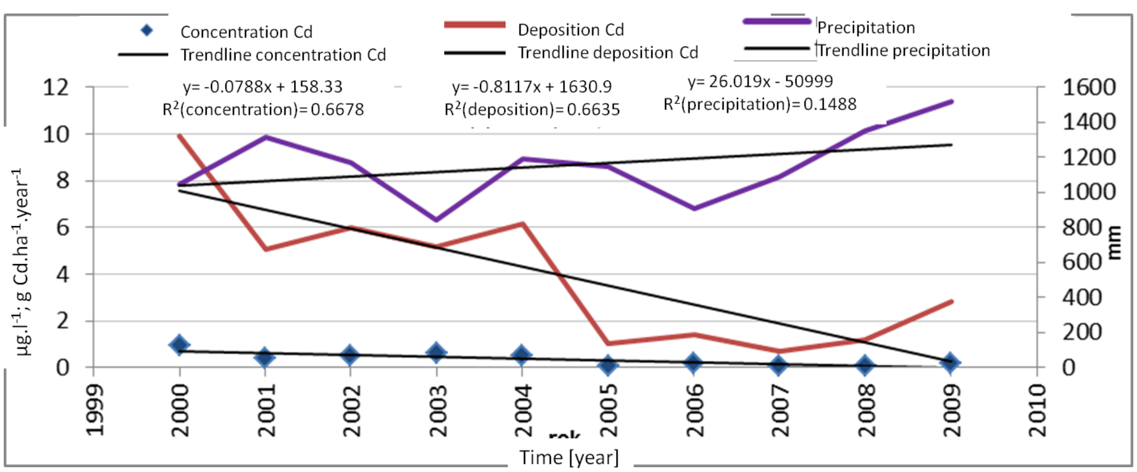


Figure 18 *Deposition of Cd, precipitation totals, concentration of Cd from annual weighted means during 2000-2009*

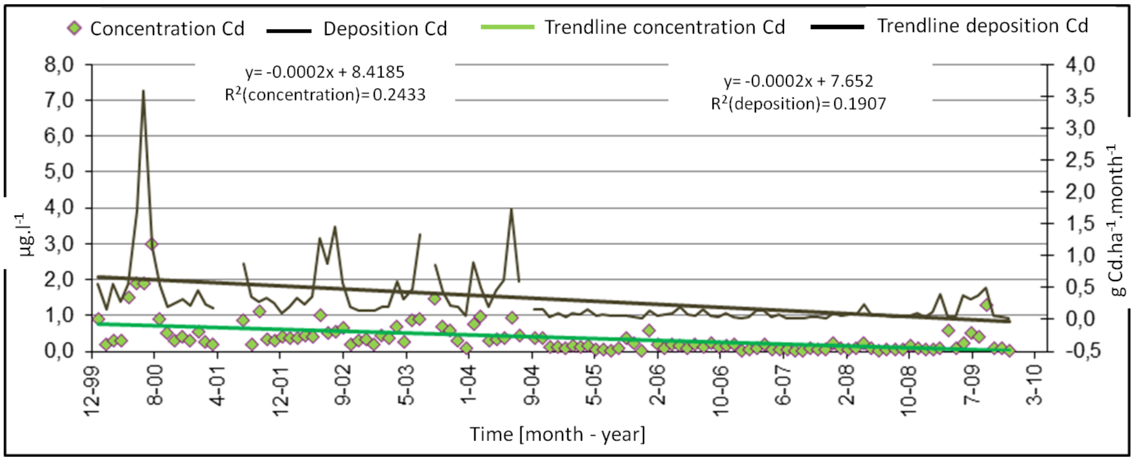


Figure 19 *Monthly weighted means of Cd concentration and deposition in precipitation during 2000-2009*

Although the trend line of As concentration in precipitation presented in Fig. 20 and 21 has a decreasing character, the analysis confirmed the significance of the sampling coefficient of correlation only at 80.00%. In the years 2008 and 2009 we can see a slight increase in both As concentration and deposition. The maximum annual deposition value was 5.5 gAs.ha^{-1}.year^{-1}.

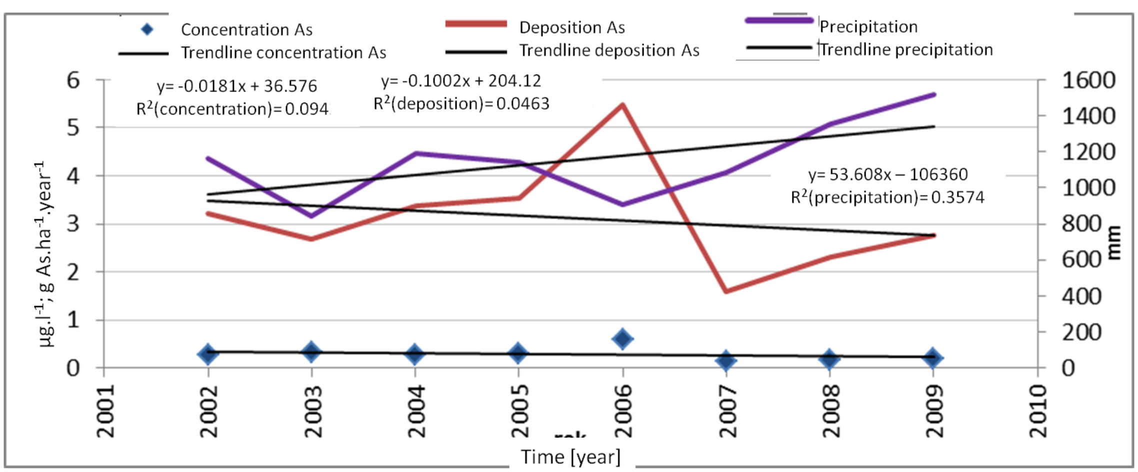


Figure 20 *Deposition of As, precipitation totals, concentration of As from annual weighted means during 2002-2009*

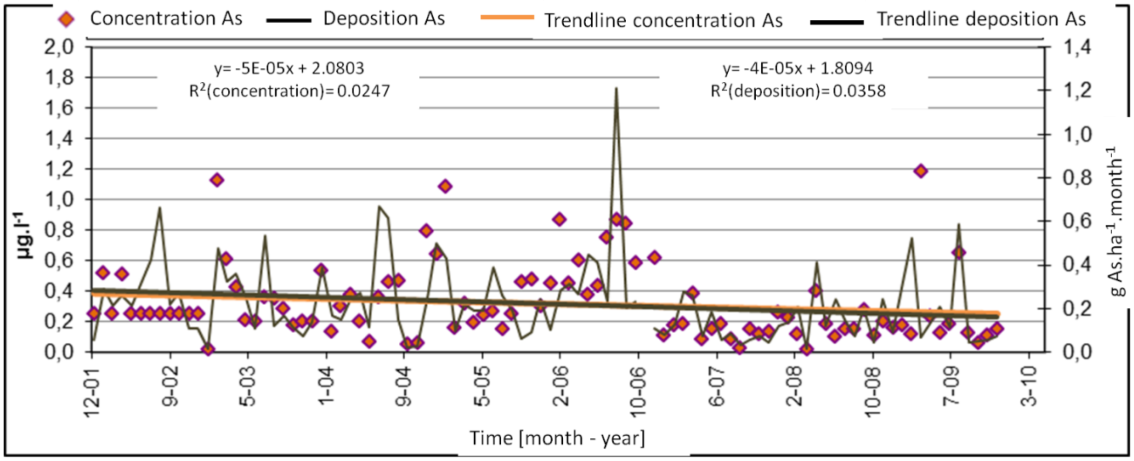


Figure 21 *Monthly weighted means of As concentration and deposition in precipitation during 2002-2009*

Discussion

The assessment of long-term changes in air quality is very important for evaluating the efficiency of measures taken in order to reduce the emissions of pollutants as well as for evaluating the impacts on e.g. ecosystems (Kunca 2007). A number of authors analysed the trends in the concentration of pollutants in precipitation, e.g. Klemm and Lange (1999) found similar trends of sulphates and nitrates in mountainous regions of Bavaria as on Chopok. Andersson et al. (2007) examined the trends in the concentration of selected parameters of air quality using a complex chemical model and came to similar conclusions as we observed on the selected station of EMEP network. Interesting changes in the concentrations of sulphates and nitrates in horizontal precipitation were found in Poľana – Hukavský grúň locality by Škvarenina and Minďaš (2001) who also observed a decreasing trend of sulphates in fog water.

Conclusion

The presented work deals with the long-term changes of precipitation quality at Chopok EMEP station situated in the mountainous region of Slovakia. From this station we had a long time series of measured data from monitoring during the period from 1978 to 2009. This period is sufficiently long for the analysis of the development of precipitation quality. The work examined the trends in the concentration of the following elements: S-SO42-, N-NH4+, N-NO3-, Mg2+, K+, Na+, Ca2+, Al, Zn, Cd, As. Processing the precipitation chemistry data and the evaluation of long-term temporal changes of vertical precipitation revealed the following conclusions:

- Sulphur concentration significantly decreased on the monitoring station. In the last years, sulphur deposition on Chopok represented 20% of the deposition at the beginning of the monitored period.
- Nitrogen concentration from ammonia ions significantly decreased. The concentration of nitrogen was reduced by 40% from maximum values.
- The concentrations of nitrate ions converted to nitrogen were decreasing on Chopok – EMEP station. However, during the last years higher concentration of nitrates was recorded, particularly in 2007 and 2008.
- The concentration of all alkaline cations in precipitation was decreasing.
- Depositions and concentrations of heavy metals in precipitation significantly decreased on Chopok monitoring station of EMEP. Slight increase of cadmium concentration was observed in the last years. Cadmium remains one of the priority heavy metals (Cd, Pb, Hg) in the Convention on heavy metals. The overall trend in the concentration and deposition has a decreasing character.

References

Andersson, C., Langner J., Bergstrom, R., 2007: Interannual variation and trends in air pollution over Europe due to climate variability during 1958–2001 simulated with a regional CTM coupled to the ERA40 reanalysis. Tellus (2007), 59B, 77–98.

Ashenden, T.W. Efects of wet deposited acidity. In: Bell, J.N.B. & Treshow, M. (eds.). Air Pollution and Plant Life. Chichester : John Wiley and Sons, 2002. s. 237-250.

Barančok,P. & Varšavová,M. : Sledovanie kyslej depozície vo vybraných prirodzených lesných ekosystémoch na území Tanapu (princípy a metódy). In: Škvarenina, J. et al (ed), Zborník referátov z medzinárodného pracovného seminára Atmosférická depozícia a ekofyziologické procesy v ekosystémoch, Poľana 12.-13. Jún 1996, Technická univerzita vo Zvolene, 1998. s.69-73

Bartoňová, A. Účinky znečistění ovzduší. In: Braniš, M. & Hůnová, Atmosféra a klima. Aktuální otázky znečištění ovzduší. Praha : Karolinum, 2009. 1.vyd., s. 160-179.

Bublinec, E. & Dubová, M. Reakcia vertikálnych zrážok podhorskej a horskej smrečiny. In: Acta Facultatis Forestalis, XXXVI. Zvolen, 1994, s.51-61.

EEA. Europe´s environment: The Second Assessment. Kidlington, 1998. Elsevier Science.

Hůnová, I.: Atmosférická depozícia, In: Braniš, M. & Hůnová, I. Atmosféra a klima. Aktuální otázky znečištění ovzduší. Praha : Karolinum, 2009, vol.1, s. 160-179.

Kunca, V. Atmosférická depozícia a kritické záťaže klimaxovej dubiny v Štiavnickych vrchoch. In: Střelcová a kol. (ed) Bioclimatology and natural hazards, international scientific conference, Poľana, 17.-20. 9. 2007. ISBN 978-80 22817-60-8.

SAŽP, 1997 : Správa o stave životného prostredia SR v roku 1996, MŽP SR

SHMÚ. Správa o kvalite ovzdušia a podiele jednotlivých zdrojov na jeho znečisťovaní v Slovenskej republike 2007. Bratislava : MŽP, 2008. 90s.

SHMÚ. Správa o kvalite ovzdušia a podiele jednotlivých zdrojov na jeho znečisťovaní v Slovenskej republike 2008. Bratislava : MŽP, 2009. 83s.

SHMÚ. Správa o kvalite ovzdušia a podiele jednotlivých zdrojov na jeho znečisťovaní v Slovenskej republike 2009. Bratislava : MŽP, 2010. 89s.

Škvarenina, J. Atmosférická depozícia v horskom jedľobukovom lese ako nositeľ depozície vybraných elementov. In: Trvalo udržateľný rozvoj a krajinnoekologické plánovanie v európskych horských ekosystémoch. Zvolen 1994, s. 271-276.

Škvarenina, J. - Minďáš, J. 2001: Long-term change in acidity and chemistry of fog/cloud water in high elevation sites in slovakia. Ed.: Schemenauer, r. – Puxbaum. H.:2nd international conference on fog and fog collection, 15 –20, july 2001, s. John`s, Canada: IDRC CRDI Ottawa, p.81-84.

ACKNOWLEDGEMENT

This work was accomplished as a part of the projects VEGA No.: 1/0281/11, 1/0463/14 of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science; and the projects of the Slovak Research and Development Agency No.: APVV-0423-10, and APVV-0303-11.

SUMMARY

Práca sa venuje spracovaniu databázy chemizmu zrážok pre stanicu EMEP – Chopok. V databáze boli spracovávané koncentrácie síranov, dusičnanov, amónneho iónu, bázických katiónov a z ťažkých kovov Cd, As, Al, Zn. Výstupom tejto databázy sú grafické znázornenia. Údaje boli spracované vo forme dlhodobých časových trendov chemizmu zrážok. Štatistické charakteristiky časových trendov boli testované Studentovým t-testom metódou významnosti výberového koeficienta korelácie. Bolo zistené, že väčšina koncentrácií vybraných elementov v zrážkach štatisticky významne klesá.

CONTACT

Ing. Miriam Hanzelová

Katedra prírodného prostredia, Lesnícka fakulta, Technická univerzita vo Zvolene

T.G.Masaryka 24, 960 53, Zvolen, Slovenská republika

+421 908 236 461

mirowka@gmail.com

EFFECT OF DIFFERENT SOURCES OF CLIMATE DATABASES ON THE ASSESSMENT OF GROWTH RESPONSE IN DENDROCLIMATIC ANALYSES

ROMAN SITKO[1], NATÁLIA SRNCOVÁ[2], JAROSLAV ŠKVARENINA[2], JAROSLAV VIDO[2]

1) Department of Forest Management, Faculty of Forestry, TUZVO, ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

2) Department of Natural Environment, Faculty of Forestry, TUZVO, ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

ABSTRACT

The paper deals with the comparison of the time series from different climate databases. We compared the measured data with the modelled data of monthly and seasonal temperature means and precipitation totals. Reliable and as long as possible time series of such data represent the basic starting point of dendroclimatic analyses. We evaluated the differences in the growth response of spruce derived using different databases of the stated climatic characteristics. The stem cores used to derive the cross-correlation function were taken from Hårås locality situated in the boreal zone of the Swedish part of Lapland. We compared the measured records from the nearest meteorological stations situated 18 km and 40 km away from the locality with the interpolated values from CRU TS 3.21 climate database and with the reconstructed 502-year-long database. The spatial resolution of the modelled databases was 0.5° x 0.5° of latitude and longitude. We found a systematic error of different magnitudes in the modelled values, and we also quantified a random error and the overall accuracy of the data. The temperature model underestimated the data in comparison with the measured values, while the precipitation model overestimated the data. We also found that the radial increments of spruce correlated more strongly with the temperature than with the precipitation. Hence, in the conditions of the boreal zone, temperature is a more important factor affecting tree-ring formation. We found significantly higher correlations between the radial increment and the

modelled precipitation data than with the data measured at the precipitation station situated 18 km from the locality of interest.

Key words: dendroclimatology, radial increment, growth response, climatic databases

INTRODUCTION

Dendroclimatology as a branch of dendrochronology uses dated ring series to reconstruct the current and past climate. Currently, its main potential is to provide the information about the growth responses of tree species on the currently ongoing climate change.

One of the currently greatest challenges is to understand and predict climate change impacts on the development of forest ecosystems. This covers systematic monitoring and detection of climate change, evaluation of climate models, their calibration and creation of climate scenarios, while climate variability affects many natural and anthropogenic systems. Due to this, the need has arisen to create standard climate databases for different climate elements that would cover the whole land area of the Earth. In dendroclimatology, monthly and seasonal databases of climate elements are mainly used. Climate databases are usually created for the basic period of reference climate of 1961-1990 defined by the World Meteorological Organisation (WMO) and are annually updated. Several databases have been created for different primary and secondary climate variables (MITCHELL, JONES, 2005).

In dendroclimatological works (e.g. BABST et al., 2013, Büntgen et al., 2007, GOUIRAND et al., 2007, Wang et al., 2013), the world-wide database created by Climatic Research Unit (hereafter as CRU), which belongs to University of East Anglia, is frequently used. Main data sources for this database are (HARRIS et al., 2013):

- International monthly data of CLIMAT swopped between the countries within WMO (around 2,400 meteorological stations)
- Monthly Climatic Data for the World (MCDW), created by National Climatic Data Center (NCDC) for WMO (around 2,500 meteorological stations)
- World Weather Records (WWR) – 10-year-long databases, which are swopped between the National Meteorological Services (NMSs) and NCDC
- The Australian Bureau of Meteorology (BoM).

In dendroclimatological applications the selection of climate data is necessary for the unambiguous explanation of climate impact on the creation of tree radial increment. It is important that these data reflect real conditions under which the increment was created. However, considering the density of meteorological stations and the variability of meteorological elements conditioned mainly by the morphological roughness of the Earth surface, this condition cannot always be met. Therefore, the main goal of this work is to compare the interpolated data of temperature and precipitation from the database of CRU TS 3.21 and from the database comprising more than 500-year-long series created by LUTERBACHER et al. (2004) and Pauling et al. (Pauling et al., 2006), with directly measured data from the nearest meteorological and precipitation stations. The essential question was to analyse the influence of different sources of climatic data on explaining the formation of radial increment of spruce.

MATERIALS AND METHODS

The area of interest, where the data were collected, was the locality called Hårås situated in the Swedish part of Lapland. Hårås is located 60 km north of polar circle border in Norrbotten region, 70 km west from Jokkmokk town. Its elevation is around 585 m a.s.l. From the geomorphological point of view, Hårås belongs to the Scandinavian Mts. Pedologically, podsol soils dominate.

Regarding tree species composition, *Pinus* sp. and *Picea* sp. dominate in the stands at the locality. As the elevation increases, crown canopy becomes released and the share of *Betula* sp. in species composition increases. The upper tree line at an elevation of around 715 m a.s.l. is formed by pure birch stands.

One group of climate data used in the analysis consists of the monthly series measured at the nearest meteorological stations. From Kvikkjokk meteorological station (N 66°57´58.28´´, E 17°44´27.35´´) we used the data about air temperature. The data about monthly precipitation totals were taken from Tjåmotis precipitation station (N 66°55´57.06´´, E 18°32´31.04´´). The positions of Hårås locality and both meteorological stations are shown in Fig. 1.

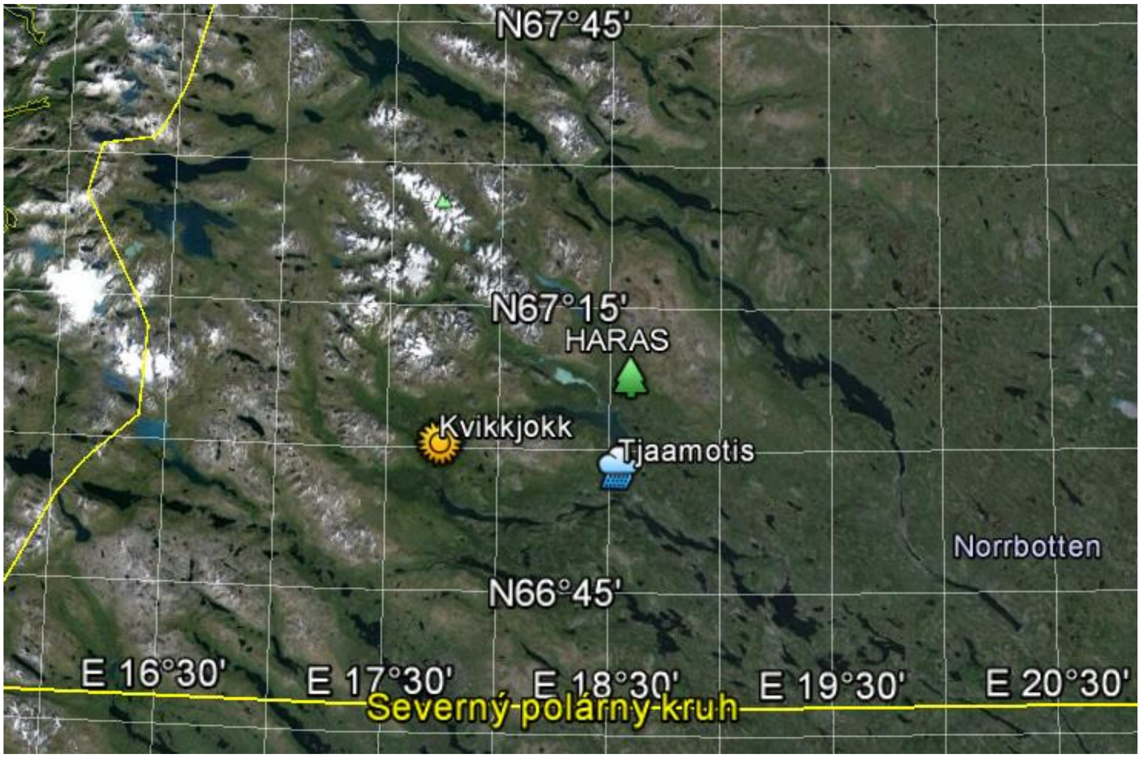


Fig. 1 *Hårås locality and Kvikkjokk and Tjåmotis meteorological stations*

Kvikkjokk meteorological station is situated at an elevation of 337 m a.s.l., approximately 40 km from Hårås. Tjåmotis station is located at an elevation of 300 m a.s.l., approximately 18 km from Håråsu. The region is characterised by subarctic climate with short, cold summers and long, cold winters.

The measured climate data of temperature and precipitation at Kvikkjokk and Tjåmotis stations were obtained from NORDKLIM database, which was prepared by the Swedish Meteorological and Hydrobiological Institute (SMHI, 2014) for Scandinavia. The monthly mean temperatures at Kvikkjokk station were available for the period from 1890 to 2001, while the monthly precipitation totals at Tjåmotis were available for the years from 1909 to 1997. For simplification we will call the data from NORDKLIM database as „measured“ data.

The second group of the climate databases encompassed interpolated time series. For the position of both weather stations and Hårås locallity we generated the data using the web application of the Royal Netherlands Meteorological Institute called KNMI Climate Explorer, which was created in order to enable the analysis of time series of climate data (CLIMEX.KNMI, 2014). The data about temperature and precipitation were generated at the level of monthly and seasonal (three monthly) temperature means and precipitation totals. For monthly data we used CRU TS 3.21 database, from which the temperature and precipitation data were available for the periods 1901-2012, and 1901-2009, respectively.

The database of CRU TS 3.21 (hereafter as CRU) has been created by interpolating the data from a large number of meteorological and precipitation stations. The values have been interpolated on a regular square grid with resolution of 0.5°, 1.0° and 2.5° of latitude and longitude. The data are available only for terrestrial areas including ocean islands (excluding Antarctica). The method of interpolating climate data (gridding), which results in the creation of temperature grid, is thoroughly described in Harris et al. (2014). For the purposes of this work we used the data with the smallest available grid spacing, i.e. 0.5° x 0.5°.

From the same web service (KNMI Climate Explorer) and with the same grid resolution (0.5° x 0.5°) we also obtained the seasonal means of temperatures for 502-year-long series from the period between 1500 and 2002, and seasonal precipitation totals for the period from 1500 and 2000. The database of temperatures is named as Luterbachet et al. Temperature (hereafter as LT), as the work by LUTERBACHER et al. (2004) deals with the methodology of creating such a long time series. The database of precipitation in the given web application is named Pauling et al. Precipitation (hereafter as PP) after the work of PAULING et al. (2006) devoted to its creation. For simplification, we call all four databases generated from the application of KNMI Climate Explorer as “modelled“ climate data.

At Hårås locality, 20 increment cores were taken from spruce tree stems at a height of 1.3 m. After pre-processing of samples, they were analysed in WinDENDRO computer image analysis system. The analysis consisted of measuring tree ring widths and their dating. The created tree-ring series were synchronised with the regional curve derived from the tree-ring curves, which showed each other the closest correlation (highest values of coefficients of correlation). We used visual synchronisation supported by a graphical method of „skeleton plot“ (Cropper, 1979). The series was considered to be satisfactorily synchronised if the value of the Gleichläufigkeit score (G) exceeded 70 %. Tree ring series, which did not exceed this threshold, were excluded from further analyses. With regard to the open crown canopy of the stands, the tree ring series were standardised using a modified negative exponential function. The final tree ring chronology was performed with the method of robust double-weighted-averaging of tree ring indices that included the removal of temporal autocorrelation. The values of tree ring indices were calculated using the formula of (Cook, Briffa, 1990).

The impact of climate on increment was evaluated by deriving the cross-correlation function between monthly or seasonal values of climate characteristics (temperature, precipitation) and tree-ring indices within 18-month-long (April_{n-1} to September_{n}) or 7-season-long (March, April, May_{n-1} to September, October, November_{n}) dendroclimatic year. Student t-test was used to evaluate the significance of the coefficients of correlation at 5 % and 1 % significance level.

With regard to the goal of the work, we compared the results of growth response derived from the measured climate data and from the modelled climate data. We wanted to reveal the cases in the results with different statistical significance of correlation coefficients caused by different climate databases (measured vs. modelled data).

The comparison of climate data from climate databases gives us information about the systematic and random error of the modelled climate data. From the differences between the modelled and measured data we calculated the average difference ($\bar{e}$) and the standard deviation of differences (S_e). Student t-test was applied to test the significance of the systematic error at 5% and 1% significance levels. The final accuracy of the modelled data was quantified by mean quadratic error (m_e). The above-described evaluation was performed separately for the mean temperature and precipitation totals. For each climatic characteristic we also analysed the differences in monthly and seasonal climatic series. The differences were calculated for the overlapping intervals, in which both the modelled and the measured data were available. Hence, in the case of monthly temperature, the overlapping time interval was 1901-2001, while for the seasonal values the period was 1890-2001. In the case of precipitation, the overlapping period was the same for both monthly and seasonal data (1909-1997). The measured seasonal data were derived by aggregating the measured monthly values.

Results

Evaluation of errors in modelled climate databases

The differences between the modelled and measured climate data were calculated separately for monthly and seasonal data of mean temperatures and precipitation totals. We analysed the deviation of the modelled data from the measured values, the presence of the random error, and the overall accuracy of the modelled data. The final values of the errors of the analysed databases are presented in Tab. 1.

In the case of mean temperature, the model underestimated the monthly data by 1.43°C, and seasonal data by 1.39°C, as documented by the values of average deviation ($\bar{e}$) in Tab. 1. The significance of bias was proved with the statistical test at α = 1% significance level.

Tab. 1 *Statistical evaluation of the differences between the measured and modelled data of monthly and seasonal temperatures (** significant value at α=1 %)*

	Temperature	
	CRU	**LT**
Mean bias [°C]	-1.43**	-1.39**
Mean error [°C]	±0.69	±1.19
Mean quadratic error [°C]	±1.59	±1.83

The random error was quantified with the mean error of differences (s_e). It describes the variation of the differences around the average difference $\bar{e}$ and is considered a measure of precision of the modelled values of temperature. The precision of the modelled monthly temperatures was found to be ±0.69°C (± 27.26%), while the precision of the seasonal data was ±1.19°C (± 46.49%). The comparison of the relative mean errors shows that the monthly temperature data were approximately half as more precise than the seasonal data. However, this results from the fact that s_e of the seasonal data was calculated from the differences, the number of which was probably by two thirds smaller than the amount of the measured data. The advantage of the database of the modelled seasonal temperatures is that it encompasses the time series of more than 500 years (starting in the year 1500). If it had been possible to calculate the differences for such a long time series, the mean error of the seasonal data would have probably decreased.

The overall accuracy of the modelled monthly temperature data was ± 1.59°C, and of the modelled seasonal temperature was ± 1.83°C.

Tab. 2 presents the statistical comparison of the differences between the measured and the modelled data of monthly and seasonal precipitation totals.

Similarly to temperature, the results of the statistical test proved systematic deviation of the modelled data from the measured data. On the contrary to temperature, the precipitation model overestimated the measured values. In the monthly database, the model overestimated the values by 4.46 mm on average, while in the case of seasonal data the overestimation was 15.75 mm. Greater deviation of the seasonal data results from the nature of the data, since they were calculated as a sum of precipitation of three months in one season. Relative average differences were almost equal (11% or 12.5%).

Tab. 2 *Statistical evaluation of the differences between the measured and modelled data of monthly and seasonal precipitation totals (** significant value at α=1 %)*

	Precipitation	
	CRU	**PP**
Mean bias [mm]	4.62**	15.75**
Mean error [mm]	±5.12	±31.84
Mean quadratic error [mm]	±6.90	±35.52

The precision of the monthly and seasonal precipitation was ±5.12 mm (±11%), and ±31.84 mm (±22%), respectively, which is very similar to temperature. This means that the variability of the differences in monthly precipitation was approximately half of the variability of the differences of the seasonal data. However, similarly to temperature, we have to account for the fact that the result is influenced by a shorter series of the measured seasonal data in comparison to the model, as for Tjåmotis station the available series encompassed only 88 years.

The final accuracy of the modelled monthly and seasonal precipitation totals was ±6.90 mm and ±35.52 mm, respectively (Tab. 3).

On the base of the obtained results we can say that with 99% confidence the modelled data of both climatic characteristics were significantly different from the measured data. This bias can be eliminated from the data by extracting the value of the mean bias from every value of the modelled climatic series.

Comparing the suitability of the climatic databases for dendroclimatic analyses

In the first step of evaluating the suitability of the climatic databases for dendroclimatic analyses we examined the correlation between the data measured at the nearest meteorological stations (Kvikkjokk and Tjåmotis) and the modelled data generated using the KNMI Climate Explorer application for the position of Hårås with the resolution of 0.5°.

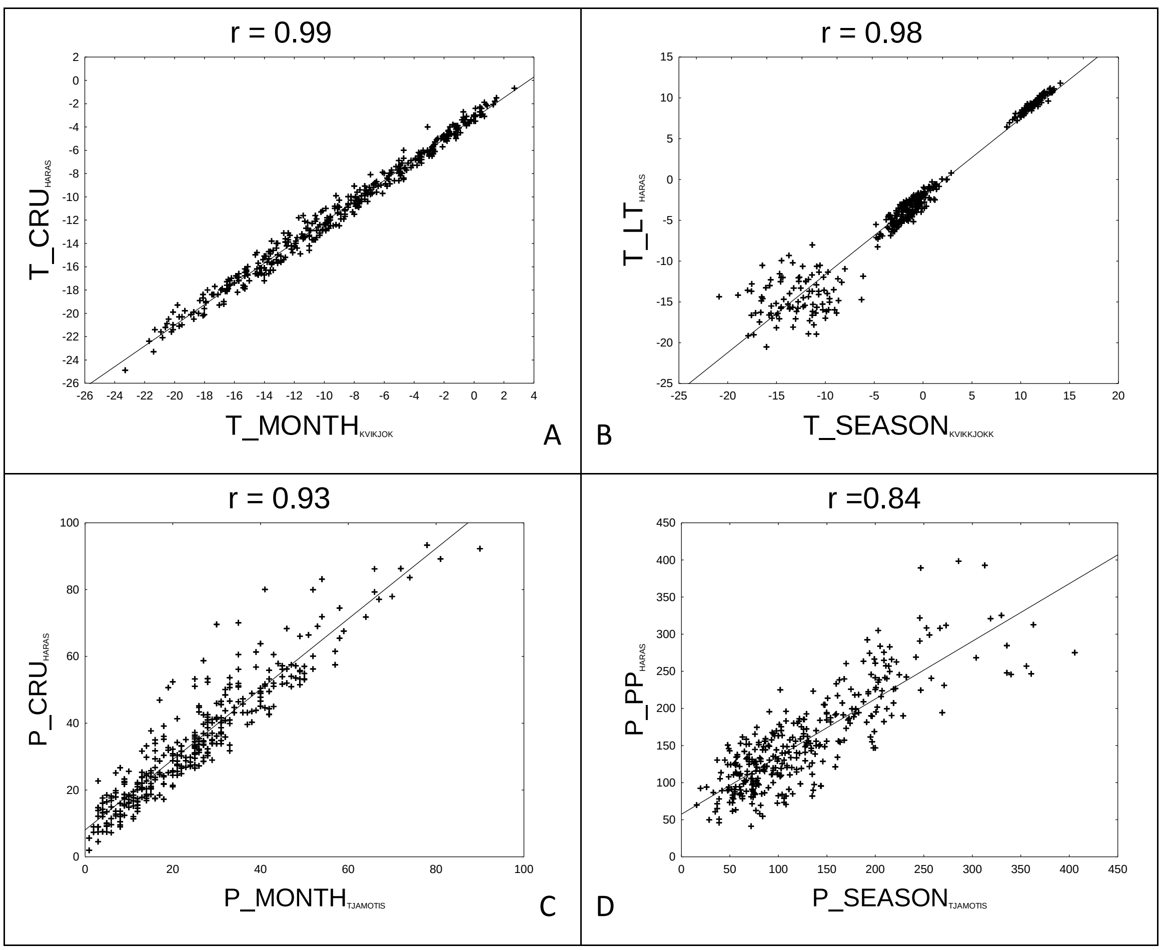


Fig. 2 Graphs of correlation between A modelled monthly temperatures (T_CRUHARAS) and measured monthly temperatures (T_MONTHKVIKJOK), B modelled seasonal temperatures (T_LTHARAS) and measured seasonal temperatures (T_SEASONKVIKJOK), C modelled monthly precipitation (P_CRUHARAS) and measured monthly precipitation (P_MONTHTJAMOTIS), D modelled seasonal precipitation (P_PPHARAS) and measured seasonal precipitation (P_SEASONTJAMOTIS).

The relationship between the temperatures is shown in Fig. 2A and 2B. In both cases, we revealed close correlations between the compared databases of temperatures documented by high values of coefficients of correlation. The comparison of 100-year-long series of the monthly temperature means obtained from the CRU database (T_CRU_{HARAS}) and the measured data from Kvikkjokk meteorological station situated 40 km away ($T\_MONTH_{KVIKJOK}$) revealed that the coefficient of correlation reached the value of 0.99 (Fig. 2A). Similarly, 111-year-long series of the modelled seasonal temperature means (T_LT_{HARAS}) and of the measured seasonal means ($T\_SEASON_{KVIKJOK}$) also showed to be tightly correlated with the coefficient of correlation equal to 0.98 (Fig. 2B).

The correlation between the databases of precipitation totals was lower than that of temperature, particularly in the case of seasonal data. The coefficient of correlation between the seasonal precipitations had a value of 0.84, which indicates that the variability of the modelled seasonal precipitation at Hårås (P_PP_{HARAS}) least corresponded with the variability of precipitation measured at Tjåmotis precipitation station ($P\_SEASON_{TJAMOTIS}$) situated 18 km from Hårås (Fig. 2D). The correlation between the modelled monthly precipitation (P_CRU_{HARAS}) and the measured precipitation totals ($P\_MONTH_{TJAMOTIS}$) was tighter (r = 0.93) as documented in Fig. 2C. The comparison of the databases was performed using 88-year-long climatic series of precipitation.

The next step was to evaluate the cross-correlation functions derived from the data of spruce radial increments and individual climate databases. For this analysis, we selected such periods from the databases of both climatic characteristics, within which the measured time series were available. Hence, the period for temperature and precipitation was 1902-2001, and 1910-1997, respectively.

The values of coefficients of correlation presented in the graph (Fig. 3) quantify the strength and the sign of the relationship between the indices of radial increment and the mean of monthly (Fig. 3A) or seasonal (Fig. 3B) temperatures within the 18-month-long or 7-season-long dendroclimatic year. The values of the correlation coefficients were tested at α = 1% or 5% significance level.

From Fig. 3A we can see that the annual increment was significantly negatively correlated with the temperatures in April, July and August of the preceding year, or its summer season (JJA_pre). In July of the preceding year, the values of the coefficient of correlation were significant at 1 % significance level for both measured and modelled data. This means that with 95 % confidence, high values of temperatures in July of the preceding year negatively affected increment formation in the next year. On the other hand, temperatures in the summer season in the year of increment formation were positively correlated with increment. Particularly June and July were the months that significantly promoted the formation of the radial increment at 1 % significance level. However, the differences between the growth response of spruce depending on the database used were not revealed in any period.

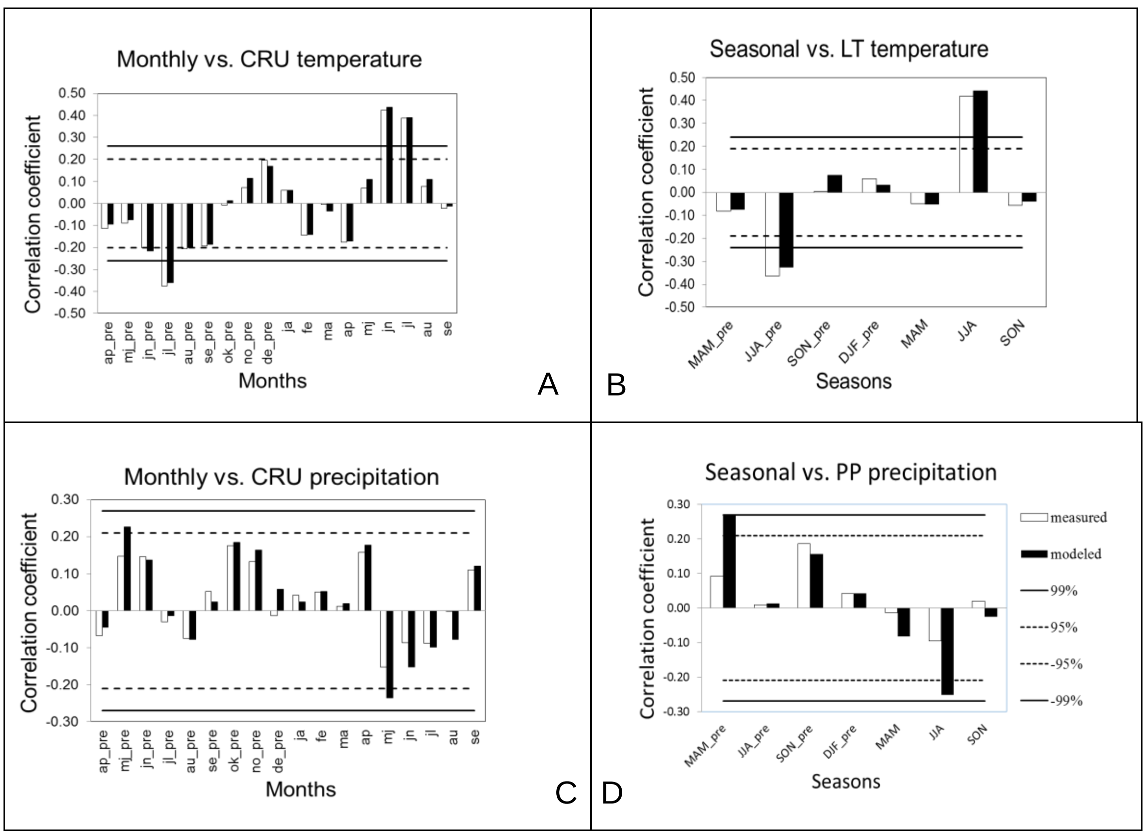


Fig. 3 *Coefficients of correlation derived from the relationship between the indices of spruce radial increment and A monthly temperature databases, B seasonal temperature databases, C monthly precipitation databases, D seasonal precipitation databases*

Overall, the coefficients of correlation derived from the databases of the measured and modelled temperature data did not significantly differ in their values and in the trend of the correlation. The only exception was found for December of the preceding year. The value of $r = 0.20$ for the measured temperature data was proven to be significant at $\alpha = 5$ %, while in the case of the modelled data the statistical test did not confirm the value of coefficient of correlation equal to $r = 0.17$ to be significant.

The evaluation of the growth response of spruce to precipitation showed an opposite trend as in the case of temperature. The increasing amount of precipitation in the spring season (MAM_pre) of the year preceding the increment formation positively correlated with the increment formation (Fig. 3D), and its impact on increment formation was confirmed with 95 % confidence. In the database of the monthly data, we found that the month May had a significant effect on increment formation at 5% significance level (Fig. 3C). In the year of the increment formation, the amount of precipitation in the summer season (JJA) had a significant negative impact on increment formation (Fig. 3D). If we used the database of monthly precipitation totals, we revealed that May was a significant month at 5% significance level (Fig. 3C).

From the graphs in Fig. 3C and 3D we can see that the significant influence of precipitation on increment was confirmed only for the cross-correlation function derived from the database of precipitation modelled in a square grid of 0.5° x 0.5°. The coefficients of correlation derived from the measured precipitation data were significantly lower than those from the modelled data ($\Delta r \geq 0.05$) in the case of three out of 18 months of the dendroclimatic year, namely May of the preceding year, and May and June of the year of increment formation (Fig. 3C). In both cases concerning the month May we confirmed statistical significance of coefficients of correlation at α=5% significance level, while the significant correlations were derived from the modelled precipitation data.

In the 7-season-long climatic year (Fig. 3D) we found significant differences in the growth response of spruce to precipitation in the spring season of the preceding year (MAM_pre) and in the summer of the increment formation year (JJA). The amount of precipitation in the spring of the preceding year promoted increment formation. Summer precipitation in the year of increment formation decreased its formation. In the season of JJA, the difference between the coefficients of correlation derived from the measured and modelled precipitation was 0.16. For both seasons (MAM_pre, JJA) we confirmed significant influence of precipitation on increment formation at α = 5% only when we used the database with the modelled precipitation values. The significant effect of precipitation data measured at a distance of 18 km (Tjåmotis) from the place of increment formation was not confirmed by the cross-correlation analysis using either seasonal precipitation database (PP) or monthly data (CRU).

DISCUSSION AND CONCLUSIONS

The assessment of the suitability of using different climate databases for the purposes of dendroclimatic analyses performed within this paper revealed that the data in CRU TS 3.21 (CRU) database as well as those in the 502-year-long database of temperatures named Luterbacher et al. Temperature (LT) or in the 500-year-long database of precipitation named Pauling et al. Precipitation (PP) for the two meteorological stations situated in the Swedish part of Lapland (Kvikkjokk and Tjåmotis) had systematic errors of different magnitudes. The temperature databases of CRU and LT underestimated the values measured at Kvikkjokk station by 1.43°C or 1.39°C. On the contrary, the precipitation databases of CRU and PP overestimated the data measured at Tjåmotis precipitation station by 4.62 mm, or by 15.75 mm in the case of three-monthly (seasonal) totals. The given systematic errors can be extracted from the data of the databases by subtracting the mean difference from every value in the database. We assume that spatial resolution of the modelled data is the main source of this error. The resolution determines that the values in the database represent uniform values for the whole grid square of 0.5° x 0.5°, although in reality there are differences in the values of climatic characteristics also inside such an area.

In order to avoid the bias in the data, in some updated databases it is preferred to express the data in the form of anomalies in spite of their absolute expression. Anomaly for temperature is a difference between the absolute temperature value and the value of the long-term average determined from the period 1961-1990. In the case of precipitation, anomalies are relative values, i.e. they are given as a percentage of the deviation from the long-term average.

From the databases that prefer expressing the values in the form of anomalies we can name CRUTEM 4.2.0.0 (OSBORN, JONES, 2014), and HadCRUT4 (MORICE et al., 2012). The climate data expressed in this way enable the reduction or the complete elimination of systematic errors from the modelled data. Since the model of CRUTEM 4.2.0.0 is currently available only in a grid resolution of 5° x 5°, we decided to use the database of the modelled data from the version of CRU TS 3.21, which provides the data modelled in a grid of 0.5 ° x 0.5°. Here it is necessary to note that the systematic deviation (bias) of climate data does not affect the evaluation result of the growth response of spruce tree species. In order to correctly assess the impact of temperature and precipitation on the formation of radial increment it is important to ensure that the variability of the time series of the stated climatic characteristics corresponds with the variability of the climate at the place of increment formation.

Due to this fact, in the next part we analysed the agreement or the difference in the examined climate factors between the data measured at the nearest meteorological stations and the data interpolated for Hårås locality (modelled data). The comparison revealed that the precipitation data correlated less than the temperature data in spite of the fact that the precipitation station was only 18 km away from Hårås, while the station with the measured temperature was at a distance of 40 km. This confirms the long-term known fact that precipitation is more variable than temperature. This fact was also accounted for during the development of CRU model, in which the interpolation of precipitation values is performed within a smaller radius per one grid point than the interpolation of temperatures. In the case of precipitation, the correlation decreases faster as the distance increases, which is expressed by CDD (correlation decay distance) value during the selection of the stations for the interpolation of the grid point (Harris et al., 2014).

Less agreement in the variability of the data from the precipitation databases also resulted in greater differences between the coefficients of correlation when evaluating the growth response of spruce using the measured and the modelled data. The obtained results of the cross-correlation function can be interpreted as follows. The statistically significant precipitation signal for the formation of the radial increment was revealed only in the case of the modelled precipitation data. In the case of measured data, the significance of the precipitation impact on increment could not be confirmed. Hence, the results showed that the selection of the precipitation database had an impact on explaining the growth response of spruce. A stronger correlation between the increment and precipitation was obtained if we used the modelled data from CRU and PP databases.

When comparing both climatic characteristics, temperature signal was found stronger. Temperature was shown to be a more significant factor influencing the increment of spruce. This is in coincidence with the results of BABST et al. (2013), who evaluated the impact of precipitation and temperature on spruce increment in the boreal zone of the northern Scandinavia. The examined impact of mean temperatures in the individual months of the dendroclimatic year on the increment corresponds with the results of the cited work. The only difference was in the magnitude of the derived coefficients of correlation, which were in our case greater. This is probably caused by the fact that our growth responses represented only one locality (Hårås), while the cited paper analysed the growth responses of a larger area of the northern Scandinavia.

From the point of evaluating the utilisation of different temperature databases for the explanation of the growth response, we did not find any significant differences between the measured and the modelled data. A small difference was found only in the statistical interpretation of the coefficient of correlation (r) for December of the preceding year. In the case of the measured temperature at Kvikkjokk station, r reached the value of 0.2, which was confirmed significant at α = 5 %. However, the value of r = 0.17 derived from the modelled temperatures of CRU database was not confirmed significant.

REFERENCES

Babst, F., Poulter, B., Trouet, V., Tan, K., Neuwirth, B., Wilson, R., Carrer, M., Grabner, M., Tegel, W., Levalic, T., Panayotov, M., Urbinaci, C., Bouriaud, O., Iais, P., Frank, D., 2013: Site and species-specific responses of forest growth to climate across to European continent. Global Ecology and Biogeography 22 (6): 706–717

Büntgen, U., Esper, J., Verstege, A., Nievergelt, D., Frank, D.C., Wilson, R.J.S., 2007: Growth responses to climate in a multi-species tree-ring network in Western Carpathian Tatra Mountains, Poland and Slovakia. Tree Physiology 27: 689–702.

Climexp.KNMI, 2014: [online 2014-04-18] <http://climexp.knmi.nl>.

Cook, E.R., Kairiukstis, L.A., 1990: Methods of Dendrochronology: Aplications in the Environmental Sciences. Dordrecht: The International Institute for Applied Systems Analysis: 394 p.

Cropper, J.P., 1979: Tree-ring skeleton plotting by computer. Tree-Ring Bulletin, 39: 47–54.

Gouirand, I., Linderholm, H.W., Moberg, A., Wohlfarth, B., 2007: On the spatiotemporal characteristics of Fennoscandian tree-ring based summer temperature reconstruction. Theoretical and Applied Climatology 91: 1–25

Harris, I., Jones, P.D., Osborn, T.J., Lister, D. H., 2014: Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. International Journal of Climatology 25 (3): 623–642.

Luterbacher, J., Dietrich, D., Xoplaki, E.. Grosjean, M., Wanner, H., 2004: European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500. Science, 303 (5663): 1499–1503.

Mitchel, T. D., Jones, P. J. 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25 (3): 693–712.

Morice, C.P., Kennedy, J.J., Rayner, N.A., Jones, P.D., 2012: Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set. Journal of geophysical research 117: 1–22.

Osborn, T.J., Jones, P.D., 2014: The CRUTEM4 land-surface air temperature data set: construction, previous version and dissemination via Google Earth. Earth System Science Data 6: 61–68.

Pauling, A., Luterbacher, J., Casty, C., Wanner, H., 2006: Five hundred years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Climate Dynamics, 26 (4): 387–405.

SMHI, 2014: Nordklim – Nordic co-operation within climate activities [online 2014-04-18], <http://www.smhi.se/hfa_coord/nordklim/index.php?page=dataset>.

Wang, X., Zhao, X., Gao, L., 2013: Climatic response of Betula ermanii along an altitudinal gradient in the northern slope of Changbai Mountain, China. Dendrobiology. 70: 99–107.

ACKNOWLEDGEMENT

This work was accomplished as a part of the projects VEGA No.: 1/1130/12, VEGA 1/0281/11, VEGA 1/0463/14 of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science; and the projects of the Slovak Research and Development Agency No.: APVV-0423-10, and APVV-0303-11. The authors thank the agencies for the support.

SUMMARY

Práce se zabývá porovnáním časových řad různých klimatických databází. Porovnávané jsou měřené údaje s modelovanými údaji měsíčních a sezónních (tříměsíčních) průměrů teplot a měsíčních a sezónních úhrnů srážek. Spolehlivé a co nejdelší časové řady těchto údajů jsou základním východiskem při dendroklimatických analýzách. Vyhodnoceny byly diference v růstové odezvě dřeviny smrk, jejichž zdrojem bylo použití různých databází uvedených klimatických charakteristik. Kmenové vývrty použity pro odvození křížové korelační funkce pocházejí z lokality Hårås , která je situována za polárním kruhem, v boreální zóně švédské části Laponska. Na vývrtech byly změřeny šířky letokruhů a po synchronizaci a detrendování vlivu věku stromu na velikost přírůstku, byla vytvořena regionální chronologie reprezentována hodnotami indexů radiálního přírůstku. Byla zjišťována závislost radiálního přírůstku od měřených údajů z nejbližších meteorologických stanic vzdálených od lokality 18 km (Tjåmotis) resp. 40 km (Kvikkjokk), od interpolovaných údajů z klimatických databáz CRU TS 3.21 (CRU) a rekonstruované přes 500 leté databáze Luterbacher et al. Temperature (LT) a Pauling et al. Precipitation (PP). Prostorové rozlišení modelovaných databází je 0.5 ° x 0.5 ° zeměpisné šířky a délky. Zjistili jsme, že v modelovaných údajích se vyskytuje různé velká systematická chyba a kvantifikována byla také náhodná složka chyby a celková správnost údajů. Teplotní model měřené údaje podbízel, naopak srážkový model jejich přesáhl. Rovněž jsme zjistili, že radiální přírůstky smrku více korelují s teplotou než se srážkami, z čehož vyplývá, že v daných podmínkách boreální zóny se teplota projevuje jako důležitější faktor ovlivňující tvorbu letokruhů. Z hlediska posouzení dopadů použití různých teplotních databází na růstovou odezvu se neprojevily výraznější rozdíly mezi měřenými a modelovanými údaji. Při srážkových

databázích se projevil vliv použití různého zdroje klimatických dat na rozdílné růstové odezvě smrku. Silnější vztah přírůstku se srážkami se prokázal na modelovaných údajích z databáze CRU a PP. Při měřených údajích se signifikantnost vlivu srážek na přírůstek nepotvrdila.

CONTACT

Ing. Roman Sitko, PhD.

Department of Forest Management and Geodesy, Faculty of Forestry, TECHNICAL UNIVERSITY IN ZVOLEN

T.G.Masaryka 24, 960 53 Zvolen, SLOVAKIA

Tel: +421 45 5206 294, Email: roman.sitko@tuzvo.sk

INTENSITY OF LIGHT POLLUTION AND ITS IMPACT ON PHENOLOGICAL PHASES OF TREES

MÁRIA TUHÁRSKA, DOMINIKA KRNÁČOVÁ, JANA ŠKVARENINOVÁ, MATÚŠ HRÍBIK

Technical University in Zvolen

Slovak Republic

ABSTRACT

The work evaluates the intensity of light pollution in two towns of Central Slovakia from September 2013 to April 2014. Under different weather conditions we performed 20 measurements at 7 sites with the instrument of Lux Meter Velleman DVM 1300 during night hours. We found the relationship between the actual weather conditions and measured values. In comparison with STN EN 12464-2, the valid norm of Slovakia, the threshold of 5 lux was exceeded at 5 observed sites by 1.3-10.4 lux. Some trees react to strong light sources. Intensive night lighting caused the visible delay of autumn phenological phase of leaf colouring on some crown parts of several trees.

Key words: Light pollution, light intensity, phenology, Central Slovakia

INTRODUCTION

Environment and its health condition affects the whole set of physiological and psychological reactions of living organisms. Everyday life of organisms on the Earth is influenced by pollution of basic environmental components – soil, water sources, and air. Currently, a new phenomenon has occurred – pollution by undesirable and excessive lighting (HABEL et al., 2013). Increased attention has been paid to this issue since the 70s of the 20th century as a reaction to the increasing urbanisation. New questions concerning light radiation, which are being dealt by a great number of professionals from physiology, biology, psychology, architecture, construction engineering, technology and environment hygiene, are emerging (SUCHAN, 2003).

The term „pollution" is generally understood as a contamination of environment, which means the release of environmental contaminants into environment as well as their presence in the environment. In case of „light pollution", light coming from the artificial public lighting is the contaminant. The International Dark-Sky Association (IDA) defines light pollution as: "any undesirable impact of artificial lighting causing excessive sky brightness, radiance, infiltration of excessive light into houses, reduced visibility on roads and wasteful energy spending." (www.vesmir.sk). It can be best observed in towns and wide-spread agglomerations, where the light scatter from public lighting occurs. Light directed towards the sky is reflected from the atmosphere particles (dust, water vapour) and is spread far behind the place of its origin. This is shown by visibly lighter sky also at greater distances from the sources due to which natural darkness that is necessary for the conservation of night ecosystems is lost. Natural darkness is needed for living organisms active during a day and during a night, and also for humans to rest and to ensure the correct course of their circadian rhythms. The issue of light pollution is very broad, affects many areas of life, and has a negative impact on health, animals, plants, transport accidents, economy, and astronomy (RAPAVÝ, 2009).

Some trees also react to strong light sources. If they are situated near the lamps, they do not recognise that winter is approaching. Leaves do not colour, but they freeze fully green. Artificial lighting gives plants a signal that it is a constant day and summer. This causes their continual extinction due to the destruction of their annual physiological cycle. The majority of plants react to this factor by delayed leaf falling and premature mortality (http://www.astronomie.cz/). A man with his demands on intensive light during night destructs environment and indirectly contributes to the increase of greenhouse gases in the atmosphere, and hence, also to the global warming.

MATERIAL AND METHODS

The measurements of light pollution intensity were performed from September 2013 to April 2014 in two towns situated in Central Slovakia at different elevations, geographic positions, and climatic conditions. Zvolen as the first town is located in the south-western part of the Zvolenská valley at an elevation of 300 m. It belongs to a warm climatic region, a slightly moist sub-region, to the type of valley climate with great temperature inversion and annual average precipitation total of 703 mm. In Zvolen we selected three sites. Banská Štiavnica is situated at an elevation of 600 m in the Štiavnické Mts. on the border between two climatic types. The region belongs to a slightly warm and a cool climatic region, a slightly warm, very moist and a slightly cool sub-region with the annual precipitation total of 826 mm (Lapin et al., 2002). Both thermophilic and Carpathian mountainous flora can be found here. In the second town, we performed measurements at 4 sites under approximately same conditions.

The measurements were taken in both towns for a period of six months one night per month between 9pm and 10:30pm using Lux Meter Velleman DVM 1300 instrument. The measurements were performed under different weather conditions – clear and cloudy sky.

We used the methodology described in the work by Lázna (2009). The individual sites were divided into a square grid of 100 x 100 m in GIS environment. At each site, we performed 20 partial measurements, from which we calculated the arithmetical mean representing the final value of sky brightness in lux units (lx).

We followed these three principles:

- no obstacles that can cast shadows (buildings, trees) shall be between the instrument and sky
- the measurements shall not be performed on places with direct shadows of the light sources
- the worker performing measurements shall not stand on the place, on which the light flux falls from the source (e.g. under the lamp) (LÁZNA, 2009).

To compare the intensity of pollution in both towns we followed the norm STN EN 12464-2 valid for Slovakia. According to the norm, the highest allowed values of disturbing light in the town centres and residential suburbs fluctuate between 2-5 lux.

RESULTS

In both towns, we performed the measurements under different weather conditions to examine if the change in cloudiness and hence the change in temperature and air humidity affect the measurement values. The measured values are given in Table 1.

***Tab. 1**. Light intensity (lx) on the sites in Zvolen (ZV) and Banská Štiavnica (BŠ) under different weather conditions*

Weather/site	clear sky	clear sky	cloud sky	cloud sky
ZV 1	1.1	1.2	1.5	1.3
ZV 2	3.1	3.3	4.1	4.6
ZV 3	6.0	6.1	6.3	6.6
BŠ 1	13.8	13.9	17.4	16.9
BŠ 2	5.9	6.3	7.2	8.4
BŠ 3	7.3	6.4	11.1	11.9
BŠ 4	10.3	10.7	16.1	16.9

The results confirmed the relationship between the actual weather conditions and the measured values of light intensity. Higher average light intensity was observed in the case of higher air humidity and cloudiness; under clear sky conditions the values were lower. This is caused by higher reflectance of light from rain drops.

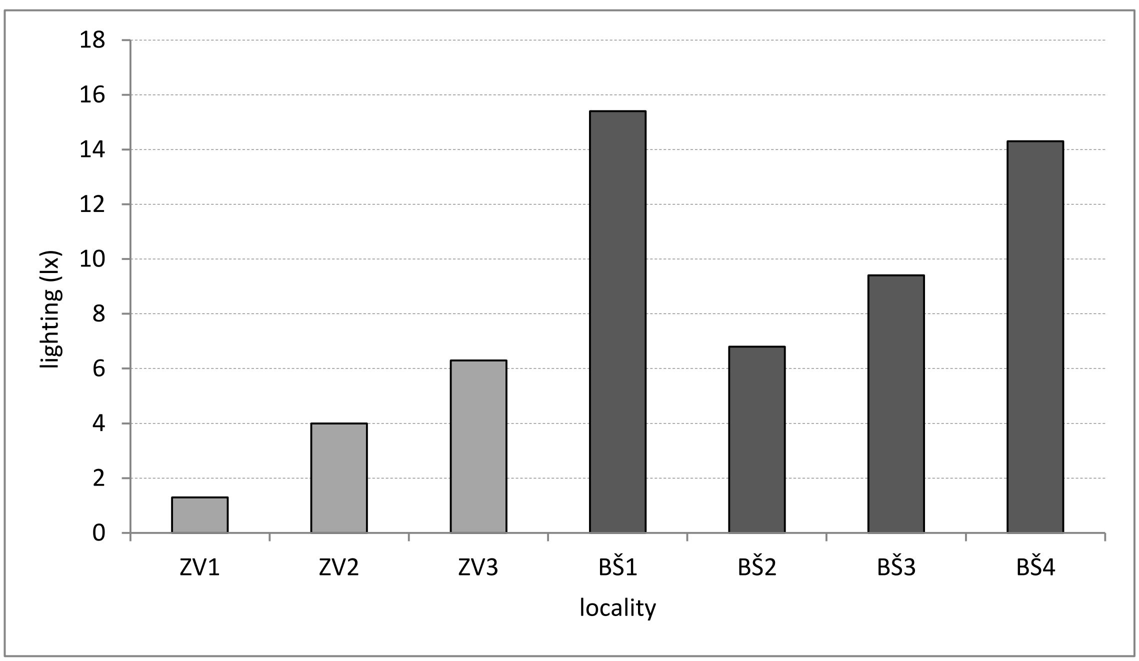


***Fig. 1**. Final average values of light intensity at individual sites during the measured period*

From Fig. 1 we can see that the highest measured values of light intensity were in the central part of Zvolen (ZV 3) and at two sites in Banská Štiavnica (BŠ 1, BŠ 4), probably because of inappropriate type of lighting. The obtained values were compared with the values given in STN

EN 12464-2 norm for Slovakia. In the centres of small towns and residential suburbs, the highest allowed value of disturbing light after 10pm is 2 lux. In the areas with high luminosity, such as town centres and shopping areas, 5 lux is allowed. For our sites we selected 5 lux to be the threshold value. We found that at one site in Zvolen, the average value during the whole observed period exceeded this threshold by 1.3 lux. Hence, inhabitants as well as fauna and flora are exposed to the increased concentration of undesirable artificial lighting. At two other sites in Zvolen, the values did not exceed the norm threshold. In Banská Štiavnica, light intensity significantly exceeded the threshold values of the norm at all sites by 1.8-10.4 lux. The lighting in this town is considered inappropriate. It would be desirable to change it with the lamps with flat and tight diffusers. The current state of light pollution affected physiological processes of trees in both towns. The visible impact of intensive night lighting caused the delay of the autumn phenological phase of leaf colouring in some crown parts of several trees of staghorn sumac (*Rhus typhina* L.) (Fig. 2).

Fig. 2 *Impact of artificial public lighting on trees in the town of Zvolen. (Tuhárska, 2013)*

The solutions for eliminating light pollution are not complicated and costly. In many cases it is sufficient to change the direction of light rays, to decrease the luminance by substituting fluorescent lamps with sodium arc discharge lamps having orange spectrum, or to restrict lighting by time switches that react to movements during the night hours.

CONCLUSION

The measurements of light intensity pollution were performed at seven sites of Central Slovakia from September 2013 to April 2014. The sites were situated in two towns (Zvolen, Banská Štiavnica) located at different elevations, geographical positions and climatic conditions. The measurements were performed during night hours with Lux Meter Velleman DVM 1300 instrument following the method described by Lázna (2009). Weather conditions significantly affected light intensity. Under cloudy conditions the average light intensity was higher than under clear sky conditions. Light intensity in Zvolen was 1.1-6.1 lux and 1.3-6.6 lux, under clear and cloudy sky conditions, respectively. In Banská Štiavnica, higher values were measured most probably due to inappropriate type of lighting, which under clear sky conditions reached the values between 5.9 and 13.9 lux, while under cloudy sky the values were from 7.2 to 17.4 lux. According to the valid norm of STN EN 12464-2, the allowed threshold after 10 p.m. in the centres of small towns and residential suburbs is 5 lux. This norm was exceeded at one site in Zvolen by 1.3 lux, and by 1.8-10.4 lux at all sites in Banská Štiavnica. The current state of light pollution also influenced physiological processes of trees in both towns. Intensive night lighting caused the visible delay of autumn phenological phase of leaf colouring on certain crown parts of several individuals of staghorn sumac (*Rhus typhina* L.). The leaves did not change their colour, but they froze green. Artificial lighting disturbs the annual biorhythm of trees and may cause their earlier mortality.

A man with his demands on intensive night lighting disturbs environment. Our days do not finish by sunset. We got used to the life in the light of towns. Let us think if it is not often at the expense of some other parts of our environment that are inevitable for the life of our civilisation.

References

HABEL, J., DVOŘÁČEK, K., DVOŘÁČEK, V., ŽÁK, P., 2013: Svetlo a osvětlování. Vydavateľstvo FCC Public s. r.o, 624 s.

Lapin, M., Faško, P., Melo, M., Šťastný, P., Tomlain, J., 2002: Klimatické oblasti 1:1 000 000. In: Atlas krajiny Slovenskej republiky. MŽP SR Bratislava, SAŽP Banská Bystrica.

LÁZNA T., 2009: Měření světelného znečištění v Prostějově. , Prostějov, s. 10 –11.

RAPAVÝ, P., 2009: Svetelne znečistenie . In: Tvorivy učiteľ fyziky II, Národný festival fyziky 2009. Košice: Equilibria, s.r.o., s. 135 –139.

SUCHAN, P., 2003: Analýza znečisťovateľov svetlom na území Českej republiky. Dostupné online:http://amper.ped.muni.cz/noc/old/zprava_noc.pdf.

STN EN 12464-2: Svetlo a osvetlenie. Osvetlenie pracovných miest. Časť 2: Vonkajšie pracovné miesta (online).

http://www.vesmir.sk/?id=svetelne_znecistenie
http://www.astronomie.cz/data/2010/11/letakweb.pdf

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract VEGA No. 1/0463/14, 1/1130/12 and No: APVV-0423-10.

SUMMARY

Na strednom Slovensku prebiehali od septembra 2013 do apríla 2014 merania intenzity svetelného znečistenia. Lokality boli umiestnené v dvoch mestách (Zvolen, Banská Štiavnica) s rozdielnou nadmorskou výškou, geografickou polohou a klimatickými pomermi. Za rôzneho stavu počasia sa uskutočnilo 20 meraní na 7 lokalitách. Merania prebiehali v nočných hodinách pomocou prístroja Lux Meter Velleman DVM 1300 podľa metodiky, ktorú popísal vo svojej práci Lázna (2009). Počasie výrazne ovplyvnilo intenzitu osvetlenia. Pri zamračenej oblohe dosiahla priemerná intenzita osvetlenia vyššie hodnoty, pri bezoblačnej poveternostnej situácii boli hodnoty nižšie. Vyššiu intenzitu spôsobil vyšší odraz svetla od kvapiek zrážkovej vody.

Vo Zvolene dosiahla intenzita osvetlenia pri jasnom počasí 1,1-6,1 luxov, pri zamračenom počasí 1,3-6,6 luxov. V Banskej Štiavnici pravdepodobne vplyvom nevhodného typu osvetlenia boli namerané vyššie hodnoty, ktoré sa pri jasnej oblohe pohybovali v intervale 5,9-13,9 luxov, pri zamračenej oblohe od 7,2 do 17,4 luxov. Podľa platnej normy STN EN 12464-2 pre územie Slovenska je v centrách malých miest a obytných prímestských oblastiach povolená najvyššia prípustná hodnota rušivého svetla po 22:00 hod. do 5 luxov. Táto norma bola prekročená na jednej lokalite vo Zvolene o 1,3 luxov, v Banskej Štiavnici na všetkých lokalitách o 1,8-10,4 luxov. Súčasný stav svetelného znečistenia v obidvoch mestách sa prejavil aj na fyziologických prejavoch drevín. Viditeľný vplyv intenzívneho nočného osvetlenia spôsobil oneskorenie jesennej fenologickej fázy žltnutia listov na časti koruny viacerých jedincov sumachu pálkového (*Rhus typhina* L.). Listy sa nesfarbia, ale zelené zmrznú a opadnú. Umelé osvetlenie ruší fyziologické procesy drevín a môže spôsobiť ich predčasný úhyn. Negatívne dôsledky svetelného znečistenia výrazne ovplyvňujú aj faunu. Živočíchy zvyšujú svoju fyzickú aktivitu v noci, čím menia svoj biorytmus, orientáciu v krajine, koncentráciu za potravou a reprodukciu.

Znečisťovanie nežiadúcim a nadmerným osvetlením ničí životné prostredie, nepriamo prispieva k zvyšovaniu podielu skleníkových plynov v atmosfére a tým aj ku globálnemu otepľovaniu.

CONTACT

Doc. Ing. Jana Škvareninová, PhD.

Technická univerzita vo Zvolene

Fakulta ekológie a environmentalistiky

T. G. Masaryka 24, 960 53 Zvolen

skvareninova@tuzvo.sk

CHANGES IN THE COURSE OF THE SPRING GENERATIVE PHENOLOGICAL PHASES IN MANNA ASH (FRAXINUS ORNUS L.) IN DEPENDENCE ON THE AIR TEMPERATURE CONDITIONS

BRANKO SLOBODNÍK[1], JURAJ ŠUFLIARSKY[1], LENKA SLOBODNÍKOVÁ[2], JAROSLAV ŠKVARENINA[2]

1) Faculty of ecology and environmental sciences, Technical University in Zvolen, T. G. Masaryka 24, SK-96053 Zvolen, Slovakia

2) Faculty of Forestry, Technical University in Zvolen, T. G. Masaryka 24, SK-96053 Zvolen, Slovakia

ABSTRACT

Manna ash (*Fraxinus ornus* L.) is the small tree of warm and dry localities with the center of geographic distribution in Mediterranean and the northern border of its native area in southern regions of Slovakia. The course of the spring generative phenological phases of this species was studied in allochthonous population in Central Slovakia (Radvaň – Vartovka in the vicinity of Banská Bystrica) during two vegetation periods with significantly different air temperature conditions. In the first season of our investigations (2008), the winter and early spring months were, from the viewpoints of air temperatures, only slightly above the long-term average at most. In most of the observed individuals, the end of the flower bud burst fell on 28th April. The start of the stigma receptivity and the start of the pollen release were mostly registered in 4th May and 10th May, respectively. In 2014, after the extremely warm winter and early spring, the advance of the generative bud burst was as high as 11–14 days and the advances of the start of the pollen release/receptivity of stigmas involved 6 and 7 days, compared to 2008. The achieved results are discussed in context of the reproductive biology of manna ash, as well as in relation to the older phenological data from two autochthonous localities of manna ash in southern Slovakia.

Key words: Phenology, changing climate, flowering

INTRODUCTION

The woody plants of warm and dry localities are the frequent objects of phenological studies, carried out in context of the climatic changes (Walkowszky 1998, Llorens *et al.* 2004, Škvareninová 2013). The research of such plant species is, in addition to their importance as bioindicators, related to the assumed shift or enlargement of their areas due to the increase of the average air temperature, changes of water regime, increase of the frequency of meteorological extremes and the shifts of the whole climatic regions or subregions (Ogaya, Peñuelas 2004, Bertin 2008, Škvareninová *et al.* 2009).

One of the woody plants, tolerating the high temperatures and shortage of water, is manna ash (*Fraxinus ornus* L.), small tree or higher shrub from the family of olives (Oleaceae), native to Mediterranean and southern Europe. The northern border of its natural distribution reaches the southern parts of Slovakia. Due to its frequent artificial planting in the past (Bertová 1984, Dostál 1989, Manica, Slobodník 2008), as well as its expansive properties, that express extraordinarily markedly out of the borders of its native area (Thébaud, Debussche 1991, Gojdičová *et al.* 2002, DAISIE 2009), however, according to our opinion there exists the possibility of its spontaneous spreading, in consequence of changing climate as well.

The studies on manna ash, aimed preferably at the impact of meteorological extremes on its phenological traits, will thus help us to assess its response to the intensive changes of outer environment in context of changing climate.

MATERIAL AND METHODS

Characteristics of studied species

Manna ash (*Fraxinus ornus* L.) has its natural range, above all, in northern Mediterranean from the eastern part of Spain (Valencia) through the south-eastern France, Italy and Balkan Peninsula to Turkey and Middle East (north-western Syria and Lebanon). The southernmost parts of its natural distribution involve Hungary and south of Slovakia (FRAXIGEN 2005).

It differs from the other European ashes (*Fraxinus* L.) not only by its lower habitus, but also by an atypically smooth bark, pubescent grayish bud scales and much bigger flowers. These are, unlike the flowers of common ash and narrow-leaved ash, aggregated in rich terminal panicles and have four whitish leaflets of corolla. They are hermaphrodite or male and these two types of flowers never occur together within the same individual. From the viewpoint of reproductive biology, manna ash is thus characterized as the morphologically androdioecious species (Dommée *et al.* 1999). Nevertheless, newer studies confirmed the functional dioecy of manna ash. This means that, despite the coexistence of male and hermaphrodite individuals in common populations, the paternal function in the sexual reproduction is really effective only in males. The decisive role in elimination of the male function of the morphological hermaphrodites is played by postzygotic factors, above all, by a much higher viability of the progenies, sired by the pollen of male individuals (Verdú *et al.* 2004). An eventual importance of prezygotic mechanisms in this process, e.g. the phenological advance of male individuals, remains still unknown.

In terms of reproductive phenology, manna ash belongs to the woody plant species with the late start of flowering. The exact data are available only from autochthonous localities in southern Slovakia. Due to the relatively frequent reforestations of abandoned and degraded biotopes in the past, however, there exist many scattered allochthonous localities of manna ash, situated in western, central and eastern regions of Slovakia as well (Bertová 1984, Dostál 1989, Manica, Slobodník 2008). The fact, that manna ash is well-adapted or even spontaneously expands in many sites with its allochthonous distribution, accounts for its high ecological plasticity. That could even mean that the area with the secondary occurrence of manna ash might further enlarge due to its expansive traits and global climatic changes, i.e. without a direct contribution of human. The last mentioned fact even more enhances the importance of further studies on the biological and ecological properties of this species, including monitoring of the time course of the phenological phases not only in its natural range, but also on the allochthonous localities.

Description of locality

In the presented paper, the flowering of manna ash is observed on its allochthonous locality Radvaň – Vartovka in the immediate vicinity of Banská Bystrica (region of Central Slovakia). The artificial planting of manna ash carried out here in late 1950s after the marked devastation by pasturing and the following erosion of soil (Midriak, Lipták 1965, Hladká 2010). At the present, manna ash is very well adopted here, regenerates naturally and even spontaneously expands (Manica, Slobodník 2008).

The locality is situated on the south-western slope of the Vartovka hill in Bystrická vrchovina Mts. and its altitude is about 450 m a. s. l. The bedrock is formed by dolomites and the most frequent soil type is rendzina (calcisol). The soil is flat, stony and, although the locality is characterized by the perhumid climate ((Midriak, Lipták 1965), also considerably dry. The extremity of site is even enhanced by the maximum slope of approximately 65 %.

The main native forest tree species are sessile oak – *Quercus petraea* (Matt.) Liebl. and common beech – *Fagus sylvatica* L. Nevertheless, the forest stands were markedly negatively influenced by human activity and their contemporary character is significantly determined not only by manna ash, but also by other allochthonous or originally only admixed species, e.g. Scots pine – *Pinus sylvestris* L., black pine – *Pinus nigra* Arnold, black locust – *Robinia pseudoacacia* L., common hornbeam – *Carpinus betulus* L. etc. Due to the intensive shading by the dense stand by manna ash, the herbal layer is relatively poor, with the occurrence of calciphytes, e.g. white sedge – Carex alba Scop., hairy violet – *Viola hirta* L., branched St. Bernard's lily – *Anthericum ramosum* L. and sword-leaved helleborine – *Cephalanthera longifolia* (L.) Fritsch, accompanied by some species of sessile oek stands, e.g. cypress spurge – *Tithymalus cyparissias* (L.) Scop., swallow-wort – *Vincetoxicum hirundinaria* Medik., and some of the species of forest-steppes, e.g. purple gromwell – *Buglossoides purpurocaerulea* (L.) I. M. Johnst. and wall germander – *Teucrium chamaedrys* L. From among the species of common beech forests, only the rare occurrence of Early dog-violet – *Viola reichenbachiana* Jord. ex Boreau was registered (Miňová 2012). The locality is also characterized by the occurrence of lady orchid – *Orchis puspurea* Huds.

Temperature conditions

Our research on the described locality was carried out during two vegetation periods with the markedly different air temperature conditions. While in the first season of our investigations (2007/2008) the winter and spring months from this point of view were only slightly above the long-term average at most, in the second season of our research (2013/2014) the monthly average values were much higher. According to the data from the near meteorological station (Sliač), in winter 2013/2014 all the monthly average temperatures of air were higher than the freezing point and the extremely high air temperatures were also registered during early spring (Fig. 1).

The highest difference of monthly average temperatures of air between the seasons of investigations (3.6 °C in 2008, 7.7 °C in 2014) is characteristic of March, i.e. the month that precedes the flowering of manna ash. This difference is even enhanced due to the relatively small precipitations in March 2014 (35.2 mm vs. 76.5 mm in March 2008).

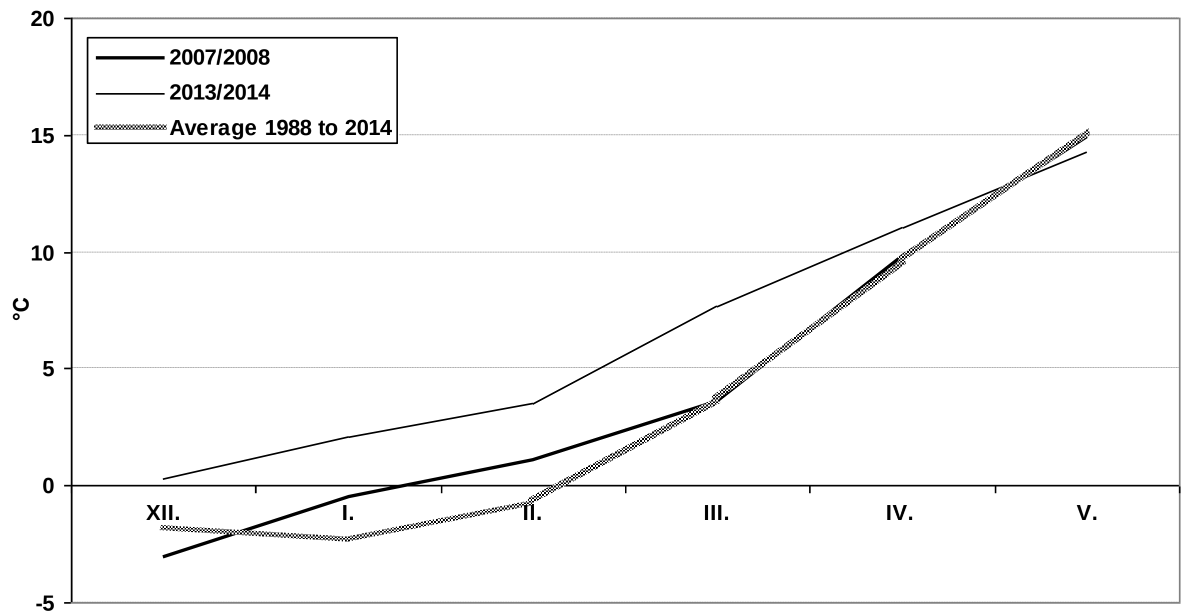


Fig. 1: *Average monthly air temperatures during the winter and spring periods (December to May) of 2007/2008 and 2013/2014, and the long-term averages of the monthly air temperatures from 1988 to 2014, achieved from the near meteorological station Sliač.*

Methods of field observations

Before the first season of our investigations, 60 individuals of manna ash from the studied locality were randomly chosen and tagged by numbers. Their morphological sexual type or gender (hermaphrodite, male) was estimated on the basis of presence or absence of fruits from the previous vegetation periods. Later, at the time of the full flowering, the sexual type (hermaphrodite, male) was determined definitely on the basis of presence or absence of pistils.

The course of the spring generative phenological phases of the chosen and tagged individuals was observed and recorded at the intervals of 3 to 4 days. We evaluated the course of the flowering according to the methodology, which had already been used in our previous research (Slobodník *et al.* 2006). This methodology is based on the detailed assessment of each observed individual (phenological phases are recorded for each individual separately), as well as the separate assessment of male and female generative organs, i.e. stamens and pistils.

The used methodology enables the exact comparison of the achieved data with the results of the previous research, carried out on the other localities. In addition, the finding of eventual phenological differences between the sexual types (hermaphrodites and males) could contribute to the improvement of our knowledge of the biological properties of the studied species. Numbers and descriptions of the assessed spring generative phenological phases are summarized in Tab. 1.

Tab. 1: *Numbers and descriptions of the assessed spring generative phenological phases in manna ash. Note: Course of the phenological phases 2, 2/3 and 3 is assessed separately for male generative organs (stamens) and female generative organs (pistils).*

Number	**Description**	
0	Closed generative buds	
0/1	Start of the bud burst (opening of the generative bud scales)	
1	Opened generative buds with non-receptive flowers (butonization)	
2	♂: Start of the pollen release	♀: Start of the stigma receptivity
2/3	♂: Peak of the pollen release	♀: Peak of the stigma receptivity
3	♂: End of the pollen release	♀: End of the stigma receptivity

RESULTS

Sexual structure of population

From among 60 individuals of manna ash, chosen and tagged at the beginning of our observations in 2008, 27 were determined as males. The morphological hermaphroditiism was ascertained for the same number of individuals, 27. The rest 6 individuals did not flower in 2008 and were classified as sterile.

In 2014, the flowering of the manna ash on the studied locality was much poorer: 18 flowering individuals were classified as males, i.e. they contains exclusively male flowers and 17 flowering individuals were classified as morphological hermaphrodites, i.e. their flowers were complete and contained stamens and pistils. The rest 25 tagged individuals were in 2014 sterile.

Thus, the male/hermaphrodite ratio of studied population is considered balanced. Eventual changes of the sexual type (gender) were not observed. Thus, this trait of the individuals of manna ash could be considered stable.

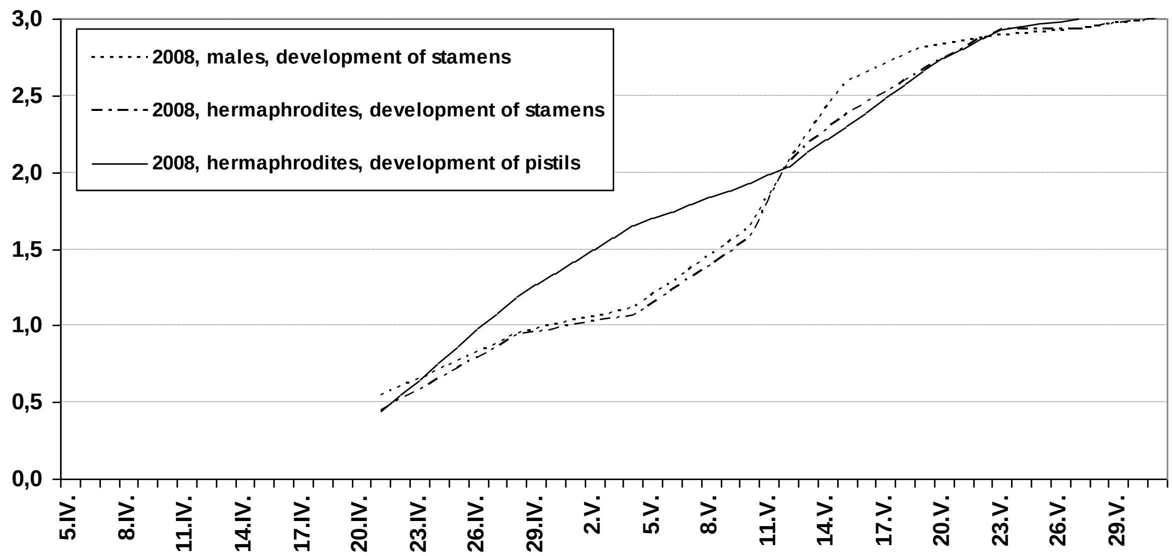


Fig. 2: *Average number of achieved phenological phases, recorded during the observations of manna ash on the locality Radvaň – Vartovka in 2008.*

Course of the spring generative phenological phases

The first of the main assessed phenological phases, opened generative buds with the non-receptive flowers, i.e. the phenological phase 1 was in 2008 in most of the observed individuals registered on 28th April, without the apparent differences between the hermaphrodite individuals and males. In 2014, when the start of our observations was preceded by the winter months with abnormally high monthly average temperatures, this phase was in most of the males registered as early as on 14th April, i.e. two weeks earlier than in 2008. In most of the morphological hermaphrodites, this phenological phase was achieved on 17th April, i.e. 11 days earlier than in 2008.

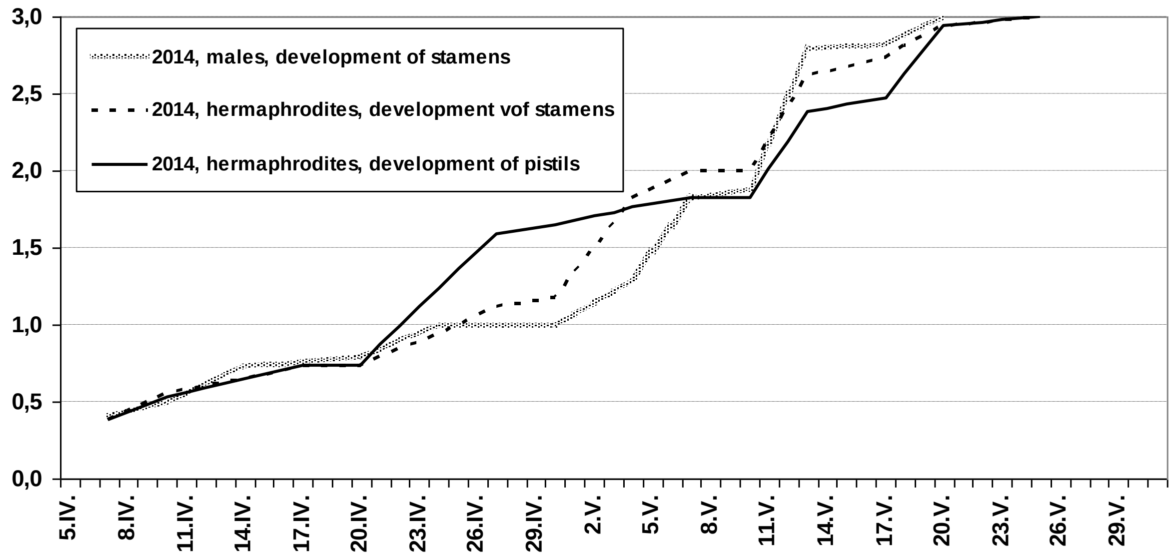


Fig. 3: *Average number of achieved phenological phases, recorded during the observations of manna ash on the locality Radvaň – Vartovka in 2014.*

Achieving phenological phase 2, i.e. the start of the release of pollen and the start of the receptivity of stigmas, respectively, fell on the different dates in the different years, as well as in the different types of generative organs (pistils, stamens).

In 2008, the start of the release of pollen fell, in the majority of the observed individuals, on 10th May, without apparent differences between morphological hermaphrodites and males.

The start of the receptivity of stigmas was in the majority of morphological hermaphrodites observed 6 days earlier, i.e. on 4th May. This fact is giving the evidence for protogyny, i.e. the phenological advance of female generative organs (pistils) in comparison with the male generative organs (stamens).

In 2014, the start of the pollen release was observed on 4th May, i.e. 6 days earlier than in 2008 in most of the observed individuals (hermaphrodites as well as males). The same date fell on the median of the start of the pollen release in morphological hermaphrodites. In the majority of males, however, this phase was registered a little later, on 7th May. Protogyny of manna ash was demonstrated in 2014 too, because the median of the start of the receptivity of stigmas fell on 27th April.

Unlike the previous phenological phases, the phase 3 (end of the release of pollen and end of the receptivity of stigmas, respectively) was achieved on the very similar dates in both seasons of investigations. This fact is perhaps connected with the very similar average monthly temperature of air in May 2008 and May 2014 (Fig. 1). In 2008, this phase was in most individuals achieved on 15th May (end of the pollen release in males) and 19th May (end of the stigma receptivity and end of the pollen release in morphological hermaphrodites). In 2014, it fell on 13th May (end of the release of pollen in males), 17th May (end of the release of pollen in hermaphrodites) and 20th May (end of the stigma receptivity in hermaphrodites).

The mean numbers of achieved phenological phases, recorded during our observations in 2008 and 2014, are shown on Fig. 2 and Fig. 3.

DISCUSSION

In general, flowering period of manna ash starts relatively late, at latest from among the European species of *Fraxinus* L. Under conditions of Sicily, Wallander (2001) observed the most intensive flowering of manna ash approximately at the turn of April and May. Even later flowering (turn of May and June) was characteristic of the population of relative, also androdioecious and partly insect-pollinated Japanese species *Fraxinus lanuginosa* Koidz, without apparent differences between male individuals and hermaphrodites (Ishida, Hiura 1998). According to the recent knowledge (Bolmgren *et al.* 2003), the late flowering period of ash species from section *Ornus* (Boehm.) DC. is perhaps a result of the partial adaptation to the pollination by insects.

Under conditions of Slovakia, phenological observations of manna ash were carried out by Slobodník *et al.* (2006) on autochthonous localities near to the border with Hungary. Their results are following:

(1) Median value for the achieving of the phenological phase 1 (opened generative buds) fell in the studied year (2003) on 16th April in case of the very warm locality in one of the southernmost regions of Slovakia (Kováčovské kopce) and on 23rd April in case of slightly cooler

locality (Príbelce). Presented results from Central Slovakia (year 2014) are thus, from this point of view, very similar to the achieved data from the vicinity of Hungarian border (year 2003).

(2) On the southern border of Slovakia, phenological phase 2 fell in most of the observed individuals on 29th April (start of the receptivity of stigmas) and on 2nd and 4th May (start of the pollen release in males and hermaphrodites, respectively). On the second locality (Príbelce), phenological phase 2 was achieved in the majority of individuals on 3rd May (start of the stigma receptivity) and on 5th and 7th May (start of the pollen release in males and hermaphrodites, respectively). The values, recorded in Central Slovakia after the extremely warm winter and early spring in 2014 (27th April, 4th May and 7th May, respectively) are thus, also for this phenological phase, very similar to the phenological data, achieved on the much warmer localities 11 years ago.

(3) On average, the anthers of the male individuals started to open 2 days earlier than the anthers of the morphological hermaphrodites.

(4) The end of the receptivity of stigmas was observed about 10th May (medians represented 8th May for the warmer locality Kováčovské kopce and 12th May for a little cooler locality Príbelce). On average, the stigmas were receptive more than 8 days. On both localities, the end of the pollen release was in male individuals recorded several days earlier than the end of the release of pollen in morphological hermaphrodites. In the male individuals, the total length of the period of the pollen release was thus longer.

Nevertheless, the last mentioned facts (paragraphs 3 and 4) were not demonstrated in case of the allochthonous population of manna ash. The problems of an eventual prezygotic reproductive advantage of males (and an eventual prezygotic elimination of the male function of the hermaphrodites) are therefore still under debate. Nevertheless, the experimental studies of common ash (*Fraxinus excelsior* L.) demonstrated the importance of the time advance of pollination and the relation between the phenological advance of the pollen donors and their paternal reproductive success (Bochenek, Eriksen 2011).

CONCLUSION

The results of the phenological observations of manna ash (*Fraxinus ornus* L.) from Central Slovakia suggest the possible shift in the time course of its spring generative phenological phases in case of the expected increase of the frequency of the extremely warm periods, similar to the winter 2013/14 and early spring 2014. In comparison with 2008, we recorded as high as 11 to 14 days advance in the opening of buds and 6 to 7 days advance in the start of the release of pollen and the receptivity of stigmas, respectively. Such phenological advance means an imaginary movement of studied locality from Central Slovakia to its southernmost regions, where the spring generative phenological phases were investigated in 2003 (Slobodník *et al.* 2006).

References

Bertin, R. I., 2008: Plant phenology and distribution in relation to recent climate change. Journal of the Torrey Botanical Society 135(1): 126–146.

Bertová, L., 1984: Oleales – Olivotvaré. In: Flóra Slovenska IV/1. L. Bertová (ed.). Veda, Bratislava, p. 63–78.

Bochenek, G. M., Eriksen, B., 2011: First come, first served: delayed fertilization does not enhance pollen competition in a wind-pollinated tree, Fraxinus excelsior L. (Oleaceae). International Journal of Plant Sciences 172(1): 60–69.

Bolmgren, K., Eriksson, O., Linder, H. P., 2003: Contrasting flowering phenology and species richness in abiotically and biotically pollinated angiosperms. Evolution 57(9): 2001–2011.

DAISIE, 2009: Handbook of alien species in Europe. Invading nature: Springer series in invasion ecology 3. Springer, 399 pp.

Dommée, B., Geslot, A., Thompson, J. D., Reille, M. & Denelle, N., 1999: Androdioecy in the entomophilous tree Fraxinus ornus (Oleaceae). New Phytologist 143(2): 419–426.

Dostál, F., 1989: Nová květena ČSSR 2. Academia, Praha, 802 pp.

FRAXIGEN, 2005: Ash species in Europe: biological characteristics and practical guidelines for sustainable use. Oxford Forestry Institute, University of Oxford, 128 pp.

Gojdičová, E., Cvachová, A., Karasová, E., 2002: Zoznam nepôvodných, inváznych a expanzívnych cievnatých rastlín Slovenska 2. Ochrana prírody 21: 59–79.

Hladká, D., 2010: Analýza vegetácie na lokalite Urpín – Radvanské terasy. In: Krajinná ekológia a chrana prírodného dedičstva v socioekonomických premenách. T. Lepeška (ed.). Univerzita Mateja Bela, Banská Bystrica, pp. 125–130.

Ishida, K., Hiura, T., 1998: Pollen fertility and flowering phenology in an androdioecious tree, Fraxinus lanuginosa (Oleaceae) in Hokkaido, Japan. International Journal of Plant Sciences 159(6): 941–947.

Llorens, L., Peñuelas, J., Estiarte, M., Bruna, P., 2004: Contrasting growth changes in two dominant species of a Mediterranean shrubland submitted to experimental drought and warming. Annals of Botany 94(6): 843–853.

Manica, M., Slobodník, B., 2008: Poznámky k výskytu a rozšíreniu jaseňov (Fraxinus L.) na Slovensku. Acta Facultatis Ecologiae Zvolen 18: 35–46.

Midriak, R., Lipták, J., 1965: Zalesňovanie spustnutých pôd pomocou plôtikových terás v Radvani pri Banskej Bystrici. Lesnícky časopis 11: 683–693.

Miňová, L., 2012: Analýza rastových a reprodukčných vlastností jaseňa mannového. Doktorandská dizertačná práca. Technická univerzita vo Zvolene, Fakulta ekológie a environmentalistiky, 114 pp.

Ogaya, R., Peñuelas, J., 2004: Phenological patterns and reproductive effort of Quercus ilex, Phillyrea latifolia and Arbutus unedo growing under a field experimental drought. Ecoscience 11(3): 263–270.

Slobodník, B., Čaňová, I., Paule, L., 2006: Fenológia kvitnutia a olisťovania dvoch druhov mediteránnych jaseňov (Fraxinus L.) na severnej hranici ich rozšírenia. In: Fenologická odezva proměnlivosti podnebí. J. Rožnovský, T. Litschmann, I. Vyskot (eds.). Česká bioklimatologická společnost, Praha, Český hydrometeorologický ústav, Brno, 13 pp (CD).

Škvareninová, J., 2013: Vplyv zmeny klimatických podmienok na fenologickú odozvu ekosystémov. Technická univerzita vo Zvolene, Fakulta ekológie a environmentalistiky, 132 pp.

Škvareninová, J., Čaňová, I., Domčeková, D., Leštianska, A., Melo, M., Mezeyová, I., Mezey, J., Paule, L., Pokladníková, H., Rožnovský, J., Slobodník, B., Středa, T., Střelcová, K., Šiška, B., Škvarenina, J., 2009: Fenológia rastlín v meniacich sa podmienkach prostredia. Technická univerzita vo Zvolene, Fakulta ekológie a environmentalistiky, 102 pp.

Thébaud, Ch., Debussche, M., 1991: Rapid invasion of Fraxinus ornus L. along the Hérault River system in southern France: the importance of seed dispersal by water. Journal of Biogeography 18(1): 7–12.

Verdú, M., Montilla, A. I., Pannell, J. R., 2004: Paternal effects on functional gender account for cryptic dioecy in a perennial plant. Proceedings of the Royal Society of London, Series B – Biological Sciences 271(1552): 2017–2023.

Wallander, E., 2001: Evolution of wind-pollination in Fraxinus (Oleaceae) – an ecophylogenetic approach. PhD thesis. Göteborg University, Göteborg.

Walkowszky, A., 1998: Changes in phenology of the locust tree (Robinia pseudoacacia L.) in Hungary. International Journal of Biometeorology 41(4) 155–160.

ACKNOWLEDGEMENT

The paper was prepared with the financial support of Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of Slovak Republic and Slovak Academy of Sciences (VEGA), Grant Nr. 1/0463/14 „Influence of weather extremes upon the phenological expressions of plants".

SUMMARY

Jaseň mannový (*Fraxinus ornus* L.) je nízky strom teplých a suchých lokalít s ťažiskom zemepisného rozšírenia v Stredomorí a s výrazne vysunutou severnou hranicou svojho areálu, prechádzajúcou južnými regiónmi Slovenskej republiky. Priebeh jarných generatívnych fenofáz tejto dreviny bol sledovaný pri umelo založenej populácii v centrálnej časti Slovenska (Radvaň – Vartovka pri Banskej Bystrici) počas dvoch vegetačných periód s výrazne odlišnými teplotnými pomermi. V prvej sezóne našich pozorovaní (2008), keď boli zimné a skoré jarné mesiace z hľadiska teplotných pomerov nanajvýš iba mierne nadpriemerné, pripadlo ukončenie otvárania kvetných púčikov pri väčšine pozorovaných jedincov na 28. apríl a začiatok štádia receptivity blizien, resp. uvoľňovania peľových zŕn bol pri väčšine sledovaných indivíduí zaznamenaný 4., resp. 10. mája. V roku 2014, ktorý bol charakteristický extrémne teplou zimou a začiatkom jari, sme v porovnaní s rokom 2008 zaznamenali až 11–14-dňový predstih v otváraní púčikov a 6–7-dňový predstih pri začiatku uvoľňovania peľu, resp. začiatku receptivity blizien.

Dosiahnuté výsledky naznačujú možný posun v časovom priebehu jarných generatívnych fenofáz jaseňa mannového pri predpokladanom náraste frekvencie extrémne teplých období, podobných zime 2013/14 a začiatku jari 2014. Fenologický predstih, zaznamenaný v roku 2014 oproti roku 2008, predstavuje pomyselný posun sledovanej lokality zo stredného Slovenska na

úroveň jeho najjužnejších častí, v ktorých sa jarné generatívne fenofázy jaseňa mannového sledovali v roku 2003 (Slobodník *et al.* 2006).

CONTACT

doc. Ing. Branko Slobodník, PhD.
Fakulta ekológie a environmentalistiky
Technická univerzita vo Zvolene
T. G. Masaryka 24
SK-96053 Zvolen
Slovensko
Tel.: +421 45 5206496
E-mail: slobodnik@tuzvo.sk, branko.slobodnik@tuzvo.sk

INCREASE OF ANNUAL AND SEASONAL AIR TEMPERATURES IN THE CZECH REPUBLIC DURING 1961 – 2010

JAROSLAV STŘEŠTÍK[1], JAROSLAV ROŽNOVSKÝ[2], PETR ŠTĚPÁNEK[2], PAVEL ZAHRADNÍČEK[2]

[1] *Geophysical Institute of the Czech Academy of Sciences, Prague, Czech Republic*

[2] *Czech Hydrometeorological Institute, Department Brno, Czech Republic*

ABSTRACT

Using the monthly means of air temperatures at 267 stations in the Czech Republic, the long-term change has been estimated at each station for the last 50 years. Annual mean temperatures for the whole country show a considerable increase, more pronounced than that for global temperature, however, supplemented by strong fluctuations from year to year. Long-term changes in air temperatures at different stations and in different regions vary. Stronger increase in air temperatures can be seen in Bohemia, whereas in Moravia temperature increase is not so significant. This difference is more pronounced in the winter, whereas in the summer, the differences are smaller and perhaps of opposite nature. This means that the continentality of the climate in Moravia increases, while in Bohemia it very slightly decreases. Long-term changes depend only marginally on the absolute values of annual mean temperatures at the respective station. The increase of autumn temperatures is considerably lower than that of other seasons.

Keywords: air temperatures, long-term change, regions, seasons

INTRODUCTION

The climate change – global warming – has been the subject of intensive research for many decades. The observed temperature increase started more than a century ago and in the last decades has become more and more rapid. It is believed that the main cause of this increase is the increasing concentration of greenhouse gases in the atmosphere due to human activity (Smith, 1993). The process is irreversible and so the increase of global temperature is expected to continue in the future (Hansen and Sato, 2004) as well. There are also some natural long-term temperature fluctuations (Pfister, 1992), which may mean some necessary corrections of the supposed increase.

The temperature increase varies in different regions. In general, in the Northern Hemisphere the temperature increases more than in the Southern one. Especially, compared to the tropic region (between 30^{o} N and 30^{o} S), the increase is more pronounced towards North and less pronounced towards South (Brohan et al., 2006). Moreover, some preliminary studies suggest that also within the European territory, even over some small regions, the temperature increase is not equal.

In this paper, data from a network of stations on the territory of the Czech Republic will be processed and the increase at each station will be determined. The differences among the individual stations will be analyzed in order to find possible dependence of this increase on the position of the station.

MATERIALS AND METHODS

As a source material, the monthly mean temperatures observed at 267 stations in the Czech Republic have been used. From these data, the annual and seasonal mean for each station and mean values for the Czech Republic as a whole have been calculated. For comparison, also the global temperatures have been included.

RESULTS

Annual mean temperature for the whole Czech Republic over the entire period analyzed is 7.62 degrees centigrade. During the individual years, however, one can see a large variation in the observed data: in the warmest year 2000 it was 9.07 ^{o}C, in 2007 it was 9.04 ^{o}C, in the coldest ones 1980 and 1996 only 6.27 ^{o}C, in 1962 it was 6.31 ^{o}C. There are very large differences between temperatures observed at the individual stations. In general, the temperature depends on the altitude (corr. coefficient -0.75). Therefore the warmest regions are lowlands, especially South Moravia, and the Elbe lowland. Nevertheless, the highest mean annual temperature

(10.36 ^{o}C) has been observed in Prague (197 m above sea level) due to the urban heat island effect. The coldest regions are mountains, the lowest mean annual temperature (1.26 ^{o}C) has been observed at Praděd (1492 m). These numbers are means for the whole period of 1961-2010. The highest annual mean temperature has been observed in 2007 in Prague (12.1 ^{o}C), the lowest one in 1980 at Praděd (-0.3 ^{o}C). The mean temperature also depends to a smaller extent on the latitude (corr. coefficient -0.20) and longitude (corr. coefficient 0.15), but this dependence is masked by the unequal distribution of mountains and lowlands in the Czech Republic territory and therefore no conclusions can be derived from this dependence. The distribution of annual mean temperatures over the territory of the Czech Republic is presented in Fig. 1.

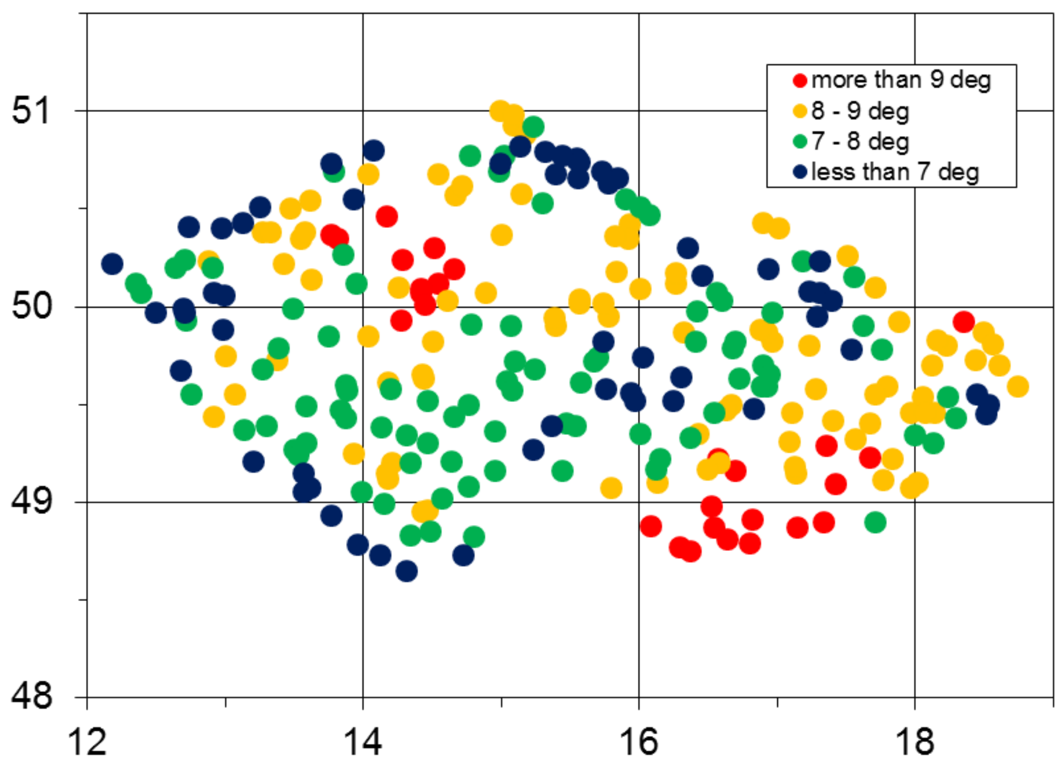


***Fig. 1**. Distribution of annual mean air temperatures during 1961-2010 over the territory of the Czech Republic.*

During the last 50 years, the annual mean temperature has clearly been increasing. This increase is supplemented by considerable fluctuations from year to year. The course of the mean annual temperatures for the Czech Republic as a whole is shown in Fig. 2 together with the course of the global temperature during the same time period. A constant has been added to the global temperature in order to achieve the same mean value as the temperature for the Czech Republic (7.62 ^{o}C.). It is clear that the increase of the temperature in the Czech Republic is more pronounced than that of the global temperature. Based on the regression lines, the increase was determined to be 1.40 ^{o}C for the temperatures in the Czech Republic, whereas for the global temperatures the increase is only 0.70 ^{o}C and for the NH region not including the tropics (above 30^{o} N) it is 0.89 ^{o}C (Brohan et al., 2006). Regression lines are mathematically expressed as $T = 0.028 * y - 48.36$ for the Czech republic and $T = 0.034 * y - 68.07$ for the global temperature (where T is the temperature and y is the year).

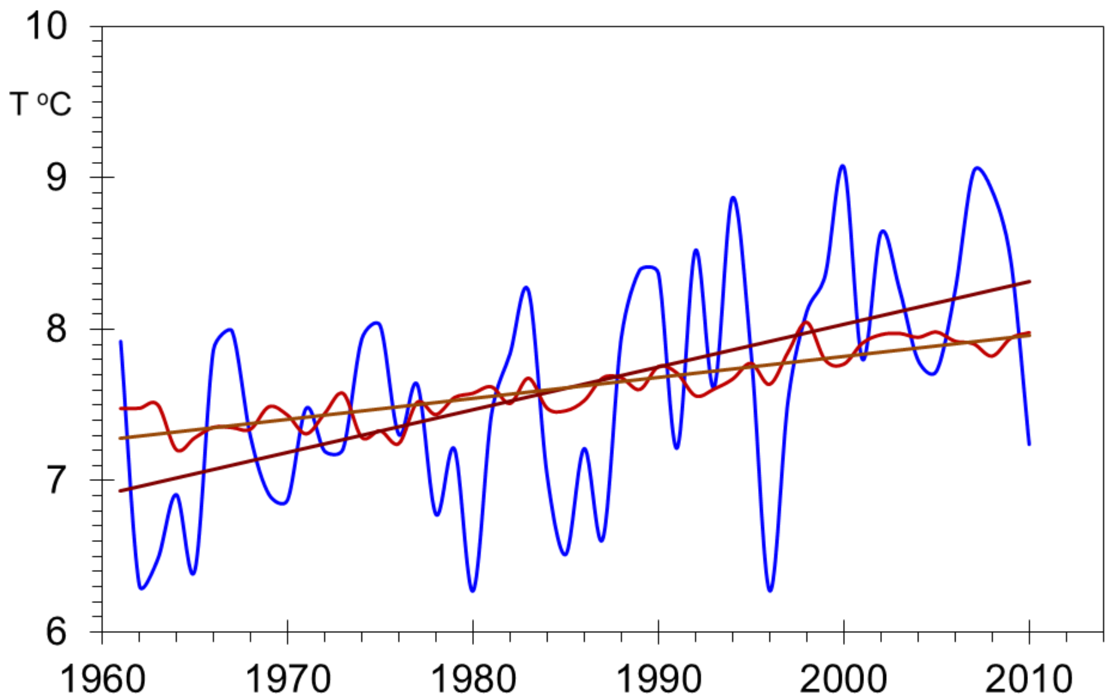


Fig. 2*. The course of annual mean air temperatures for the Czech Republic during 1961-2010 (blue) and of the global temperature (red). Approximation by regression lines (brown) is also shown.*

In addition, there are many fluctuations, which are quite different for both series. Their amplitude for the data from the Czech Republic is considerable; the temperature sometimes ranges by more than 2 degrees during 1-2 years. Similar fluctuation in the global temperature is much less apparent because these data are smoothed over the whole Earth. There is no evident long-term periodicity (for periods of about 3 – 10 years) which would suggest that warm and cold years alter regularly. The mean air temperature for the first half of the period investigated (1961-1985) is 7.24 ± 0.58 °C, for the second half (1986-2010) 8.00 ± 0.71 °C. Using Student's test of significance, the parameter ***t*** = 4.08 and therefore the difference between the means in the two halves is highly significant (the limit for the 99% significance is ***t*** = 2.79). For the global temperature, the increase itself is not so pronounced, nevertheless, the parameter ***t*** = 9.32 because of a much lower fluctuation.

The same pattern concerning the long-term change can be seen from the mean values for the individual decades, or the individual 20- or 30-year overlapping periods, respectively. These means are presented in Table 1. It should be pointed out that the increase also continued in the last decade (2001-2010), whereas the global air temperature during the same time period stagnated (the highest global temperature was observed in 1998).

Table 1. *Mean air temperatures in the individual decades and in 20- a 30-yr periods for the whole Czech Republic.*

1961-1970	1971-1980	1981-1990	1991-2000	2001-2010
7.10	7.30	7.56	7.94	8.21
1961-1980	1971-1990	1981-2000	1991-2010	
7.20	7.43	7.75	8.08	
1961-1990	1971-2000	1981-2010		
7.32	7.60	7.91		

The increase of annual mean temperatures at the individual stations differs considerably from the mean increase for the Czech Republic as a whole. Its values range from -0.6 °C (Horská Kvilda in the Bohemian Forest) to +2.4 °C (Vítkovice in Giant Mountains) during a period of 50 years.

All 267 stations have been subdivided into five groups based on the observed temperature increase at the respective station. Their distribution in the Czech Republic territory is depicted in Fig. 3 by circles with different colors. One can see that the distribution is not random. There is a substantial difference between Bohemia and Moravia. In Bohemia, larger increase is observed, values higher than 1.5 ^{o}C prevail and an increase of less than 1.0 ^{o}C occurs only occasionally. In Moravia, the temperature increases slowly, values lower than 1.25 ^{o}C prevail and values higher than 1.5 ^{o}C occur only occasionally. This difference leads to the conclusion that the air temperature increase also slightly depends on the longitude, in particular that at stations further from the Atlantic Ocean, the temperature increases more slowly. Moreover, it seems that in Moravia smaller increases are observed more at stations in mountains (in the Northern part), but this regularity is not unambiguous and is not seen in Bohemia. For the whole Czech territory there is a slight dependence of the temperature increase on the longitude (corr. coefficient -0.19), latitude (corr. coefficient 0.18) and on the altitude (corr. coefficient being -0.23). However, these correlation coefficients are not significant. The dependence of the temperature increase on the mean temperature at a station is also very low and not significant (corr. coefficient 0.23). The ***t*** parameters have also been calculated for temperatures at the individual stations. They show a very high correlation with the temperature increase (shown in Fig. 3) at the same station, correlation coefficient being 0.93. This means that the fluctuations are almost equal at all stations and that the value of ***t*** is determined predominantly by the temperature increase.

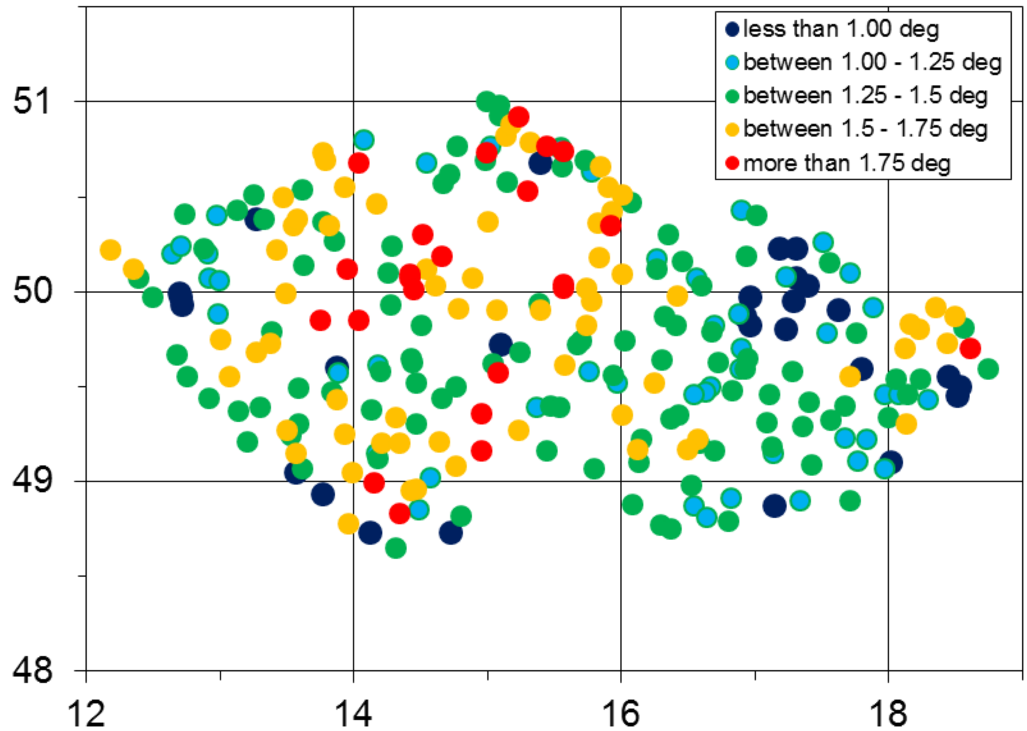


Fig. 3. *Distribution of the increases of annual mean air temperatures during 1961-2010 over the territory of the Czech Republic.*

Mean spring temperature for the whole Czech Republic is 7.49 ^{o}C, at the individual stations the values range between 0.22 ^{o}C and 10.32 ^{o}C. Mean summer temperature is 16.52 ^{o}C (between 9.23 ^{o}C and 19.47 ^{o}C), mean autumn temperature is 7.80 ^{o}C (between 0.09 ^{o}C and 10.29 ^{o}C) and mean winter temperature is -1.49 ^{o}C (between -6.55 ^{o}C and 1.20 ^{o}C). During all seasons, the highest temperature has been observed in Prague, the lowest at Praděd. The distribution of low and high mean temperatures in the individual seasons in the Czech Republic does not differ much from that observed for the whole year, given in Fig. 1.

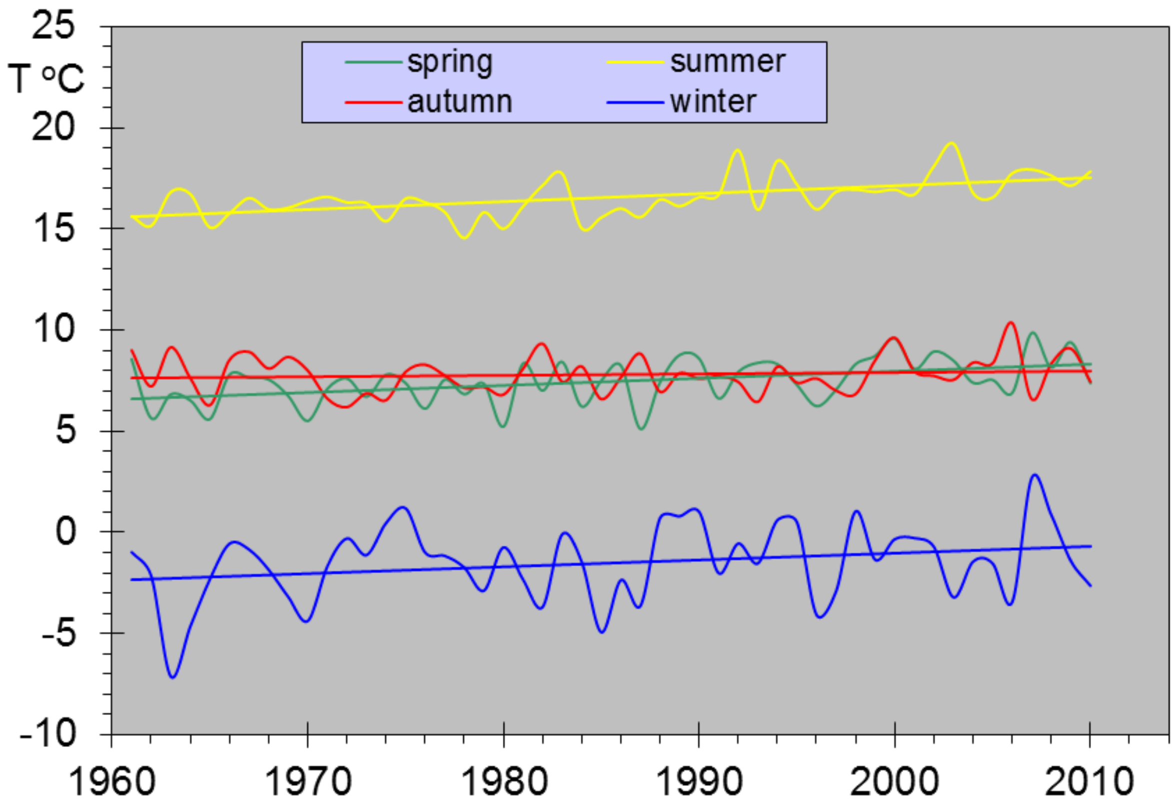


Fig. 4. *The course of seasonal mean air temperatures for the Czech Republic during 1961-2010. Approximation by regression line of the same color has been added.*

The increase of air temperature in the individual seasons is different from that for the whole year shown in Fig. 2. The course of seasonal temperatures during the period analyzed is presented in Fig. 4. Even though the vertical scale is compressed due to different temperatures in the individual seasons, some important patterns can be seen. A considerably lower increase takes place in autumn – only 0.35 °C. Differences among other seasons are not large: 1.75 °C in spring, 2.00 °C in summer and 1.65 °C in winter, all being a little higher than those for the annual temperatures (1.40 °C). Short-term fluctuations do not differ much from those observed for annual temperatures, only in the winter they are significantly more apparent. Regression lines are expressed by $T = 0.034 * y - 68.07$ for winter, $T = 0.035 * y – 62.22$ for spring, $T = 0.040 * y – 62.33$ for summer and $T = 0.007 * y - 7.00$ for autumn. The Student's parameter (calculated in the same way as for the annual temperatures) ***t*** = 1.88 for winter (so small and not significant due to the larger fluctuations compared to the other seasons), ***t*** = 3.26 for spring, ***t*** = 4.48 for summer and ***t*** = 0.77 for autumn (not significant, due to the very small increase).

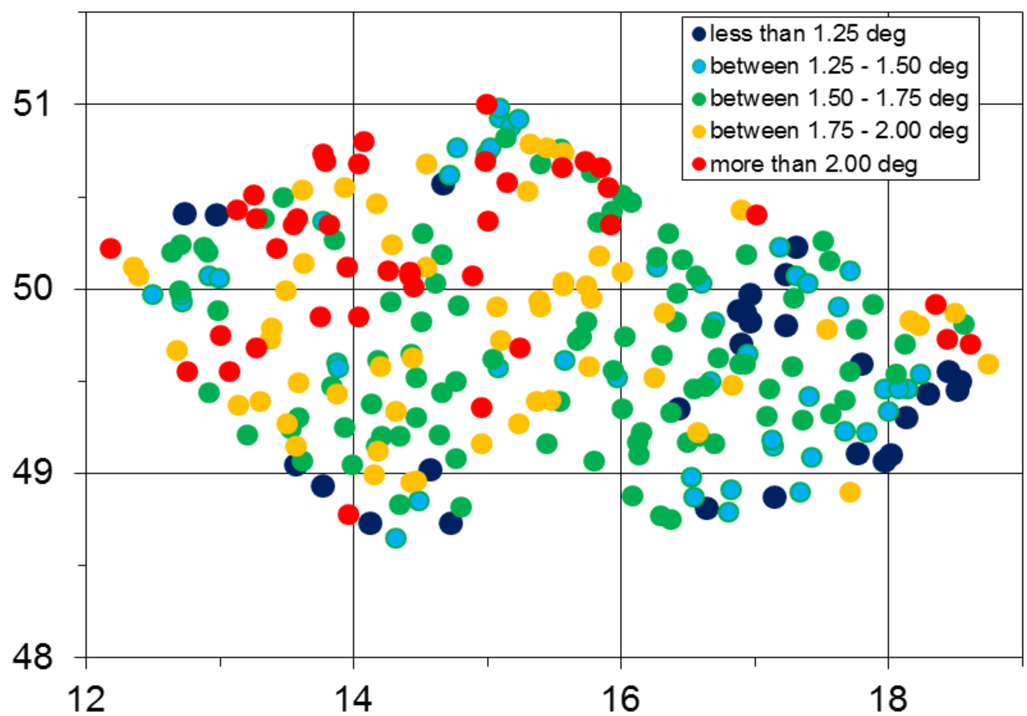


Fig. 5*. Distribution of the increases of winter mean air temperatures during 1961-2010 over the territory of the Czech Republic.*

The increase of the mean air temperature described above differs at different stations. In general, the increase follows similar distribution as shown in Fig. 3 – the increase is larger in the western regions than in the eastern. However, the difference is larger in the winter (Fig. 5). In Bohemia a strong increase has been observed at more stations than in case of the annual temperatures, whereas in Moravia more stations exhibit a weaker increase, especially in the South. In summer, the situation is opposite. Stations at Moravia, especially in its southern part, exhibit a strong increase, whereas in Bohemia the increase is a little weaker. However, the difference between Bohemia and Moravia is small in summer (Fig. 6). In spring, the distribution is similar to that of the whole year (not shown graphically); during autumn, the increase is very small at all stations.

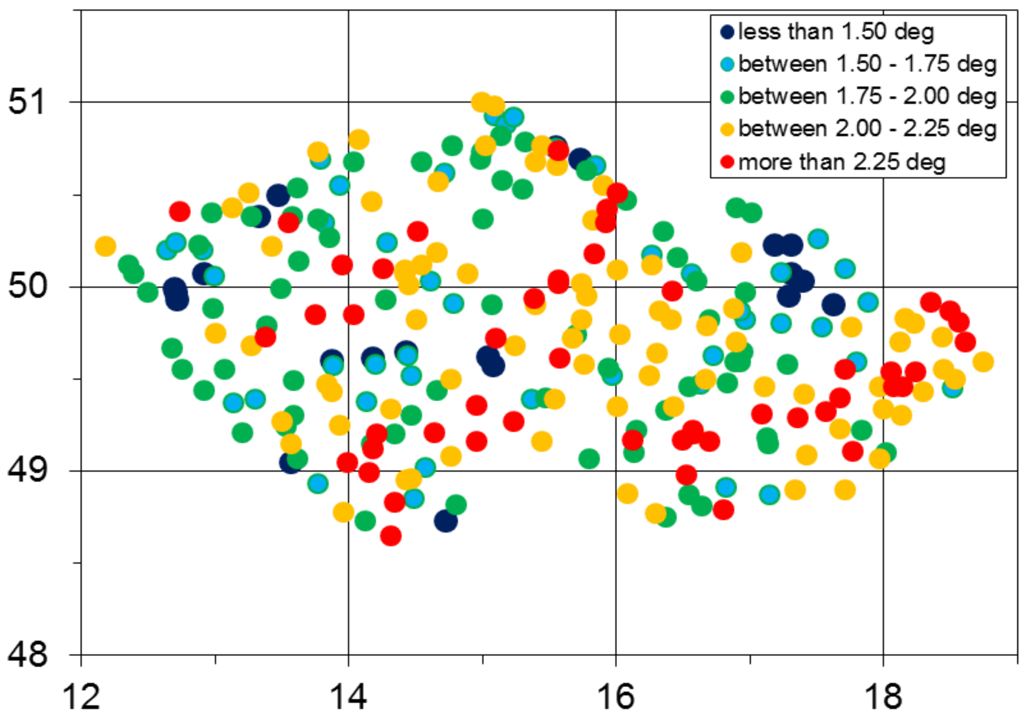


Fig. 6. *Distribution of the increases of summer mean air temperatures during 1961-2010 over the territory of the Czech Republic.*

The distribution of the temperature increase is different also for the individual months, even within the same season. The differences, however, are not very significant. Showing these courses for all months in one graph (similar to that in Fig. 4) would not be very clear. More convenient is to show the annual variation of the air temperature for different time intervals. This was done for three 30-yr overlapping intervals and the results are given in Fig. 7. For easier interpretation, the winter months are repeated on the right side of the graph. No changes in autumn months or significant increases in summer and in winter are apparent. In summer, there is no difference between June, July and August, whereas in the winter some differences occur. The temperature increases most in January, the increases in February and in December are less pronounced.

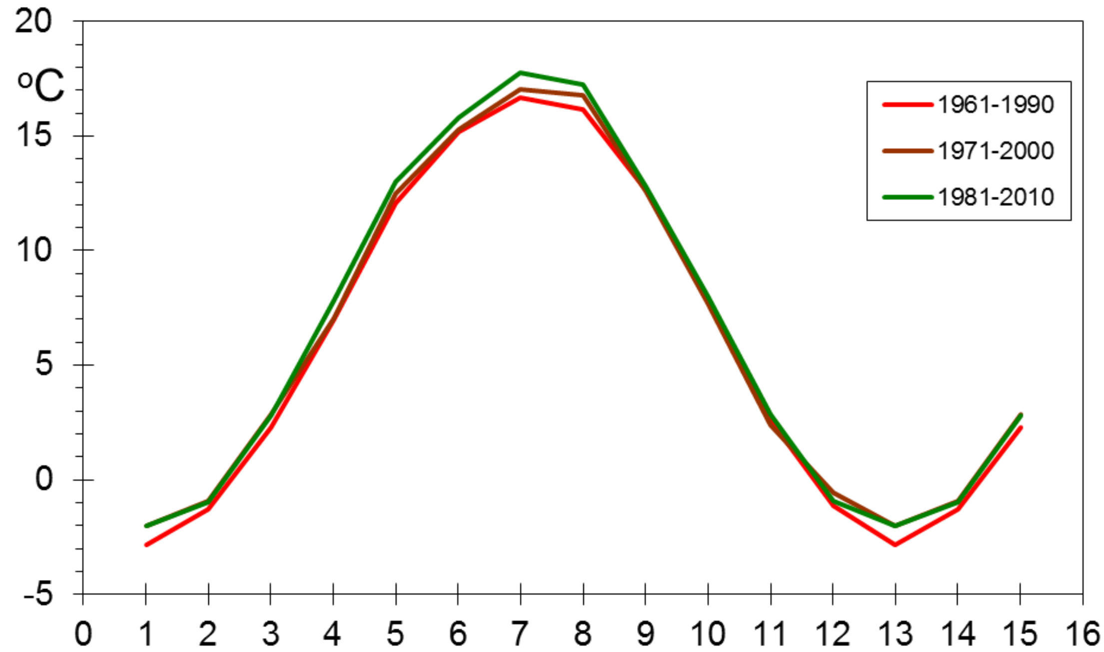


Fig. 7. Mean monthly air temperatures in the territory of the Czech Republic in three 30-yr periods. Months No 1-3 (January-March) have been added at the end labeled as 13-15.

DISCUSSION AND CONCLUSION

The above presented results show that the air temperature increases on the territory of the Czech Republic at a higher rate than the global temperature. There is also a clear difference between this increase at stations located in the western part of the Czech Republic (Bohemia) and the eastern part (Moravia). The increase of the temperature is more pronounced in Bohemia than in Moravia. There are also some differences among seasons. The increase in autumn is very weak, in other seasons it is a little stronger than that for the whole year. In the winter, the difference between the increase in Bohemia and Moravia is more apparent, whereas in the summer, the temperature increase is a little stronger in Moravia. The strong increase of mean summer temperatures in Moravia is not favorable for the agriculture because at the same time, a decrease of total precipitation is being observed over the same region (Střeštík et al., 2014). Stronger increase of the temperature in the summer than that in the winter in Moravia means that the difference between summer and winter temperature increases, i.e., a small increase of continentality of the climate takes place. This point is valid only for Moravia, whereas in Bohemia the continentality decreases only very little. Regression lines for the temperature course in all seasons and for both parts of the Czech Republic do not suggest any change in the last decade, as is the case for global temperatures, and therefore the continuation of the described trend is expected.

References

Brohan, P., Kennedy J. J., Harris I., Tett S. F. B., Jones P. D., 2006. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. Geophys. Res. 111, D12106, doi: 10.1029/2005JD006548.

Hansen J., Sato M., 2004. Greenhouse gas growth rates. Proc. Natl. Acad. Sci. USA 101, 16109-16114.

Pfister C., 1992. Monthly temperature and precipitation patterns in Central Europe from 1525 to the present. a methodology for quantifying man made evidence on weather and climate. In: Bradley R.S., Jones P.D. (eds.): Climate since 1500 A.D., 118-143.

Smith I. M., 1993. CO2 and climatic change: An overview of the science. Energy Conversion and Management 34, 739-735.

Střeštík J., Rožnovský J., Štěpánek P., Zahradníček P., 2014. Změna ročních a sezonních srážkových úhrnů v České republice v letech 1961-2012 (The change of annual and seasonal precipitation totals in the Czech republic during 1961-2012). Proceedings of the conference “Extremes of the water circulation in the landscape“, Mikulov, electronic publication, pages not numbered (in Czech).

Summary

Na základě měsíčních průměrů teploty vzduchu registrované na 267 stanicích v České republice byla určena dlouhodobá změna průměrné teploty vzduchu na každé stanici za posledních 50 let. Roční průměrná teplota vzduchu vypočtená pro celou zemi vykazuje značný růst, který je mnohem větší než růst globální teploty vzduchu. Je ovšem doprovázen silnými fluktuacemi z roku na rok. Dlouhodobá změna na různých stanicích a v různých regionech je odlišná. Vyšší růst teploty je pozorován na stanicích v Čechách, zatímco na Moravě je růst nižší. Tento rozdíl je výraznější v zimním období, zatímco v létě je velmi malý a snad i opačného smyslu. To znamená, že kontinentalita klimatu na Moravě roste a v Čechách velmi slabě klesá. Dlouhodobá změna

závisí jen velmi nepatrně na absolutních hodnotách průměrné teploty na konkrétní stanici. Růst teploty v podzimním období je podstatně nižší než v jiných ročních obdobích.

CONTACT

RNDr. Jaroslav Střeštík, CSc.

Geofyzikální ústav AV ČR, v.v.i.

Boční II 1401, 141 31 Praha 4

Tel. 267103321, e-mail: jstr@ig.cas.cz

Drought Severity in Agricultural Land of Slovakia in the Years 2011-2013

Jozef Takáč, Andrej Morávek, Zuzana Klikušovská, Rastislav Skalský

National Agricultural and Food Centre – Soil Science and Conservation Research Institute, Gagarinova 10, 827 13 Bratislava, Slovak Republic

Abstract

Assessment of drought severity in agricultural regions of Slovakia in the years 2011-2013 is presented in the paper. Drought severity assessment is based on the soil water balance routine running on daily step. Standardized index based on daily available soil water content was used for drought severity classification. Criteria for the drought occurrence were 1) available soil water content below 50% of available water capacity; 2) soil water content below long-term average soil water content and 3) duration of continuous drought for fifteen or more days. Normal climate period 1961–1990 was chosen as reference period to enable historical comparison of drought severity and climate change impacts. Cumulative sum of available soil water index was used for drought quantification throughout its duration. Using the soil database allowed to analyse the spatial aspect of the drought severity. The results of the analysis confirmed the occurrence of meteorological drought in the years 2011 and 2012 and the occurrence of agronomic drought in the years 2011-2013. Greater areal extend of the impact of drought on crop production was observed only in the years 2012 and 2013.

Key words: Water balance, available soil water, soil texture, crop yield

Introduction

The growing and development of plants in conditions of Slovakia is largely determined by water regime. Soil water regime in Slovak lowlands depends mainly on atmospheric precipitation. Lack of soil water is a stress factor negatively affecting crop yields. Crop yields vary from year to year depending on the weather. On the one hand, crop production is adapted to long-term climate conditions, but on the other hand, frequent extreme weather conditions (droughts and heat waves) may be a limiting factor in agricultural production.

The drought differs in duration, severity and extent of the affected area. The term drought expresses a negative deviation from the normal water balance in a given area (Brázdil et al, 2009). Quantitative definition of the degree of abnormality of the drought through various climatic indices is difficult due to the interaction of meteorological, hydropedological, agronomical and the other factors. According to the meteorological dictionary (Sobíšek et al, 1993) we can distinguish meteorological drought, agronomic drought, hydrological drought and physiological drought.

In Europe, the increasing incidence of barren years is expected due to drought and heat waves, which will also have economic consequences (EEA, 2012). The territory of Slovakia in European context is not considered as an area prone to droughts. The risk of unfavourable dry years as a result of climate change will increase in Central Europe, which will result in an increased risk of soil erosion and lower productivity (Trnka et al, 2013). In hot and dry years, *Podunajská nížina* lowland, production potential will be increasingly limited by decreasing of water availability for crops and by heat waves (Eitzinger et al, 2012).

Spatial definition of drought and the likelihood of its occurrence is a prerequisite for the formulation of follow-up measures and activities related to building the necessary capacities and mitigation of its consequences.

MATERIALS AND METHODS

The crop growth is limited by sufficiency of soil water for evapotranspiration and therefore methods that include soil moisture are considered as the most suitable for evaluation of drought. The soil water dynamics is a result of flow of water in the system atmosphere - vegetation - soil - groundwater and it is one of the most dynamic soil properties. The time when meteorological drought (precipitation deficit) passes into agronomic drought (soil water deficit) depends on the water storage capacity of soils.

Soil water available for plants is considered to be the soil water in the interval between field capacity FC [mm] and wilting point WP [mm]. Soil water content below wilting point is not accessible for plants. Amount of soil water available for the plants is called available water capacity AWC [mm]. In agronomic practise soil water storage is usually expressed as available soil water content ASWC [mm]:

ASWC=SWC-WP

Soil water content SWC as well as FC and WP are calculated as weighted averages of horizons. Actual SWC_i in the day *i* can be calculated from the water balance equation:

$$SWC_i = SWC_{i-1} + P_i + CR_i - ET_i - RO_i$$

Where P_i is the precipitation, CR_i is capillary rise, ET_i is the evapotranspiration and RO_i is the runoff in the day *i*.

To evaluate anomalies in time series standardised indices are suitable. Standardised indices express relative relation of variable deviation from the average to standard deviation of time series. Standardisation allows achieve index distribution close to the Gaussian distribution (Takáč 2012). Standardization of the soil water allows to compare not only the intensity of droughts at different times, but also in different regions with different soil and climatic conditions. Proposed available soil water index $ASWI_i$ in the day *i* is calculated from available soil water content $ASWC_i$ in daily steps according to the equation:

$$ASWI_i = \frac{ASWC_i - ASWC_{AVE}}{ASWC_{SD}}$$

where $ASWC_{AVE}$ is long term average of *ASWC* and $ASWC_{SD}$ is standard deviation of *ASWC*. Similarly as in the case of climatic indices for $ASWC_{AVE}$ and $ASWC_{SD}$ calculation it is required 30 year duration of the time series. Normal climate period 1961–1990 was chosen as reference period to enable historical comparison of drought severity as well as climate change impacts.

In accordance with assessment established in climatology (Lapin *et al*. 1988) boundaries of 25 % exceeding probability for moderate drought, 10 % exceeding probability for severe drought and 2 % exceeding probability for extreme drought have been set (Takáč, 2012).

Drought is related to the long term mean conditions and it is defined as long term occurrence of *SWC* below average value. Basic assumptions for drought are 1) the SWC is below 50 % of AWC and 2) SWC is below long term average SWC at the same time. Drought duration was defined as consecutive days of negative *ASWI*. Exceeding probability intervals of *ASWI* were used for drought severity classification (Table 1). The beginning of a drought period of a given degree is determined by the day when *ASWI* falls below threshold value and the drought continues until the threshold is exceeded again. In order to classify the drought in a particular degree the duration must be continuous for at least 15 days. In the case that two dry periods are interrupted by a short wetter period, this interruption is ignored under condition that it lasts for less than 10 % of the length of the two dry periods. (Takáč, 2013a). Cumulative sum of *ASWI* was used for the drought quantification throughout its duration:

$$ASWI_{CUM} = \sum_{i=1}^{N} ASWI_i$$

where *i* is the number of the day and N is the number of the days in the period with negative *ASWI*. Based on the probability of occurrence in the reference period 1961-1990 the rounded values of $ASWI_{CUM}$ were chosen for dry period classification (Table 2).

1x1 km (soil) and 10x10 km (climate) spatial resolution data served the input for the soil moisture balance routine running on daily step. Daily climate data (1961 – 2013) on minimum, maximum and average air temperature (°C), sunshine duration (hour), vapour pressure (hPa), average wind speed ($m.s^{-1}$) and rainfall (mm) from totally 71 climate stations distributed regularly across agricultural land of Slovakia was provided by Slovak Hydrometeorological Institute. Data was interpolated to 10x10 km grid locations by algorithm developed by JRC (Crop Growth Monitoring System – CGMS) and further modified for national needs by Novakova (2007). Reference crop evapotranspiration and actual evapotranspiration was calculated for each cell afterwards using Penman-Monteith equation (Allen et al, 1998) implemented within the CGMS system. Land evaluation maps in 1:5000 scales (Linkeš et al 1996) provided information on agricultural soil texture class distribution. Spatially dominant topsoil texture class from the map was then assigned to each relevant 1x1 km cell location and taken as representative value for the whole 120 cm deep soil profile. National soil profile database (AISOP, Linkeš et al. 1988) counting 17 740 soil profile records provided data on soil analytical properties. Soil texture class representative sand, silt and clay content was calculated as an average from the AISOP data and all other necessary hydro-physical parameters (soil bulk density, soil water content at field water capacity and wilting point) were then estimated by HYPRES pedotransfer functions (Wosten et al. 1998, 1999). Available water capacity (AWC) for the soil profile was calculated as follows:

AWC = (FC-WP)*h,

where AWC is available water capacity (mm), FC is water content at field water capacity (cm^3/cm^3), WP water content at field wilting point (cm^3/cm^3), and h is soil depth (mm) which is 120 cm in our case. Representative soil profile values used for pre-defined soil texture classes are listed in Table 3.

The 120 cm soil profile value of AWC was then modified for each 1x1 km grid cell based on information on dominant soil depth and stone content coming from Land evaluation maps (Linkeš et al 1996). If soil depth was less than 60 cm or stone content in top 60 cm of soil was more than 50% the AWC value was decreased of 25%. If soil depth was less than 60 cm and stone content in top 60 cm was more than 50%, the AWC value was decreased of 50%. Un-modified AWC value was left in all other cases. Groundwater influence was assumed for all locations (1x1 km grid cells) with dominant Gleysols, Histosols or Gleyic Fluvisols having also heavy texture. Groundwater influence as estimated based on soil information well corresponds with spatial distribution of the lowest parts of the big alluvial areas of the *Podunajská nížina* lowland. Spatial intersection of climate and soil grid data yielded totally 3.865 simulation units (SimU) which represent spatial units homogenous as for its climate and soil (AWC, groundwater influence). Each SimU is a spatial zone consisting of 1 – 100 1x1 km grid cells located within the borders of only one particular 10x10 km climate cell.

Seven strategically important crops were selected for evaluation of crop yields, treated separately in two groups as:

1) winter and spring crops (winter wheat, spring barley, winter rapeseed) and

2) summer crops (corn maize, sunflower, sugar beet, and potato).

Long-term average yields of all crops (1997 – 2010) were calculated from NUTS3 level statistical data provided by the Statistical Office of the Slovak Republic. Yields for 2011-2013 were then compared to long-term averages using relative deviation as the statistical measure of observed differences:

$$RD_i = 100 * \frac{(Y_i - Y_{avg})}{Y_{avg}}$$

Where RD_i is relative deviation (%), Y_i is respective yield (t/ha) in the considered year, and Y_{avg} is long-term average yield.

Results

Yield variability is significantly affected by soil water dynamics during growing period as well as during non-growing period. Consequence is given to the winter water supply. It is optimal if sufficient snow cover was formed during the winter and snow melts slowly in early spring. In general, the soil moisture has an annual cycle. Maximum soil water storage is at the end of the winter and minimum occurs in the summer months. SWC almost every year during the summer months falls below 50% of AWC in the southern regions of Slovakia. This is a normal recurring phenomenon. Crop production is adapted by the structure of crops and their varieties or supplementary irrigation.

Duration of the period with SWC below 50 % of AWC is different in the individual regions and it varies from year to year. Such period occurs in the west Slovakian lowlands almost every year. Continuous period with SWC below 50 % of AWC lasts from 50 days to 100 days in average on *Podunajská nížina* lowland as well as in the southern part of *Záhorská nížina* lowland. Locally, especially on light sandy soils, it is more than 100 days in average. On the contrary, duration of the period with SWC below 50 % of AWC is in average less than 50 days in the most of the country territory (Fig 1).

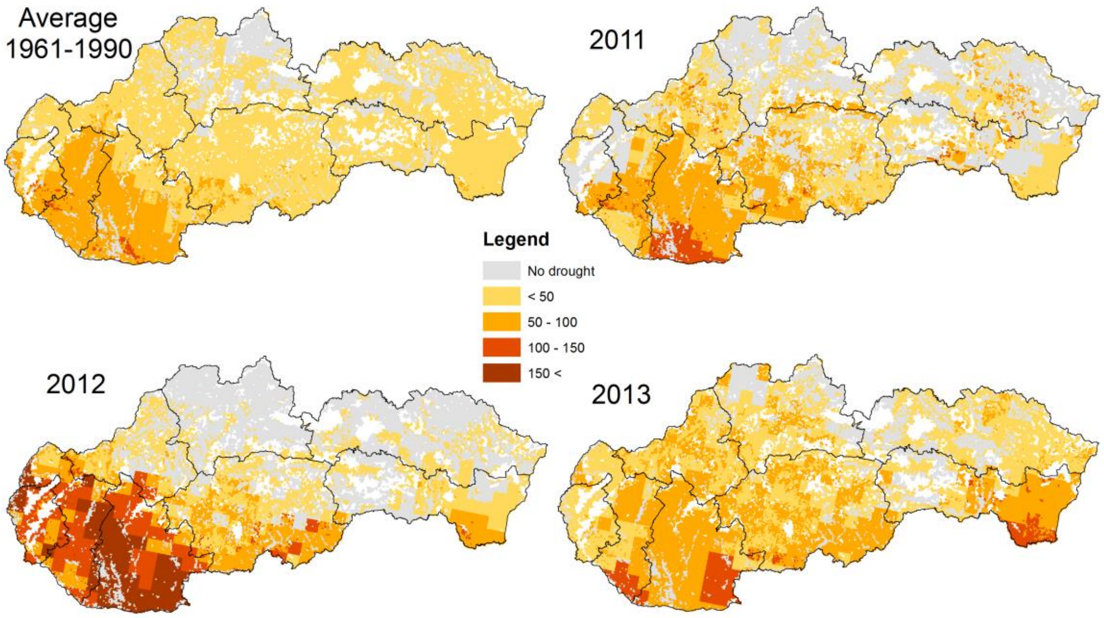


Fig 1 *Number of days with SWC below 50 % of AWC in the period 1961-1990 and in the years 2011, 2012 and 2013*

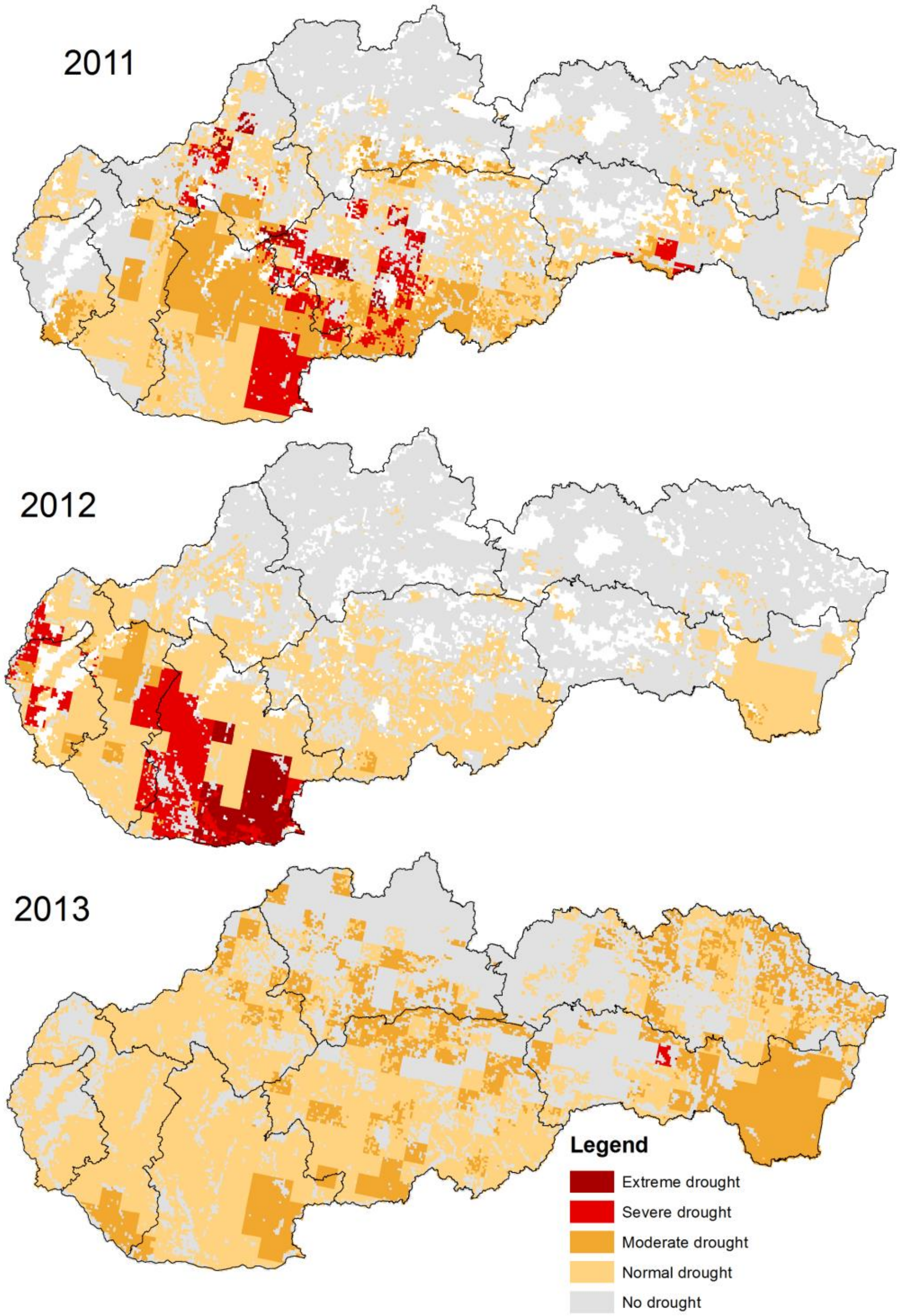


Fig 2 *ASWI$_{CUM}$ in the years 2011, 2012 and 2013 for the longest continuous drought period*

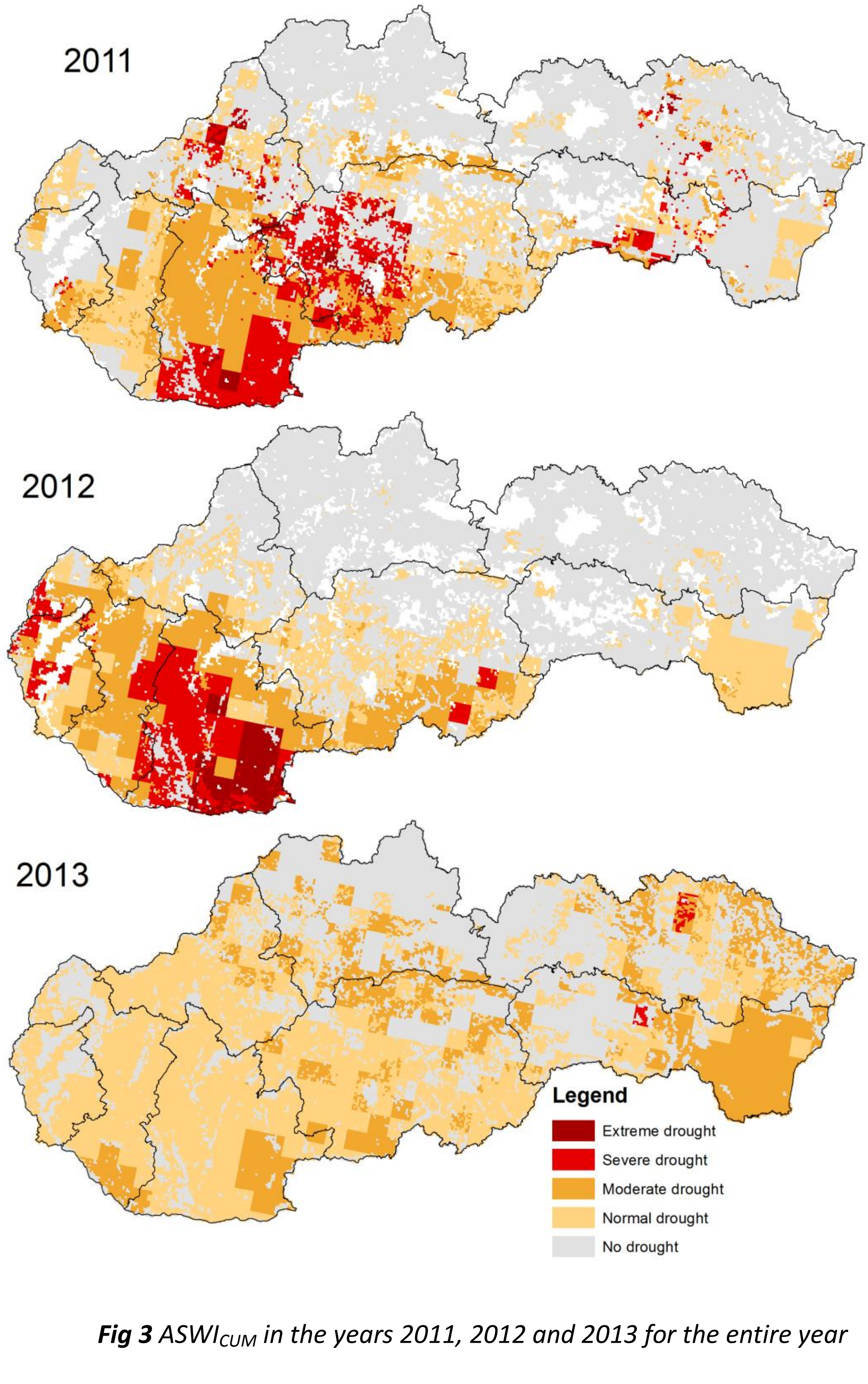


Fig 3 *$ASWI_{CUM}$ in the years 2011, 2012 and 2013 for the entire year*

In 2011, the dry period lasted more than 100 days in the southeast part of the *Podunajská nížina* lowland and in 2012 in the whole south-western Slovakia, while in the central and eastern part of the *Podunajská nížina* lowland as well as on *Záhorská nížina* lowland it was more than 150 days. In 2013, the dry period lasted more than 100 days in the southeast of the *Podunajská nížina* lowland, in lower part of *Žitný ostrov* and in the southern part of *Východoslovenská nížina* lowland (Fig 1).

From the statistical point of view the year 2012 was similar to the year 2011 according to available soil water content anomalies. Drought occurred on 45 per cent and 44 per cent of the area in the years 2011 and 2012, respectively. The areal average of $ASWI_{CUM}$ was -138 and -137 and the areal standard deviation of $ASWI_{CUM}$ was 88 and 90 in the years 2011 and 2012, respectively. Severe drought occurred on the 9 per cent and 8 per cent and extreme drought occurred on 1 per cent and 3 per cent of the area in the years 2011 and 2012, respectively (Fig 4).

According to the $ASWI_{CUM}$ continuous severe drought occurred on the southeast of *Podunajská nížina* lowland, central part of *Váh* valley and in the western part of *Banská Bystrica* region while locally reached the extreme severity in the year 2011 (Fig 2). Several short periods of normal or moderate drought appeared also in the east Slovakia. The total sum of these shorter periods reached threshold of severe drought in some locations (Fig 3).

In the year 2012, severe drought occurred in the eastern part of *Podunajská nížina* lowland and in the part of *Záhorská nížina* lowland. Extreme drought was in 2012 in the southeast of *Podunajská nížina* lowland. In the year 2013, severe drought appeared only locally in the east Slovakia (Fig 2).

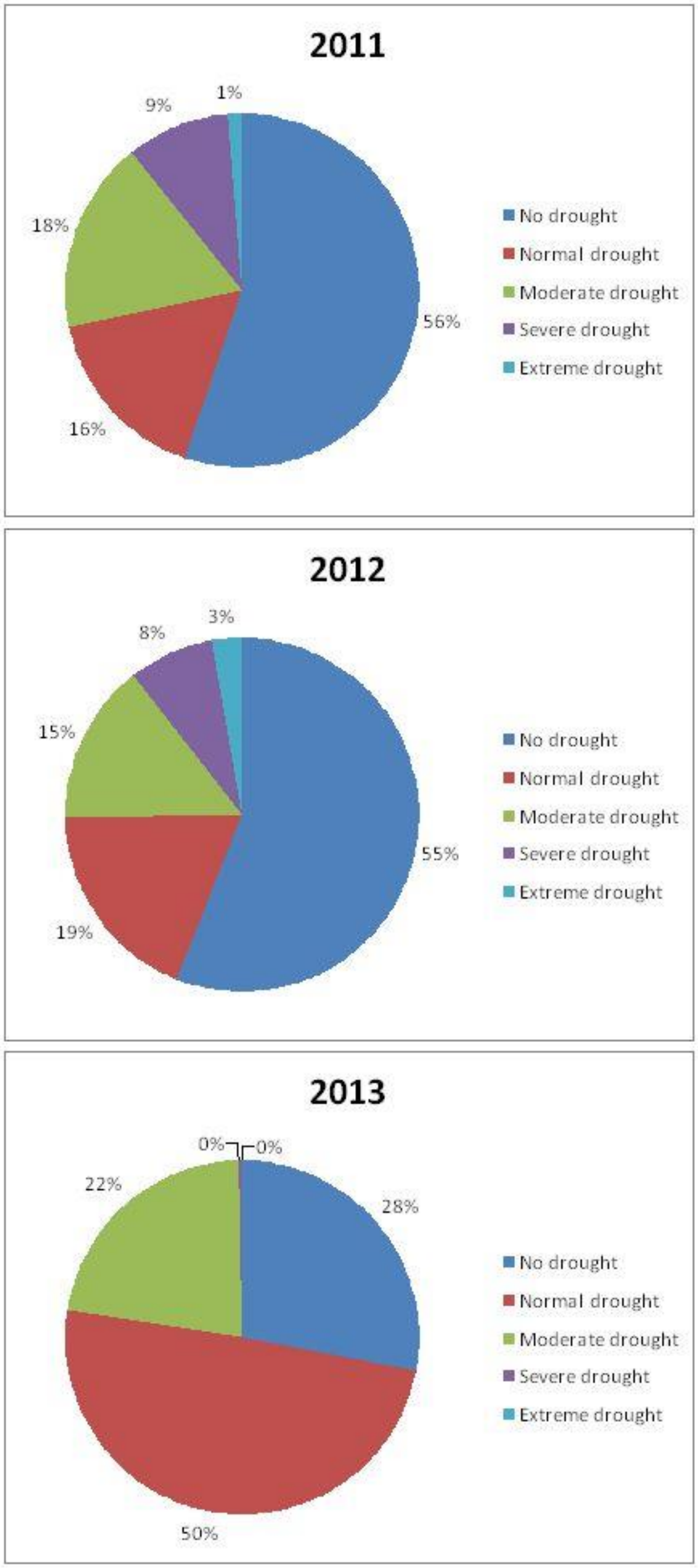


Fig 4 *Statistical distribution of drought degree in the years 2011, 2012 and 2013*

DISCUSSION

According to the precipitation percent of normal the year 2011 was driest from the years in question. Year 2012 was dry in the most of territory. The year 2013 was normal or wet (Faško et al, 2014).

According to SPI the year 2011 was drier than the year 2012 (Takáč, 2013b). Annual SPI average from 33 meteorological stations was -0.90 in the year 2011 while in the year 2012 it was -0.36. Extreme drought occurred in the southern part of *Podunajská nížina* lowland, southwest part of *Košická kotlina* basin and central part of *Váh* valley in the year 2011. Moderate drought according to the annual SPI was in northern part of *Podunajská nížina* lowland and some submountain regions in the year 2011. On the other hand, according to the annual SPI only moderate drought occurred in the western part of *Záhorská nížina* lowland, central part of *Podunajská nížina* lowland and in *Rimavská kotlina* basin in the year 2012. On the contrary, the year 2013 was normal or wet according to the precipitation totals. Despite this fact, normal or moderate drought occurred on the 72 per cent of the area of agricultural land according to $ASWI_{CUM}$. This was caused by increased demand for the evapotranspiration due to high temperatures.

Dry years are usually characterised by decreases in crop yields. Compared to long-term average yield, normal yield of winter and spring crops (winter wheat, spring barley) were observed for most regions of the Slovakia in 2011, slightly higher yields were observed mostly in northern regions of Slovakia. Different situation was recorded in 2012 when in western parts of Slovakia the yields were lower than long-term average, whereas in eastern regions yields attained were normal or higher then long-term average. In the year 2013, below average spring barley yields were observed especially in the southern districts while the winter wheat yields were mostly above average (Fig 5).

Higher yields than long-term average were observed for summer crops in most regions of Slovakia in 2011. In 2012 the spatial pattern of relative deviations for summer crops followed the pattern of winter and spring crops; i.e. lower yields than long term average in western regions and higher in eastern regions. Similar pattern was observed also for the summer crops in the year 2013 (Fig 6).

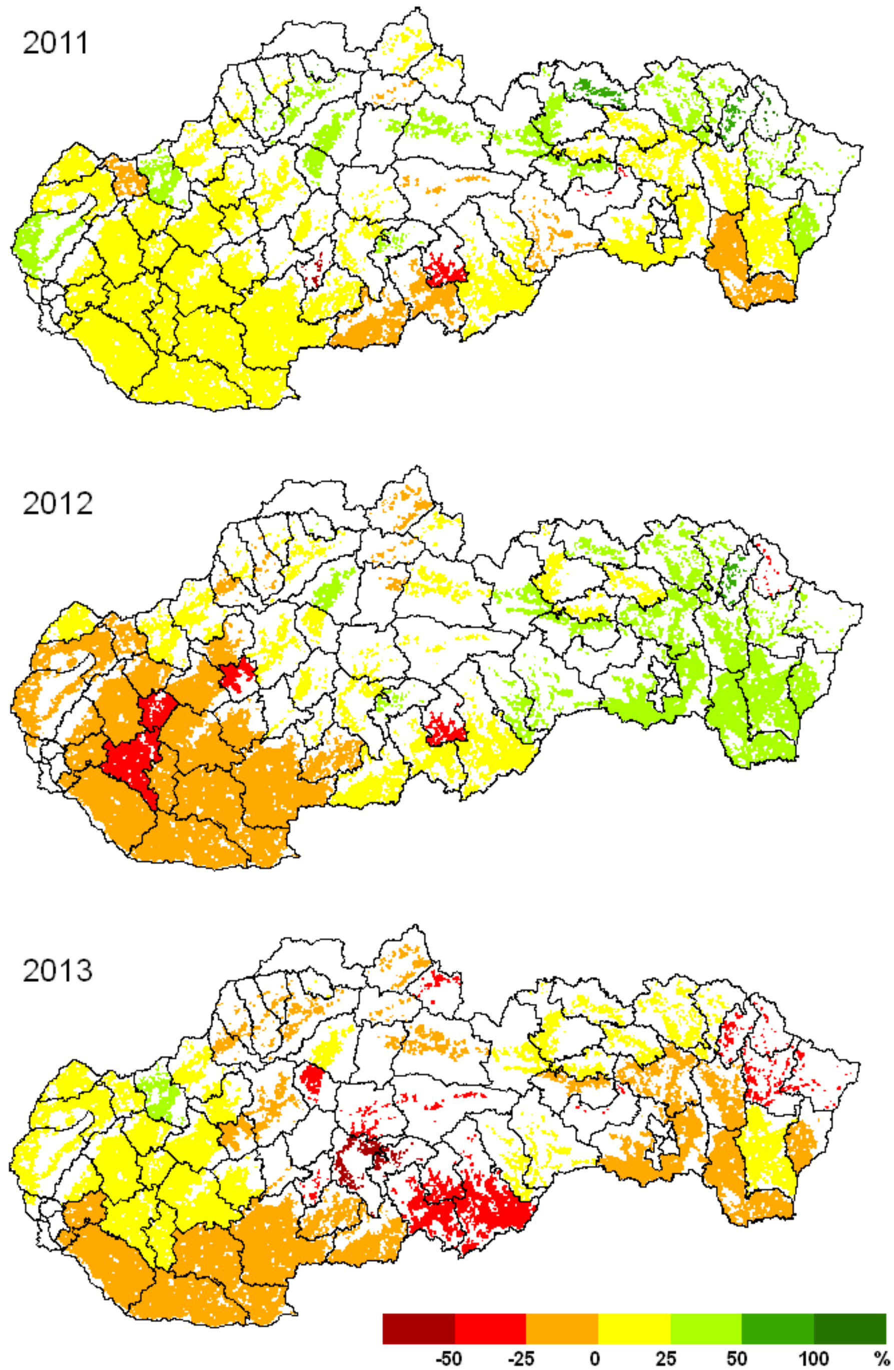


Fig. 5 *Relative deviation (%) of spring barley yield in 2011-2013 from long-term average yield for 1997 – 2010*

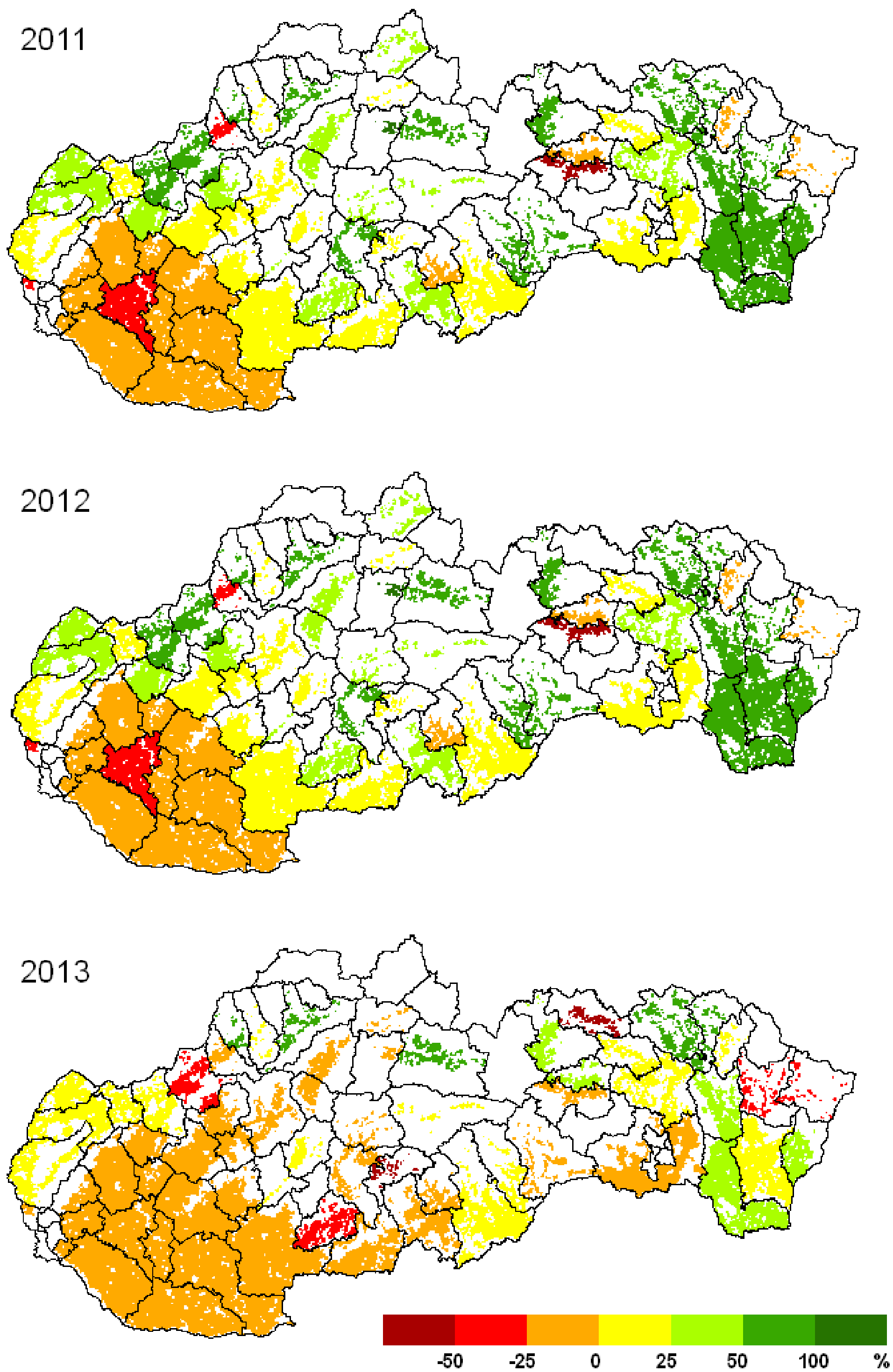


Fig. 6 *Relative deviation (%) of maize yield in 2011-2013 from long-term average yield for 1997 – 2010*

Regarding to the drought impacts on crop yields it is important in which part of growing season the drought occurs. In the year 2011, the severe drought started in August and lasted till December while in the year 2012 the severe drought occurred in the spring and lasted till July. In the year 2013, the drought in the southern regions lasted from June to September.

CONCLUSION

The results of the analysis confirmed the occurrence of meteorological drought in the years 2011 and 2012 and the occurrence of agronomic drought in the years 2011-2013. Regarding to the drought impacts on crop yields the distribution of the precipitation during the growing season and hence the period of drought occurrence plays an important role.

Standardised available soil water anomaly index gives information on drought severity for the particular day. It can be employed in real-time assessment of actual drought situation development as a part of early-warning system and also for taking the decisions on drought mitigation at local level directly by individual soil users. Cumulative value of the standardised available soil water anomaly index gives an opportunity to quantify and classify even the extremely long drought event during the whole period of its impact. Introduction of the reference period can moreover help to describe the drought severity within the particular region in historical context and as such, on higher decision-making levels to support decisions on compensation payments for farmers or for to plan long-term mitigation measures. Climate data, soil data and GIS coupling gives an opportunity for building-up the National drought information system based on this methodology.

Table 1 *Degrees of drought severity based on the available soil water index ASWI (Takáč, 2013a, 2013b)*

Drought degree	Extreme drought	Severe drought	Moderate drought	Normal drought
Probability interval [%]	≤ 2%	2.1% to 10%	10.1% to 25%	25.1% to 50%
ASWI interval [–]	≤ –1.8	–1.8 to –1.151	–1.15 to –0.721	-0.72 to 0

Table 2 *Degrees of drought severity based on the cumulative available soil water index $ASWI_{CUM}$ (Takáč, 2013b)*

Drought degree	Extreme drought	Severe drought	Moderate drought	Normal drought
Probability interval [%]	≤ 2%	2% to 10%	10.1% to 25%	25.1% to 50%
$ASWI_{CUM}$ interval [–]	≤ –300	–299 to –200	–199 to –100	-99 to 0

Table 3 *Soil texture class specific average sand, silt, and clay content, estimated soil hydro-physical properties and available soil water capacity in 120 cm soil profile.*

Texture class	clay	silt	sand	Bulk density	Field capacity	Wilting point	AWC
	%			g/cm^3	%		mm
Sand and loamy sand	7.7	22.3	70.0	1.6	21.69	4.19	210
Sandy loam	13.0	41.3	45.7	1.45	29.28	7.60	260
Loam	20.9	53.3	25.8	1.4	34.18	11.95	266
Clay loam	31.4	52.4	16.2	1.35	37.87	16.81	252
Clay	44.3	46.4	9.4	1.3	41.91	21.54	244

References

Brázdil, R., Trnka, M., Dobrovolný, P., Chromá, K., Hlavinka, P., Žalud, Z. 2009. Variability of Droughts in Czech Republic, 1881-2006. Theor Appl Climatol (2009) 97. 297-315.

Eitzinger, J., Trnka, M., Semerádová, D., Thaler, S., Svobodová, E., Hlavinka, P., Šiška, B., Takáč, J., Malatinská, L., Nováková, M., Dubrovský, M.,Žalud, Z. 2012. Regional Climate Change Impacts on Agricultural Crop Production in Central and Eastern Europe – Hotspots, Regional Differences and Common Trends. The Journal of Agricultural Science, Cambridge University Press. 1-26.

European Environmental Agency. 2012. Climate Change, Impacts and Vulnerability in Europe 2012. An Indicator Based Report. EEA Report No. 12/2012. EEA, Copenhagen, 2012. 300 pp.

Faško, P., Šťastný, P., Švec, M. 2014. Modeling of Atmospheric Precipitation Field in Slovakia. EMS2014-352, 4th EMS Annual Meeting & 10th European Conference on Applied Climatology (ECAC), Prague, Czech Republic (in print)

Lapin, M., Faško, P., Kveták, Š. 1988. Metodický predpis 3-09-1/1. Klimatické normály. Bratislava : SHMÚ. 25 pp.

Nováková, M., 2007. Interpolácia meteorologických údajov pre potreby monitoringu stavu vývoja a odhadu úrod poľnohospodárskych plodín. In Bujnovský, R., (Ed.), Vedecké práce č. 29, VÚPOP, Bratislava. 95 – 105.

Linkeš, V., Gromová, A., Lupták, D., Pestún, V., Poliak, P., 1988. Informačný systém o pôde. Príroda, Bratislava. 198 pp.

Linkeš, V., Pestún, V., Džatko, M., 1996. Príručka pre používanie máp bonitovaných pôdno-ekologických jednotiek. Výskumný ústav pôdnej úrodnosti, Bratislava. 103 pp.

Sobíšek, B. a iní 1993. Meteorologický slovník výkladový a terminologický. ACADEMIA, MŽP ČR, Praha. 594 pp.

Takáč, j. 2012. Hodnotenie závažnosti sucha založené na modelovaní vlhkosti pôdy. In Vedecké práce Výskumného ústavu pôdoznalectva a ochrany pôdy, 34, VÚPOP, Bratislava. 153–168.

Takáč, J. 2013a. Assessment of Drought in Agricultural Regions of Slovakia Using Soil Water Dynamics Simulation. Agriculture (Poľnohospodárstvo), 59, 2013 (2). 74−87.

Takáč, J. 2013b. Závažnosť sucha v poľnohospodárskych regiónoch Slovenska v rokoch 1961-2012. Vedecké práce Výskumného ústavu pôdoznalectva a ochrany pôdy, 35, VÚPOP, Bratislava. 174-191.

Trnka, M., Kersebaum, K.C., Eitzinger, J., Hayes, M., Hlavinka, P., Svoboda, M., Dubrovský, M., Semerádová, D., Wardlow, B., Pokorný, E., Možný, M., Wilhite, D., Žalud, Z. 2013. Consequences of Climate Change for the Soil Climate in Central Europe and the Central Plains of the United States. Climate Change, Volume 120, Issue 1-2, 405-418.

Wösten J.H.M., Lilly A., Nemes A., C. Le Bas, 1998. Using Existing Soil Data to Derive Hydraulic Parameters for Simulation Models in Environmental Studies and in Land Use Planning. Final report on the EU funded project, Report 156, Wageningen, DLO-Staring Centre, 1998, 106 pp.

Wösten J. H., Lilly A., Nemes A., C. Le Bas, 1999. Development and Use of a Database of Hydraulic Properties of Europen Soils. Geoderma, 70, 169-185.

Acknowledgement

Presented results were obtained in the framework of activities related to Integrated Drought Management Programme in Central and Eastern Europe supported by Global Water Partnership Central and Eastern Europe.

Summary

Rastlinná produkcia je v podmienkach Slovenska vo veľkej miere determinovaná vodným režimom pôdy. V príspevku prezentujeme hodnotenie sucha na Slovensku v rokoch 2011-2013 z hľadiska jeho závažnosti. Pre výpočet zásoby vody v pôde sme použili zjednodušenú rovnicu vodnej bilancie, ktorá berie do úvahy údaje o počasí aj o pôde. Pre klasifikáciu závažnosti sucha bol použitý štandardizovaný index využiteľnej dennej zásoby vody v pôde. Kritériami pre posudzovanie výskytu sucha boli zásoba využiteľnej vody v pôde menšia ako 50% využiteľnej vodnej kapacity, podpriemerná zásoba vody v pôde v porovnaní s dlhodobým priemerom a súvislé trvanie obdobia 15 a viac dní. Normálové klimatické obdobie 1961-1990 bolo vybrané ako referenčné obdobie na historické porovnávanie závažnosti sucha a dôsledkov zmeny klímy. Kumulatívna hodnota indexu bola použitá na kvantifikáciu sucha počas celej doby jeho trvania. Využitie pôdnej databázy umožnilo analyzovať sucho aj z priestorového hľadiska. Výsledky analýz potvrdili výskyt meteorologického sucha v rokoch 2011 a 2012 a výskyt agronomického sucha vo všetkých hodnotených rokoch. Väčší územný rozsah dopadov sucha na úrody poľných plodín bol pozorovaný len v rokoch 2012 a 2013.

CONTACT

RNDr. Jozef Takáč, PhD.

National Agricultural and Food Centre – Soil Science and Conservation Research Institute Gagarinova 10, 827 13 Bratislava, Slovak Republic

Tel. +421 2 48 20 69 22

e-mail j.takac@vupop.sk

BIOCLIMATOLOGICAL CHARACTERISTICS OF SOIL MOISTURE IN HURBANOVO

MÁRIA TEKUŠOVÁ; VIERA HORECKÁ; ĽUBICA JANČOVIČOVÁ

Slovak Hydrometeorological Institute in Bratislava, Slovak Republic

ABSTRACT

The paper deals with the analysis of the bioclimatological characteristics of soil moisture (field capacity, available water capacity of the soil, atmospheric precipitation) determined on the basis of the results of the long-term agroclimatological measurements in the vegetation periods from 1990 to 2013 in Hurbanovo. The agroclimatological characteristics of soil moisture were determined for the layers at the depths of 10 cm to 80 cm below the soil surface under standard surface (without stand). The field capacity and the available soil moisture were normally carried out by the gravimetric technique at the agroclimatological stations of the SHMI.

Key words: Soil water regime, available soil water capacity (available soil moisture), field capacity, soil water deficit, permanently wilting point, atmospheric precipitation.

INTRODUCTION

Soil moisture regime is characterized by the time course of changes of moisture condition of the whole soil profile, as well as the active layer of soil. In addition to soil moisture regime is a common characteristic of soils analyzed the soil water regime, which means the sum of hydrological processes associated with the penetration of water into the soil, movement of soil moisture and water loss from the soil. Soil water regime is characterized by its water balance.

The issue of soil moisture is in detail studying in pedology, the role of agrometeorological specialist is to determine certain characteristics of soil moisture, such as field capacity, permanent wilting point and available soil water condition.

The field capacity (FC) is called amount of water that penetrates into the soil. The available soil moisture (ASM) is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point. The wilting point represents soil moisture at which the plant will not accept soil water, to plant this water is unavailable. Permanent wilting point (PWP) is the soil moisture content at which the plant will wilt and die. While there still may water in the soil, the plant is no table to extract sufficient water from the soil to meet it´s needs. The soil water penetrates into the lower layers in the soil gradually through gravity. Sandy soils may infiltrate through available profile within a few hours but fine textured soils such as clay or loam may take it a few days. Only a portion of the available water is easily used by the plant. The maximum soil water deficit (MSWD) is the amount of water stored in the plant´s root zone that is readily available to plant. To prevent plant water stresses (PWS) an allowable depletion factor is used to calculate the manageable allowable depletion. This factor varies but it is usually around 50%, (Nyvall et al., 2002). Saturation occurs when all the voids in the soil are completely filled with water. Although there is plenty of water available to the plant at saturation, water uptake is seriously curtailed by the lack of oxygen in the soil at soil water contents greater than field capacity. Under the total volume of water in the soil it means the amount of water in the soil, which is determined by the following limit conditions: upper limit of soil water saturation and lower limit completely dry soil.

Soil water regime interact with air and soil temperature schedule is a fundamental factor affecting the biochemistry of the processes of growth and development of vegetation and hence the yield of agricultural crops.

The reasons for creating unbalanced water regime may be: zonal - subject to weather and climatic conditions of the place, locally - the orographic, hydrological and soil conditions of interest and combined the resulting combination of zonal and local conditions.

Soil water regime can be evaluated according to the state of soil moisture, climatic elements and the condition of the plants in the stand.

Soil moisture content, it means all forms of water in the soil, expressed as a percentage of weight or volume. Available soil water is the amount of water that plants are capable of with their roots from the soil taken. Numerically, this is a positive difference between the total content of soil water (except groundwater) and permanent wilting point, expressed in mm (i.e. liters per 1 m^2) or in %, (Havlíček et al., 1986).

MATERIALS AND METHODS

This paper analyses the results of the agroclimatological measurements (field capacity and available soil water capacity) at the climatological station Hurbanovo in the vegetation periods from 1990 to 2013.

The soil water capacity was measured by the still gravimetric method under standard surface (bare, loam black soil). The soil samplings were carried out at the individual SHMI's agrometeorological stations in the warm half-year (from March, 1^{st} until October, 31^{st}) on Thursdays.

This gravimetric method consists of directly determining the amount of water according to the difference in weight of wet and dried sample of the soil. The quantity of water in the soil is determined the following way: The extracted soil samples were weighed, and then they dried in the oven at 105 °C, after drying weighed again and the weight difference before and after weighing. The tested samples were taken from layers at the depths from 10 cm to 80 cm. To the calculation of the available water capacity of the soil (available soil moisture) is important to determine the physical properties of soil and hydrolimits. The available water capacity is determined by the calculating the retention or field capacity and wilting point as their difference. Water holding capacity is a multitude of capillary bound water, which can keep the soil relatively long time. It is therefore equivalent to a field water capacity, which it is determined in the field. When the soil water content is greater than the field capacity then already is not sufficiently aerated soil. The optimum soil moisture is between wilting point and field capacity.

For the processing agroclimatological characteristics of the other long-term series of the total atmospheric precipitation, air temperature and soil temperature there are used the results of the daily measurements in Hurbanovo during the same period as measurements the soil water capacity. The processed data file absence in some years, measurements at the beginning and the end of the vegetation period (VP), because it does not allow the current status of the soil. All used data were synchronized; the missing data of field capacity and the available soil water capacity were completed by the data from Beluša station using the method of modelling causality for 3 months in 1996.

RESULTS

The resulting of the agroclimatological characteristics of examined available soil moisture in layers 0 - 80 cm below the soil surface in Hurbanovo during the vegetation period (VP) in the period 1990 - 2013 are evaluated as follows: The average air temperature was 15,2 ^{0}C, the maximum, i.e. 27,1 ^{0}C was reached at 23th week of the year 2003, the minimum was in 2nd week of the vegetation period in the year 2005 and it reached -2,6 ^{0}C. The maximum rainfall in the vegetation period was 94,6 mm in 12th week of vegetation period in the year 2010. The minimum values of rainfall, i.e. 0,0 mm, they were recorded at least one week in the year. During the reporting vegetation period, in each week (except 19th week) it measured the minimal rainfall. In the year 1992, there were the most weeks (9) with zero precipitation. The long-term average of rainfall was 411,5 mm. The long-term average of precipitation in the cold season (CS) of years from the season 1989/1990 to 2012/2013 was 141,8 mm, the maximum precipitation, i.e. 251,7 mm was in cold seasons 2005/2006 and the minimum, i.e. 65,8 mm was reached in season 1989/1990.

The average soil temperature layering in the soil profile in Hurbanovo during vegetation periods from 1990 to 2013 is expressed in graphical form (Fig. 1). In the layer of 0 - 30 cm, there is the mean soil temperature 16,1 ^{0}C with the peak in July (28,1 ^{0}C), and the minimum in March (0,1 ^{0}C). In the layer of 0 - 80 cm, there is the mean soil temperature 15,0 ^{0}C with the peak in July (25,2 ^{0}C), and the minimum in March (2,3 ^{0}C).

The typical layering (isochrones) of the field water capacity (FC) in Hurbanovo is presented in the Fig. 2. These results of soil moisture layering show that maximum of field capacity in all soil profile occurs in spring months. This phenomenon is affected by the soil water storage obtained from winter precipitation (Fig. 6 and 7). The soil moisture (FC) reached to a depth of 30 cm values about 73 mm and the maximum reached value 142,1 mm in the long-term average. The soil moisture (FC) receives in the layer of 0 - 80 cm about 207 mm and the maximum of 324,6 mm per week in the long-term average. Minimum of field capacity generally occurs in summer, usually in some week of August. The condition of field capacity relatively balanced at the depths more than of 60 cm throughout all vegetation period.

The isochrones in the Fig. 3, 4 and 5 express the course of the available soil moisture (ASM) in mm gradually in the 10 cm layers to a depth of 80 cm below bare soil surface during warm seasons. There are visualized the results of the available soil water capacity during all analyzed period and especially in the years 2003 (extra dry season) and 2010 (extra wet season), see Fig. 6 - 9. The year 2003 was characterized by particularly extreme high temperatures during the season from May to August and by very low rainfall of the season from February to August. In the year 2010 was recorded very wet, there were record of rainfall and floods in Slovakia, it fell the most rainfall, at least since year 1881.

In the Fig. 4, there can see that after extra dry weeks it leads to reversing the storyline, the upper layers of soil are supplied with the moisture from the lower layers.

The following analyze of results of determining amount and course of available soil moisture is evaluated from point of view of useable for plants, separately for plants with shallow roots (layer 0 - 30 cm) and plants with deep roots (layer 0 - 80 cm),(Tužinský et al.,2002). These results are visualized in the Fig. 6 – 9.

The Fig. 6 and 7 present the weekly courses of available soil moisture during the vegetation periods from 1990 to 2013, separately in years 2003 and 2010 and their relation to weekly total precipitation in the both chosen soil layers at the depths of 0 - 30 cm and 0 - 80 cm. The calculated values of available soil moisture show, that at the beginning of the vegetation periods is the soil water capacity relatively uniform and precipitation occurs in small amounts, then with the increasing temperature and thus to the increasing of the evaporation of soil water also, the soil water capacity in the soil profile, particularly in the surface layers, gradually decreasing. The repeated process of the increasing of the available soil moisture is beginning at first in the 25th week in the tested vegetation periods. The available soil moisture copied the courses of the new fallen precipitation, but it effects with the lag about two weeks in the layer 30 cm bellow the surface.

The upper limit for the classification "dry soil" is < 50% for the values of available soil moisture. Analyzing the results of long-term series from 1990 to 2013 of the minimum seasonal values of available soil moisture it was found, that these values of available soil moisture were in the layer of 0 - 30 cm some weeks with the available soil moisture < 50 %, in the year 2003 were seven consecutive weeks and opposite it only one week in 2010. This limit of "dry soil" appeared also in the layer of 0 - 80 cm, it was together of ten weeks in the year 2003.

The Fig. 8 and 9 show the long-term series of available soil moisture evaluated in vegetation periods and their relation to total precipitation in the previous cold seasons and vegetation periods also. The results of the average values of available soil moisture during all vegetation periods show, that values of available soil moisture copied the time course of air precipitation.

DISCUSSION

The water content in the soil is determined by climatic conditions, soil properties and its cover. For the available soil moisture in the case of soil surface with plants it is necessary to have knowledge about rainfall conditions, evapotranspiration, soil type and structure, type of vegetation cover with its characteristic root system.

Our presented results of long-term gravimetric measurements in Hurbanovo are realized in the locality with the bare surface (without vegetation). The field water capacity during vegetation periods has significantly seasonal character which is strongly dependent on precipitation conditions not only during vegetation period, but especially in the spring months and surface coverage during the previous cold season (e. g. snow cover, leafs). The course of amount of the field water capacity in the soil layer depend of amount of precipitation, their previous moisture and from their further retention in the soil, therefore it shows a time lag wear course of total precipitation (Fig. 2 – 6).

The main tested characteristic in our paper is available soil water capacity (available soil moisture). The isochrones of available soil moisture are determinate for the average condition of vegetation seasons during the period from 1990 to 2013 and for years with the maximum and the minimum rainfall in tested periods, i.e. the vegetation period 2003 a 2010, see Fig. 3 - 5. The weekly course of available soil moisture corresponds to the theoretical assumptions, i.e. the maximum values are at the beginning of vegetation period, with the gradual decrease, the minimum is usually entering in August, the repeated course of the increasing of available soil moisture occurs usually in October (Fig. 6 and 7). The long-term course of changes of ASM from year to year has irregular nature during 1990 - 2013, but it may be observed that years with extreme values is alternated until after two consecutive peaks, resp. lows, for example this are years 1997 - 2003. In the contrast, the seasonal average values of available soil moisture are upcoming to the average available soil moisture during 1990 - 2013 when it is occurred the subsequent to six years in a row. These results agree with the analogous characteristics for determine amount of available soil water capacity, which were especially calculated to determine the drought periods, (Takáč, 2013).

CONCLUSION

The published results of the analysis of the soil moisture during the vegetation seasons in Hurbanovo (1990 – 2013) could be applied by the study of climate changes and for the practical purposes in determining the extent and occurrence of drought and also for irrigation needs of Danube lowland region with prevailing black loam soil type.

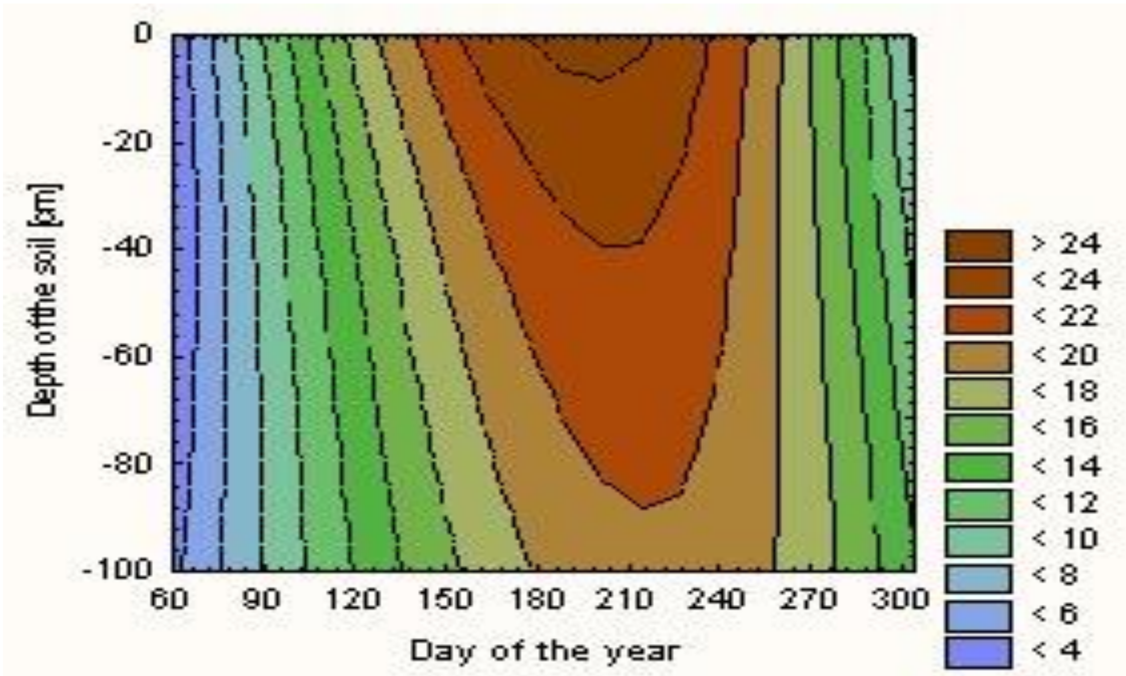


Figure 1. *Isochrones of the soil temperatures at the depths of 0 to 100 cm in Hurbanovo during the vegetation periods 1990 – 2013.*

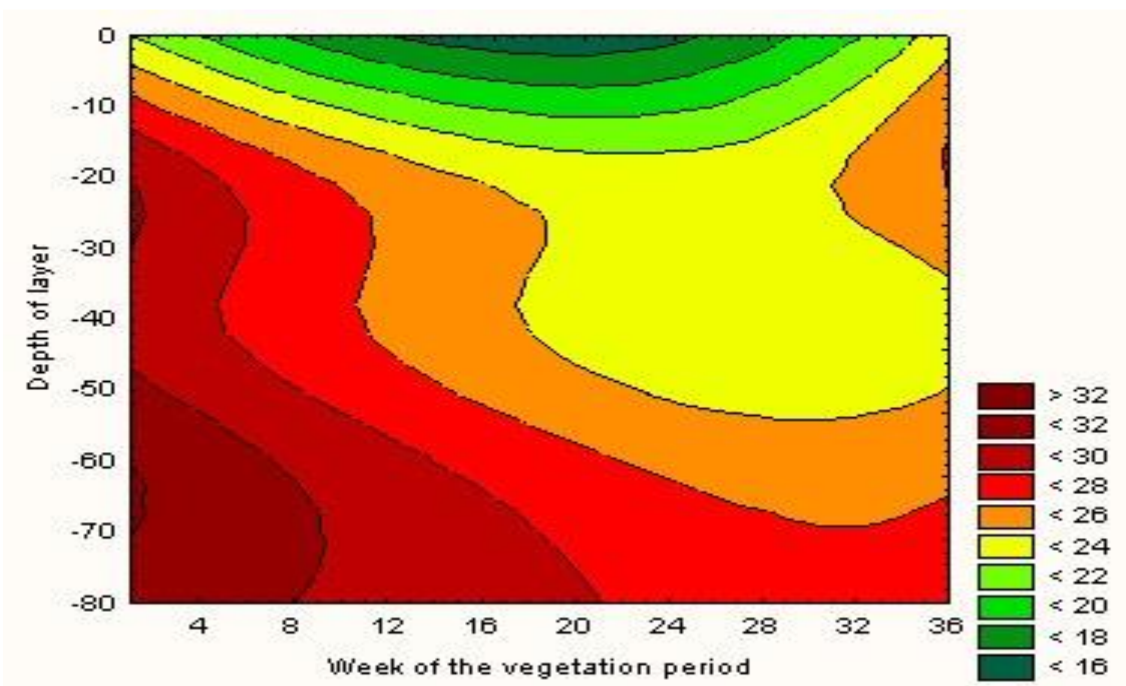


Figure 2. *Isochrones of the field capacity (FC) [mm] in 10 cm layers at the depths from 10 to 80 cm in Hurbanovo during the vegetation periods 1990 – 2013.*

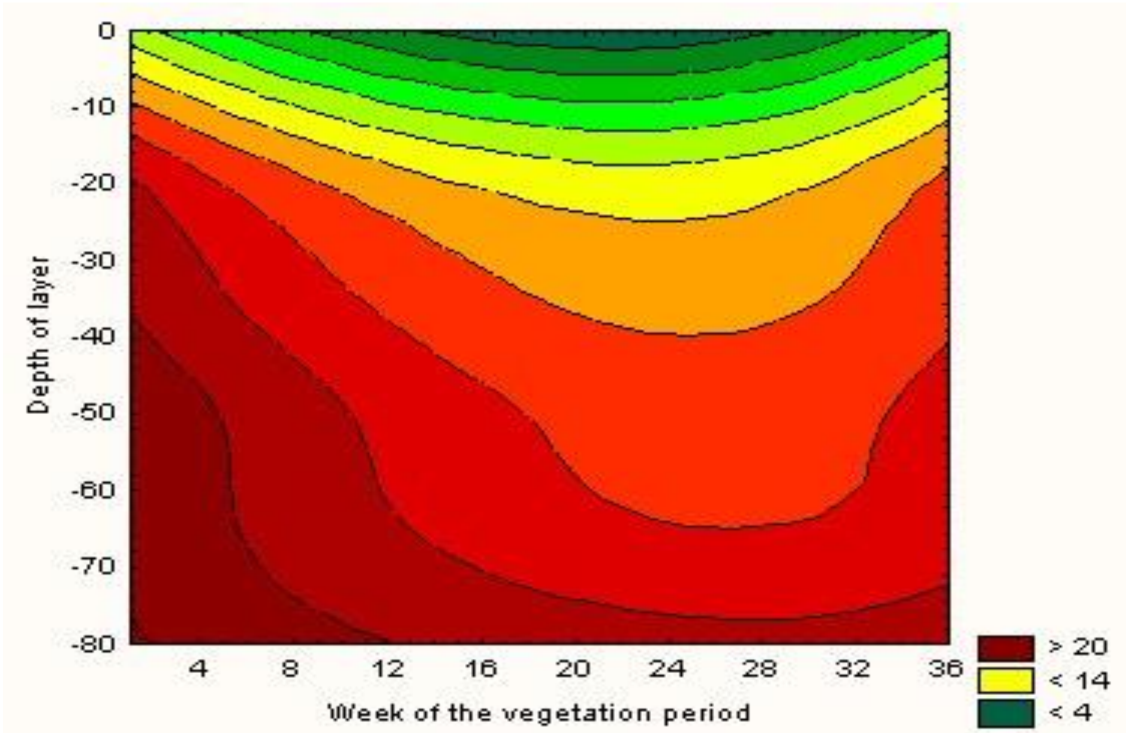


Figure 3. *Isochrones of the available soil moisture (ASM) [mm] in 10 cm layers at the depths from 10 to 80 cm in Hurbanovo during the vegetation period 1990 – 2013.*

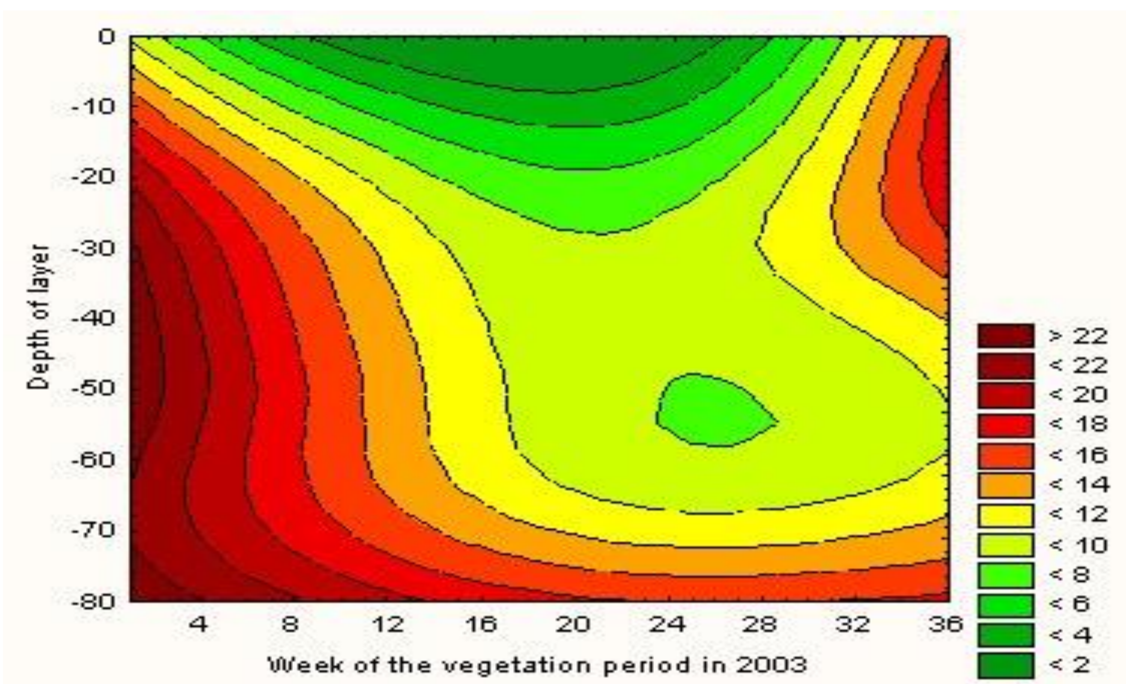


Figure 4. *Isochrones of the available soil moisture (ASM) [mm] in 10 cm layers at the depths from 10 to 80 cm in Hurbanovo during the vegetation period in 2003.*

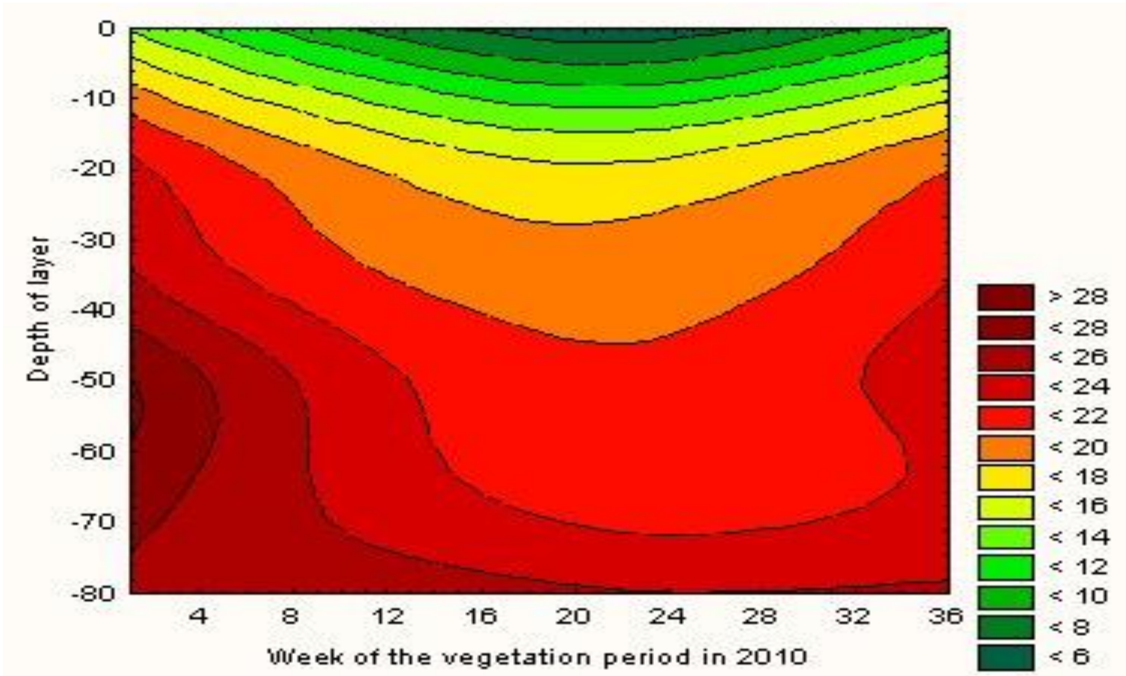


Figure 5. *Isochrones of the available soil moisture (ASM) [mm] in 10 cm layers at the depths of 10 to 80 cm in Hurbanovo during the vegetation period 2010.*

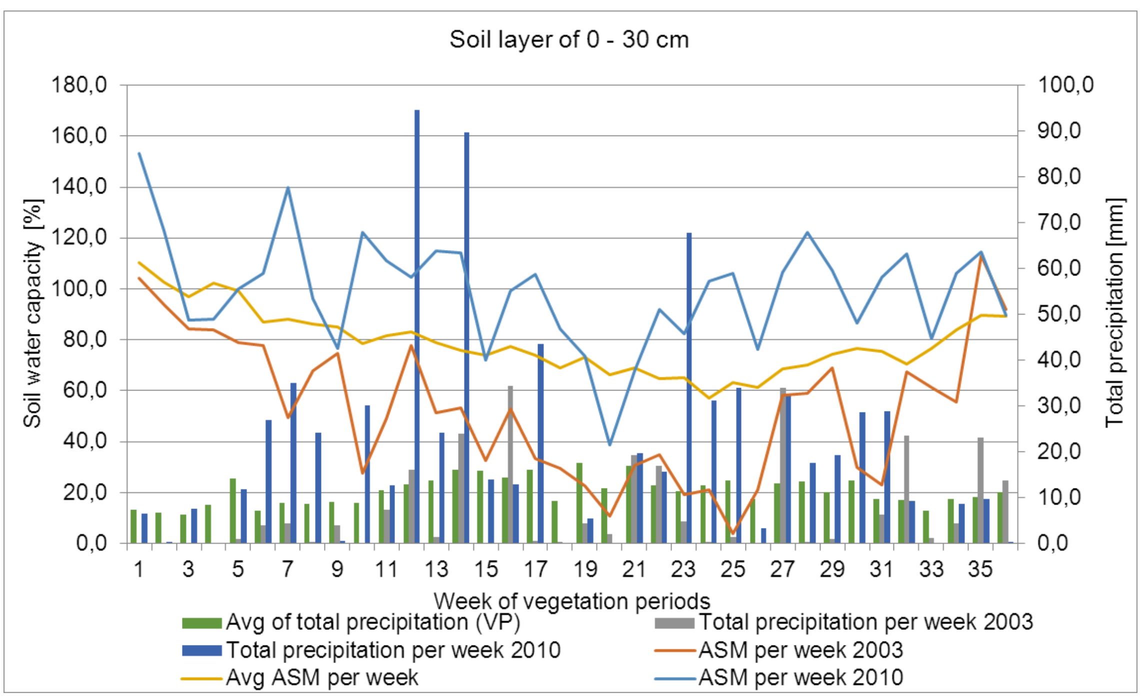


Figure 6. *Courses of available soil moisture (Avg of ASM) [%] and average (Avg) of total precipitation per week [mm] in the soil layer 0 - 30 cm below the surface in Hurbanovo during the vegetation periods 1990 – 2013, 2003 and 2010.*

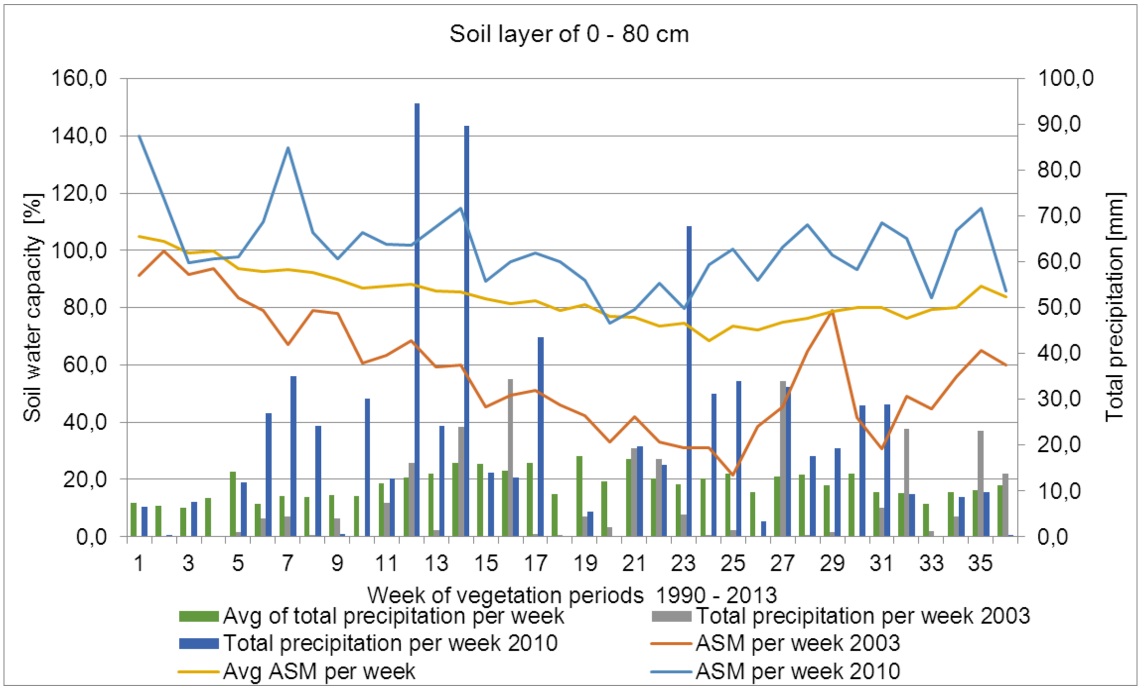


Figure 7. *Courses of available soil moisture (Avg of ASM) [%] and average (Avg) of total precipitation per week [mm] in the soil layer 0 - 80 cm below the surface in Hurbanovo during the vegetation periods 1990 – 2013, 2003, 2010.*

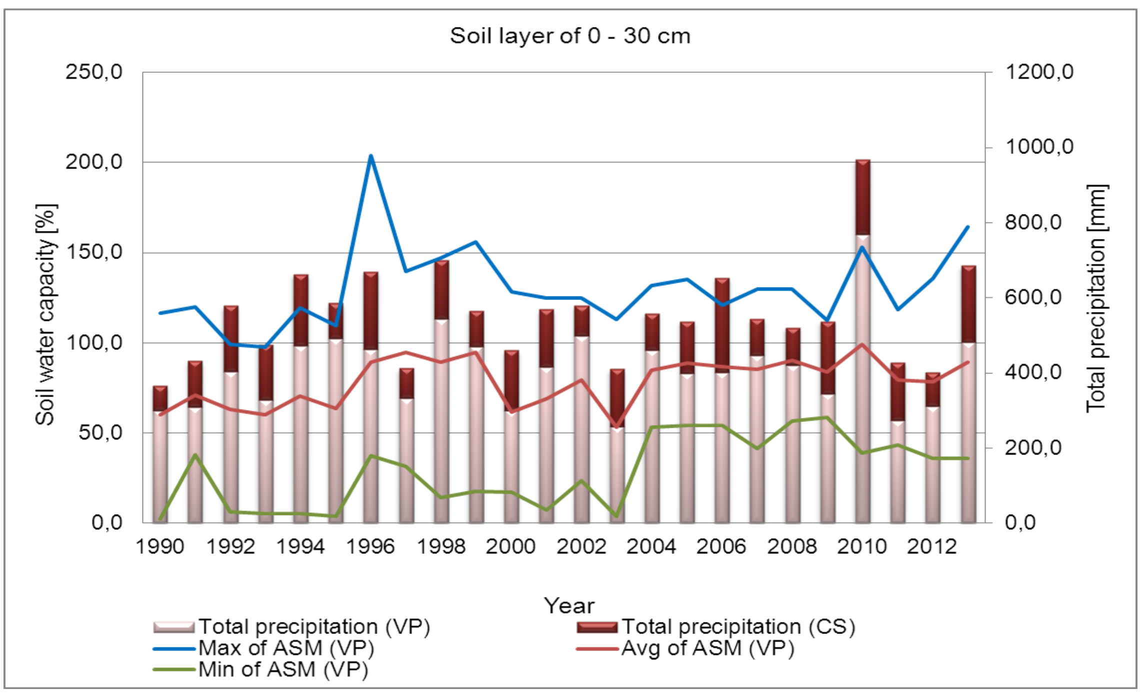


Figure 8. *Long-term series of average available soil moisture (Avg of ASM) [%] in VP and total precipitation in VP and CS [mm] in the soil layer 0 - 30 cm below the surface in Hurbanovo during the vegetation periods 1990 - 2013.*

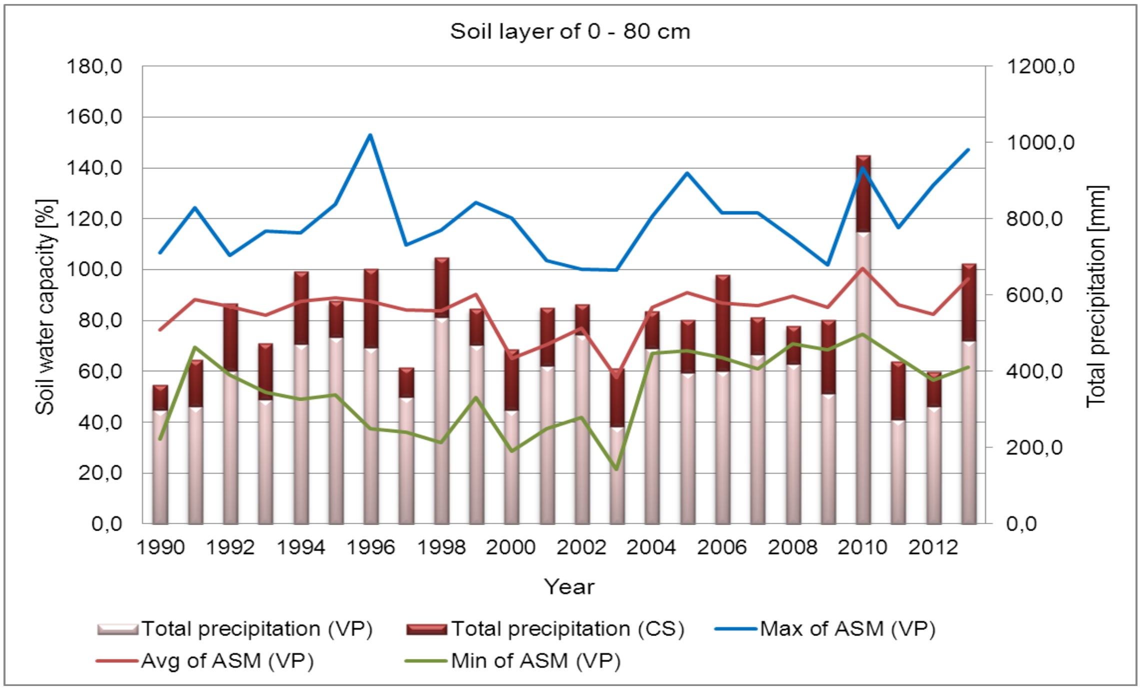


Figure 9. *Long-term series of average available soil moisture (Avg of ASM) [%] in VP and total precipitation [mm] in the soil layer 0 - 80 cm below the surface in Hurbanovo during the vegetation period 1990 - 2013.*

REFERENCES

Havlíček V., et al., AGROMETEOROLOGIE, Státní zemědělské nakladatelství, Praha, 1986, pp. 171 – 173

Nyvall J., et al., Soil water storage capacity and available soil moisture, in Water Conservation FACTSHEET, Ministry of Agriculture, British Columbia, February 2002, http://www.agf.gov.bc.ca/resmgmt/publist/600Series/619000-1.pdf

Takáč, J., Drought Severity in Agricultural Regions of Slovakia in the

Years 1961 – 2012, Proceedings of Soil Science and Conservation Research Institute, VÚPOP, Bratislava 2013/35, ISBN 978-80-8163-003-3

Tužinský L., Soroková M., Ondruš M., REGIME AND DYNAMICS OF SOIL MOISTURE IN FOREST ECOSYSTEMS OF MIDMOUNTAIN AREA OF POĽANA, International Scientific Conference, Lednice, 2002, ISBN 80-85813-99-8, pp. 465 - 473

SUMMARY

V článku sa analyzujú výsledky dlhodobého radu meraní celkovej a využiteľnej vodnej kapacity pôdy v Hurbanove počas vegetačných období (od začiatku marca do konca októbra) v rokoch 1990 až 2013. Merania vodnej kapacity pôdy sa uskutočňovali gravimetrickou metódou v týždenných intervaloch (vždy vo štvrtok) pod holým povrchom pôdy (hlinitá černozem). Využiteľná vodná kapacita bola vypočítaná z poľnej kapacity a bodu vädnutia ako ich rozdiel.

Agroklimatické podmienky v Hurbanove počas hodnoteného obdobia analyzovaného dlhodobého radu využiteľnej pôdnej vlhkosti sú charakterizované výsledkami synchronizovaných dlhodobých charakteristík teploty pôdy a vzduchu s dôrazom na zhodnotenie zrážkových pomerov vo vegetačných obdobiach ako aj predchádzajúcich chladných období roka.

V práci sú vizualizované výsledky meraní poľnej kapacity a využiteľnej vodnej kapacity pôdy v 10 cm vrstvách od povrchu až do hĺbky 80 cm. Z hľadiska praktického využitia získaných výsledkov je dôležité poznanie využiteľnej pôdnej vlhkosti vo vrstvách, v ktorých majú koreňové systémy rastliny a dreviny, preto sú podrobnejšie analyzované výsledky využiteľnej vodnej kapacity vo vrstvách 0 – 30 cm a 0 – 80 cm. Výsledky určovania využiteľnej pôdnej vlhkosti sú zhodnotené ako výsledky dlhodobých meraní 1990 - 2013 a podrobnejšie v rokoch 2003 a 2010 s extrémnymi vlahovými pomermi počas vegetačných období.

CONTACT

RNDr. Viera Horecká

Slovak Hydrometeorological Institute

Sk - 83115 Bratislava, Jeséniova 17

Slovak Republic

+421 2 59415170, viera.horecka@shmu.sk

ANALYSIS OF SAMPLES OCCASIONED DURING THE PERIOD OF THE EROSIVE DANGEROUS WINDS

PAVLÍNA THONNOVÁ, HANA STŘEDOVÁ

Department of Applied and Landscape Ecology, Faculty of Agronomy,
Mendel university in Brno

ABSTRACT

Wind erosion is a natural phenomenon. The wind is acting on the soil surface with its mechanical force. It also erodes the soil and releases soil particles that are set in motion. The wind transmits the soil particles to a different distance, where are stored when there is a reduction in wind speed. The work deals with the comparison of the samples, which were collected by device for catching soil particles ("general deflameter") with active trap soil particles and time recording ("deflameter") at the time of occurrence of erosion dangerous winds. Deflameter with active trap soil particles and time recording allows monitoring of the qualitative and quantitative properties including time recording of macroscopic and microscopic soil particles, carried by the wind. Measurements were carried out at three locations in the South Moravian Region on the soil surface without vegetation.

Key words: deflameter, wind erosion, wind speed

INTRODUCTION

Wind erosion is one of the many causes of serious threats to production and non-production functions of agricultural soils. The erosion deprives the soil of the most fertile part, reduces the amount of nutrients and humus, damaging crops and impedes movement of machinery for land and causing losses of seeds and seedlings. It is reported that wind erosion in Moravia is already currently threatened 45% of agricultural land (JANEČEK, 2007). Wind transports soil particles that may also contribute to air pollution as part of the airborne dust and thus negatively affects the health of the population.

Climate change scenarios and the climate models predict a significant increase in climate aridity of the Czech Republic by the year 2100. It is likely that the South Moravia Region will be increasingly endangered by the drought. (KALVOVÁ et al., 2002). Reduction of soil moisture will have an adverse impact on soil and will result in wind erosion (MATEJKA et al. 2004, ROŽNOVSKÝ a KOHUT 2004). These changes could have a significant impact on increasing the vulnerability of the soil to wind erosion (DUFKOVÁ a TOMAN, 2004).

Two basic factors affect the emergence of wind erosion. The first factor is the weather, especially wind speed, its duration and frequency of occurrence. Sometimes only a low wind speed can cause the movement of soil particles. The second important factor is the soil moisture. Wind erosion can be observed especially in drier and warmer climate areas with light soils. The most likely period of threat of wind erosion is in spring (March to May) and autumn (September to November). In this time the high wind speed occurs and the soil is not covered by vegetation.

Literature indicates only the approximate value of the size of soil particles, which are subject to erosion (particles in the range of 0.05 to 0.5 mm, larger and heavier particles 0.5 to 2 mm). The critical wind speed, at which the wind erosion occurs, ranges from 8.0 $m.s^{-1}$ to 22.0 $m.s^{-1}$ according to the soil type (CHEPIL, 1958).

MATERIALS AND METHODS

Potential threat of soil to wind erosion can be based on analysis of pedologic and climatic data (light soil in arid areas). This determination is not complicated. On the other hand monitoring of actual wind erosion is rather challenging. In addition to a detailed analysis of the wind field, the current amount of suspended soil particles must be recorded and evaluated. Due to the lack of simple and effective device for field research for current threat of soil to wind erosion a direct measurement of wind erosion was carried out only sporadically. It is possible to detect the relative amount of eroded particles with various constructions of passive device for catching soil particles (passive deflameter), but not the date of occurrence of erosion episodes. In 2012 the patent of "deflameter with active trap soil particles and time recording" was inscribed. The owners of a utility model are Czech Hydrometeorological Institute, Prague – Komořany and Research Institute of Soil and Water Conservation, Prague. Originators are Ing. Hana Středová, Ph.D. and Ing. Jana Podhrázská, Ph.D. and Ing Tomáš, Středa, Ph.D. It combines also a measurement of wind speed. Deflameter with active trap soil particles and time recording allows monitoring of the qualitative and quantitative properties including time recording of macroscopic and microscopic soil particles, carried by the wind. This deflametr was developed to determine the relative amounts of soil particle and composition of soil particles eroded by wind and to determine the actual soil erosion.

The available data on current wind conditions and current weather conditions (especially in period without vegetation cover) were continuously monitored and evaluated. The field measurements held depending on the weather.

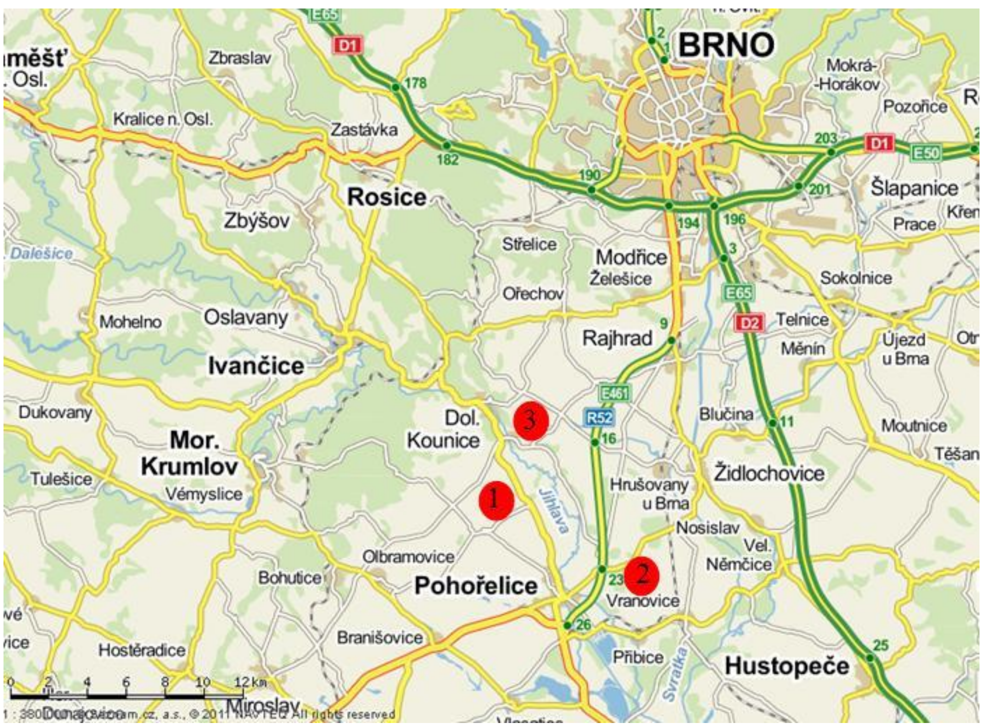


***Fig. 1** Map of the field research, three locations, source: http://mapy.cz/, adjusted by the author*

Based on the analysis of the state of soil the vulnerable erosion locations were identified. The South Moravian Region was area of interest in terms of good accessibility and greater flexibility for the research team. Fig. 1 shows the location of the three sites. The soil sampling for subsequent laboratory analysis (determination of grain size) was performed from monitored areas.

The field research at the first location (Fig. 1, number 1) was held on 24. 5. 2012. The type of soil is sandy-loam. Another location is shown in Fig. 1 (number 2) and field measurement was there on 15. 3. 2014. Soil is also sandy-loam. Last measurement was carried out on 19. 4. 2014 (Fig. 1, number 3) and the soil is loamy.

Simultaneous measurements of wind speed and soil particles (trapped by deflameter) allowed comparison of spectrum of these particles with a specific value of the wind speed. Wind speed was measured by an anemometer as a part of deflametric measurement (25 cm above the surface). Subsequently the laboratory analysis of deflametric records was determined. The method of digital image analysis using a microscope OLYMPUS CX 41 and QuickPHOTO Micro Software 2.3 with the function of measuring the size of objects was used. In combination with meteorological measurements of wind speed (anemometer registering wind speed in one-second frequency) it was possible to specify the conditions at the time of the episode.

RESULTS

If we compare the histograms of the maximum wind speed (recorded by an anemometer, Fig. 2, 3 and 4), we find that in every episode of erosion the most frequent wind speed varies. The most recorded wind speed was between 8.00– 9.00 $m.s^{-1}$ on 24. 5. 2012, episode 15. 3. 2014 the wind speed was between 11.00 and 12.00 $m.s^{-1}$ and 19. 4. 2014 it was between 9.00 and 10.00 $m.s^{-1}$. The highest maximum wind speed was recorded on 15. 3. 2014; 13.69 $m.s^{-1}$ (Tab. 1), which can be also seen in the box plot (Fig. 5).

Fig. 6 shows a histogram of the particle size observed by deflameter on 24. 5. 2012. Average particle size was 47 µm. The largest measured particles analyzed in this period corresponded to 559 µm. The number of measured particles was 17 959.

Tab. 1 *Statistic of the maximum wind speeds*

MAX wind speed	Average	Median	Maximum	Standard deviation
24.5.2012	8,68	8,60	12,02	1,39
15.3.2014	10,53	10,87	13,69	1,91
19.4.2014	9,48	9,34	10,64	0,78

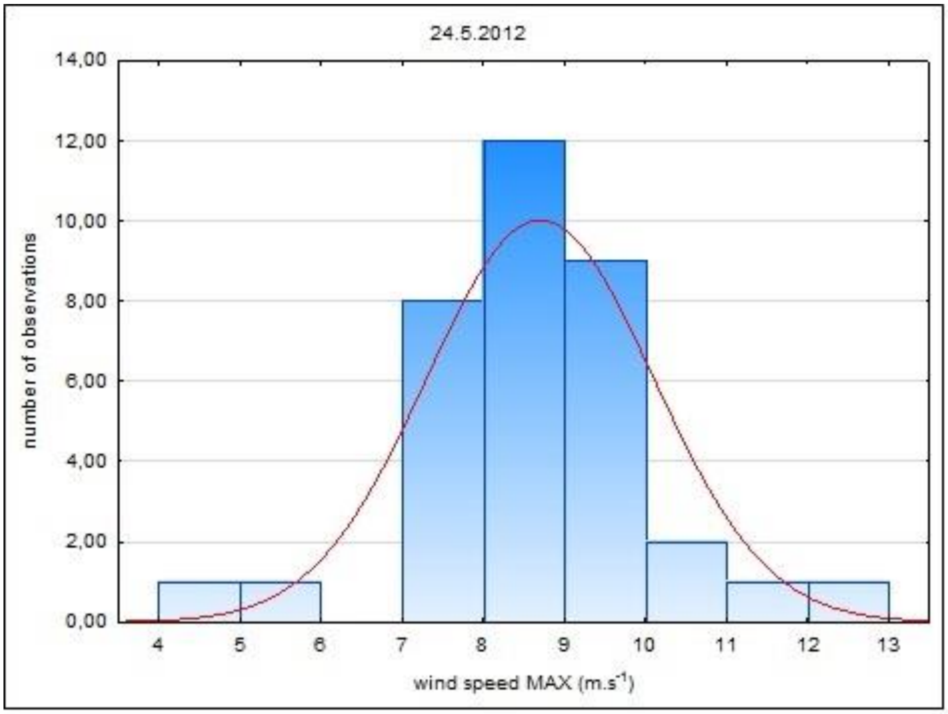


Fig. 2 *Histogram maximum wind speed, 24.5.2012*

Another histogram particle size (15. 3. 2014, Fig. 7) shows an average particle size of 33 µm. The largest measured particles analyzed in this period corresponded to only 287 µm. The total measured amount of particles using the software was 6 555. This episode was poorer in the number and size of particles, but the wind speed was measured as the highest.

The last histogram particle size (19. 4. 2014, Fig. 8) can be enumerating the smallest average particle size of 32 µm. The largest measured particles analyzed in this period corresponded to 377 µm. It was measured the largest total quantity of particles of all measurements (29 635).

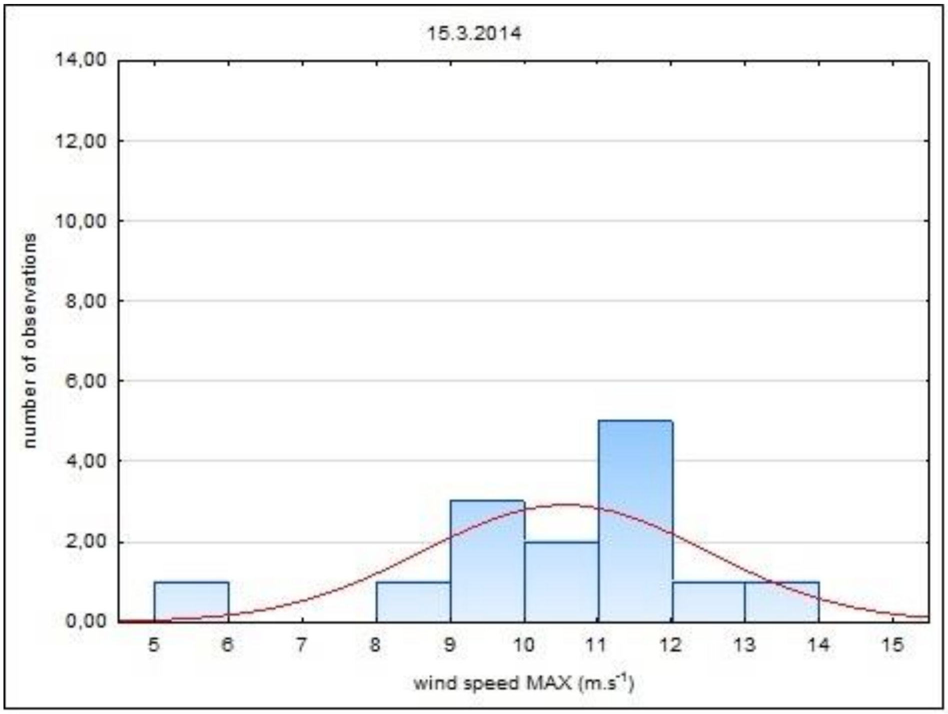


Fig. 3 *Histogram maximum wind speed, 15.3.2014*

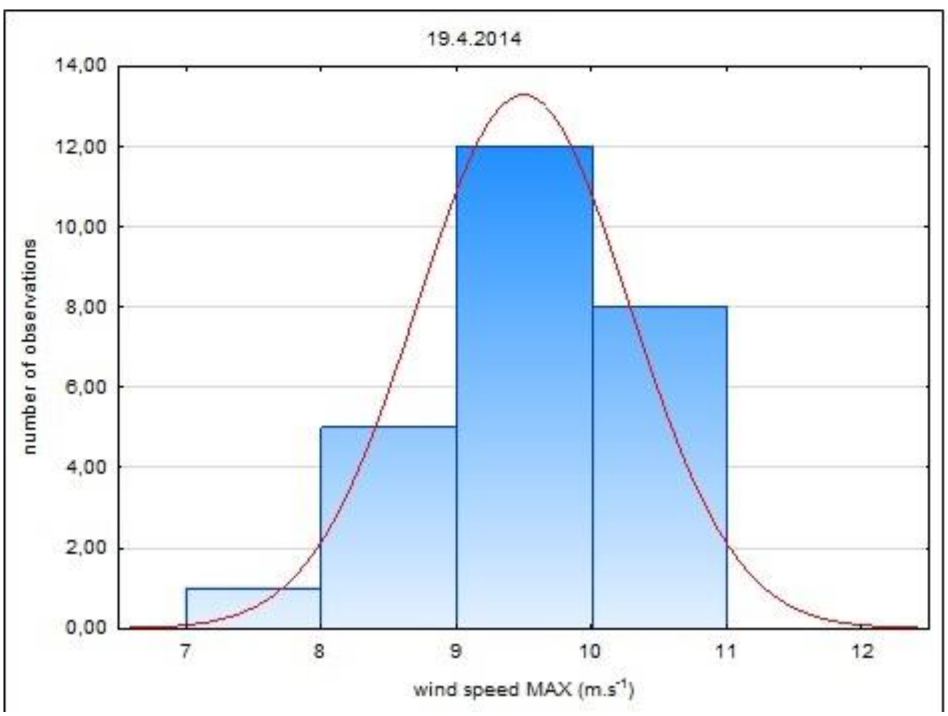


Fig. 4 *Histogram maximum wind speed, 19.4.2014*

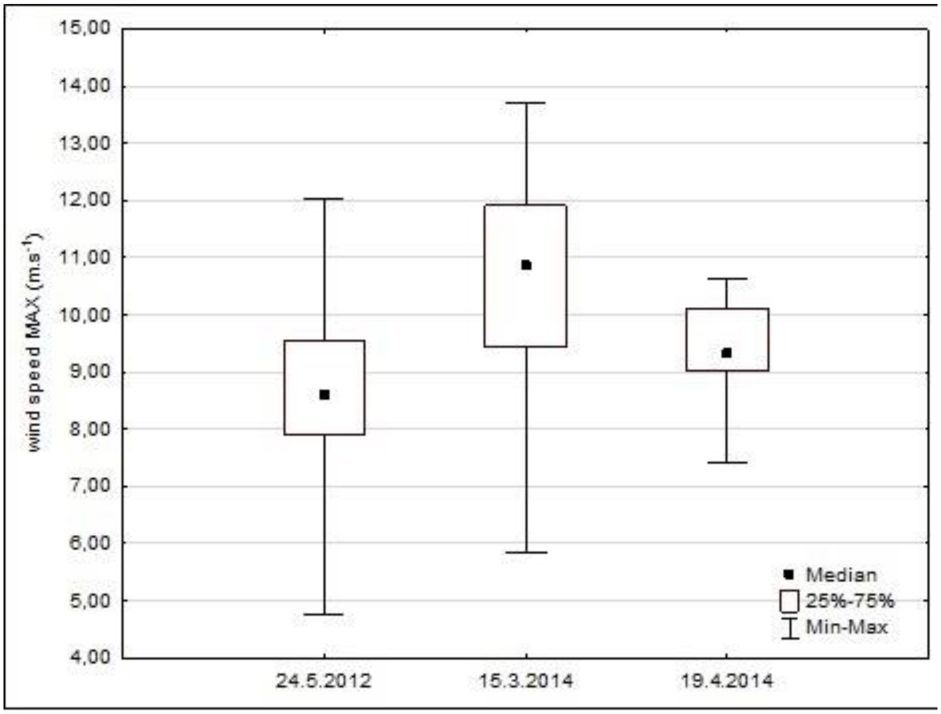


Fig. 5 *Graph of maximum wind speed measured in three locations, 24.5.2012, 15.3.2014, 19.4.2014*

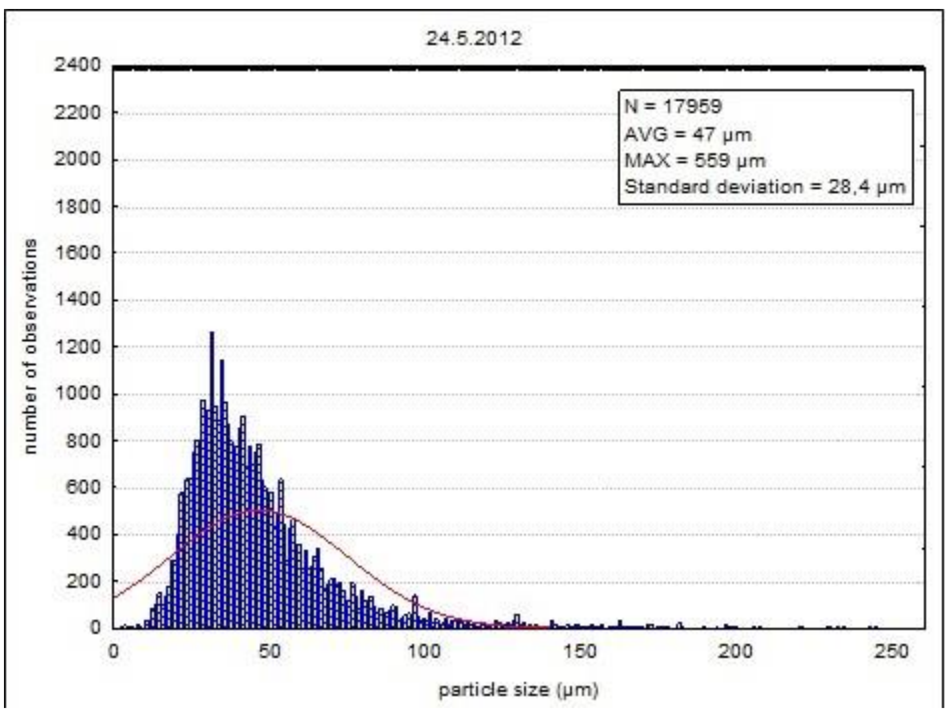


Fig. 6 *Histogram particle size, 24.5.2012*

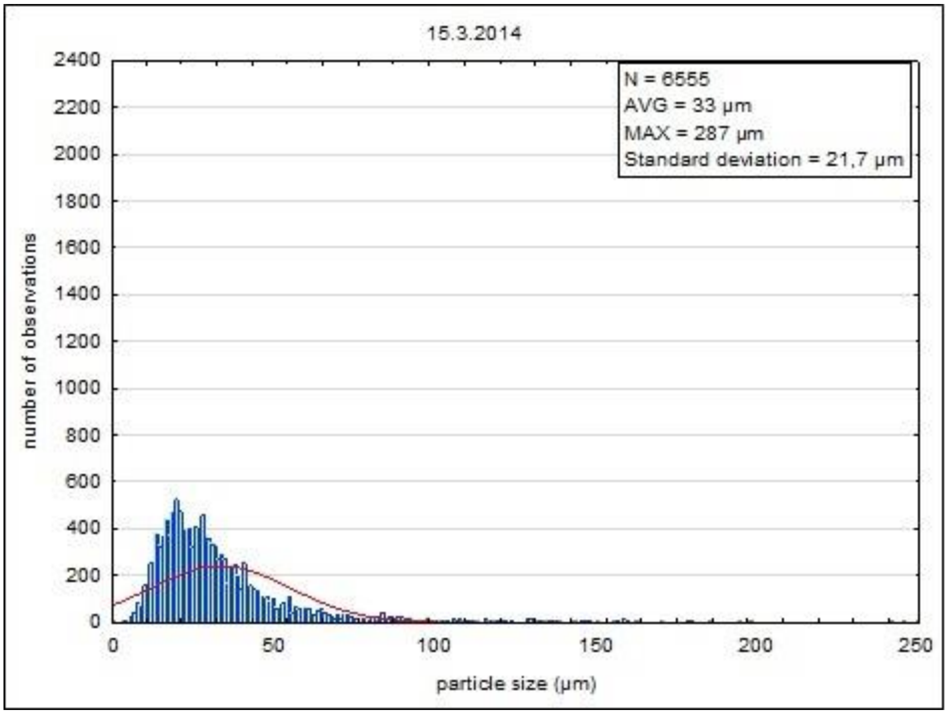


Fig. 7 *Histogram particle size, 15.3.2014*

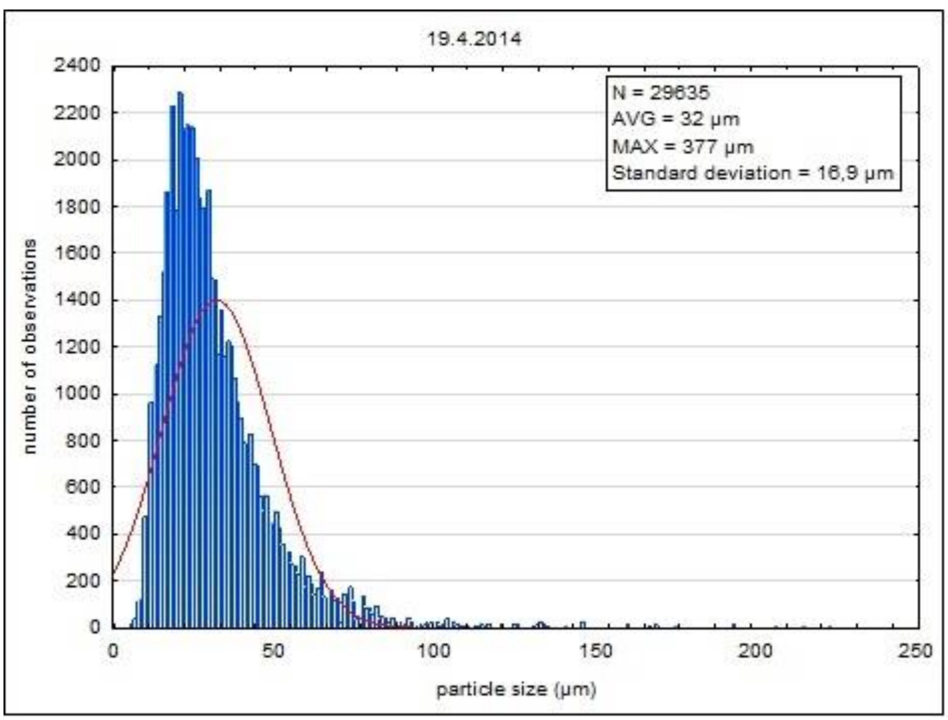


Fig. 8 *Histogram particle size, 19.4.2014*

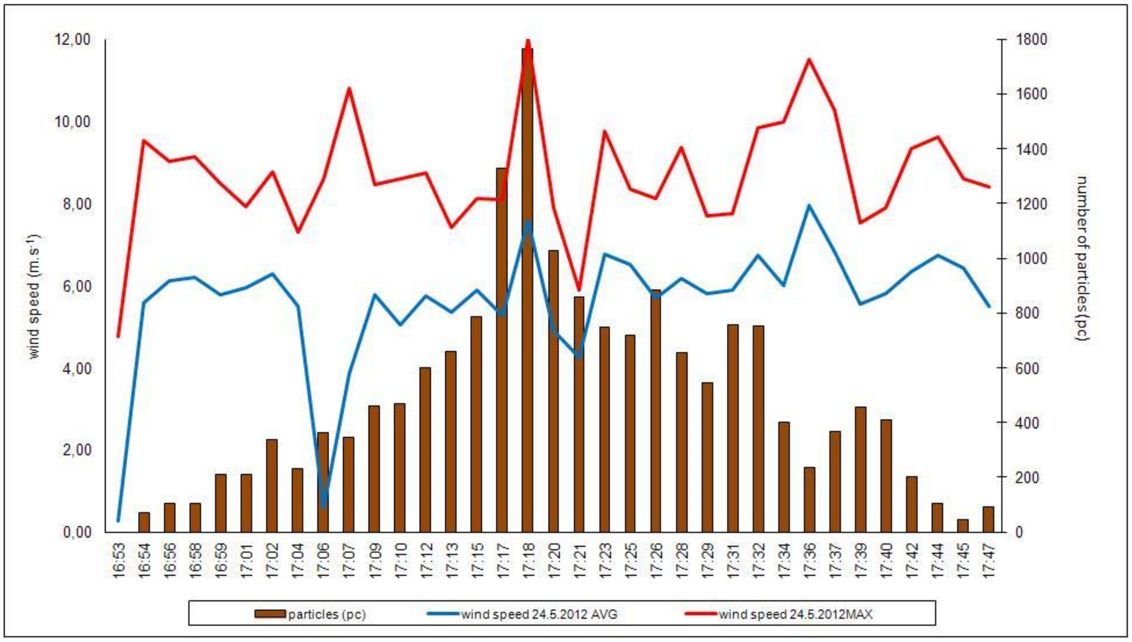


Fig. 9 *Graph of the wind speed and distribution of the number of particles in time, 24.5.2012*

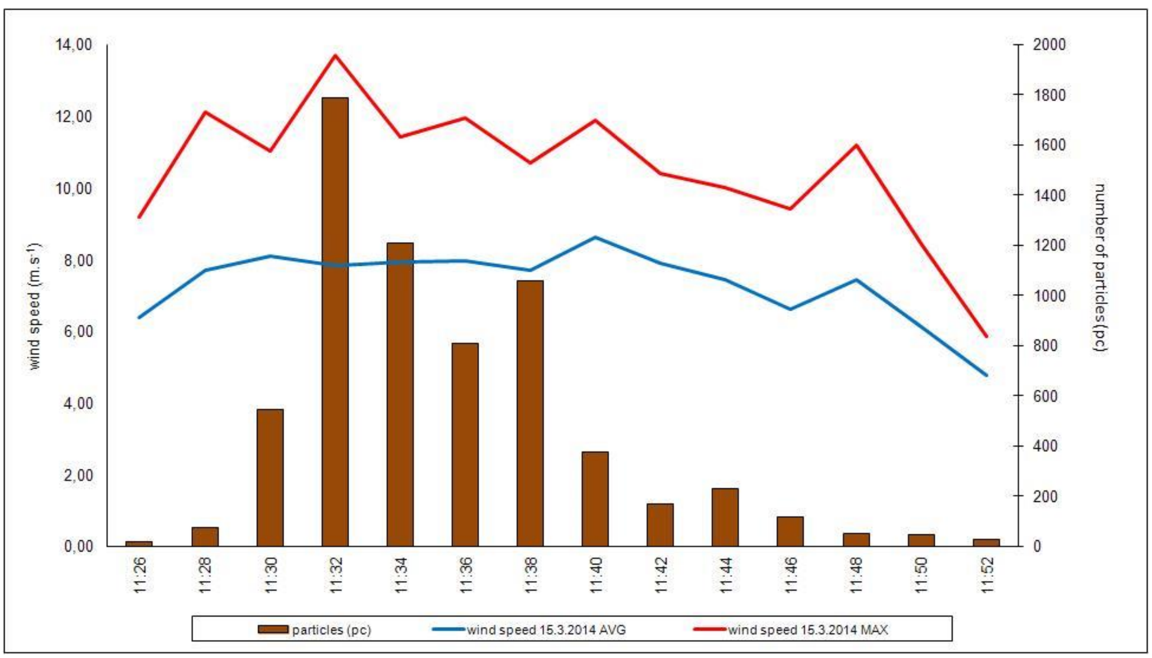


Fig. 10 *Graph of the wind speed and distribution of the number of particles in time, 15.3.2014*

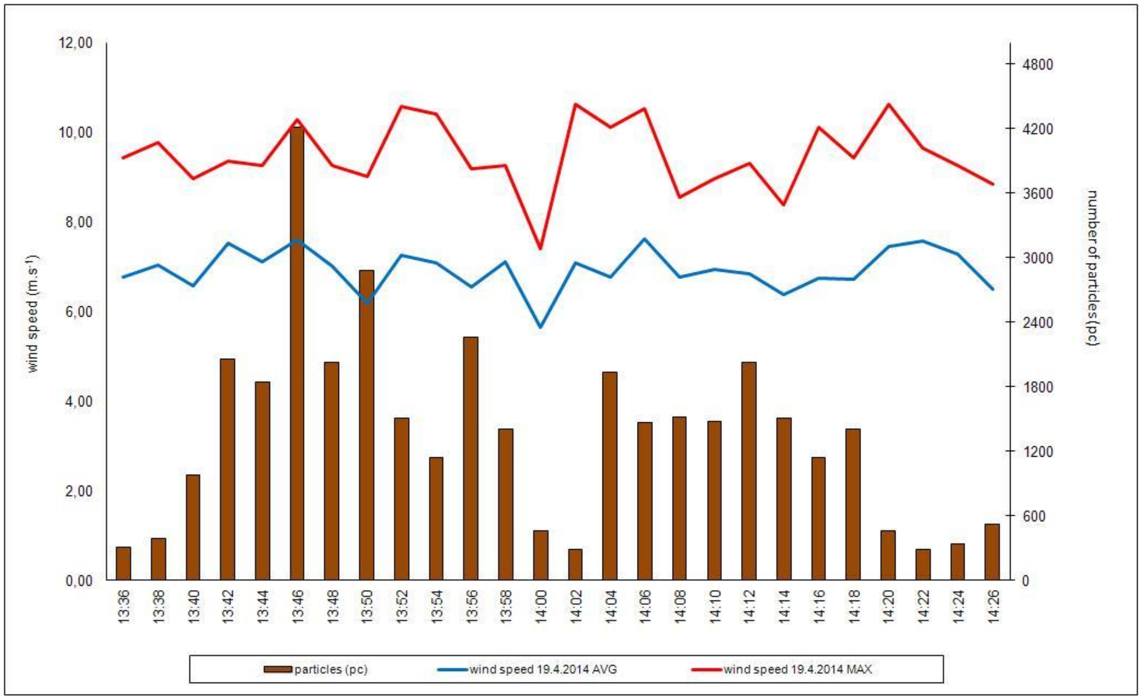


Fig. 11 *Graph of the wind speed and distribution of the number of particles in time, 19.4.2014*

The graphs in Fig. 9, 10 and 11 show the behavior of individual episodes of erosion (max and average wind speed), accompanied by the distribution of the number of particles in time as they were recorded by deflameter. It is evident that there is not always the number of particles coincided with the course of the wind speed. On the other hand, in each measurement there is at least one section in which it is. In the episode of 24. 5. 2012 it is in the time 17:18, when the largest number of particles (1754) and considerable wind speed (12.02 m.s^{-1}) was registered. In this case, it was the highest maximum winds speed of the entire measurement. The same case was during the episode of 15. 3. 2014, when deflameter recorded 1787 particles at 11:32. Thus, the largest number of particles correlates with the highest maximum wind speed that was recorded (13.69 m.s^{-1}). The episode dated 19. 4. 2014 does not support this trend. The highest maximum wind speed was measured twice (14:02 and 14:20), but the highest amount of the particles (4 212) were recorded by deflameter at 13:46 with a maximum wind speed of 10.29 m.s^{-1}. On the other hand, it must be said that there is a noticeable decrease in wind speed. At 14:00 the lowest maximal wind speed was observed (7.40 m.s^{-1}) and also a low number of measured particles (successively 464 and 288), which was subsequently increased depending on increasing of the wind speed. The example of dust particles from this episode is shown in Fig. 12.

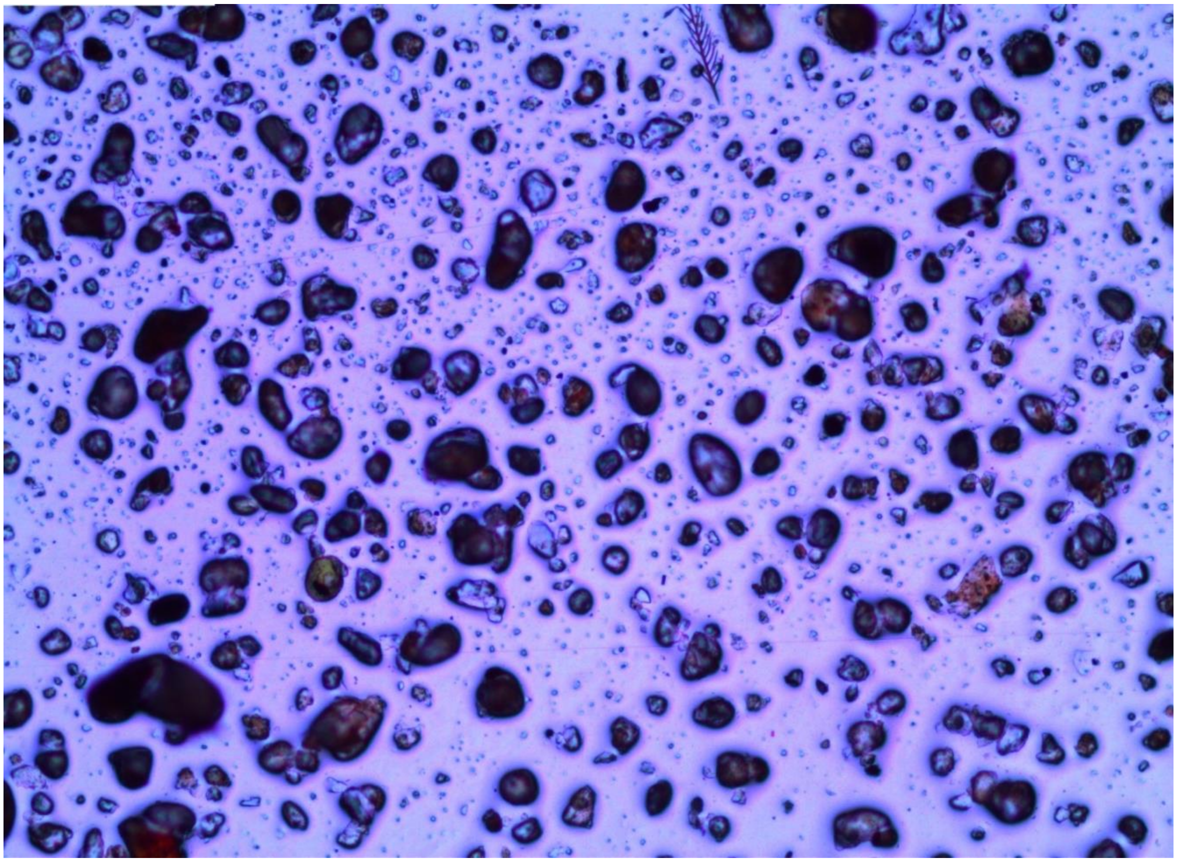


Fig. 12 *Example of the dust particles, 19.4.2014*

CONCLUSION

The aim of this work was the analysis of deflametric records occasioned during the period of the erosive dangerous winds evaluated in areas of the South Moravian Region, in days 24. 5. 2012, 15. 3. 2014 and 19. 4. 2014. So it was the period without vegetation on the soil surface. The deflametric samples were acquired through field research and were evaluated in a laboratory by a microscope. Thanks to this, the relative amount and grain size of dust particles eroded and drifted by the wind were determined. Also the exact time of particle transport was identified

The largest wind gusts were identified. They reached 12.02 $m.s^{-1}$ (24. 5. 2012), 13.69 $m.s^{-1}$ (15. 3. 2014), 10.64 $m.s^{-1}$ (19. 4. 2014). High wind speeds were accompanied by obvious signs of soil particles drift.

The largest measured size of transported particle analyzed under these erosion conditions correspond to 559 µm (sandy-loam soil on 24. 5. 2012), 287 µm (sandy-loam soil, 15. 3. 2014) and 377 µm (loamy soil, 19. 4. 2014). The largest total amount of dust particles measured by the software was 29 635 (19. 4. 2014).

The result of this work will be a risk assessment methodology of wind erosion, which will be used to evaluate the degree of threats to soil. Outputs at least partially confirmed how much the wind erosion contributes to air pollution caused by suspended particles.

Since it was confirmed that a high wind speed under suitable conditions (surface without vegetation, the absence of obstacles, drought) has the ability to abduct soil particles sizes of 50 µm or more, but also particles of much smaller dimensions. Simply said, the wind transports soil particles that may contribute to air pollution as part of the airborne dust and thus negatively affects the health of the population. It is planned a continuation in field measurements and further analysis of soil particles.

REFERENCES

DUFKOVÁ, J., ROŽNOVSKÝ, J.,POKLADNIKOVÁ, H.: Aplikace scénářů změny klimatu na meteorologické prvky ovlivňující větrnou erozi, In: Meteorologické zprávy: Meteorological Bulletin. Praha: Český hydrometeorologický ústav. 2005, ročník 58, č. 2, str. 47 - 50.

DUFKOVÁ, J., TOMAN, F.: Eroze půdy v podmínkách klimatické změny. In: Rožnovský, J., Litschmann, T. (ed): Seminář „Extrémy počasí a podnebí“. Brno 11.3.2004. ISBN 80-7157-723-5.

HLAVÁČKOVÁ, V.: Sborník ze semináře: Eroze půdy a protierozní ochrana půdy. 1. vyd. Praha 1: Institut vzdělávání v zemědělství o.p.s., 2011. ISBN 978-80-87262-11-5.

HOLÝ, M.: Eroze a životní prostředí, Vydavatelství ČVUT, Praha. 1994. 383 s.

CHEPIL, W. S.: Soil conditions that influence wind erosion. Tech. Bul., no. 1185. U.S. Dept. Agr., Washington. 1958.

JANEČEK, M. a kol.: Ochrana zemědělské půdy před erozí: metodika. Vyd. 1. Praha: Výzkumný ústav meliorací a ochrany půdy, 2007, 76 s. ISBN 978-80-254-0973-2.

KALVOVÁ, J, KAŠPÁREK, L, JANOUŠ, D, ŽALUD, Z, KAZMAROVÁ, H.,: Zpřesnění scénářů projekce klimatické změny na území České republiky a odhadů projekce klimatické změny na hydrologický režim, sektor zemědělství, sektor lesního hospodářství a na lidské zdraví v ČR. NKP: Praha. 2002. S. 151.

MATEJKA, F., ROŽNOVSKÝ, J., KOHUT, M., HURTALOVÁ, T.: The evapotranspiration of a maize stand at high evaporative demands of the atmosphere. Meteorologický časopis 7, 4, 2004. S. 161-165.

MUŽÍKOVÁ, B. a kol.: Ochrání větrolam půdu i při vysoké rychlosti větru?. In: Acta horticulturae et regiotecturae, Nitra, Slovac Unoversitas Agroculturae Nitrae, roč. 15, 2012, č. Mimoriadne – Special, str. 40 – 42.

ROŽNOVSKÝ, J., KOHUT, M.,: Drought 2003 and potential moisture balance. Contributions to Geophysics and Geodesy, 34, 2, 2004. S. 195-208.

ŠVEHLÍK, R.: Větrná eroze na jihovýchodní Moravě v obrazech. V Uherském Hradišti: Přírodovědný klub, 2002, 78 s. ISBN 80-86485-02-1.

ACKNOWLEDGEMENT

This work was prepared with the support from the National Agency for Agricultural Research, Czech Republic. Project QJ1230056 – “The impact of the expected climate changes on soils of the Czech Republic and the evaluation of their productive functions”.

SUMMARY

Problémem současné zemědělské krajiny je tzv. nadměrná (zrychlená) eroze zemědělské půdy, kdy dochází k odnosu povrchových vrstev půdy rychlostí vyšší než rychlost přirozené tvorby půdy z půdotvorného substrátu. Větrná eroze je jedna z mnoha příčin vážného ohrožení produkční i mimoprodukční funkce zemědělských půd. Transportované částice, které jsou větrem unášeny, a na ně vázané látky způsobují především poškozování klíčících rostlin, znečišťování ovzduší a škody navátím ornice. Na vznik větrné eroze mají vliv dva základní faktory. Prvním je faktor meteorologický, především rychlost větru, doba jeho trvání a četnost výskytu. K pohybu půdních částic stačí někdy i malé rychlosti větru. Druhým důležitým faktorem je struktura a vlhkost půdy. Větrnou erozi můžeme zaznamenat především v sušších a teplejších klimatických oblastech s lehkými půdami. Jaro (březen až květen) a podzim (září až listopad) jsou

období s nejvýznamnějším ohrožením půdy větrnou erozí. Vyskytují se totiž rychlosti větru, které jsou erozně nebezpečné, a půda je bez vegetačního krytu.

Práce si kladla za cíl analyzovat deflametrické záznamy, které byly pořízeny díky polním měřením v období výskytu erozně nebezpečných rychlostí větru v Jihomoravském kraji ve dnech 24. 5. 2012, 15. 3. 2014 a 19. 4. 2014. Tedy době, kdy půda není kryta vegetací. Následně byly deflametrické záznamy vyhodnoceny v laboratoři pomocí mikroskopu. Tím bylo stanoveno relativní množství a zrnitostní složení prachových částic erodovaných a unášených větrem a byl také určen přesný termín transportu částic.

Byly zjištěny nejvyšší nárazy větru, které dosahovaly 12,02 $m.s^{-1}$ (dne 24. 5. 2012), 13,69 $m.s^{-1}$ (dne 15. 3. 2014), 10,64 $m.s^{-1}$(dne 19. 4. 2014). Vysoké rychlosti větru byly provázeny zřejmými projevy vznosu půdních částic. Největší naměřené částice analyzované v těchto erozních epizodách dosahovaly rozměru 559 µm (písčito-hlinitá půda, dne 24. 5. 2012), 287 µm (písčito-hlinitá půda, 15. 3. 2014) a 377 µm (hlinitá půda, dne 19. 4. 2014). Největší celkové množství prachových částic naměřených pomocí software bylo 29 635 (dne 19. 4. 2014).

Výsledkem práce je především metodika hodnocení rizika větrné eroze, která poslouží k vyhodnocení míry ohrožení půdy. A to z pohledu současného stavu i při možných vývojích klimatu. Výstupy alespoň částečně potvrdily, jakou měrou se větrná eroze podílí na znečištění ovzduší suspendovanými částicemi. Jelikož bylo potvrzeno, že vysoká rychlost větru má za vhodných podmínek (povrch bez zapojené vegetace, nepřítomnost překážek, bezesrážkové období apod.) schopnost unášet půdní částice o velikostech 50 µm a více, avšak i částice mnohem menších rozměrů. Do budoucna je plánované pokračovaní v měření v terénu a další analyzování půdních částic zachycených deflametrem. Důležité bude sledovat předpověď povětrnostních podmínek, které budou z hlediska nebezpečí větrné eroze nejvhodnější.

CONTACT

Ing. Pavlína Thonnová

Department of Applied and Landscape Ecology, Faculty of Agronomy,

Mendel university in Brno

Zemědělská 1, 613 00 Brno, Czech Republic

545 132 480, e-mail: thonnovapavlina@seznam.cz

THE THERMAL REGIME OF ICE PITS OF THE BOREČ HILL

LUBOŠ TÜRKOTT[1]; EVA MARTINČÍKOVÁ[2]; VERA POTOP[1]

[1]*Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Agroecology and Biometeorology, Prague, Czech Republic, turkott@af.czu.cz*

[2]*Institute of Computer Science, Academy of Sciences of the Czech Republic, Prague, Czech Republic*

ABSTRACT

The ecological stability of the sites with stenoec organisms is important factor for maintaining them at given location. Phonolite system of the Boreč hill creates a unique labyrinth of vents. Thermal anomalies occur during the year in the fissure system and create specific microclimate. Flow direction is given by the temperature gradient inside and outside of the system. The lower part of fissure system is located in the debris fields, while the upper part on top of the hill. Phonolite rocks are cooled down by air streaming from the debris fields during the winter. Direction of the air flow changes in the spring and summer. The cold air is exhaled from these vents on the lower parts of system and creates ice pits with the typical vegetation.

Key words: ice pit, air temperature, Boreč hill, ventarole

INTRODUCTION

The occurrence of ice caves in the world is quite abundant. Ice decoration of the karst formations is largely described. Ice caves and ice pits can also emerge in pseudo-karst areas. In the Czech Republic several sites with ice pits are described. Kubát (1972, 1974) describes the exhalation with the formation of ice pits in the Giant Mountains on the Velká kotelní jáma, Malý Šišák and Malá čertova zahrádka. Váně (1992) observed strong emissions at Lake Mountain near Klášterec nad Ohří. The highest incidence of this phenomenon in the Czech Republic can be found in the Czech Central Mountains. Czech Central Mountains is the largest volcanic area in the country. Geologically consists mainly of basalt, in a smaller amount of trachytic and andezit rock. Outflow of magma into the softer layers and their subsequent erosion formed the shapes of so-called lakonits - one of these is the Boreč hill. In this pile of phonolite (449 m above sea level) can be found a large system of fissures called ventarols. According to Váně (1992), the fissures were created thanks to the high viscosity of the lava flow, which is characteristic for this type of rock. Fissures are formed both parallel and perpendicular to the surface. Sufficient height difference and continuity of fracture system, which has one outfall at the bottom part of the hill and the second at its top, creates air flow inside the system. Several possible causes of the airflow in ventarols are described. The most common are follows: (1) Balch effect (Balch, 1900; Zacharda, 2007) the influence of gravity on air flow according to its specific weight; (2) chimney effect (Kubát, 1974 Wakonigg, 1996); (3) interaction with the atmosphere according to the current synoptic situation (Váně, 1992); (4) the influence of latent heat based on consumption and releasing of latent heat during evaporation and condensation (Wakonigg, 1996); (5) impact of geothermal energy (Schwarz, 1959). Váně (1992) assumes that the direction and strength of the airflow inside the system depends on the temperature gradient. Air vents at the top of the Boreč hill are especially noticeable in winter, when vapor is exhaled and during the snow periods, when the snow is melted by the warm air. Water vapor condenses on the vegetation around vents and creates frosting. The air is inhaled in the scree slope at the bottom of the hill. Direction of the air flow in fracture system turns back with increasing ambient air temperature and ventarols on top of the hill start to inhale the air. Cold air is blown out in the scree at the foot of the hill and land creates ice pits that can be observed until late spring or early summer. The temperature of the turning point (i.e. changes of the airflow direction) is variable over time. The drop in winter temperature in the system significantly decreases when the hill cools. Therefore, in early spring the direction of the airflow changes, when the temperature of the ambient air is around 12 °C, compared to that in the autumn around 16 °C, because the hill accumulates heat during the summer (Pospíšilová, 2013).

Ecological stability of these systems provides unique conditions suitable for stenoec organisms that benefit of the warm and humid air at the top of the hill in the cold period of the year. The most representative species is inconspicuous liverwort *Targionia hypophylla* L., a thermophilic species widespread in regions with a Mediterranean climate. There is only one locality in the

Czech Republic, where *Targionia hypophylla* L. can be found - on the top of the Boreč hill. It is a relic of the Tertiary flora, which survived an ice age and is maintained only thanks to special microclimatic conditions that are caused by the convection in ventarols.

Its developmental stages and the life cycle are bound by the direction of flow in the fracture system. *Targionia hypophylla* L. vegetates at the period, when the warm and humid air is exhaled in its vicinity and the water vapor condensates in the ventarol vents. This occurs outside the growing season of the vast majority of plant species. The main growing season of *Targionia hypophylla* L. is from autumn to spring (Türkott, 2013). Vegetation in the lower vent of fracture system inside ice pits is similar to species of damp and cold mountain habitats. Among of vertebrates it is possible to find a number of endangered species (*Salamandra salamandra* and glacial relict invertebrates *Pterostichus negligens).* The occurrence of these stenoec species on the Boreč hill is dependent on the specific climate and microclimate of the site and any unbalanced of these conditions would be risky.

MATERIALS AND METHODS

The research started in 2011 and was performed till 2013. Boreč hill is located in the Lovoš Highlands in Czech Central Mountains. Environmental features were monitored in several points of the fissure system. Data collected from the mobile Tinytag data loggers were used to measure the air temperature in the ice pit at the bottom of the fissure system. The pit is located in the scree slope with a volume of 0.03 m^3. Temperature sensors PT100 were located in the cave. At the same time shielded sensors measured the air temperature at 2 m height above the ground. The temperature was measured every hour of the local time from April 3, 2012 to July 5, 2013. Average daily ambient air temperature, average daily air temperature of ice pits and differences between of air temperature both inside and outside ($\Delta t = t_{ins} – t_{out}$) were calculated. The fluctuations and extreme temperatures during study period were determined. Data were statistically processed in Statistika 12 software.

RESULTS

The airflow in the ice caves changes the direction during the year. The change of the flow direction is called a turning point and it is dependent on the temperature gradient. The turning point can be observed by decreasing variations of the t_{out} and the t_{ins} of the ice cave. The change of the direction does not allow performing regression analysis of the entire data set; it must be divided into shorter periods without the turning point. It is ideal to analyze the data between extreme values close to turning points where the flow is steady and unidirectional. The last turning point was observed on April 16, 2012 and October 7, 2012. The period between these reversals is called the summer flow regime. The t_{out} is significantly higher than the t_{ins} of the fissure system and the air is inhaled to vents on the top of the hill. The flow is driven by the Balch effect, when the heavier cold air flows out of the system through ice pits in the bottom of the hill. Consequently, the ice formations are created in ice pits and they remain here until the summer (Figure 3b). The summer flow regime in 2012, the highest ambient air temperature was 38.3 °C at 5 p.m. local time on 20 August. Whilst the temperature of the air exhaled in the ice cave was 2.3 °C and the highest Δt was -36.0 °C. At this time, the absolute maximum air temperature was exceeded on many climatological stations in the Czech Republic and new temperature (40.4 °C in Dobřichovice) record in the CR was measured. The smallest temperature difference (0.6 °C) between ambient air temperature and the temperature inside of the ice pit was measured during the spring turning point on April 17, 2012 in the morning, when the air temperature was 0.0 °C, and the temperature in the ice pit was -0.6 °C. The highest temperature inside (6.9 °C) of the ice pit in summer flow regime was measured on September 12, 2012 and October 7, 2012 at 10 a.m. and 11 a.m. local time, respectively. The lowest ambient air temperature (-0.5 °C) and the lowest temperature of the ice pit (-1.8 °C) were measured on April 18, 2012 at 6 a.m.

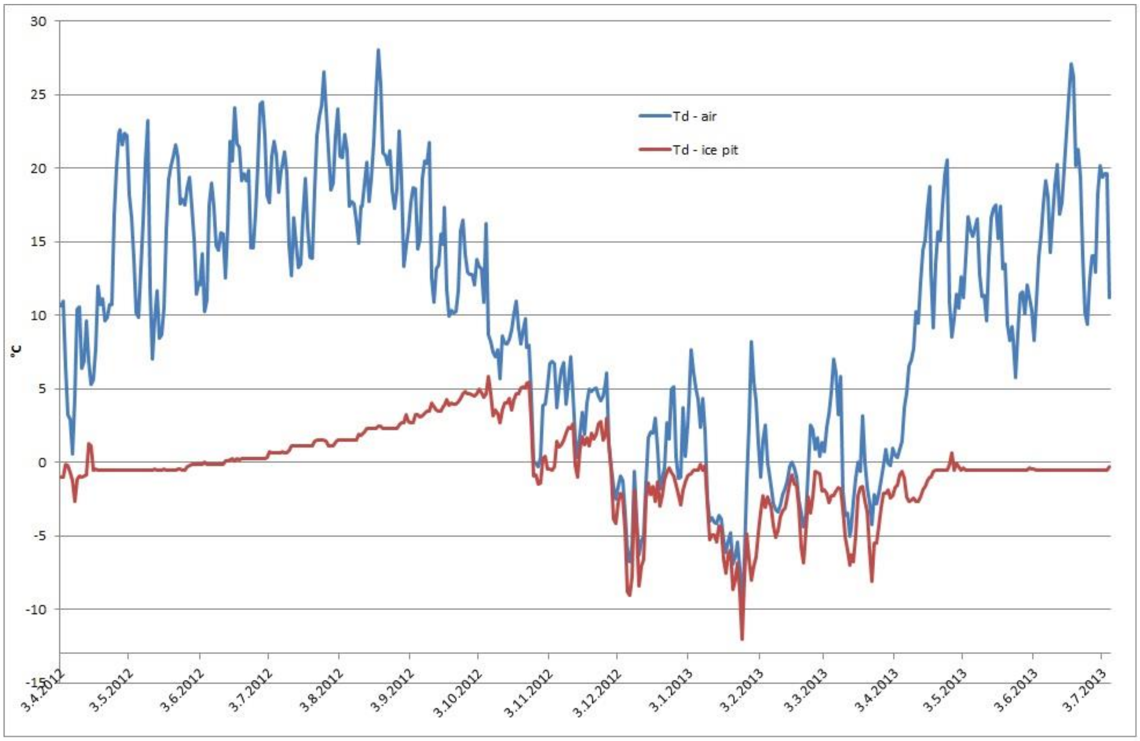


Fig. 1 The average daily ambient air temperature and temperature inside of the ice pit.

The interface period between summer and winter flow regimes to occur so-called mixed regime. In the short time intervals the air flow direction turns back in this period or the flow stops for a particular period of time. Temperature of the turning point is different for spring and autumn season; its temperature decreases during winter as the rock cools down. Therefore, in the early spring lead to change of the flow direction even at the t_{out} was only 12 °C. The fall turning point temperature was around 16 °C, because the rock accumulated the heat during the summer.

Winter flow regime (Fig. 3a) is based on air intake through ice pits and exhalations through vents on the top of the hill. The Δt achieved the highest values in periods of heavy frost, when the flow direction is invariable, upward and exhalations are strong. The driving force of the flow is mainly a chimney effect, supplemented by the influence of the current synoptic situation and latent heat. The temperature of ice pits strongly depends on the ambient air temperature in this period and the difference between them is small. The winter mode measurements took place from October 17, 2012 to April 5, 2013. During the winter flow regime, the highest measured temperature in the ice pit was 5.8 °C (October 21, 24 and 25). The lowest temperature was -14.6

°C (January 26, 2013). The lowest air temperature outside of the ice cave (-12.1 °C) was measured on the same day. On 25 and 26 January 2013 were the coldest days of the winter season 2012/2013 in the Czech Republic.

The ice pit average temperature for the period from April 3, 2012 to July 5, 2013 was -0.4 °C, while the highest and lowest measured temperature were 6.9 °C and -14.6 °C, respectively. The lowest ambient air temperature during the study period was -12.1 °C. The fact that the air exhaled out of the fissure system was colder than the ambient air could indicates a presence of permafrost in the bottom parts of the Boreč hill and the existence of another mechanism of cooling of the exhaled air. Regression analysis indicated a low dependence of the ice pit summer temperature on the ambient air temperature (Figure 2a).

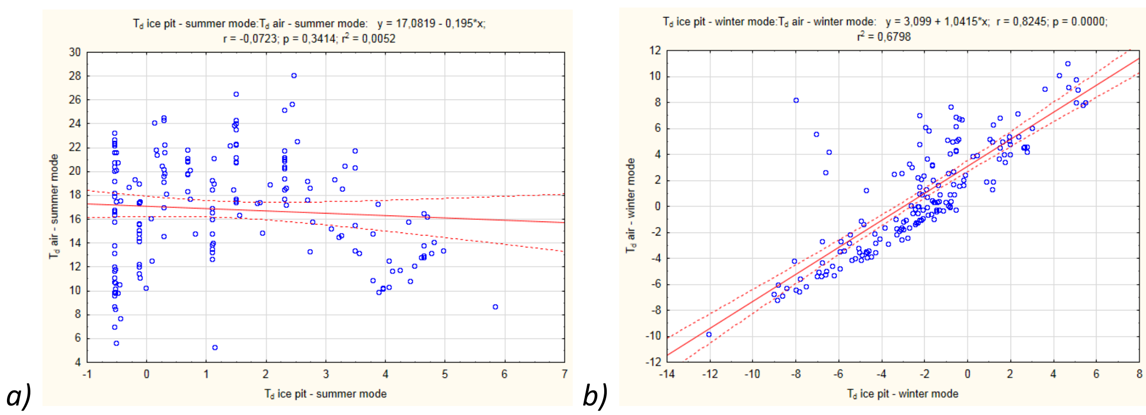


Fig. 2 Graphical representation of data used for statistical calculations of summer (a) and winter (b) air flow regime.

Ice pits temperature strongly depends on the ambient air temperature during the winter. The correlation coefficient (r) was 0.825 and the r^2 fits 0.68 (Fig. 2b).

Fig. 3 Ice pit in winter (a) and summer (b) air flow regime.

DISCUSSION

The average air temperature in the ice pit was -0.4 °C for the measured period. Fialová (2012) stated that the average temperature in one of the ice pits was 0.52 °C and considers the Boreč ice pit is the coldest in compared with others in the Czech Central Mountains. The fact that the lowest temperature measured in the ice pit was lower than the lowest measured ambient air temperature, supposes the existence of permafrost at the bottom of the fracture system. It also confirms the presumption of Režný (1966) and Váně (1992) that ice pits are independent on the air flow dynamic of the whole system to some degree.

Režný (1966) studied fissure ventarols with similar microclimatic regime near Kostelec nad Orlicí. Režný (1966) believes that it is not possible to reveal the structure of the underground ice caves without an underground exploration, but claims that they are not involved in the overall dynamic system. It is assumed that the vents are closed with ice and snow in winter, while in the warm season they are able to emit only a part of undercooled air from the cavities, creating a static counterpart to the main system of fissures with the dynamic regime. Tanaka (2000) examining the microclimate of Nakayama Wind-Hole in Japan claims that in winter the coolness is stored in the scree, while in summer is protected against warming up by the stable stratification.

When the difference between the temperature of ambient air and the temperature inside of the fissure system decreases, the mixed air flow regime was turns up. It leads to frequent changes in air flow direction, and the air flow often completely ceases. As stated by Váně

(1992), the whole system can be influenced by the current synoptically conditions. According to Faimon et al. (2011), other characteristics are also very important for the speed and direction of air flow in the system, such as wind strength and direction, orientation of the vent to the wind direction, the presence of vegetation near the vents, humidity – atmospheric and in particular ventarols.

CONCLUSION

The results of the measurements demonstrated a high storage capacity of the fissure system of the Boreč hill and also the possible existence of permafrost, which can cool down the air exhaled from the ice pits. The air flow in the system is driven by the Balch effect in summer regime and mainly by the chimney effect in winter. The flow direction depends on the temperature gradient between the ambient air and the air in the fissure system. Changing of the flow direction (turning point) varies according to the current temperature of the rock. The lowest temperature in the ice pit for the period from April 3, 2012 to July 5, 2013 was -14.6 °C, which is lower than the lowest measured ambient air temperature (-12.1 °C). The average temperature in the ice pit was -0.4 °C.

REFERENCES

Balch, E. S. 1900. Glaciers or Freezing Caverns. Allen, Lane and Scott, Philadelphia, p. 377.

Faimon, J., Troppová, D., Baldík, V., Novotný, R. 2011. Air circulation and its impact on microclimatic variables in the Císařská cave (Moravan Karst, Czech Republic). Int. J. Climatol. 32 (4), 599–623.

Fialová, V., Pokorný, R. 2012. Nová mikroklimatická měření ve vybraných ledových jamách CHKO České středohoří. Studia oecologica, 6 (2), 73-85.

Kubát K. 1972. Příspěvek k mikroklimatu sutí Schustlerovy zahrádky (Krkonoše). Opera Corcontica, 9, 165-167.

Kubát, K. 1974. Proudění vzduchu sutěmi jako ekologický faktor. Opera Corcontica, 11, 53-62.
Poslíšilová, E. 2013. Mikroklimatické poměry vrchu Boreč s ohledem na výskyt ventarol. Diplomová práce. Česká zemědělská univerzita v Praze, Praha, s 77.

Režný, K. 1966. Puklinové ventaroly u Kostelce nad Orlicí. Acta Musei Reginae-hradecensis, Hradec Králové, ser. A (VII), 31−42.

Schwarz, R. 1959. Boreč, dýmající vrch v Českém středohoří. Dvacáté století. Orbis, Praha, 233–239.

Tanaka, H. L., Nohara, D., Yokoi, M. 2000. Observational Study of Summertime Ice at the Nakayama Wind-Hole in Shimogo, Fukushima. Science Reports. Institute of Geoscience, University of Tsukuba, Section A (Geographical Sciences), 21, 1-21.

Türkott, L., Pospíšilová, E. 2013. Vliv mikroklimatu ventarol vrchu Boreč na vegetaci borečky vzácné (Targionia hypophylla L.). In.: Vliv abiotických a biotických stresorů na vlastnosti rostlin 2013, Praha – Ruzyně, 202-205.

Váně, M. 1992. Exhalace par na Borči a na Jezerní hoře. Sborník Severočeského muzea – Přírodní vědy, 18, 175 – 191.

Wakonigg H. 1996. Underkühlte Schutthalden. Arbeiten aus dem Institut für Geographie der Karl-Franzens-Universität Graz, Beiträge zur Permafrostforschung in Österreich, Arb. Aus d. Inst. f. Geogr. d. Univ. Graz, 33, 209-223.

Zacharda, M., Gude, M., Růžička, V. 2007. Thermal Regime of Three Low Elevation Scree Slopes in Central Europe, Permafrost and Periglac. Process. Wiley InterScience, 18, 301–308.

ACKNOWLEDGEMENT

This work was supported by Institutional Support Program for Long Term Conceptual Development of Research Institution provided by Ministry of Education, Youth and Sports of the Czech Republic.

SUMMARY

Ekologická stabilita lokalit s výskytem stenoekních organismů je důležitým faktorem pro jejich setrvání na daném stanovišti. Puklinový systém znělcové kupy Boreč vytváří unikátní labyrint průduchů, v jejichž vyústění dochází během roku k teplotním anomáliím, které vytvářejí specifické mikroklima. Směr proudění puklinovým systémem je dán gradientem teploty uvnitř a vně systému. Dolní část puklinového systému se nachází v suťových splazech a horní část na vrcholu kopce. V ústí systému byla měřena teplota proudícího vzduchu a byl sledován gradient

teploty vydechovaného a vdechovaného vzduchu. Při zimním režimu proudění je vzduch nasáván v suťových splazech, uvnitř systému ohříván a vydechován na vrcholu kopce. Hnací silou proudění je zejména komínový efekt. V tomto období byla zjištěna velmi silná korelace teploty v ledových jamách a teploty vzduchu. Letní režim proudění spočívá v nasávání vzduchu na vrcholu kopce, jeho ochlazování od předpokládaného permafrostu uvnitř kopce a následné exhalaci v ledových jamách suťových splazů. V tomto případě je hybnou silou Balchův efekt. Nejvyšší rozdíl mezi teplotou vzduchu a teplotou exhalovaného vzduchu v ledových jamách byl 36,0 °C, kdy teplota vzduchu byla 38,3 °C a teplota exhalovaného vzduchu 2,3 °C. Na rozhraní letního a zimního režimu proudění mluvíme o tzv. smíšeném režimu. V krátkých časových intervalech se v tzv. bodech zvratu směr proudění otáčí o 180°, popřípadě proudění na určitou dobu ustává. Teplota jarního a podzimního bodu zvratu byla 12 °C resp. 16. °C. V bodech zvratu je teplotní rozdíl mezi teplotou vzduchu a teplotou uvnitř ledové jámy nejmenší. Průměrná teplota v ledové jámě za období 3.4.2012 až 5.7.2013 byla -0,4 °C, nejvyšší 6,9 °C a nejnižší naměřená teplota byla -14,6 °C. Nejnižší naměřená teplota vzduchu mimo ledovou jámu byla za sledované období -12,1 °C. Fakt, že naměřená minima exhalovaného vzduchu puklinovým systémem dosahují, v porovnání s teplotou vzduchu, nižších hodnot ukazuje na možnou přítomnost permafrostu ve spodních partiích vrchu Boreč a na existenci dalšího mechanismu ochlazujícího exhalovaný vzduchu.

CONTACT

Ing. Luboš Türkott, Ph.D.
KAB FAPPZ ČZU v Praze
Kamýcká 129, Praha 6 – Suchdol, 165 21
e-mail: turkott@af.czu.cz
telefon: +420224382783

INFLUENCE OF METEOROLOGICAL FACTORS AND AGRICULTURAL MANAGEMENT FORM ON WEED SPECIES STRUCTURE IN MODEL TERRITORY OF AGRICULTURAL COOPERATIVE OČOVÁ

MIRIAM VÁĽKOVÁ[1]

The Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, T.G.Masaryka 24, SK-96053 Zvolen, Slovakia

ABSTRACT

The paper is aimed at evaluation edaphic, ecological , climatic conditions and agricultural management forms on weed diversity structure in relation to optimisation of land use on the model territory of Agricultural Cooperative (AC) Očová (Central Slovakia). The research was carried out using standard methodology for determining the potential weed infestation,, seeds of weed species classification methodology according to Líška (2002), determining the weed species spectrum, richness and diversity via Shannon-Wiener index of diversity and range of ecological dominant weed species in the cultural stands of winter wheat, winter oilseed rape, maize, alfalfa and spring barley for the duration of the experiment. In total, 30 weed species were determined. The most abundant species were: *Persicaria maculata, Sinapis arvensis Amaranthus retroflexus, Chenopodium album, Tripleurospermum maritimum, Rumex acetosa, Fallopia convolvulus.* The research results confirm the influence of soil conditions and amount of atmospheric rainfall only partially. The obtained data indicate that soil quality and rainfall amount play a singnificant role especially in such agrocoenoses where the same crop was cultivated for several years (i.e., alfalfa or permanent lawn).

Key words: weed species richness, agro-environmental scheme, diversity, segetal vegetation, cultural crop

INTRODUCTION

Agroecosystems and natural ecosystems have many common features, but differ in several aspects. However, the same biological patterns and relations are characteristic for both types. The functionality of each type of agroecosystems depends on many factors, the major role played by particular climatic factors (rainfall, temperature) closely related to edaphic factors as land as a basic component of agroecosystems contributes significantly to the segetal vegetation diversity within agroecosystems (Tóth 2006).

Agrophytocenoses are sensitive to climate changes, which are accompanied by irregularity of rainfall and an increase of average annual temperatures and average temperatures changed little winter. The influence of climate changes is relatively slow, but is manifested in range of weed vegetation generally and in weed species at particular locations. Booth & Murphy (2003) results refer to plants occurring in warm areas, getting the opportunity to expand into other localities and proceed towards the north, to places inappropriate for them in the past. In recent years we can observe a relatively rapid spread of thermophilic and mediterranean weed species from lowlands to mountainous areas, i.e., *barnyardgrass, pigweed, jimsonweed* and many others by Fjellstad & Dramstatd (2001).The way of agricultural crop management, edaphic and climatic conditions applied in the experimental sites on the model territory of Agricultural Cooperative (AC) allow to assess the influence of edaphic and climatic factors on the weed species abundance and diversity. The aim of this paper is to verify whether the agricultural crop management, edaphic and climatic factors influence the weed species diversity and abundance in chosen cultures of farm crop (Demo et al. 1984).

MATERIALS AND METHODS

The study area was situated on the western foot of the Poľana Mts (eastern border of the Zvolenska kotlina basin, Central Slovakia) and its geographic coordinates are 48º34´04˝ – 48º38´21˝ N and 19º16´52˝ – 19º20´50˝ E (Dublan 1993; Alberty 1999)

The research was carried out in three pairs of sites (6 sites in total). The same crop was planted on both sites within each pair, using different forms of agricultural management (3 crops × 2 management forms = 6 sites). In particular, the conventional form with the application of synthetic fertilizers and pesticides was altered with the basic agro-environmental scheme or sustainable form (environment-friendly agriculture), without the application of synthetic fertilizers and pesticides.

This method allowed us to study how these two basic forms of agroecosystem management and agricultural crops influence the weed species diversity and abundance in study areas.

The temperature was also one of the main climatic factors, which, together with atmospheric rainfall determined the climatic features of the different locations. Atmospheric rainfall tend to be considered along with the air temperature as the most important meteorological element (Barberi et al. 1998; Borschenius et al. 2004). The occurrence of individual weed species significantly affect inter mentioned meteorological factors, edaphic factors, therefore it is necessary for a comprehensive research on the abundance and identification of weed species on arable land to obtain relevant information on the nature of the climate region and the soil characteristics.

The research was carried out during three growing seasons from 2011 to 2013. Weed seeds samples were collected by PVC cups with volume 100 cm cubic, from depth 0 – 0,1m five times from one site. Weed seeds were sorted manually from the obtained biological material. Subsequently, they were determined to species level ((Hron & Kohout 1986; Černuško 1988).

From the primary data we determined the range of weed species on the sites and weed seeds spectrum, moreover we calculated the weed seeds richness and the number of weed species, identify dominant species, abundance of biological groups of weeds and the Shannon-Wiener index (H´) of species diversity for each year of the experiment.

To assess the impact factors on the value of the total weed abundance, biological groups weed abundance, noxious weed species, weed variety and diversity were used multi-factorial analysis of variance and nonparametric statistical methods by Statistica software and a statistical program Past (Hammer 2001).

RESULTS

The study area was characterized by an average annual temperature of 8.71 ° C. The lowest average monthly temperature was measured in January (-3.2 ° C) and the highest in July (19.5 ° C). Average total atmospherical rainfall for the period was 588 mm. Growing season in 2011 and 2012 was characterized by slightly higher average monthly air temperatures in the long-term average. Especially during the summer months July and August. The rainfall accounted 437.9 mm in 2011, 551.5 mm in 2012, 774.8 mm in 2013; of which the growing season (April-September) rainfall accounted 324.3 mm respectively 308.5 mm and 411.2 mm.

In total, 30 weed species were obtained on the model terrritory. The number of weed species on individual sites varied between number 13 – 23.The most abundant species were: *Persicaria maculata, Sinapis arvensis Amaranthus retroflexus, Chenopodium album, Tripleurospermum maritimum, Rumex acetosa, Fallopia convolvulus.*

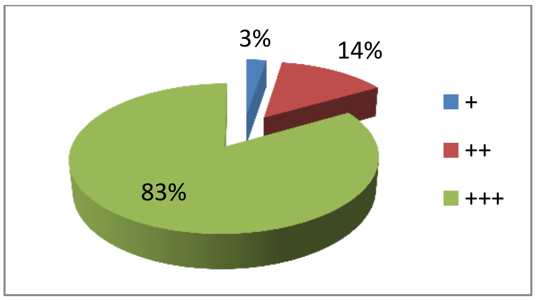


Figure 1. Economic harmfulness of weed species from 2011 to 2013

Population of an individual weed species was quite variable and depends on the amount rainfall fallen during growing season and local average temperatures. For weed species classification according economic harmfulness to the (+ + +) very noxious weeds, (+ +) less noxious weeds, (+) and insignificant species (*) quarantine species were used the Hron and Vodák, (1959) method, which includes general weed species biological characteristics (Fig.1). The phytocenoenoses AC Očová were occupied particular weeds with high potential harmfulness i.e. very noxious, less noxious weed species and quarantine weed species (*), which with extreme competitiveness reduced the quality of chosen cultural crops. Among the quarantine weeds occurring in the area were determined *Datura stramonium, Iva xantifolia.* Based on the biological properties of weeds, we found that the sites were occurred by ephemeral (E), early spring germinated weeds (JS), late spring germinated weeds (JN), winter life cycle weed species (OZ), biennial and perennial weed (DT), perennial shallow rooting (DT / p), perennial deep rooting (DT / h) weed species (Fig. 2). For improving quality of the cultural crops and elimination invasive crop associated weed species was significant factor an agricultural management form. Cultural crops significantly affected the species composition and abundance of individual weed species (Váľková 2011).

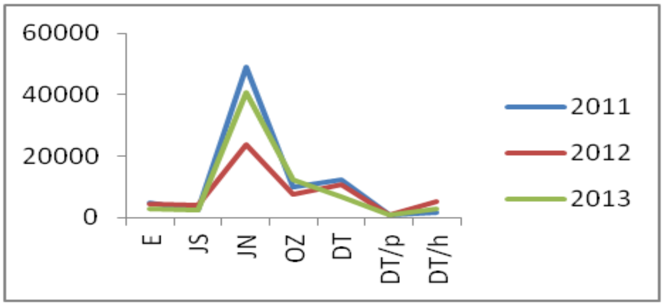


Figure 2. Number of weed seed in biological groups during the period 2011 – 2013

In evaluating the total weed species richness on study sites during the experiment, we recorded a shift in the spectre of weed communities in favor of noxious and very noxious weed species (Liška et al., 2002) in chosen crop plants. Dominant weed species were represented especially by *Persicaria maculata Chenopodium album, Rumex acetosa* and *Echinochloa crus-galli.*

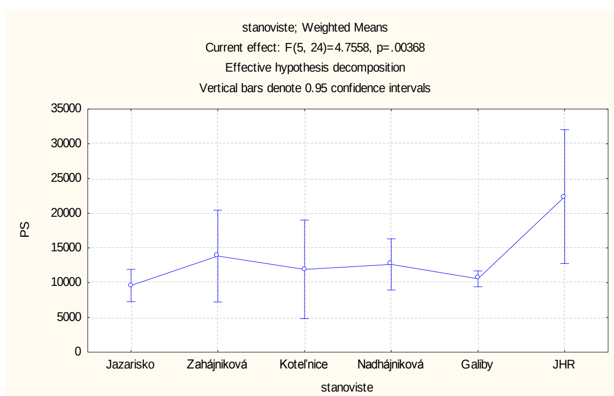


Figure 3. The average abundance of weed seed on study sites in 2011

Meteorological factors affected the abundance of seeds of weed species in agrophytocenoses and largest group represented weed species adaptable to changing climatic and edaphic conditions of individual sites (Gotelli & Colvel 2001).

Evaluating the average abundance of weed seed in 2011 were recorded meteorological factors as a significant factor (ANOVA: df = 5, F = 4.755, p = 0.003), the confidence interval of 0.95. The smallest weed infestation was on low-input site Jazarisko, we measured the highest weed infestation in barley crop on the site JHR (Fig 3). Temperature and rainfall had a significant dependence on the distribution of weed seeds in the soil.

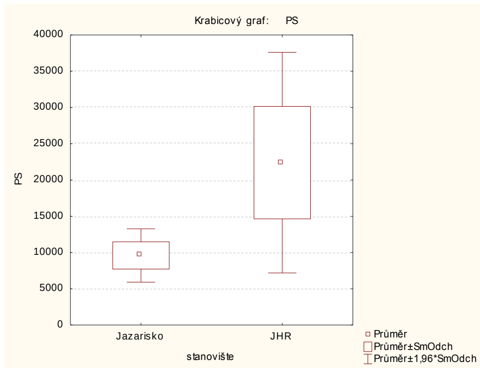


Figure 4. Weed seed richness on the sites Jazarisko-JHR

In 2012, the total proportion of weed infestation on study sites was lower in comparison with 2010. The highest weed infestation in cultural crop was measured on the site JHR (Fig.4). The dominant weed species were represented *Persicaria maculata (Raf.) SF Gray Chenopodium album, Fallopia convolvulus and Echinochloa crus-galli, Amaranthus retroflexus and Atriplex nitens* (Fig 5).

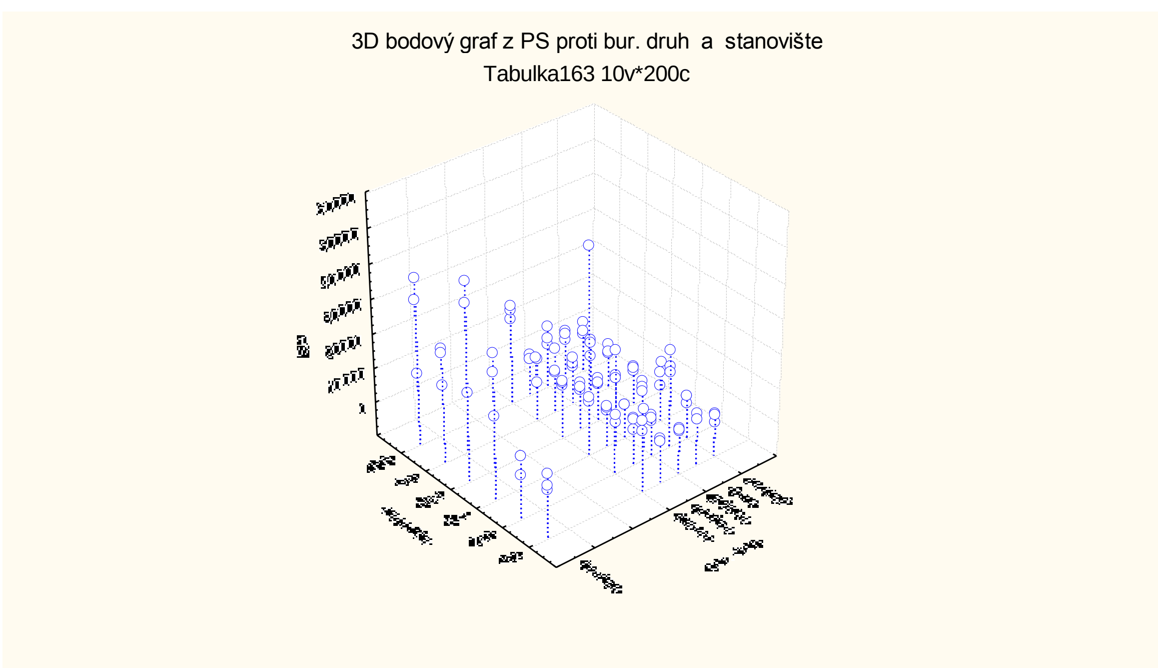


Figure 5. Dominant weed species abundance for the entire duration of the experiment

Furthermore the frequency evaluation of weed species in the crop systems another significant value was diversity in weed communities. The determination of diversity significance of weed species had high explanatory value for understanding the development of agroecosystems. In assessing the dynamics segetal vegetation we calculated the Shannon diversity index H´ for various weeds of the total in agrophytocenoses and Shannon diversity index for sites and monitored according to the chosen statistical factor in each year of the experiment (Shannon 1948). Based on the statistical evaluation and comparison of the total Shannon diversity index for each research site (ANOVA: df = 5, F = 7.599, p = 0.0002) at 0.95 confidence interval the statistically significant factors with the highest influence to weed communities were atmosperical rainfall and habitat (Fig 6).

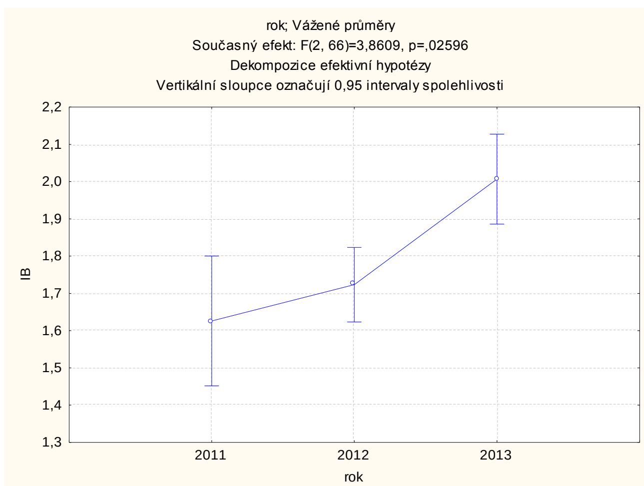


Figure 6. Weed species diversity index for the entire duration of the experiment

Discussion

Determination and weed control in the cultivation system was a complex and systematic activity. Weed agrophytocoenoses were affected by a number of factors. Weeds species found in planted crops were largely influenced by the nature of the habitat, climatic conditions, edaphic factors, methods of land management, Moreover the cosmopolitan weeds have had higher ability of adaptability to wider territories (Černuško & Kollár 1992)., 1997). Changes in weed communities were influenced by agricultural management and environmental factors (Buryšková 1997). The most widespread weed species were *Cirsium arvense (L.) Scop.,* *Persicaria maculata (Rafin.) Fourr., Sinapis arvensis L., Echinochloa crus-galli (L.) PB, Chenopodium album L., Rumex acetosa L., Galium aparine L., Capsella bursa-pastoris (L.) Med. , Fallopia convolvulus (L.). Lovey*. What corresponded with the relevant souces (Černuško, 2003; Kohout & Vach 1982; Klaasen & Freitag 2004). Relatively poor species richness composition was reported in 2012 from the entire model territory. This fact probably resulted from unfavourable ecological conditions characterised by specific habitats with large fluctuations of meteorological conditions. Such conditions were unfavourable for many weed species.

In terms of species diversity the sites with sustainable agricultural management was higher than conventional planted sites. Weed species were significantly interconnected to natural environmental and climatic factors, obtained results correspond with Lacko - Bartošová et al 2000; Váľková 2007). Dominant weed species were recorded in both agricultural management forms but the weed seed number difference was not statistically significant value.

The highest number of weed seeds was recorded at JHR site with sustainable agricultural management. JHR was the smallest site with moderate slightly loamy skeletal soil, which was usually seasonally flooded. Dominant weed species represented perennial weeds and the late spring germinated weeds, which were connected to the specific soil type and the type of unit. According to Kováč (2003) the determinated weeds occured in cultural crop plants, which provide the optimum conditions for their life cycle and hence the structure of the composition of the weed crop rotation.

All determined dominant weed species were accounted as very noxious (+++) which required attention to their abundance determination from study area and management for their elimination Kohout 1996; Jehlík et al. 1998).

Conclusion

The obtained results suggest that the land management forms without application agrotechnical measures are important for the increase of weed species diversity conservation in agroecosystems. However, the quality of weed vegetation management is a complex process based on the interaction of many factors and disciplines, to conserve the richness of segetal vegetation within the context of climate changes

REFERENCES

Aalberty, J. at al. 1999. Očová história a súčasnosť. Žilina : Knižné centrum, 1999. 152 pp. ISBN 80- 8064-026-2.

Barberi, P. – Cozzani, A. – Macchia, M. – Bonari, E. 1998. Size and Composition of the weed seedbank undr different management systems for continuous maize cropping. In Weed Research, vol. 38, 1998, pp. 319 – 334.

Booth, B. D. - Murphy, S. D. - Swanton, C. J. 2003. Weed Ecology in Natural and Agricultural systems. London, CABI Publishing, 2003. 303 pp. ISBN 0851995284

Borschenius, F. - Nielsen, P. K. - Lawesson, J. E. 2004. Vegetation structure and diversity of an ancient tempe-rate deciduous forest in SW Denmark. In Plant Ecology, 175(1): pp.121-135.

Buryšková, L. 1997. Průzkum výskytu a rozšírení plevelů v České republice. Brno : Odbor prostředků ochrany rostlin, 1997. 18 pp.

Černuško, K. 1988. Kľúč na určovanie semien burín. Nitra : VŠP Nitra, 1988.

Černuško, K. - Kollár, B. 1992. Náuka o burinách. Nitra : VES VŠP v Nitre, 1992. 172 pp. ISBN 80-7137-063-0.

Černuško, K. 2003. Vývoj výskytu burinných druhov v hustosiatych obilninách v SR v rokoch 1997-2000. In Ochrana intenzívne pestovaných obilnín proti škodlivým činiteľom. Ziskové pestovanie repky olejky. DAS Praha, 2003. pp. 6-9.

Demo, M. - Bartošová, M. - Černuško, K. - Štiffel, R. 1984. Návody na cvičenia z poľnohospodárskych sústav. Bratislava : Príroda, 1984. 220 pp.

Dublan, L. 1993. Chronostratigrafia polygénneho stratovulkánu Poľana. Západné Karpaty. In Seria Geologica. Bratislava. 1993. pp. 75-120 .

Fjellstad, W. J. – Dramstatd, W. E. – Strand, G.-H. – Fry, G. L. 2001. Heterogenity as ameasure of spatial pattern for monitoring agricultural landscapes. Oslo : Norsk geogr.Tidsskr. Vol. 55, pp. 71–76.

Gotelli, C. - Colvel, L, R. K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. In Ecology Letters, vol.4. pp. 379-391.

Hammer, O. - Harper, D.A.T. - Ryan, P.D.: PAST. 2001. Paleontological statistics software package for education and data analysis. In Paleontologia Electronica, 2001, Hron, F. - Kohout, V. 1986. Polní plevele – část obecná. 1. vyd. Praha : Skriptum VŠZ Praha, 1986. 146 s., vol. 4,nm.1, p. 9.

Hron, F. - Vodák, A. 1959. Polní plevele a boj proti nim. 1. vyd. Praha : SZN – Praha, 1959. 379 pp.

Jehlík, V. et al, 1998. Cizí expanzivní plevele České republiky a Slovenské republiky. Praha : Academia, 1998. 506 pp. ISBN 80-200-0656-7.

Klaassen, H. - Freitag, J. 2004. Dvojklíčnolistové buriny a burinové trávy - znaky pre skoré rozlíšenie. Limburgerhof : Munster-Hiltrup a BASF, 2004. 270 pp.

Kohout, V. - Vach, M. 1982. Plevele v agroekosystému – metody integrované obrany. Brno : Dúm techniky, Brno : ČSVTS. 1982.

Kohout, V. et al. 1996. Herbologie: Plevele a jejich regulace. Praha : Agronomická fakulta ČZU v Prahe, 1996. 116 pp. ISBN 80-213-0308-5.

Kováč a kol. 2003. Všeobecná rastlinná výroba. Nitra : SPU, 2003. 335 pp. ISBN 80-8069-136-3.

Lacko–Bartošová, M. – Minár, M: - Vranovská, Z. – Štrasser, D. 2000. Vývoj potenciálnej zaburinenosti v ekologickom a integrovanom systéme hospodárenia. In Rastlinná výroba, roč. 46, 2000, pp. 319 – 324.

Liška, E. - Černuško, K. - Hunková, E. 2002. Biológia burín. Nitra : SPU v Nitre, vydavateľské a edičné stredisko, 2002. 221 pp. ISBN 80-8069-001-4.

Shannon, C.E. (July and October 1948): A mathematical theory of communication. In: Bell System Technical Journal, 1948, vol.27, pp. 379–423; 623–656.

Tóth, Š. 2006. Výskyt burín na Slovensku v kontexte klimatických zmien. In: Fenologická odezva v proměřivom podnebí. ISBN 80-86690-35-0, 2006. pp. 94 - 101.

Váľková, M. 2007. Návrh metodiky stanovenia zaburinenosti a diverzity burinných druhov na ornej pôde PD Očová. In Ekológia a environmentalistika. Zborník príspevkov zo 4. Študentskej vedeckej konferencie. Zvolen : Vydavateľstvo TU vo Zvolene. 186 pp.

Váľková, M. 2011. Posúdenie vplyvu obhospodarovania krajiny na segetálnu vegetáciu na vybraných typoch agrofytocenóz. Dizertačná práca. Zvolen : TU Zvolen, 2011. 97 pp.

ACKNOWLEDGEMENT

This study was supported by the Slovak grant agency VEGA, grant number 1/0281/11 and Slovak research and development agency APVV, grant number 0423-10.

SUMMARY

V práci sme sa zamerali na výskum a hodnotenie segetálnej vegetácie na modelových plochách katastrálneho územia PD Očová v súvislosti so súčasným trendom racionalizácie poľnohospodárskej výroby a managementu burín v kontexte globálnych klimatických zmien.

Naším cieľom bolo zhodnotenie základných pôdnych, meteorologických a ekologických podmienok výskumných plôch a agrotechnických opatrení, ktoré priamo ovplyvňujú dynamiku segetálnej vegetácie v agroekosystémoch na modelovom území. Vyhodnotili sme meteorologické a pôdno-ekologické charakteristiky modelových plôch podľa systému Bonitovaných pôdno-ekologických jednotiek.. Môžeme konštatovať, že výskumné plochy majú rovinnú expozíciu, nachádzajú sa v mierne teplom a vlhkom regióne, pôda je stredne ťažká a ťažká, hlinitá, utlačená so sklonom k sezónnemu zamokreniu s charakteristickým druhovým zložením sprievodnej vegetácie, ktorá je viazaná na dané pôdno-klimatické podmienky stanovišťa. Definovali sme základné agtechnické opatrenia v konvenčnom a ekologickom systéme hospodárenia a dynamiky segetálnej vegetácie v oboch schémach hospodárenia v súčinnosti s meteorogickými faktormi (teplotou a atmosférickými zrážkami).

Získané semená burinných druhov sme klasifikovali podľa stupnice Hrona, Vodáka(1959). Vyhodnotili sme početnosť a diverzitu burinných druhov pre jednotlivé stanovištia a stanovili sme ekologické dominanty v jednotlivých rokoch trvania experimentu.

Získané empirické údaje sme využili pri štatistickom hodnotení závislostí k stanoveným faktorom- teplota, atmosférické zrážky, stanovišťe a schémy obhospodarovania pôdy a kultúrnej plodiny.

CONTACT

Mgr Miriam Váľková, PhD.

Technická Univerzita vo Zvolene

Katedra prírodného prostredia

T. G. Masaryka 24

960 53 Zvolen, Slovenská republika

tel. +421 45 5206 205

email: valkova@tuzvo.sk

MODEL ESTIMATION OF POTENTIAL INFESTATION PRESSURE OF CODLING MOTH (*CYDIA POMONELLA*) IN CONDITION OF CHANGING CLIMATE IN SLOVAKIA

JURAJ VAVROVIČ[1], EVA SVOBODOVÁ[2], MARIANA ELIAŠOVÁ[1], JÁN KOLLÁR[3], BERNARD ŠIŠKA[1]

1) *Department of Ecology, Faculty of European studies and Regional Development, Slovak University of Agriculture in Nitra, Slovakia*
2) *Institute for Agrosystems and Bioclimatology, Mendel University of Agriculture and Forestry Brno, Czech Republic*
3) *Department of Planting Design and Maintenance, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovakia*

ABSTRACT

The occurrence of Codling Moth (*Cydia pomonella*) was estimated on the basis of meteorological data from Climatological Station Network of Slovak republic using CLIMEX model. The conditions of climate change were simulated according to GCM ARPEGE and SRES scenario A1B for three time intervals: 1961-1990, 2021-2050 and 2071-2100. Spatial changes of potential codling moth distribution were estimated using GIS application. As concerning number of generations, during reference period 1961-1990 and period 2021-2050, there were conditions suitable for one generation development. However, during time period 2071-2100, the area where second generation could occur increased to 38% and at 11% of area third generation could occur potentially. For both future time periods, the widening of area affected by codling moth was predicted. During time period 2071-2100 the area with potential occurrence of codling moth increases to 43% comparing to 25% area affected by the moth during the reference period.

Key words: CLIMEX, Codling Moth, number of generation, future distribution

INTRODUCTION

Climate change and global warming will have serious consequences for the diversity and abundance of arthropods, and the extent of losses due to insect pests, which will impact both crop production and food security. Presently, it is estimated that the amount of food that insects consume (pre- and post-harvest) is sufficient to feed more than 1 billion people (Sharma, Prabhakar, 2014). Global warning will lead to earlier beginnings and prolongation of growing season in temperate regions and will have pronounced effect on phenology and life-history adaptation in many species (Stoeckli et al., 2012). Concerning insects, changes in the population dynamics are caused by a number of factors, but at least in temperate climates, the temperature is considered to be the most important factor affecting the developmental rate, fecundity and mortality of insects (Worner, 1992).

The codling moth, *Cydia pomonella* (L.) (*Lepidoptera: Tortricidae*), is one of the most devastating pest insects in apple orchards worldwide (Dorn et al., 1999). The pest was originally present in Eurasia; however, during the past two centuries, it has spreading globally with the commercial cultivation of apples and pears and has become one of the most successful pest insects known (Thaler et al., 2008). In Slovakia, codling moth belong to the most serious insect pests in orchards and the moth flight is for a number of years regularly monitored at the signalisation stations of the Central Controlling and Testing Institute in Agriculture to emerge signalisation alerts. The forecasting of appropriate time for spraying is based on the pheromone traps records and temperature records (www.uksup.sk). For the purpose of signalisation, the territory of Slovakia is divided to four signalisation zones defined by specific climatic conditions and latitude. But, we must consider that with changing climate the climatic characteristics of these zones will change. MEZEYOVÁ (2007) used the method of calculation the effective temperature sum above 10°C to analyse the potential number of codling moth generations in the condition of changing climate in Slovakia during the period 2001-2100. The model used here works with several climatic characteristics and could thus provide more accurate prediction on potential occurrence of pest in the future. The main goal of this paper is to estimate how the predicted climate changes may affect the occurrence and emergence of the codling moth in the Slovakia.

MATERIALS AND METHODS

CLIMEX is a simplified computer model that infers the response of a species or biological entity to climate by using its geographical distribution, its seasonal growth pattern and its mortality in different locations (BEDDOW et al., 2010). CLIMEX derives indices that describe the responses of a given species to changes in temperature and moisture. The CLIMEX model uses monthly input data (long-term monthly averages for minimum and maximum air temperatures, relative humidity at 9 a.m. and 3 p.m. and rainfall). The climatological requirements of a given species represent a key element when assessing the suitability of an area for population growth and when determining the stress induced by unsuitable climate conditions. These factors are expressed by the ecoclimatic index (EI), which describes the overall suitability of climate conditions for the establishment and long-term presence of a pest population at a given location (SVOBODOVÁ, et al. 2013). EI values range from 0–100, where EI = 0 indicates climatic conditions that are unfavourable for long-term species occurrence and EI > 30 represents very suitable climatic conditions for species occurrence (SUTHERST, MYAWALD, 1985). The modelled presence of codling moth, as well as several other pests was verified by comparing the observed pest occurrence data with the number of generations in a given modelled area in the central European domain using the 1961 – 1990 reference period. Based on this validated data three thresholds were determined for *Cydia pomonella* describing climate conditions suitable for long-term development of one (EI ≥ 24), two (EI ≥ 39) and three (EI ≥ 48) generations of the pest (SVOBODOVÁ, et al., 2013). The climate data used was derived from the model ARPEGE (SRES A1B). There are three evaluated time periods: the reference time period 1961 – 1990 and two future time periods 2021 – 2050 and 2071 – 2100. The ARPEGE model has been validated in the domain of ERA-40 within the CECILIA project. Spatial estimation of potential codling moth (*Cydia pomonella*) distribution was established by GIS software. As the input data represents an interpolated grid of 10 km x 10 km the outputs were chosen to be displayed in the same grid in order to avoid further data loss to interpolation.

RESULTS

According to CLIMEX model outputs, the conditions suitable for one generation development of *Cydia pomonella* (Figure 1) cover 25.43% of the area of Slovakia for the reference period 1961 – 1990. The most concentrated occurrence of *Cydia pomonella* can be found in Eastern Slovakian Lowlands. The occurrence of 2nd generation development is very rare (0.78%) situated also in the area mentioned above.

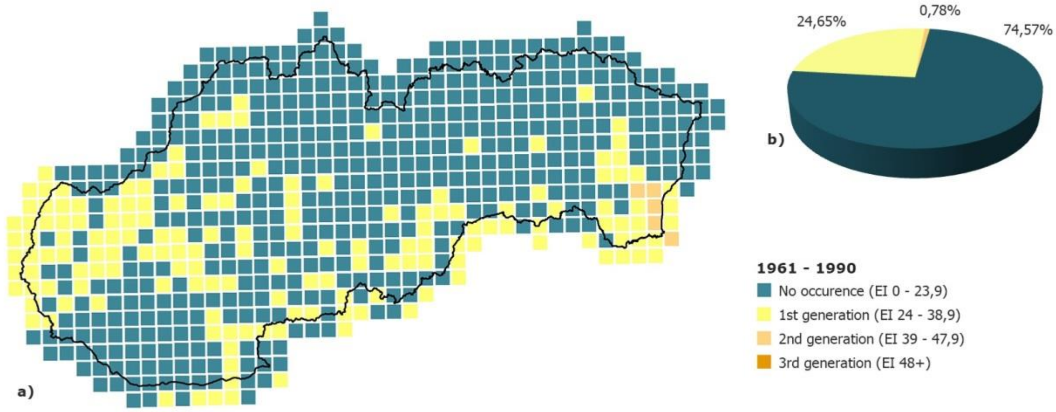


***Figure 1**: Spatial distribution (**a**) and acreage (%) of area (**b**) providing climatic conditions suitable for 1st, 2nd and 3rd generation by Cydia pomonella in the reference period 1961 – 1990 in Slovakia*

As for 2021 – 2050, the area of conditions suitable for development of *Cydia pomonella* (Figure 2) extended from 25.43% to 57.52%. On the other hand there is no projection of conditions suitable for development of 2nd generations of *Cydia pomonella* during the period 2021 – 2050. Comparing to reference period, the climatic conditions in Eastern Slovakian Lowland were found to do not provide the conditions suitable enough for even one generation development.

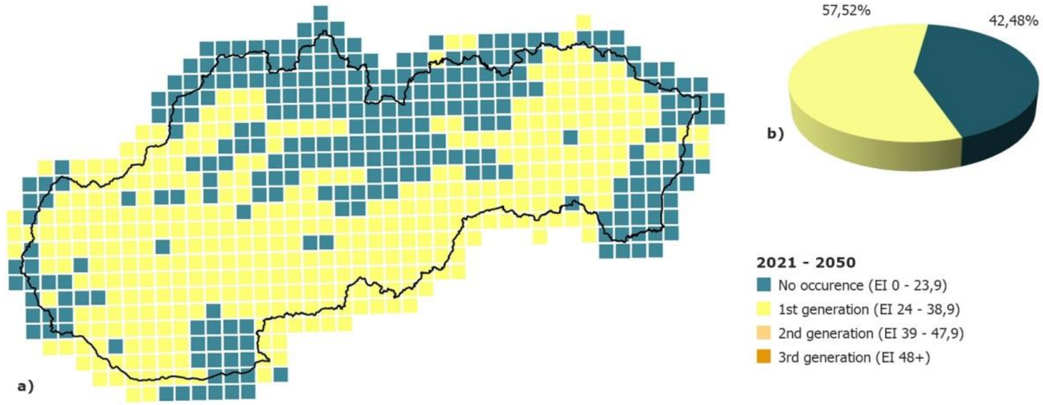


Figure 2: Spatial distribution (a) and acreage (%) of area (b) providing climatic conditions suitable for 1st, 2nd and 3rd generation by Cydia pomonella in the reference period 2021 – 2050 in Slovakia

In 2071 – 2100 the model outputs show a decline of the affected area by 14.73% (from 57.52% to 42.79%) in comparison to the period 2021 – 2050 yet still a significant rise by 17.36% compared to the reference period (from 25.43% to 42,79%). A northward range can be spotted in comparison to the period 2021 – 2050 where the southern regions of previously affected areas are now unsuitable for the development of *Cydia pomonella* while the northern regions show conditions suitable not only for one but for two (37.83%) or three (11.01%) generations development.

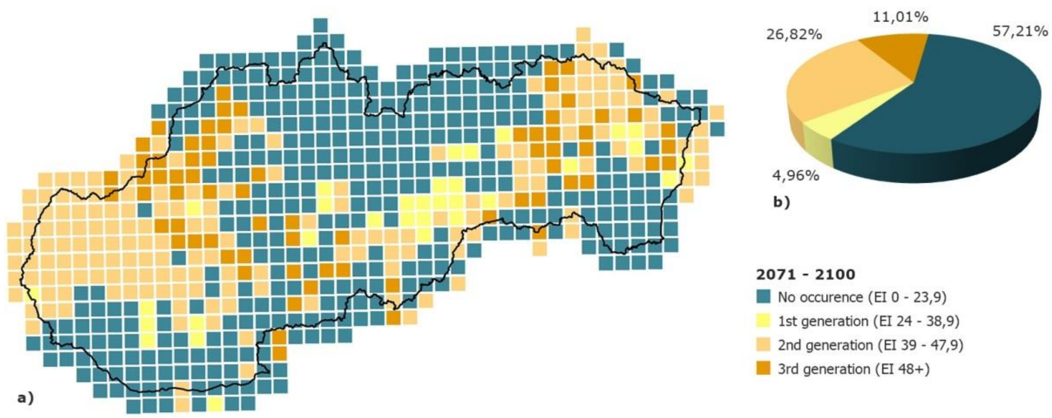


***Figure 3**: Spatial distribution (**a**) and acreage (%) of area (**b**) providing climatic conditions suitable for 1st, 2nd and 3rd generation by Cydia pomonella in the reference period 2071 – 2100 in Slovakia*

DISCUSSION

According model outputs, the pest status of codling moth is assumed to be more serious during both future periods modelled. The harmfulness of the pest during the period 2021-2050 will be increasing as the affected area will potentially cover to almost 60% of Slovakia. The affected area is expected to decrease during period 2071-2100, however, there is potential of the occurrence of conditions suitable for 2nd and even 3rd generation development. Mezeyová (2007) analysed the number of potential generations of codling moth in Slovakia using the calculation of effective temperature sum 10°C in the conditions of climate change during the period 2001–2100. The analysis stated increase in number of generations at all thirteen localities analysed. There was the presumption of three generation development and the development of one full generation cycle at the warmest and coldest localities surveyed, respectively (Mezeyová, 2007). According our model output, the occurrence of localities where codling moth would complete full three generations are situated mostly on central to northern part of Slovakia. In all account, the occurrence of 2nd generation will be expected regular at most infested localities in Slovakia in the future.

By 2050, it is thought that there will be an extra 3 billion people to feed. During this timescale, it is likely that insects will increase in numbers and in pest types. Thus, the prediction of changes in geographical distribution and population dynamics of insect pests will be useful for adapting IPM strategies to mitigate the adverse effects of climate change on crop production (Sharma, Prabhakar, 2014). Modelling the range and population dynamics of codling moth is vital in European countries. Irrespective of model or approach they use, the results indicate similar future situation: codling moth will affect wider area then currently, the key developmental stages will occur earlier, prolongation of the codling moth flight period and increasing probability of 3rd generation emergence (Hirschi et al., 2012; Juszczak et al., 2013; Pajač et al., 2012; Svobodová et al., 2013).

As the display of codling moth harmfulness within the territory of Slovakia were assumed being different during the two future periods modelled, the IPM strategies must also differ. To control additional generations of codling moth, an intensification and prolongation of control measures (e.g. insecticides) will be required, implying an increasing risk of pesticide resistances (Hirschi et al., 2012). Further to, the log-term insecticide treatments may be responsible for the changes in the behaviour of this pest as during three-year of research an additional third flight period of the codling moths was observed only in the treated orchards in Croatia (Pajač et al., 2012). The period 2071-2100 is thus appearing more critical concerning designing appropriate IPM strategies to control codling moth population in Slovakia.

Conclusion

Under future climate condition in Slovakia, the pest importance of codling moth was assumed to increase. The assumption is that codling moth will spread to the northern regions of Slovakia and will affect wider area. There was projected that the climatic condition will be unsuitable for 2nd generation development during the period 2021-2050, but, the range of codling moth may cover almost 60% of the territory of Slovakia. However the acreage of area affected by codling moth will decrease to about 43% of Slovak territory during the period 2071-2100, 2nd generation development was projected become the rule in most affected area. Furthermore, there was assumed that 3rd generation could emerge on about 11% of the territory of Slovakia during this period.

References

BEDDOW, J. M., KRITICOS, D., PARDEY, P. G., SUTHERST, R. W., 2010: Potential global crop pest distributions using CLIMEX. Harvest Choice applications. www.harvestchoice.org.

Dorn, S., Schumacher, P., Abivardi, C., Meyhofer, R.: 1999. Global and regional pest insects and their antagonists in orchards: spatial dynamics. Agric. Ecosyst. Environ. 73, 111–118.

Hirschi, M., Stoeckli, S., Dubrovsky, M., Spirig, C., Calanca, P., Rotach, M.W., Fischer, A.M., Duffy, B., Samietz, J.: 2012. Downscaling climate change scenarios for apple pest and disease modeling in Switzerland. Earth System Dynamics. 3, 33–47, 2012

Juszczak, R., Kuchar, L., Leśny, J., Olejnik, J.: 2013. Climate change impact on development rates of the codling moth (Cydia pomonella L.) in the Wielkopolska region, Poland. International Journal of Biometeorology (2013) 57:31–44. DOI 10.1007/s00484-012-0531-0

Mezeyová, I. 2007. The proposal of agroclimatic regionalization of chosen apple tree varieties (Malus domestica Borkh.) in condition of changing climate in Slovakia (thesis). Slovak University of Agriculture in Nitra. 132 p.

PAJAČ, I., BARIĆ, B, MIKAC, K.M., PEJIĆ, I.: 2012. New insights into the biology and ecology of Cydia pomonella from apple orchards in Croatia. Bulletin of Insectology 65 (2): 185-193, 2012

Sharma, H.C. - Prabhakar, C.S.: 2014 Impact of Climate Change on Pest Management and Food Security. In: Integrated Pest Management, edited by Dharam P. Abrol, Academic Press, San Diego, 2014, Pages 23-36, ISBN 9780123985293, http://dx.doi.org/10.1016/B978-0-12-398529-3.00003-8.

Stoeckli, S., Hirschi, M., Spirig, C., Calanca, P., Rotach, M.W., Samietz, J.: 2012. Impact of climate change on voltinism and prospective diapause induction of a global pest insect – Cydia pomonella (L.). PLoS ONE 7(4): e35723. doi: 10.1371/journal.pone.0035723

SUTHERST, R. W., MAYWALD, G. F., 1985: A computerised system for matching climates in ecology. Agriculture Ecosystems and Environment 13, 281–299.

SVOBODOVA, E., TRNKA, M., DUBROVSKY, M., SEMERADOVA, D., EITZINGER, J., ŽALUD, Z., ŠTĚPANEK, P.: Pest occurrence model in current climate – validation study for European domain. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 00–00

THALER R., BRANDSTÄTTER A., MERANER A., CHABICOVSKI M., PARSON W., ZELGER R., DALLA VIA J., DALLINGER R. 2008. Molecular phylogeny and population structure of the codling moth (Cydia pomonella) in Central Europe: II. AFLP analysis reflects human-aided local adaptation of a global pest species. Molecular Phylogenetics and Evolution, 48: 838-849.

WORNER S. P., 1992. Performance of phenological models under variable temperature regimes: consequences of the Kaufmann or rate summation effect. Environmental Entomology, 21 (4): 689-699.

Acknowledgement

This work was supported by the project VEGA 2/0117/13: Evaluation of state and dynamics of biotops using modelling and remote sensing; GIS outputs were created with the help of Vojtěch Lukas from MZLU in Brno, Czech Republic

SUMMARY

Obaľovač jablčný (*Cydia pomonella*) je celosvetovo najvýznamnejší škodca v ovocných sadoch jabloní. Na Slovensku sú vzhľadom na jeho veľký význam ako škodcu každoročne monitorované jeho nálety na signalizačných staniciach Ústredného kontrolného a skúšobného ústavu poľnohospodárskeho. Cieľom monitoringu je vydávanie tzv. signalizačných výstrah pre ochranu pred škodcom, pričom signalizácia je vykonaná na základe odchytov do feromónových pascí a teplotných údajov. Územie Slovenska je pre potreby signalizácie rozdelené do štyroch signalizačných pásiem definovaných klimatickými podmienkami a nadmorskou výškou. Vplyvom klimatických zmien však musíme predpokladať, že do budúcna sa klimatické charakteristiky týchto pásiem zmenia. Nakoľko klimatické zmeny ovplyvňujú aj populačnú dynamiku a priestorové rozšírenie hmyzu, cieľom príspevku je zhodnotiť, akým spôsobom môžu klimatické zmeny ovplyvniť potenciálnu škodlivosť obaľovača jablčného v podmienkach Slovenska; tu definovanú pomocou dvoch faktorov: priestorového rozšírenia a počtu dokončených generácií v jednom roku. Pre hodnotenie bol použitý matematický model CLIMEX pre územie Slovenskej republiky. Použité klimatické podmienky boli simulované podľa SRES A1B scenára GCM modelu ARPEGE pre tri časové intervaly: 1961–1990, 2021–2050 a 2071–2100. Zmeny priestorového rozpoloženia potenciálneho výskytu obaľovača jablčného boli vyhodnotené cez mapy vygenerované prostredníctvom programu EsriArcGIS. V období 1961–1990 a 2021–2050 boli prevažne podmienky vhodné pre vytvorenie iba prvej generácie hodnoteného škodcu. Bolo vyhodnotené, že počas obdobia 2021-2050 nebudú vhodné podmienky pre vytvorenie druhej generácie škodcu, avšak zasiahnuté územie sa zvýši na takmer 60% plochy Slovenskej republiky. V období 2071–2100 zasiahnuté územie poklesne na 43%. Avšak rozloha, na ktorej by sa mohla vyskytnúť i druhá generácia sa zvýšila z 0% na 38%, pričom na takmer tretine z toho, na 11% z rozlohy, by sa mohla objaviť i tretia generácia. Na základe výstupov modelu môžeme predpokladať, že pri oboch hodnotených časových intervaloch môžeme očakávať nárast jeho škodlivosti. Z porovnania s ostanými podobnými štúdiami vyplýva, že okrem zväčšenia svojho areálu a nárastu počtu generácií sa predĺži aj časový interval, počas ktorého bude potrebné používať chemickú ochranu. Intenzívnejšia chemická ochrana má za následok zmeny v populačnej dynamike škodcu ako aj nárast rezistencie voči insekticídom. Všetky tieto faktory

bude potrebné do budúcna zohľadniť pre vypracovanie efektívnej IPM stratégie pre kontrolu populácií obaľovača jablčného.

CONTACT

Ing. Juraj Vavrovič

Department of Ecology, Faculty of European studies and Regional Development, Slovak University of Agriculture in Nitra

Mariánska 10, 949 01 Nitra, Slovakia

00421 037 641 5612, xvavrovic@is.uniag.sk

THE IMPACT OF DROUGHT INCIDENCE ON YIELD VARIABILITY OF CEREALS IN SLOVAKIA AS INFLUENCED BY CLIMATE CHANGE

VERONIKA ZUZULOVÁ[1], JURAJ VAVROVIČ[1], BERNARD ŠIŠKA[1]

Department of Ecology, Faculty of European Studies and Regional Development, Slovak University of Agriculture in Nitra, Slovakia[1]

ABSTRACT

Spatial variability of drought incidence in Slovakia was evaluated on the basis of data from 10 weather stations and selected soil parameters of the sites. Palmer Drought Severity Index was used as indicator of dry and wet periods to compare the impact of climate on yield variability of winter wheat, spring barley and maize in two climatic normals, 1951 – 1980 and 1981 – 2010. The highest increase in yield variability was found in the case of maize yield; the lower variability for wheat yield. The impact of climate change resulted in increase of yield variability in the second climatic normal (1981 – 2010). As concerning spatial aspect, the occurrence of drought was more frequent in lowland areas of Slovakia. A significant connection of drought to the variability in yield was not detected.

Key words: PDSI, winter wheat, spring barley, maize

INTRODUCTION

Drought can be seen as the cause of natural disasters. Shortage of water sources during the dry periods in the conditions of changing climate can negatively affect agriculture, forestry, watercourse regime as well as natural ecosystems in Central Europe (ŠKVARENINA et al 2009, BRÁZDIL et al. 2009). One of the methods for evaluating draught is the Palmer Drought Severity Index (PALMER, 1965). PDSI calculation takes into account not only the climate but also soil characteristics. Over the past years its use gradually spread to the areas of meteorology, hydrology, forestry, economics and agriculture (LITSCHMANN, 2001, TRNKA, 2008). In terms of agriculture the water balance during the months April to June plays a key role in the estimation of total yield of most of the major crops. A significant disruption of the water balance in the mentioned period April to June occurs on average in a 20 year interval. The likelihood of this occurrence can however rise up to five times until 2050. That would mean that the water balance in the period April to June would be disrupted once every four years (HLAVINKA et al. 2009). Extensive changes in the water balance in the period April to June can be expected in whole of the Central Europe (ŠIŠKA – TAKÁČ, 2009).

MATERIALS AND METHODS

For the evaluation of drought Palmer Drought Severity Index (PDSI) was used (PALMER, 1965). The index is standardized for various regions and time periods. Therefor it is usable for the evaluation of drought in various areas with various climates (DUNKEL, 2009). The calculation of PDSI was carried out by a program developed at the University of Nebraska – Lincoln. It was written in FORTRAN by Tom Heddinghaus (TURŇA, 2014). The input data consists of: average monthly precipitation totals, average monthly air temperatures, average temperatures during the evaluated period, latitude and available water capacity. The climate data was provided by SHMI. Available water capacity was provided by the Soil Science and Conservation Research Institute in Bratislava. For the evaluation of drought ten sites were chosen: Bratislava, Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad, Košice, Milhostov and Kamenica nad Cirochou (figure 1). The sites were chosen to cover the altitude profile of the agricultural production area of Slovakia. The key stations are Hurbanovo (Danube Lowland), Čadca (northern Slovakia), Poprad (below Tatra Mountains) and Milhostov (Eastern Slovak Lowland). The evaluation was carried out on two 30-year time periods, 1951 – 1980 and 1981 – 2010. In this paper periods covering more than 10 continual dry months are recognized as long-term drought periods.

***Figure 1**: Evaluated sites: 1 – Bratislava, 2 – Piešťany, 3 – Hurbanovo, 4 – Čadca, 5 – Sliač, 6 – Boľkovce, 7 – Poprad, 8 – Košice, 9 – Milhostov, 10 – Kamenica nad Cirochou*

***Table 1**: PDSI classification*

PDSI value	Characteristics of the evaluated month
≥ 4,00	extremely moist
3,00 to 3,99	very moist
2,00 to 2,99	moderately moist
1,00 to 1,99	slightly moist
0,50 to 0,99	weakly moist
0,49 to -0,49	neutral
-0,50 to -0,99	weakly dry
-1,00 to -1,99	slightly dry
-2,00 to -2,99	moderately dry
-3,00 to -3,99	severely dry
≤ -4,00	extremely dry

For the assessment of variability of biomass production of agricultural crops winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*) and maize (*Zea mays*) were chosen. The evaluation was based on variability of PDSI values (table 1) and the production of the crops. MARKECHOVÁ, STEHLÍKOVÁ and TIRPÁKOVÁ (2011) indicate that the variability according to the value of the coefficient of variation can be: modest (0% – 4%), normal (5% – 44%), high (45% – 64%), very high (65% – 84%), extreme (85% – 104%) or anomalous (105% and more). The variability of production of the crops was evaluated individually for Western, Central and Eastern Slovakia. The data on crop yields were provided by the Statistical Office of the Slovak Republic.

RESULTS

In Bratislava during 1951 – 1980 most months were classified as slightly dry at 16.9%. Overall, 50.3% of the months were recognized as dry according to the PDSI classification. There has been recorded four long-term drought periods in 1951 – 1980. In the period 1981 – 2010 most of the months were classified as slightly dry at 15.6%. The amount of extremely dry months increased by 0.6% compared to the first evaluated period (from 2.5% to 3.1%). Overall, 52.5% of the months were recognized as dry according to the PDSI classification (an increase by 2.2%). Only one long-term drought period was recorded in 1981 – 2010 (a decrease by 3).

In Piešťany during 1951 – 1980 most months were classified as slightly moist at 16.1%, followed by neutral at 11.7% and slightly dry at 11.4%. Extremely dry months represented 3.9%. Overall, 42.2% of the months were recognized as dry according to the PDSI classification. There has been recorded 6 long-term drought periods. In 1981 – 2010 most of the months were classified as slightly moist at 16.7%, followed by slightly dry at 15%. Overall, 43.6% of the months were recognized as dry according to the PDSI classification (an increase by 1.4%) with 6.7% being extremely dry. There has been recorded 5 long-term drought periods (a decrease by 1).

In Hurbanovo during 1951 – 1980 (figure 2) most months were classified as neutral at 17.2%. During the period 46.4% of the months were recognized as dry according to the PDSI classification, with 1.1% being extremely dry. There has been recorded 3 long-term drought periods. The period 1981 – 2010 (figure 3) was mostly represented by slightly dry and moderately dry months, both at 16.1%, followed by neutral months at 15.8%. Overall, 48.6% of the months were recognized as dry according to the PDSI classification (an increase by 2.2%) with 1.9% being extremely dry. There has been recorded 6 long-term drought periods (an increase by 3).

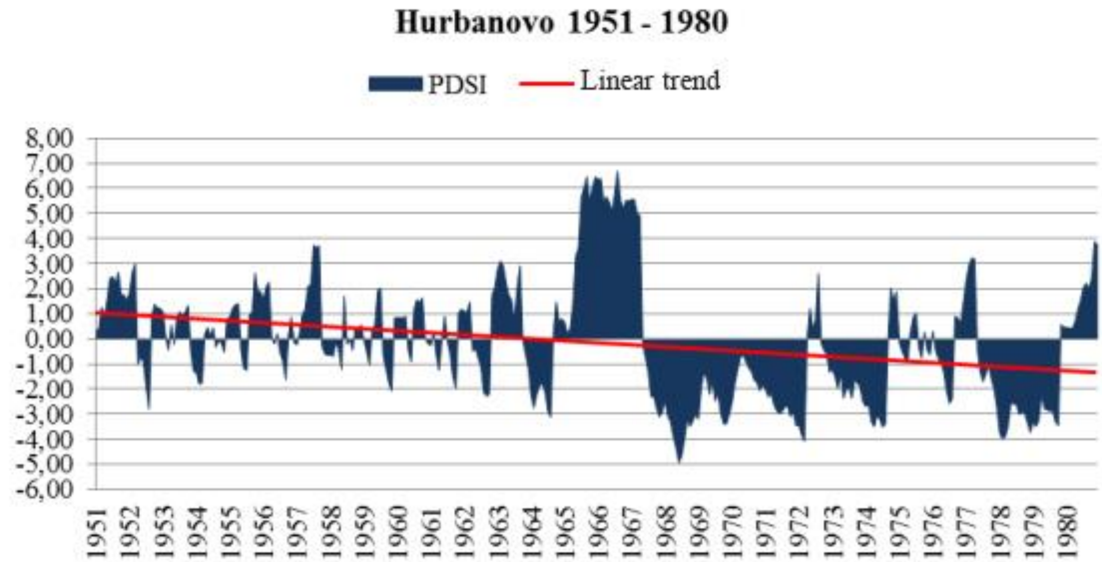


Figure 2*: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Hurbanovo*

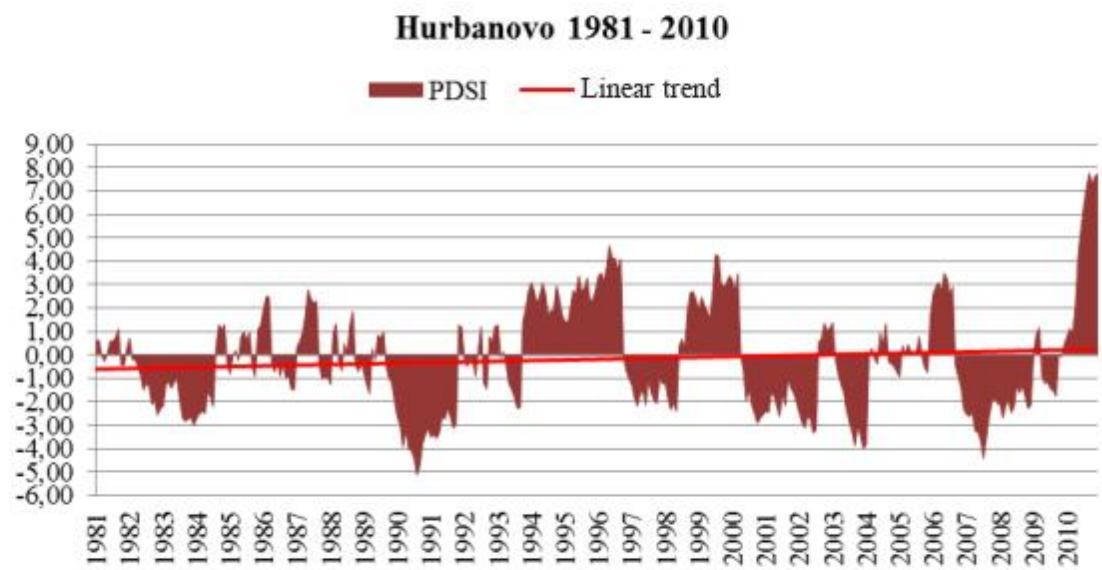


Figure 3*: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Hurbanovo*

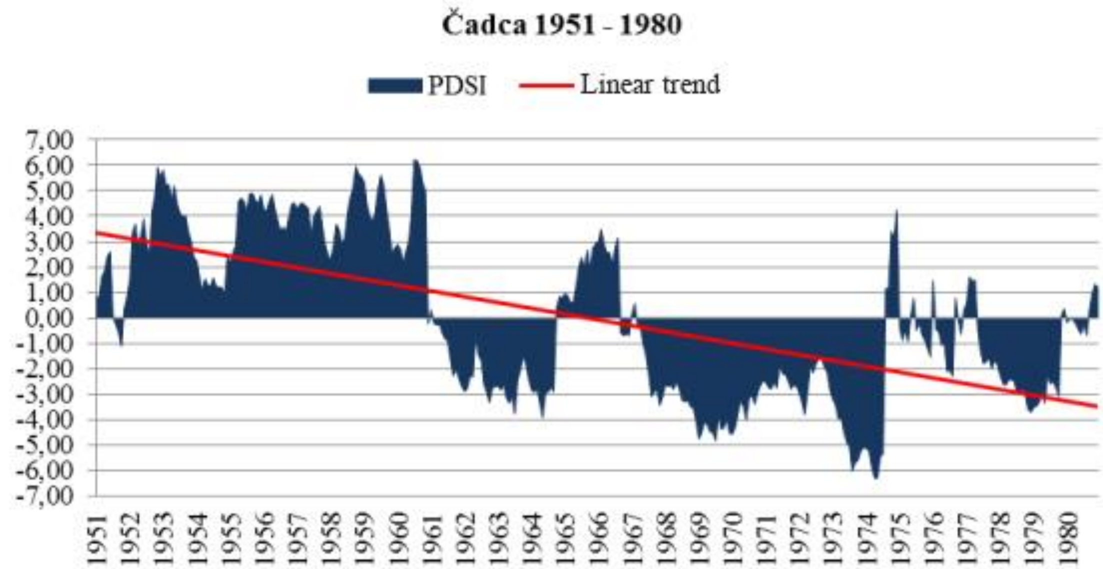


Figure 4*: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Čadca*

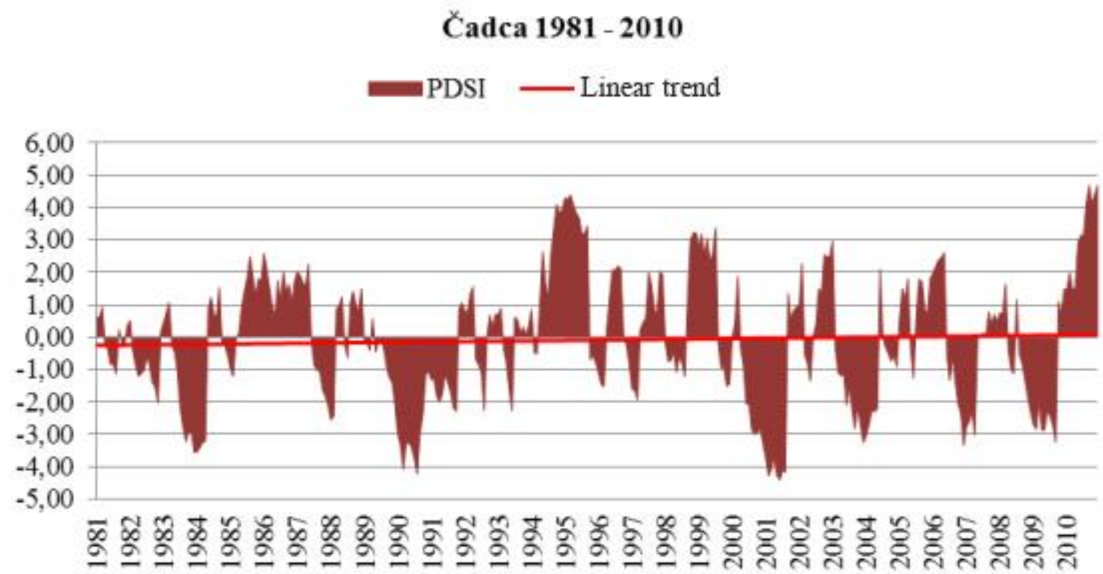


Figure 5*: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Čadca*

In Čadca during 1951 – 1980 (figure 4) most months were classified as moderately dry at 19.4%. Extremely dry months figured at a significant amount of 8.1% as well as extremely moist months with the amount of 15.6%. Overall, 49.5% of the months were recognized as dry according to the PDSI classification. There has been recorded 3 long-term drought periods out of which the longest one lasted over 7 continual years. However, in 1981 – 2010 (figure 5) only 2.2% of the months were classified as extremely dry and only 2.8% as extremely moist.This period was represented mostly by neutral months at the amount of 15.6%. Overall, 43.1% of the months were recognized as dry according to the PDSI classification (a decrease by 6.4%). There has been recorded 4 long-term drought periods (an increase by 1).

In Sliač during 1951 – 1980 most months were classified as neutral at 17.8%, followed by slightly dry at 15.3% and slightly moist at 14.4%. Overall, 42.2% of the months were recognized as dry according to the PDSI classification with 1.1% being extremely dry. There has been recorded 4 long-term drought periods. In 1951 – 2010 most of the months were classified as neutral and slightly dry, both at 15.6%. Overall, 45.3% of the months were classified within the range from weakly dry to extremely dry (an increase by 3.1%), with 1.4% being extremely dry. There has been recorded 5 long-term drought periods (an increase by 1).

In Boľkovce during 1951 – 1980 most months were classified as slightly dry at 14.7%. Overall, 45% of the months were recognized as dry according to the PDSI classification with 2.2% being extremely dry. There has been recorded 5 long-term drought periods. In 1981 – 2010 most months were classified as slightly dry at 17.8%. Overall, 49.7% of the months were recognized as dry according to the PDSI classification (an increase by 4.7%) with 2.2% being extremely dry. There has been recorded 4 long-term drought periods (a decrease by 1) with one lasting almost 4 years.

In Poprad during the period 1951 – 1980 (figure 6) most months were classified as neutral at 18.3% followed by slightly dry at 13.6%. Extremely moist months were represented by 2.5% and extremely dry months by 2.2%. Overall, 38.6% of the months were recognized as dry according to the PDSI classification. There has been recorded 4 long-term drought periods in 1951 – 1980. In the period 1981 – 2010 (figure 7) most of the months were classified as neutral at 16.7%, followed by slightly moist at 14.7% and moderately moist at 13.3%. The amount of extremely dry months has increased by 1.1% compared to the previous period, from 2.2% to 3.3%. Overall, 43.3% of the months were recognized as dry according to the PDSI classification (an increase by 4.7%). 3 long-term drought periods were recorded in 1981 – 2010 (a decrease by 1), two of which were significantly longer compared to those in 1951 – 1980.

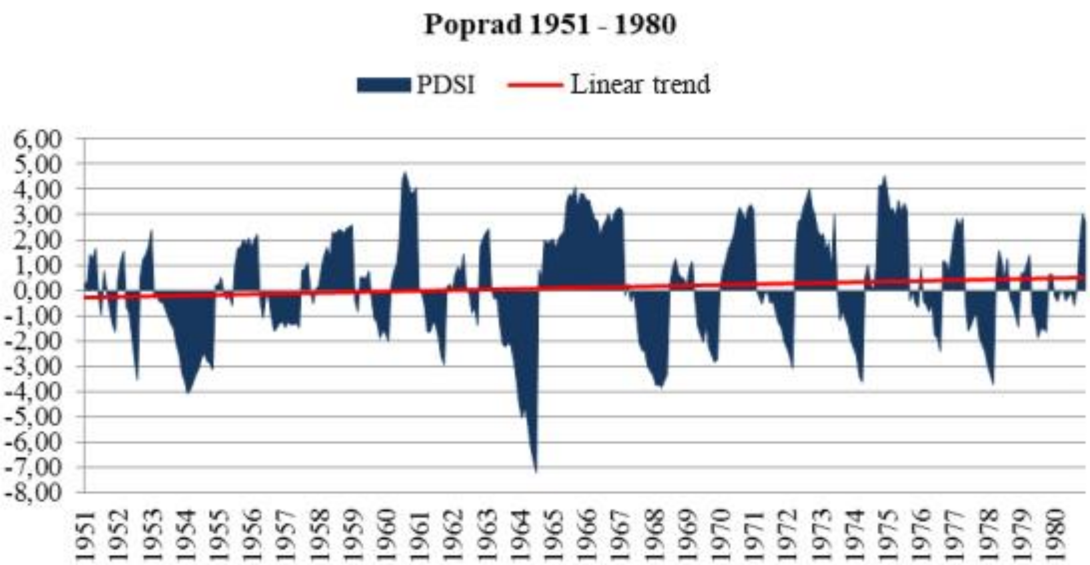


***Figure 6**: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Poprad*

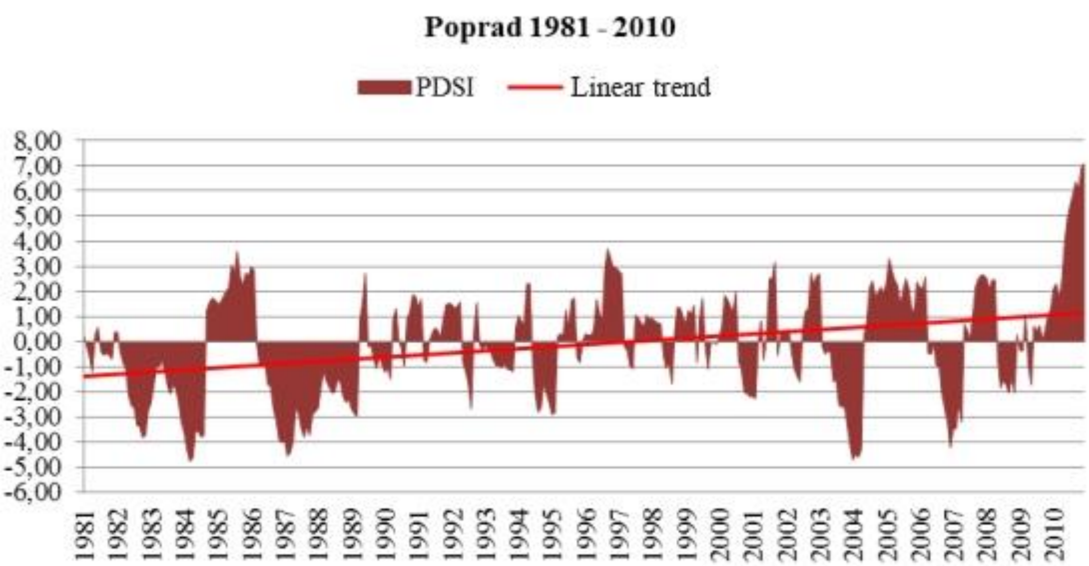


***Figure 7**: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Poprad*

In Košice during 1951 – 1980 most of the months were classified as slightly dry at 13.9%, followed by moderately moist at 13.3%. Extremely dry months were represented by 2.8%. Overall, 48.6% of the months were recognized as dry according to the PDSI classification. There has been recorded 6 long-term drought periods. In 1981 – 2010 the most frequent month classification was neutral at 16.9%, followed by slightly dry at 16.7%. Overall, 46.1% of the months were recognized as dry according to the PDSI classification (a decrease by 2.5%) with 3.1% being extremely dry. There has been recorded 5 long-term drought periods (no change).

In Milhostov during 1951 – 1980 (figure 8) most of the months were classified as neutral at 15.3%. During the period 46.7% of the months were recognized as dry according to the PDSI classification with 3.1% as extremely dry. There has been recorded 6 long-term drought periods. The period 1981 – 2010 (figure 9) was mostly represented by slightly dry months at 19.7%, followed by neutral months at 16.7%. Overall, 49.4% of the months were recognized as dry according to the PDSI classification (an increase by 2.7%) with 1.4% being extremely dry. There has been recorded 5 long-term drought periods (a decrease by 1).

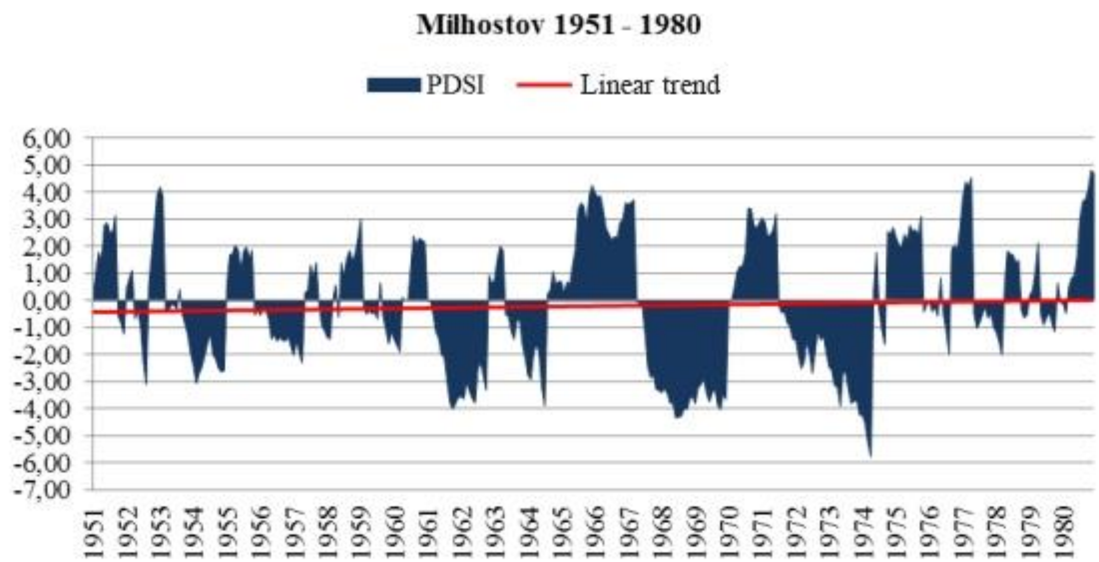


***Figure 8**: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Milhostov*

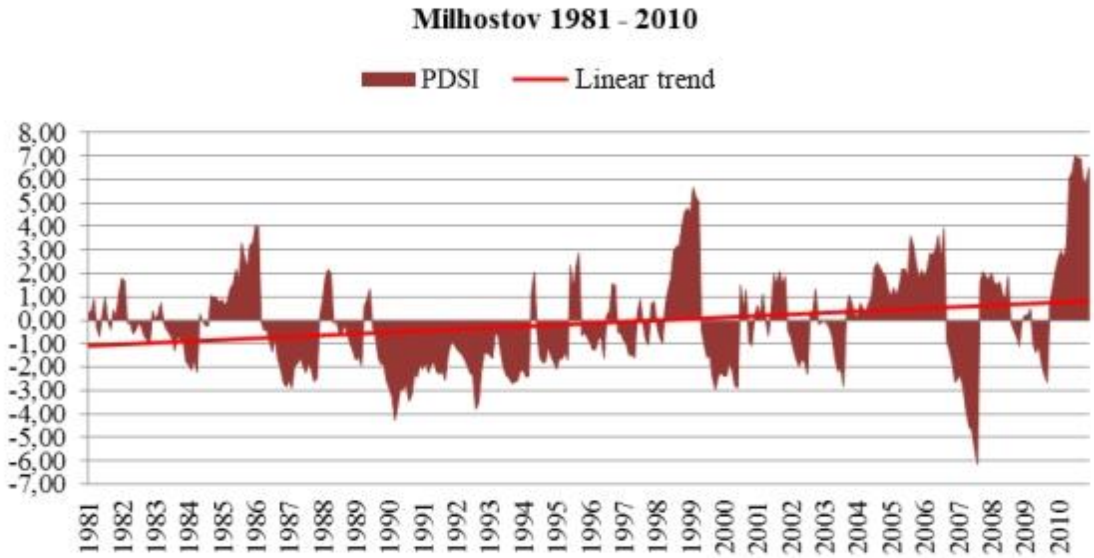


Figure 9*: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Milhostov*

In Kamenica nad Cirochou during 1951 – 1980 most of the months were classified as neutral at 15.8%, closely followed by slightly moist at 15.6%. Extremely dry months represented 8.1% which represented the highest amount from all observed sites in both evaluated periods. Overall, 41.1% of the months were recognized as dry according to the PDSI classification. There has been recorded 4 long-term drought periods. In 1981 – 2010 the most frequent classification was neutral at 14.7%, followed by weakly moist and moderately dry, both at 12.2%. Overall, 44.2% of the months were recognized as dry according to the PDSI classification (an increase by 3.1%) with 2.8% being extremely dry (a decrease by 5.3%). There has been recorded 4 long-term drought periods (no change).

The growing season of spring barley is shortest and that of winter wheat the longest of the evaluated crops. This fact could affect the relationship between drought and crop production, whereas some of the dry months were not included in the growing seasons. The coefficients of variation of crop production divided into two periods (1951 – 1980, 1981 – 2010) are given in tables 2 to 4.

***Table 2**: Coefficients of variation of crop production as a percentage for Western Slovakia*

1951 – 1980		**1981 – 2010**	
crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	50	winter wheat	69.3
spring barley	36.7	spring barley	37.7
maize	47.4	maize	58.2

In Western Slovakia the coefficient of variation of winter wheat production was 50% in 1951 – 1980. In 1981 – 2010 the coefficient of variation was 19.3% higher (at 69.3%) while the coefficient of variation of spring barley production showed an increase by 1% and the coefficient of variation of maize production showed an increase by 10.8% in 1981 – 2010 compared to 1951 – 1980. This implies that the distribution of the dry months during the growing season of spring barley during 1981 – 2010 did not change significantly compared to the period 1951 – 1980. Coefficient of variation in the case of other crops is the opposite.

***Table 3**: Coefficients of variation of crop production as a percentage for Central Slovakia*

1951 – 1980		**1981 – 2010**	
Crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	60.6	winter wheat	49.9
spring barley	47.2	spring barley	48.4
maize	29.1	maize	57.4

In Central Slovakia the coefficient of variation of winter wheat production showed a decrease by 10.7% in the period 1981 – 2010 in comparison to the period 1951 – 1980. This was the only case in this study where the coefficient of variation was lower in 1981 – 2010. The reason on this phenomenon was due to moister winters in 1981 – 2010 compared to those in 1951 – 1980. The coefficient of variation of spring barley was higher by 1.2% in 1981 – 2010. As in the case of maize, it was higher by 28.3%. This means that a situation similar to that in Western Slovakia was observed. However, the growing season of maize was affected by the dry growing season more significantly than the growing season of spring barley.

***Table 4**: Coefficients of variation of crop production as a percentage for Eastern Slovakia*

1951 – 1980		**1981 – 2010**	
crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	37	winter wheat	59.6
spring barley	10.9	spring barley	35.6
maize	38.6	maize	40.5

In Eastern Slovakia higher values of the coefficients of variation were recorded in the period 1981 – 2010 for all of the evaluated crops, by 22.6% for winter wheat, by 24.7% for spring barley and 1.9% for maize production compared to the period 1951 – 1980. On this location a change was observed compared to the Western and Central Slovakia in a significantly higher increase of the coefficient of variation of spring barley production and a significantly lower increase of the coefficient of variation of maize production. This means that the growing season of spring barley during the period 1981 – 2010 in comparison to that in 1951 – 1980 was affected by drought to a higher extent than the growing season of maize.

Discussion

The most significant drought periods mutual for all of the ten evaluated sites were observed in 1954 (except in Čadca), 1964, 1968, 1973, 1974 and 2007.

The variability of the results of other papers compared to this study is most probably caused by different evaluated periods. The 30-year periods were designed to cover the closest past. In the methods of PDSI calculations one of the inputs is the average temperature over the evaluated period. As some of the other inputs represent latitude and available water capacity it is not suitable to compare the results of this study with other papers.

It is important to mention the fast that 2010 was very rich in the means of precipitation totals which could be responsible for the positive trend on seven of the ten evaluated sites. As VIDO

(2012) mentions, this can lead to the misinterpretation of reality. Therefor one must be very cautious when trying to interpret draught. HLAVINKA, TRNKA, SEMERÁDOVÁ et al. (2009) state that the correlation between drought (PDSI values) and the production of crops was not as big in the case of maize compared to the cases of spring barley and winter wheat. This study shows that the variability of production in relation to drought is the smallest in the case of spring barley. This could be caused with the shorter growing season of spring barley compared to the growing season of maize which was annually not affected as much as spring barley.

Based on the values of the computed coefficients of variation in both of the evaluated periods it can be stated that the production variability of the selected crops in relation to drought was normal to high. The production variability of winter wheat and maize was high in Western Slovakia in both evaluated periods. The production variability of spring barley in relation to drought was normal. In Central Slovakia the production variability of maize in relation to drought was normal in the period 1951 – 1980, the production variability of maize in 1981 – 2010 was high same as of the other evaluated crops.

For Eastern Slovakia normal production variability in relation to drought was typical for all crops in both evaluated periods. The only exception was winter wheat where in 1981 – 2010 its production variability was classified as high.

By comparing the two evaluated periods it can be stated that the variability in 1981 – 2010 is higher than in 1951 – 1980. This could have been caused also by the year 2010 being overly rich on precipitations which logically lead to damage to the yields of crops.

CONCLUSION

Based on the distribution of the months according to the PDSI classification it was shown that period 1981 – 2010 featured more months classified as dry (in the range from weakly dry to extremely dry) than the period 1951 – 1980. This was proven in eight of the ten evaluated sites. The exceptions were the two sites Čadca and Košice. This could have been caused by the influence of continental climate.

From the comparison of the trends between the evaluated periods it was observed that in the period 1951 – 1980 seven out of the ten sites shown a negative (drying) trend. The mentioned sites are: Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad a Milhostov. The drying trend was only observed in three sites in the period 1981 – 2010, in Bratislava, Košice and in Kamenica nad Cirochou. The most common linear trend of the period 1981 – 2010 was mainly caused by the significantly moist year 2010 which represented the last year of the evaluated period. The influence of drought presence in relation to production variability of winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*) and maize (*Zea mays*) on the basis of their coefficients of variation can be evaluated as normal to high. The production variability in relation to drought was higher in the period 1981 – 2010 than in the period 1951 – 1980. This was caused by distribution of dry and moist years in the period 1981 – 2010 and by the extremely wet year 2010.

REFERENCES

BRÁZDIL, R. et al. 2009. Variability of droughts in the Czech Republic, 1881 – 2006. In Theoretical and Applied Climatology. vol. 97, pp. 297 – 315. ISSN 1434-4483.

DUNKEL, Z. 2009. Brief surveying and discussing of drought indices used in agricultural meteorology. In Időjárás, Quarterly Journal of the Hungarian Meteorological Service, vol. 113, No. 1 – 2, Januray – June 2009, pp. 23 – 37.

HLAVINKA, P. – TRNKA, M. – SEMERÁDOVÁ, D. – DUBROVSKÝ, M. – ŽALUD, Z. – MOŽNÝ, M. 2009. Effect of drought on yield variability of key crops in Czech Republic. In Agricultural and Forest Meteorology, vol. 149, s. 431 – 442.

LITSCHMANN, T. – ROŽNOVSKÝ, J. 2001. Palmerův index závažnosti sucha a jeho aplikace pro lokalitu Žabčice. In Sucho, hodnocení a predikce : pracovní seminář. Brno.

MARKECHOVÁ, D. – STEHLÍKOVÁ, B. – TIRPÁKOVÁ, A. 2011. Štatistické metódy a ich aplikácie. Nitra : UKF, 534 s. ISBN 978-80-8094-807-8.

PALMER, W. C. 1965. Meteorologic Drought : Research Paper NO. 45, Washington, D.C. : U.S. Weather Bureau, 58 s.

ŠIŠKA, B. – TAKÁČ, J. 2009. Drought analyses of agricultural regions as influenced by climatic conditions in the Slovak Republic. In Időjárás : Quarterly Journal of the Hungarian Meteorological Service. - Budapest : Hungarian Meteorological Service, vol. 113, no. 1-2, pp. 135-143.

ŠKVARENINA, J. – TOMLAIN, J. – HRVOĽ, J. – ŠKVARENINOVÁ, J. 2009. Occurrence of dry and wet periods in altitudinal vegetation stages of West Carpathians in Slovakia: Time-Series Analysis 1951-2005. In Bioclimatology and Natural Hazards (eds.: Strelcova et al.). Springer-Verlag, 97-106.

TRNKA, M. (ed) 2008. Metodiky sledování zranitelnosti ekosystémů a adaptačních opatření ve vazbě na změnu klimatu. In ŽALUD, Z. et al. Biologické a technologické aspekty udržatelnosti řízených ekosystémů a jejich adaptace na změnu klimatu – metodiky stanovení indikátorů ekosystémových služeb. Brno : Ediční středisko MZLU. pp. 140. ISBN 978-80-7375-221-7.

TURŇA, M. 2014. PDSI [e-mail communication]. Message for: ZUZULOVÁ, V. 2014-03-03 [cit. 2014-03-17].

VIDO, J. 2012. Zelené sucho. In Interaktívna Konferencia Mladých Vedcov 2012. Banská Bystrica : PREVEDA, s. 68.

Acknowledgement

The presented paper was supported by the project VEGA 2/0117/13: Evaluation of state and dynamics of biotops using modelling and remote sensing.

Summary

Štúdia bola zameraná na zhodnotenie stavu sucha na Slovensku v podmienkach meniacej sa klímy. Pre hodnotenie sucha bola vybraná metóda prostredníctvom Palmerovho indexu závažnosti sucha (PDSI). Tento spôsob hodnotenia sucha sa odlišuje od predchádzajúcich používaných spôsobov hodnotenia tým, že využíva aj dáta o pôdnych pomeroch (dostupnej vodnej kapacite). Pre hodnotenie bolo zvolených desať lokalít (Bratislava, Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad, Košice, Milhostov a Kamenica nad Cirochou) a dva časové rady (1951 – 1980 a 1981 – 2010). Bolo pozorovaných niekoľko spoločných období sucha na všetkých sledovaných lokalitách. Boli to obdobia v rokoch 1954 (s výnimkou Čadce), 1964, 1968, 1973, 1974 a 2007. Niektoré predstavovali časť daného roka, v iných prípadoch boli suché obdobia v spomínaných rokoch súčasťou dlhších suchých období (trvajúcich viac ako 1 súvislý rok).

Na základe percentuálneho podielu mesiacov od kategórie obdobia začínajúceho sucha až do kategórie extrémne suché mesiace možno konštatovať, že väčší podiel, a teda suchšie obdobie, predstavoval časový rad 1981 – 2010. To sa preukázalo v prípade ôsmich lokalít. Výnimku

predstavovali len dve lokality, a to Čadca a Košice, v ktorých suchšie obdobie predstavovalo časový rad 1951 – 1980. Príčinou mohol byť vplyv kontinentálnej klímy. Vplyv výskytu sucha na variabilitu produkcie pšenice letnej formy ozimnej (*Triticum aestivum*), jačmeňa jarného (*Hordeum vulgare*) a kukurice siatej (*Zea mays*) na základe variačných koeficientov možno zhodnotiť ako normálny až veľký. Variabilita produkcie v závislosti od sucha bola vyššia v rokoch 1981 – 2010 ako v rokoch 1951 – 1980. Príčinou bolo rozdelenie suchých a vlhkých mesiacov počas druhého sledovaného obdobia zakončené extrémne vlhkým rokom 2010.

Odporúčanie pre hospodárenie na Slovensku v podmienkach meniacej sa klímy predstavuje aplikáciu doplnkových závlah, ktoré sú osvedčeným opatrením pre stabilizáciu produkcie vybraných obilnín.

CONTACT

Ing. Juraj Vavrovič
Department of Ecology, Faculty of European studies and Regional
Development, Slovak University of Agriculture in Nitra
Mariánska 10, 949 01 Nitra, Slovakia
00421 037 641 5612, xvavrovic@is.uniag.sk

THERMIC CONTINENTALITY IN SLOVAKIA AND CLIMATE CHANGES

JOZEF VILČEK[1], JAROSLAV ŠKVARENINA[2], JAROSLAV VIDO[2], RADOSLAV KANDRÍK[2]

1) *Department of Geography and Applied Geoinformatics, University of Presov in Presov, Slovak Republic*
2) *Department of Natural Environment, Technical University in Zvolen, Slovak Republic*

ABSTRACT

The influence of continents and oceans plays conceptually the key role in the climate conditions of Europeans regions. Continentality is also an important phytogeographic factor of vegetation distribution in Slovakia. This study analysed continentality development at six meteorological stations in Slovakia during the periods 1951-2013, or 1961-2013. The results showed a slight non-significant increase of continentality index during the monitored period of 63 (53) years. Based on the results of CCM 2000 climate model we cannot expect significant changes of continentality by the end of 21st century, but the climate change will be significantly manifested by the increase of maximum and minimum air temperatures.

Key words: Thermic continentality Index, monthly temperature, climate change, Slovak Carpathian region

INTRODUCTION

Continentality of climate belongs to basic climatic characteristics of an area. It specifies the influence of the continent on climate formation. The opposite of continentality is called oceanity (maritimity), which is a set of climatic features influenced by ocean. According to the meteorological dictionary (Bednář *et al*. 1993), the most distinctive feature of continentality is large amplitude of air temperatures, which is the main characteristic of thermic continentality. On the base of other climatic elements we distinguish ombric and baric continentality.

From the point of bioclimatology, geography and ecology, continentality is an important characteristic of environmental parameters. For example, it assists us in understanding complex relationships between the plant distribution and geographic position. With the help of continentality or oceanity indices, phytogeography explains the changes in vegetation conditions from oceans to the interior of continents, gradual transition from forests to steppes and semi-deserts, as well as postglacial development of vegetation (species spreading in the Boreal, or Atlantic period) Ellenberg (1988). Klötzli (1976), Shidei (1974), Plesník (2002, 2004) presents that in comparison with ocean, land is characterised by basic humidity conditions and temperature differences caused by the distance from ocean (normal continentality), as well as by the elevation and the robustness of a mountain range (alpine continentality). Ocean air masses change from the edge to the interior of mountains. This increases continentality and its impact on vegetation to such an extent that horizontal zones are formed within mountain ranges, which is called as intra-mountain zonality. The Alps are a typical example Ellenberg (1988). From the edge of the mountains the vertical structures change from mesophilous atlantic plant communities up to extremely continental communities. Due to the alpine continentality, in the Alps we can see the ecological phenomena in a range of several tens of kilometres comparable to several thousand kilometres from the Atlantic coast up to the interior of Siberia. The impact of alpine continentality and subsequently also the intra-mountain zonality can also be observed in the Tatras of the Western Carpathians (Plesník 2002). This phenomenon is more thoroughly described in forestry and plant community literature, e.g.: Domin (1931), Fleischer (1994), Pagan (1992) Pagan and Randuška (1987), Somora (1958), Svoboda (1952).

In the conditions of Czecho-Slovakia, continentality or oceanity was examined by several authors. Hrudička (1933) dealt with thermic and ombric continentality. Kveták (1974) elaborated continentality of Slovakia in a complex way using several indices. Melo (2002) in Hurbanov addressed continentality in connection with climate change. He simulated future changes of continentality using CCCM 2000 and GISS 1998 climate models. Recently, some other studies, dealing with modelling of the climatic change, used the same characteristic to describe changes in continentality of climate in the twenty first century (Melo et al. 2013).

The aim of the presented paper is to examine to development of continentality on stations situated at different elevations during the years 1951 (1961) – 2013. The partial goal was to evaluate (un)suitability of continentality as an indicator of the ongoing climate change.

MATERIALS AND METHODS

The work is based on the data from the Slovak Hydrometeorological Institute (SHMI). **Table 1** presents the stations included in the analysis and their geographic characteristics. From the point of terrain we can divide the stations into three groups as follows:

- Lowlands (Michalovce, Hurbanovo)
- Valleys (Rožňava, Sliač)
- Highlands (Oravská Lesná, Skalnaté Pleso).

Continentality was calculated as a simple index of continentality (I_C) following the original definition of Supan applied by Rivas-Martinez et al. (1999):

$$Ic = (Tmax - Tmin)$$

where I_C = Continentality Index

Tmax = mean temperature (°C) of the warmest month

Tmin = mean temperature (°C) of the coldest month

In the Czech and Slovak meteorological literature, continentality index is described as annual amplitude of temperature, or as an annual range of monthly mean air temperatures in °C, (difference between the maximum and minimum monthly mean air temperatures). Continentality index was also calculated for the future climate represented by GCMs scenario of CCCM 2000 (Canadian Climate Centre Model) following the works of Lapin et al. (2000), Melo (2002), Melo et al. (2013).

***Table 1**: Main characteristic of meteorological stations, theirs temperature variables (monthly mean, minimum, maximum air temperatures) and annual amplitude of temperatures as continentality index (Ic)*

Station		**Michalovce**	**Hurbanovo**	**Rožňava**	**Sliač**	**Oravská Lesná**	**Skalnaté Pleso**
Geographic factors							
Altitude (m)		112	115	289	313	780	1778
Latitude		48°45´	47°52´	48°39´	48°39´	49°22´	49°11´
Longitude		21°57´	18°12´	20°32´	19°08´	19°11´	20°14´
Landform		Lowland		Valley		Mountain	
Climatic variables							
Observed period (years)		1961-2013	1951-2013	1961-2013	1951-2013	1951-2013	1961-2013
Mean annual temperature (°C)	Mean	9.4	10.3	8.7	8.2	4.9	2.1
	σ	(0.75)	(0.8)	(0.8)	(0.7)	(0.7)	(0.8)
Minimum monthly mean temperature (°C)	Mean	-3.5	-1.9	-3.9	-4.4	-6.4	-7.2
	σ	(2.1)	(2.2)	(1.8)	(2.2)	(2.4)	(2.1)
Maximum monthly mean temperature (°C)	Mean	20.7	21,3	19.8	19.2	15.2	10.8
	σ	(1.4)	(1.3)	(1.4)	(1.4)	(1.2)	(1.3)
Continentality Index Ic – annual amplitude of temperature (°C)*	Mean	24.2	23.2	23.7	23.6	21.6	18.0
	σ	(2.5)	(2.3)	(2.2)	(2.4)	(2.6)	(2.35)

* Ic (continentality index) is the annual range of monthly mean air temperatures in °C, (difference between the maximum and minimum monthly mean air temperatures), σ - standard deviation

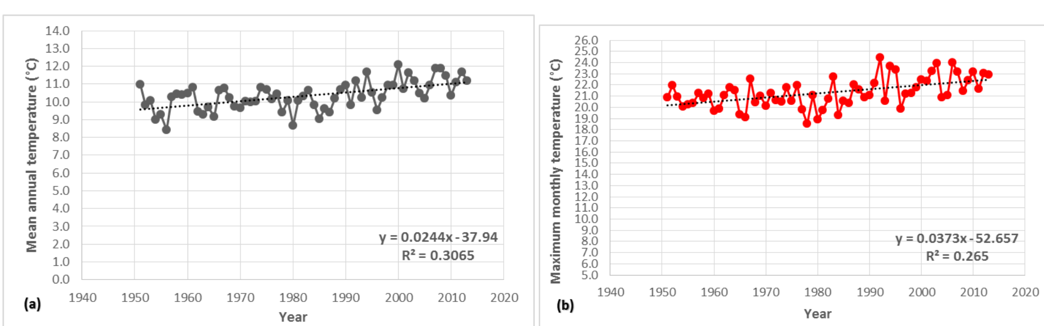
***Table 2**: The linear trend values ((°C)/year; (°C)/observed period) and their statistical significance levels of temperatures (monthly mean, minimum, maximum air temperatures and annual amplitude of temperatures as continentality index - Ic) for the 6 meteorological stations in Slovakia*

Station		**Michalovce**	**Hurbanovo**	**Rožňava**	**Sliač**	**Oravská Lesná**	**Skalnaté Pleso**
Observed period (years)		1961-2013	1951-2013	1961-2013	1951-2013	1951-2013	1961-2013
Mean annual temperature	(°C)/year	0.0305	0.0244	0.03	0.0227	0.021	0.0284
	(°C)/observed period	1.6165	1.5372	1.59	1.4301	1.323	1.5052
	Significance*	***	***	***	***	***	***
Minimum monthly mean temperature	(°C)/year	0.0403	0.0248	0.0366	0.0088	0.0281	0.0324
	(°C)/observed period	2.1359	1.5624	1.9398	0.5544	1.7703	1.7172
	Significance*	*	NS	*	NS	+	+
Maximum monthly mean temperature	(°C)/year	0.0451	0.0373	0.0477	0.0393	0.0276	0.0453
	(°C)/observed period	2.3903	2.3499	2.5281	2.4759	1.7388	2.4009
	Significance*	***	***	***	***	**	***
Continentality Index - Ic (annual amplitude of temperature)	(°C)/year	0.0049	0.0125	0.0011	0.0305	0.0005	0.0128
	(°C)/observed period	0.2597	0.7875	0.0583	1.9215	0.0315	0.6784
	Significance*	NS	NS	NS	+	NS	NS

*Significance: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; NS- not significant

Results and Discussion

Since our goal was to evaluate the continentality over the whole varied terrain of Slovakia, we selected six meteorological stations from the network of SHMI. The elevations of stations vary from 112 to 1,778 m a.s.l. **Table 1** gives detailed information about temperature conditions of the examined stations. As we see, Hurbanovo situated in Podunajská nížina (lowland) is the warmest station, while Skalnaté Pleso in the Tatras, the highest mountains of Slovakia, is the coldest station. The amplitude of air temperature is the most important characteristic of thermic continentality calculated as the difference between the monthly mean temperatures of the warmest and the coldest months in the particular year. Mean amplitudes were evaluated for the period from 1951 to 2013, or 1961 to 2013, depending on the length of observations at a particular station (**Table 1**). The highest amplitude of air temperature was found for Michalovce (24.2 °C), which is the lowland station situated in the Eastern Slovakia. The difference between the temperature amplitudes in Podunajská nížina (lowland) and Východoslovenská nížina (lowland) is 1°C. An interesting finding was that the amplitude of air temperature of the stations situated in valleys was also high: Rožňava (23.7 °C) and Sliač (23.6 °C). This is probably the result of their inversion positions with relatively low air temperatures in winter half-years, and high summer air temperatures. Skalnaté Pleso situated in the mountains has the lowest amplitude (18.0 °C). From the statistical point of view, the amplitude is a rather conservative parameter. The value of its standard deviation is almost equal for all stations (2.2 – 2.6). We can state that our results confirmed the opinion of Gorczynský ex Kveták (1983), etc., that continentality decreases with increasing elevation, and that from the point of thermic continentality the area of Slovakia still belongs to 3rd maritime transition zone (Ic = 10.1 až 25.0 °C)



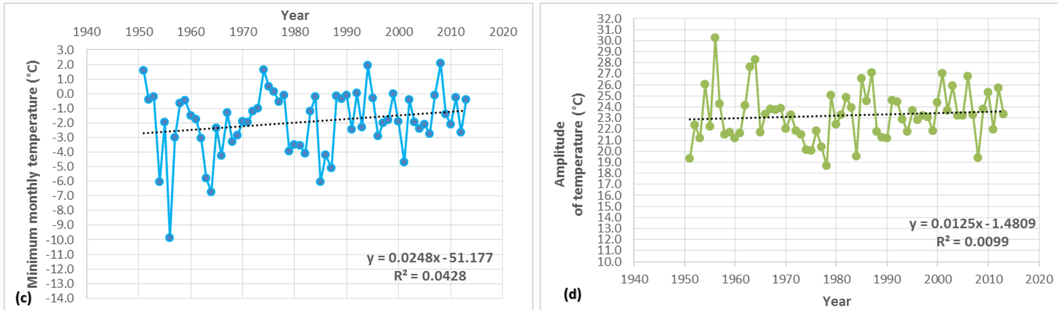


***Figure 1**: Lowland station **Hurbanovo** (115 m a. s. l.) - yearly variation, temperature pattern and trend line of the mean annual temperature (**a**), maximum monthly temperature (**b**), minimum monthly temperature (**c**) and continentality index Ic – annual amplitude of temperature (**d**) for the perion 1951-2013*

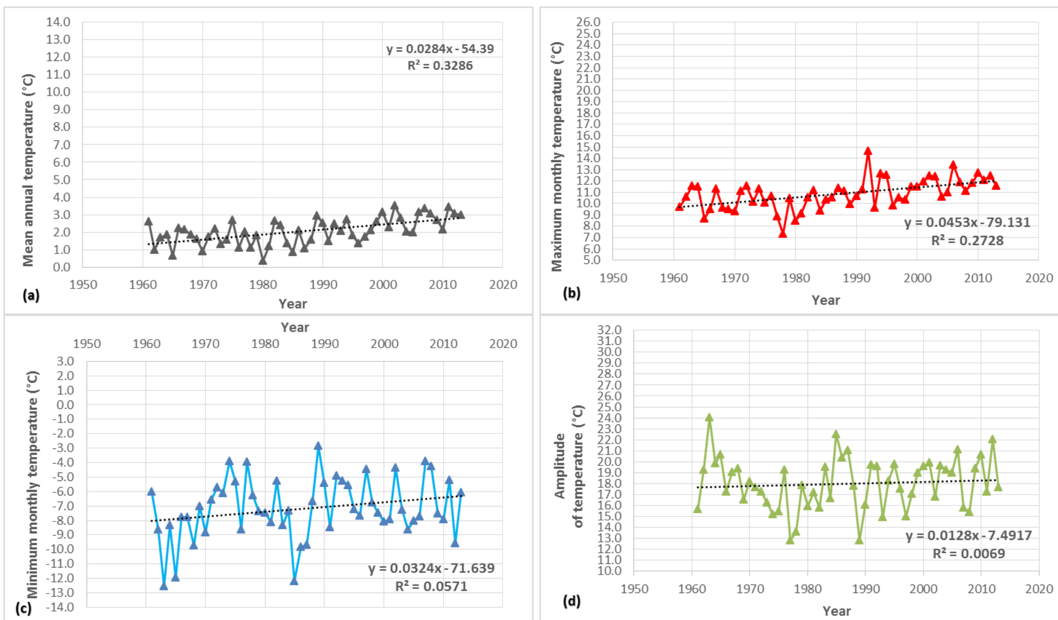


***Figure 2**: Mountain station **Skalnaté Pleso** (1778 m a. s. l.) - yearly variation, temperature pattern and trend line of the mean annual temperature (**a**), maximum monthly temperature (**b**), minimum monthly temperature (**c**) and continentality index Ic – annual amplitude of temperature (**d**) for the perion 1961-2013*

Table 2 evaluates the developmental trend of temperature characteristics (mean, minimum, maximum air temperature) and of temperature amplitude, i.e. continentality index. **Figures 1 (a-d)** and **2 (a-d)** present the developmental trends of temperature characteristics from 1951 (1961) to 2013 for the lowland station of Hurbanovo (115 m a. s. l.) and the highland station of Skalnaté Pleso (1,778 m a. s. l.). Other stations are characterised in **Table 2**. All analysed characteristics of air temperature and thermic continentality have an increasing trend. **Table 2**

presents the results of the Student's t-test of significance concerning the correlation coefficients of the mean annual temperature, maximum monthly temperature, minimum monthly temperature and continentality index Ic for the period 1951-2013 and the trend of linear regression as well. The highest rate of mean annual temperature increase equal to 0.0305 °C per year was observed in Hurbanovo. It means that over the whole period of 63 years, mean annual temperature increased by 1.62 °C. The slowest rate of temperature increase (0.0305 °C per year) was found in Oravská Lesná, where the temperature increased by 1.32 °C over the last 53 years. The increasing trend of mean annual temperature was significant for all stations at 99.9 %. Minimum monthly temperature also increased, but the increase was less significant and had higher variability. Maximum monthly temperature significantly increased on all stations, mostly in Rožňava (2.52 °C in 53 years).

Although the developmental trend of continentality was also increasing, the increase was slight and non-significant (in the case of Sliač station it was significant at 90.0%). The increasing trend fluctuated from 0.0005 to 0.0305 °C/year.

Tab. 3*: Annual amplitude of temperature as continentality index (Ic) pre referenčné obdobie a pre klimatický scenár CCCM pre roky 2030 a 2075*

Years/Scenario	Hurbanovo	Michalovce	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
1951-1980	21.6	22.8	22.3	22.1	19.8	15.5
2030*	21.4	22.6	22.1	21.9	19.6	15.3
2075*	21.2	22.4	21.9	21.7	19.4	15.1
*Scenario CCCM						

Table 3 presents the trend of continentality until the year of 2075 according to the scenario of CCCM. It is expected that the continentality of all stations will slightly decrease. The amplitudes will decrease by 0.4 °C by the year 2075. Melo (2002) presented a similar result.

Many naturalists ask themselves a question: „***why do we not observe an increase of thermic continentality during the last period of the ongoing climate change?*** " The main cause is the increase of both maximum and minimum monthly temperatures. Since the amplitude is the difference between them, it remains without significant changes. Faster rate of maximum monthly temperature increase stimulates the increasing trend. However, it is only slight because minimum temperatures grow more slowly. Another explanation comes from the geographic definition of continentality: „continental climate is a type of climate inside the land of every continental zone affected by land features“ Činčura et al. (1985). According to this definition, the fact that the thermic continentality does not change is logical, because so far the climate change does not change the geographic distance from the ocean. Minďáš et al. (1996) and other works presented the ongoing changes in bio-climatological zonation. For example, in the southern lowlands of Slovakia, bio-climatic conditions suitable for a new community of a xeric forest of a warm temperate zone are gradually being formed. Similarly, the bio-climatic conditions of highlands also change. The modelled scenario of CCCM for the year 2075 assumes a complete extinction of alpine communities, and their replacement by a sub-alpine very moist forest (Minďáš et al. 1996). It follows that the thermic continentality remains more or less constant even under the conditions of changing climate. It is the bio-climatic conditions of the vegetation zone that changes. If in the future we want to include continentality in the studies dealing with climate change or the changes of bio-climatic conditions, continentality needs to be linked to a climatic zone, vegetation zone, etc. For example, the change from a warm temperate moist forest (continentality index Ic=23) to a warm temperate dry forest (Ic=23) following the change of humidity conditions, or the change from a warm temperate moist forest (Ic=23) to a cool temperate moist forest (Ic=23) following the change in temperature according to bio-climatological classification of Holdridge (1947).

CONCLUSION

Continentality as well as oceanity represent an important climate characteristic of a particular area. At the same time, they are also an important factor of natural vegetation distribution, not only in the postglacial period of Holocene. Thus, it is logical that a number of climatologists, geographers, geo-botanists and foresters have dealt with continentality in Slovakia. We evaluated continentality using a simple index of continentality expressed by the amplitude of air temperature defined as the difference between the monthly mean air temperatures of the warmest and the coldest months in the year. We analysed the development of continentality during the years 1951 (1961) -2013 at six meteorological stations. We selected the stations so that they represented lowlands (Michalovce, Hurbanovo), valleys (Rožňava, Sliač) and highlands (Oravská Lesná, Skalnaté Pleso). We found only a slight non-significant increase of continentality. While the temperature of the warmest month increased by 1.74 to 2.52 °C at all stations during 63 (53) years, the temperature of the coldest month increased by 0.55 to 2.14 °C. The continentality of the year 2075 was calculated using GCMs model of CCCM 2000 following the work of Lapin et al. (2000). The results of the climatic scenario indicate that by the end of 21st century we cannot expect significant changes in continentality, although the climate change will be closely coupled with the increase of maximum and minimum air temperatures.

REFERENCES

Bednař, J., et al. (1993): Meteorologický slovník výkladový a terminologický. Academia, Ministerstvo ţivotního prostředí ČR, Praha, 1993, p. 147.

Činčura, J. et al. (1983): Encyklopédia Zeme. Obzor, Bratislava, p. 287.

Domin, K. (1931). Československé bučiny. Ministerstvo zemědělství republiky Československé. Sborn. Výzk. Ústavů Zeměděl. RČS 70: 1−87.

Ellenberg, H. (1988). Vegetation ecology of central Europe. Cambridge University Press. 731 pp.

Fleischer, P. (1994): Lesné rastlinné spoločenstvá. In: Vološčuk, I. (ed.): Tatranský národný park: Biosférická rezervácia. Gradus, Martin. p.149–162.

Holdridge, L. R. (1947): Determination of World Plant Formations from Simple Climatic Data. Science 105: 367-368.

Hrudička, B. (1933): Doba polovičních srážek a periodická amplituda ročního srážkového průběhu v Československu. Spisy vydávané přírodovědeckou fakultou Masarykovy university, Brno, p. 1-22.

Klötzli F. (1976): Grenzen von Laubwäldern in Europa. Berichte der Deutschen Botanischen Gesellschaft 89: 371–380.

Kveták, Š. (1983): Príspevok ku kontinentalite podnebia na Slovensku. Zborník prác SHMÚ Zv. 22, Alfa, Bratislava, p. 95-218.

Lapin, M., Melo, M., Damborská, I., Gera, M, Faško, P., (2000): Nové scenáre klimatickej zmeny pre Slovensko na báze výstupov prepojených modelov všeobecnej cirkulácie atmosféry. In.: Národný klimatický program SR, MŽP SR, 8, p. 5-34.

Melo M. (2002) Očakávané zmeny kontinentality podnebia v 21. storočí pre Hubanovo na základe výstupov dvoch klimatických modelov.In: Rožnovský, J., Litschmann, T. (eds.): XIV. Česko-slovenská bioklimatologická konference, Lednice na Moravě 2.-4. září 2002, p. 312–323

Melo, M., Lapin, M., Kapolková, H., Pecho, J., Kružicová, A. (2013): Climate Trends in the Slovak Part of the Carpathians. In: J. Kozak et al. (eds.): The Carpathians: Integrating Nature and Society Towards Sustainability. Springer Berlin Heidelberg, p. 131-150.

Minďáš, J., Lapin, M., Škvarenina, J. 1996: Klimatické zmeny a lesy Slovenska. In Národný klimatický program SR, Bratislava: MŽP SR, 5, 96 p.

Pagan, J. (1992): Lesnícka dendrológia. Vydavateľstvo Technickej univerzity, Zvolen, 343 pp.

Pagan, J., Randuška, D. (1987): Atlas drevín. Obzor, Bratislava, I. 360pp.

Plesník, P. (2002). Niektoré nové aspekty diverzity biosféry. Geografický časopis 54: 115-130.

Plesník, P. (2004). Všeobecná biogeografia. Univerzita Komenského, 428 pp

Shidei, T. (1974): Forest vegetation zones. In: Numata, M. ed.: The flora and vegetation of Japan. Kodansha, Tokyo, Japan.p. 87-124

Rivas-Martínez, S., Sánchez-Mata, D., Costa, M. (1999): North American boreal and western temperate forest vegetation. Itinera Geobotanica 12:5-316

Somora, J. (1958): O rozšírení niektorých lesných drevín v skupine Lomnického štítu. Vydavateľstvo Osveta, Martin. 152 pp.

Svoboda, P. (1952). Život lesa. Praha, Brázda, 894.

ACKNOWLEDGEMENT

This work was accomplished as a part of the projects VEGA No.: 1/0008/13, 1/0281/11, 1/0463/14 of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science; and the projects of the Slovak Research and Development Agency No.: APVV-0423-10, APVV-0131-11 and APVV-0303-11.

SUMMARY

Kontinentalita ako aj oceanita predstavujú dôležitú charakteristiku klímy daného územia. Zároveň sú však aj významným faktorom pre prirodzené rozšírenie vegetácie, a to nielen v postglaciálnom období holocénu. Je preto logické že problematike kontinentality na Slovensku sa venoval celý rad klimatológov, geografov, geobotanikov a lesníkov. Zhodnotili sme kontinentalitu na pomoci jednoduchého indexu kontinentality, ktorý predstavuje amplitúdu teploty vzduchu, čiže rozdiel medzi priemernou mesačnou teplotou vzduchu najteplejšieho a najchladnejšieho mesiaca v roku. Analyzovali sme vývoj kontinentality v rokoch 1951 (1961) - 2 013 a to na šiestich meteorologických staniciach. Výber staníc sme uskutočnili tak aby reprezentovali nížinné polohy Nížiny (Michalovce, Hurbanovo), kotliny (Rožňava, Sliač) ako aj pohoria (Oravská Lesná, Skalnaté Pleso). Zistili sme síce nepatrný trend rastu kontinentality, no tento nie je štatisticky významný. Zatiaľ čo teplota najteplejšieho mesiaca na všetkých sledovaných staniciach za 63 (53) rokov vzrástla v rozsahu 1.74 až 2.52 °C a teplota najchladnejšieho mesiaca vzrástla o 0.55 až 2.14 °C/sledované obdobie hodnota indexu kontinentality sa menila len nepatrne. Pre výpočet kontinentality v roku 2075 sme použili GCMs model CCCM 2000 podľa práce Lapin *et al.* (2000). Na základe výsledkov klimatického scenára nemôžeme očakávať výraznejšie zmeny kontinentality do konca 21. storočia, no klimatická zmena bude výrazne spojená s nárastom maximálnych minimálnych teplôt vzduchu.

CONTACT

Škvarenina Jaroslav, prof. Dr.

Department of Natural Environment,

Technical University in Zvolen,Masarykova 24

96053 Zvolen

Slovak Republic

e-mail: skvarenina(a)tuzvo.sk

THE INFLUENCE OF PRECIPITATION AND SOIL TILLAGE ON WEEDS IN WINTER WHEAT

JAN WINKLER, SVĚTLANA CHOVANCOVÁ, JAN BROTAN

Mendel University in Brno

ABSTRACT

The field trial is located at an experimental station of Mendel University in Brno (location Žabčice, Czech Republic). Long-term annual average temperature is 9.3 °C and long-term annual precipitation is 483.3 mm. Temperature and precipitation data were obtained from meterological site at the experimental station in Žabčice. It was used a seven-step crop rotation system at this field attempt. Three variants of soil tillage (conventional tillage, minimum tillage, no-tillage) were applied to each crop within the seven-step crop rotation system. A weed infestation was evaluated by counting method in growths of winter wheat. It was found 44 weed species within the ten years of monitoring. We can state based on the results of canonical correspondence analysis, that the higher precipitation during the months of December and January support the higher occurrence of *Fallopia convolvulus*. Lower precipitation during February boost the incidence of species *Medicago sativa* and *Papaver rhoeas*, and on the contrary higher precipitation in this month support the occurence of species *Veronica persica.*

Keywords: weeds, precipitation, tillage, weed infestation forecast, winter wheat

INTRODUCTION

Weed occurrences significantly affected by the cultivated crop species, crop rotation, and primarily by the weather conditions in individual years. A number of works points out to excessive differences in the weed infestation intensity and the species composition of weed communities (Légère, Stevenson and Benoit 2005, Tuesca, Puricelli and Papa 2001).

The amount of precipitation influences not only soil bulk density and soil water content, but also the values of soil penetration resistance. Long-term processing of soil without plowing or shallow processing by a disc cultivator contributes to the soil compactness and water content and it was ascertained that the relationship between the penetration resistance of the soil, bulk density and soil water is linear (Carter, 1988).

The most decisive meteorological parameters affecting the intensity of weed infestation include rainfall. What is important is the amount of precipitation and the time of occurrence. All of these factors affect weed seeds in the soil and co-determine their germination. The technology of soil tillage significantly affects soil properties and changes the impact of precipitation. Ultimately, these facts may jointly influence the occurrence of weeds. This contribution deals with the relation between rainfall in selected months and subsequent weed infestation of winter wheat and suggests possibilities of a certain forecast of weed intensity based on the overall precipitation amount in the month concerned.

MATERIALS AND METHODS

The field experiment was performed at Mendel University agricultural enterprise in Žabčice, Czech Republic. This area is part of the geomorphological territory of Dyje and Svratka Basin. The altitude of the experiment is 185 meters above sea level in a flatland.

Long-term average annual temperature is 9.3 °C and long-term annual aggregate precipitation is 483.3 mm. Data concerning temperature and amount of precipitation were obtained from the meteorological station in the experimental enterprise in Žabčice.

The field experiment was established in 2010 and covers the area of 2.3 ha (100 m x 225 m). The size of individual parcels is 1,000 m^2 (100 x 10 m). The seven-step crop rotation was applied in the field experiment. The succession of crops was as follows: gourd alfalfa (*Medicago sativa*) – the first year, alfalfa wheat – the second year, **winter wheat** (*Triticum aestivum*), forage maize (*Zea mays*), **winter wheat**, sugar beet (*Beta vulgaris*), spring barley (*Hordeum vulgare*).

Three variants of tillage were applied for each crop type within the seven-step crop rotation.

Tillage variants:

- *Conventional tillage (CT)*: After the harvest of a precursor crop, the stubble is treated with Kverneland chisel cultivator to the depth of ca 0.1 m. Imposition is suitable in dry summer.

The subsequent operation is plowing to the depth of 0.2 - 0.24 m. It is performed by a Lemken double-sided rotary plow. The Accord seed combination is used for sowing.

- *Minimum tillage (MT):* Stubble cultivation is performed by Kverneland chisel cultivator to the depth of ca 0.1 m, ensuring shallow cultivation. The Accord seed combination is used for sowing.
- *No tillage (NT):* The soil surface is leaved uncultivated after the harvest of the precursor crop. The Accord seed combination is used for direct sowing.

The weed infestation was evaluated using a numerical method. Weeds were counted in area of 1 m^2 in 48 repetitions in each variant of tillage. The evaluation was held everytime each spring in the phase of spring barley tillering and before herbicide application, in 2004 and 2013. Names of found species were used according to Kubát (Kubát, 2002).

The precipitation were recorded in one-day interval. Data about precipitation totals were used from standard meteorological station, which is located directly in the experimental enterprise. Monthly totals for the months (October and April) were calculated from measured values of precipitation totals.

Multivariate analysis of ecological data were applied for detection of influence of precipitation totals on weed species. The variants of tillage and precipitation totals for the months of October and April were used as a factor of environment. Optimal analysis was based on the length of the gradient (*Lengths of Gradient*), detected by segment analysis DCA (*Detrended Correspondence Analysis*). Furthermore, CCA (*Canonical Correspondence Analysis*) was used. A total number of 499 permutations was calculated in Monte-Carlo test. Collected data were processed by a computer program Canoco 4.0 (Ter Braak, 1998).

RESULTS

Within the monitored years was found 44 weed species in winter wheat. The average number of individuals of found weed species are shown in Tab. 1. The data of monthly total precipitation from October to April are listen in Tab. 2. These monthly total precipitation of monitored period were used in the CCA analysis.

Data about weed infestation of winter wheat were initially processed by DCA analysis. Its result was the length of gradient (*Lengths of Gradient*), which amounts 5.423. On the basis of this calculation the canonical correspondence analysis (CCA) was selected for further processing. CCA analysis defines the spatial arrangement of individual weed species and total precipitation for selected months. The spatial structure is determined by the relations of total precipitation, tillage and occurrence of weed species.

The results are subsequently expressed using the ordination diagram. Weed species and soil tillage are presented as points, total precipitation for particular months are shown as vectors (arrows), which determine the amount of rainwater. The smallest amount of precipitation is displayed at the beginning of the vector and the maximum is at the end.

The results of CCA analysis (Fig. 1), which evaluated the influence of precipitation (in selected months) to the occurrence of weeds in conventional tillage conditions, are significant at the significance level of α = 0,002 (Trace = 1.075; F-ratio = 19.792).

Based on the CCA analysis is possible to conclude, that higher precipitation during the months October, December and January contributed to the higher weed infestation of following species: *Atriplex sagittata, Convolvulus arvensis, Fallopia convolvulus, Galinsoga parviflora, Chenopodium album, Chenopodium hybridum, Persicaria lapathifolia, Silene noctiflora* and *Symphytum officinale.* Conversely, lower or average rainfall during these months supported the occurrence of species *Erophila verna* and *Poa annua.*

Higher precipitation during February conduced to the higher weed infestation by these species: *Fumaria officinalis, Plantago major, Polygonum aviculare, Taraxacum officinale* and *Veronica persica.* Nevertheless lower rainfall in this month supported the incidence of species *Medicago sativa* and *Papaver rhoeas*.

Higher precipitation during March contribute to the higher weed infestation caused by these: *Beta vulgaris, Geranium pusillum, Microrrhinum minus, Phacelia tanacetifolia, Rumex obtusifolius* and *Vicia villosa.* Average and lower precipitation in March fit better to the occurence of *Cirsium arvense, Consolida orientalis, Galium aparine* and *Sinapis arvensis.*

Higher rainfall in September support higher incidence of species *Euphorbia helioscopia, Sonchus oleraceus* and *Veronica polita.*

However, some of the species appeared more significantly on the variant of no tillage, namely: *Descurainia sophia, Lactuca serriola, Senecio vulgaris, Sonchus arvensis, Stellaria media, Tripleurospermum inodorum, Veronica hederifolia* and *Viola arvensis.*

DISCUSSION

The results show, that precipitation totals in chosen months significantly affect the occurrence of most of the weed species. The amount of precipitation supposedly influence the dormancy of seeds in soil seed bank and perhaps also the regenerative ability of perennial weeds. The dormancy and the conditions of its termination are very specific for each species. The effect of precipitation at different times may terminate or extend the course of dormancy. This may result into decrease or increase of weed infestation of certain species.

The occurrence of species *Veronica polita* was strongly affected by precipitation in September. Therefore during the sufficient amount of precipitation in September we can expect higher weed infestation by this species in winter wheat. Species *Veronica persica* was promoted by higher amount of precipitation in February.

The incidence of number of late spring weeds (*Atriplex sagittata, Galinsoga parviflora, Chenopodium album, Chenopodium hybridum, Persicaria lapathifolia*) was supported by the higher amount of precipitation in December. The precipitation in this month most probably abbreviate the dormancy of seeds of these species, which subsequently germinate more in spring. Lower precipitation in spring (February, March) promote weed infestation by species *Medicago sativa* and *Galium aparine*. Lower precipitation may limit the competitiveness of wheat and allow to these species the higher weed infestation.

CONCLUSION

The results show, that the precipitation in chosen months significantly influence the incidence of various weed species in winter wheat. However, the response of particular species was markedly different. The causes of the different reactions we may seek in the influence of precipitation on the dormancy of weed species and in the influence on the competitive ability of wheat, which may limit the weed infestation. Clarification of relations between precipitation and weed occurrence may provide a basis for predicting of weed infestation. This forecast would be important for efficient herbicide selection and other regulatory methods.

REFERENCES

Carter, M. R."Temporal variability of soil macroporosity in a fine sandy loam under mouldboard ploughing and direct drilling." Soil & Tillage Research, vol. 12, pp. 37–51, 1988.

Fulajtár, E."Physical properties of soil in Slovakia, their treatment and recovery," Bratislava, Veda, Polnohospodárstvo, vol. A1/86, pp. 156–159, 1986.

Kubát, K."The key to the flora of the Czech Republic," Academia. Praha, p. 928, 2002.

Légère, A., Stevenson, F. C., Benoit, D. L.,"Diversity and assembly of weed communities: contrasting responses across cropping systems." Weed Research, vol. 45, p. 303–315, 2005.

Ter Braak, C., J., F. Canoco – a fortran program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis (version 4.0.), Report LWA-88-02 Agricultural Mathematics Group, Wageningen, 1998.

Tuesca, D., Puricelli, E., Papa, J. C.: A long-term study of weed flora shifts in different tillage systems. Weed Research, vol. 41, p. 369–382, 2001.

ACKNOWLEDGEMENT

This study was performed within the framework of the project NAZV QI111A184 "Optimization of methods of weed control within the system of precision farming".

Table 1 Average number of individuals of particular weed species found in monitored years and variants of tillage (pcs.m-2).

Weed species	Years of monitoring										Tillage		
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	CT	MT	NT
Atriplex sagittata			0,03										0,01
Beta vulgaris				0,01							0,00		
Capsella bursa-pastoris		0,22	0,11	0,10	0,94	1,33	0,84	1,29	1,39	2,43	0,28	0,67	1,41
Cirsium arvense	0,47	0,08	0,21	0,62	0,25	0,02	0,01	0,21		0,01	0,14	0,09	0,41
Consolida orientalis	0,06	0,02	0,01	0,06	0,02	0,01		0,03		0,01	0,04	0,03	0,01
Convolvulus arvensis	0,05		0,15								0,02	0,02	0,03
Descurainia sophia				0,01			0,01		0,01	0,01	0,00	0,01	0,00
Erophila verna			0,01			0,01						0,00	0,00
Euphorbia helioscopia			0,01	0,01						0,05	0,00	0,02	0,00
Fallopia convolvulus	1,76	0,09	1,72	0,03	0,02	0,01	0,03	0,17	0,31	1,38	0,79	0,57	0,63
Fumaria officinalis				0,06	0,01		0,01			0,01	0,01	0,02	0,00
Galinsoga parviflora			0,65									0,07	0,10
Galium aparine	1,04	1,31	0,52	0,59	0,24	1,40	0,72	0,26	0,02	0,09	0,56	0,72	0,69
Geranium pusillum				0,01								0,00	
Chenopodium album	1,24	0,03	2,28					0,01	0,10		0,50	0,52	0,32
Chenopodium hybridum	0,11		0,15								0,08		0,02
Lactuca serriola		0,08	0,01			0,06	0,01		0,01	0,01	0,00	0,02	0,03
Lamium amplexicaule	0,04	0,35	0,30	0,53	0,40	0,53	1,48	0,31	1,39	1,76	0,60	0,65	0,69
Lamium purpureum		0,01	0,10		0,22	0,11	0,12	0,11	0,11	1,05	0,10	0,28	0,12
Medicago sativa	0,22	1,13	1,04	0,74	0,22	3,15	0,60	0,22	0,67	0,13	0,14	0,49	1,64
Microrrhinum minus				0,04	0,01						0,01	0,01	
Papaver rhoeas	0,01	0,02		0,02	0,02	0,01	0,02	0,03	0,01	0,02	0,03	0,01	0,00
Persicaria lapathifolia			0,09		0,01						0,01	0,01	0,01
Phacelia tanacetifolia	0,00			0,03							0,01	0,00	
Plantago major						0,01							0,00
Poa annua			0,03			0,02						0,01	0,01
Polygonum aviculare	0,01		0,01					0,38	0,01		0,00	0,00	0,11
Rumex obtusifolius				0,15							0,02	0,01	0,01
Senecio vulgaris					0,03		0,01				0,00	0,00	0,01
Silene noctiflora	0,84	0,06	0,83	0,08	0,01	0,08	0,01	0,01			0,45	0,20	0,11
Sinapis arvensis	0,16	0,01	0,27	1,01	0,10			0,01	0,03	0,09	0,32	0,11	0,07
Sonchus arvensis					0,01								0,00
Sonchus oleraceus			0,02		0,04							0,00	0,02
Stellaria media	0,02	1,20	0,25	1,08	1,47	0,97	1,28	0,56	0,98	2,20	0,60	0,94	1,20
Symphytum officinale			0,01										0,00
Taraxacum officinale	0,00		0,06	0,13	0,28	0,50			0,01		0,01	0,05	0,20
Thlaspi arvense	0,01	0,01	0,04	0,06	0,19	0,13	0,17	0,20	0,18	1,22	0,17	0,13	0,31
Thlaspi perfoliatum									0,01				0,00
Tripleurospermum inodorum	0,01	0,56	0,02	0,13	0,01	0,11	0,20	0,03	0,51	0,02	0,19	0,11	0,14
Veronica hederifolia					0,27	0,01		0,03	0,01		0,02	0,03	0,04
Veronica persica		2,28		8,03	1,92	0,46	0,75	0,87		3,47	1,16	1,79	1,91
Veronica polita	0,95	1,21	1,27	1,51	1,01	1,63	1,38	1,99	0,42	6,28	1,61	1,63	1,83

Vicia villosa				0,01								0,00	
Viola arvensis		0,06	0,03	0,01			0,02	0,31	0,04	0,15	0,02	0,02	0,12
Number of species	2,66	3,55	3,22	3,66	3,24	3,17	3,46	3,33	2,87	4,44	3,22	3,36	3,31
Number of individuals	7,00	8,72	10,25	15,07	7,69	10,20	7,65	6,96	6,18	20,01	7,89	9,24	11,98

Table 2 Monthly precipitation totals (mm) for chosen months of monitored period

Years of monitoring	October	November	December	January	February	March	April
2003/2004	57,6	31,6	51,0	41,9	27,6	59,8	34,0
2004/2005	66,2	35,0	18,0	19,4	44,4	5,8	49,5
2005/2006	6,2	23,4	30,2	22,2	26,4	46,2	50,5
2006/2007	13,9	21,4	20,8	22,7	42,2	80,8	4,4
2007/2008	37,9	30,5	26,0	15,7	10,4	32,9	29,3
2008/2009	27,3	22,1	31,1	20,0	57,6	78,1	3,6
2009/2010	21,2	55,4	37,6	46,8	22,8	9,8	53,1
2010/2011	10,4	32,8	11,1	21,4	4,6	39,3	33,2
2011/2012	22,6	1,6	14,6	27,4	7,4	2,4	19,8
2012/2013	49,2	19,4	35,6	20,2	42,1	40,8	20,2

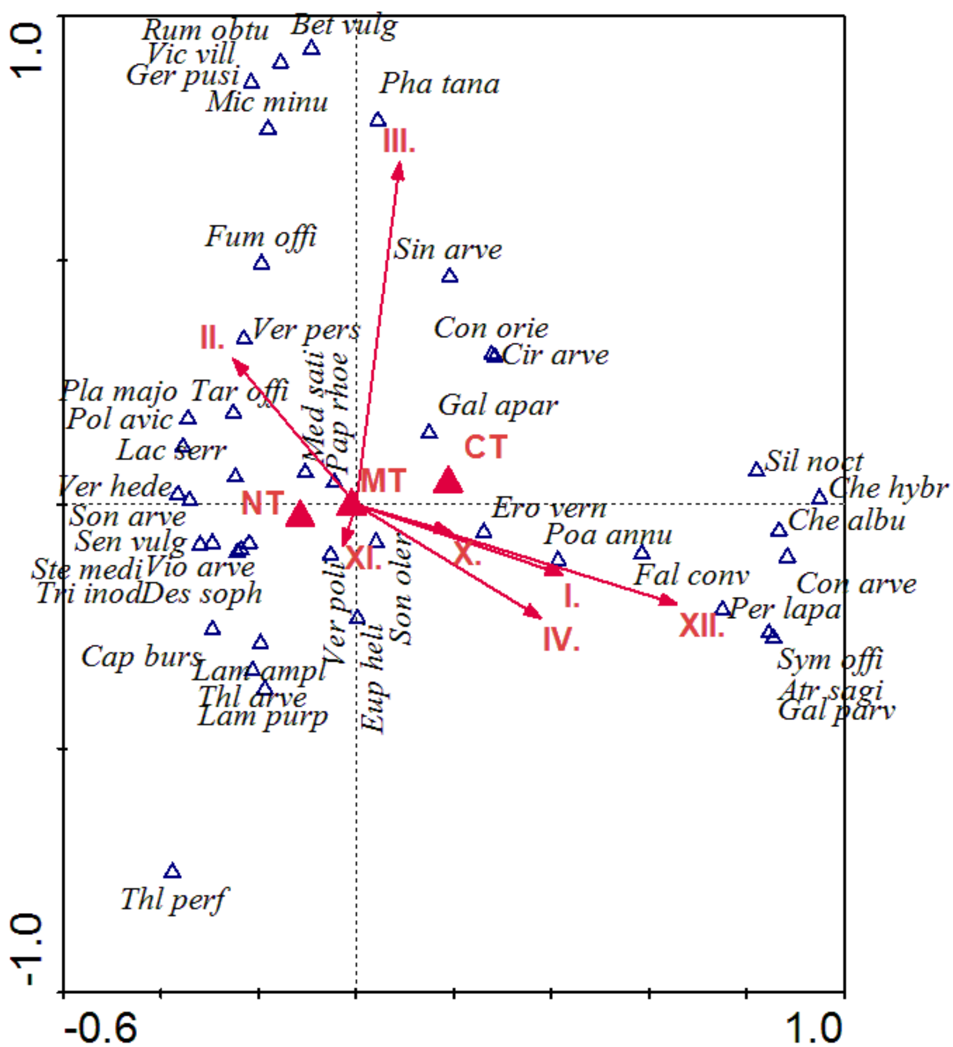


Fig. 1 The ordination diagram expressing spatial layout of the monthly precipitation effect in monitored months, soil tillage and found weed species

Notes to Fig 1: →X. aggregate precipitation for October, →XI. aggregate precipitation for November, →XII. aggregate precipitation for December, →I. aggregate precipitation for January, →II. aggregate precipitation for February, →III. aggregate precipitation for March, →IV. aggregate precipitation for April, NT – no-tillage, MT - minimization tillage, CT - conventional tillage.

Atr sagi – Atriplex sagittata, Bet vulg – Beta vulgaris, Cap burs – Capsella bursa-pastoris, Cir arve – Cirsium arvense, Con orie – Consolida orientalis, Con arve – Convolvulus arvensis, Des soph – Descurainia sophia, Ero vern – Erophila verna, Eup heli – Euphorbia helioscopia, Fal conv – Fallopia convolvulus, Fum offi – Fumaria officinalis, Gal parv – Galinsoga parviflora, Gal apar – Galium aparine, Ger pusi – Geranium pusillum, Che albu – Chenopodium album, Che hybr – Chenopodium hybridum, Lac serr – Lactuca serriola, Lam ampl – Lamium amplexicaule, Lam purp – Lamium purpureum, Med sati – Medicago sativa, Mic minu – Microrrhinum minus, Pap rhoe – Papaver rhoeas, Per lapa – Persicaria lapathifolia, Pha tana – Phacelia tanacetifolia, Pla *majo – Plantago major, Poa annu – Poa annua, Pol avic – Polygonum aviculare, Rum obtu – Rumex obtusifolius, Sen vulg – Senecio vulgaris, Sil noct – Silene noctiflora, Sin arve – Sinapis arvensis, Son arve – Sonchus arvensis, Son oler – Sonchus oleraceus, Ste medi – Stellaria media, Sym offi – Symphytum officinale, Tar offi – Taraxacum officinale, Thl arve – Thlaspi arvense, Thl perf – Thlaspi perfoliatum, Tri inod – Tripleurospermum inodorum, Ver hede – Veronica hederifolia, Ver pers – Veronica persica, Ver poli – Veronica polita, Vic vill – Vicia villosa, Vio arve – Viola arvensis.*

SUMMARY

Polní pokus se nachází v pokusné stanici Mendelovi university v Brně (lokalita Žabčice, Česká republika). Dlouhodobá průměrná roční teplota je 9,3 °C a dlouhodobí roční úhrnu srážek činí 483,3 mm. Teplotní a srážkové údaje byly získány z meteorologické stanice v pokusné stanici v Žabčicích. V polním pokusu byl použit sedmihonný osevní postup. V rámci sedmihonného osevního postupu byly ke každé plodině použity tři varianty zpracování půdy (konvenční technologie zpracování půdy, minimalizační technologie zpracování půdy, bez zpracování půdy). Zaplevelení bylo hodnoceno pomocí početní metody v porostech ozimé pšenice. V průběhu 10 let sledování bylo nalezeno 44 druhů plevelů. Na základě výsledků kanonické korespondenční analýzy můžeme konstatovat, že vyšší srážky v měsících prosinci a lednu podporují vyšší výskyt druhu *Fallopia convolvulus*. Nižší srážky v měsíci únoru podporovaly výskyt druhů *Medicago sativa, Papaver rhoeas* naopak vyšší srážky v tomto měsíci podporovaly výskyt druhu *Veronica persica.*

CONTACT

Ing. Jan Winkler, Ph.D.

Mendel University in Brno,

Department of Agrosystems and Bioclimatology, ,

Zemědělská 1, 61300 Brno, Czech Republic,

phone: +420 545 133 371, e-mail: winkler@mendelu.cz

PHYSIOLOGICAL EQUIVALENT TEMPERATURE AS AN INDICATOR OF THE UHI EFFECT WITH THE CITY OF PRAGUE AS AN EXAMPLE

PAVEL ZAHRADNÍČEK[1,2], MICHAL ŽÁK[1,3], PETR SKALÁK[1,2]

1) *Czech hydrometeorological Institute*
2) *Czechglobe – Global Change Research Centre AS CR, v.v.i.*
3) *Dept. Of Meteorology and Environment Protection, Faculty of Mathematics and Physics of the Charles University, Prague*

ABSTRACT

Description of an Urban Heat Island (UHI) using the difference in air temperature is one of the world's most studied characteristics. If, however, one wants to express how the temperature is perceived by humans, one must consider the overall effect of air temperature, wind speed, air humidity and radiation flows, which is expressed using temperature bioclimatological indexes. One of them is the so-called physiological equivalent temperature (PET), which is used for quantification of the overall effect of meteorological parameters combined with human energetic balance and which is perceived by humans. The RayMan (Matzarakis et al 2007, 2010) microscale models in the city of Prague were used to simulate biometeorological conditions describing the effect on humans using PET.

Key words: Physiological equivalent temperature, UHI, RayMan, Prague,

INTRODUCTION

Studying climates of cities is a very current topic especially because the population density of cities and metropolises is on the rise. In developing countries the ratio of urban population is about 50 % and in developed countries more than 75 % (Lambin and Geist, 2006). The effects of the climate on such a large population are therefore quite important and meanwhile the activities of such a large group of people influence the climate of that particular region itself. In the context of the current climate change and possible increase of extreme situations such as heat waves, the quality of life in large cities can significantly decrease, including impacts on human health, or even worse, increase the population mortality rate.

Built-up areas in cities create a urban climate, for which there exists a particular specific regime of most meteorological parameters (Dobrovolný et al, 2012). This regime is not only different between cities and countryside, but also between city centers and their suburbs. The reason for the creation of this specific city climate lies in several factors (e.g. Oke, 1981). First are the heat and radiation properties of active surfaces, which are crucial for the intensity of absorption and reflection of short-wave electromagnetic radiation and emission of long-wave radiation. Another factor is the change of the active surface, because the current usage of synthetic materials (asphalt and concrete) leads to changes in energetic balance, including decreased intensity of evaporation. Also geometric layout of active surfaces has negative effects, as it increases the total area and creates the so-called street valleys and increases surface roughness. Human activities also lead to the production of waste heat and increase atmospheric pollution (for example heating, industries, transportation). The increasing intensity of urban heat islands is not an issue just for climatologists, but especially for city architects and designers, who should aim to decrease this undesirable effect by using new technologies and findings and thus increase the quality of life of people living in the cities. To help to achieve this goal there is the project "UHI – Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon", financed from the Central Europe Programme, which ends this year. Its goal was to begin cooperation between experts from various fields and integration of their results. The Czech Republic was also invited to join this project and was represented by the Czech Hydrometeorological Institute (CHMI), Faculty of mathematics and physics of the Charles University and the Institute for planning and development of the capital city of Prague.

MATERIALS AND METHODS

The urban heat islands are often analyzed based on the individual meteorological elements, most commonly the air temperature. This, however, is not an ideal indicator of human perception. For this reason, various bioclimatological indexes were developed. These take into account not just the air temperature, but consider the combined effect of other factors as well, such as humidity, wind speed, radiation characteristics and other non-meteorological factors like clothing, gender, age etc.

As an index for the assessment of the changes in thermal bioclimate, the physiological equivalent temperature (PET) was used. It is defined "as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the energy budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed" (Höppe 1999). It is one of the most commonly used indices for thermal bioclimate, so results can be easily compared to those from other studies (Matzarakis and Endler 2010; Lin et al. 2010a, b; Lopes et al. 2011). Another big advantage of PET is the use of °C as unit, making results more easier for interpretation by people without knowledge in the field of human biometeorology.

As is the case with many other thermal bioclimatic indices, PET is also based on a human energy balance model. For the case of PET, the Munich Energy Balance Model for Individuals (MEMI, Höppe 1984), is used. One of the most important determining factors for PET is the mean radiant temperature, Tmrt. Tmrt is defined as the temperature of a perfectly black and equal surrounding environment that leads to the same energy balance as the current environment (VDI 1998; Fanger 1972).

The PET index was calculated using the numerical model RayMan developed

by Meteorological Institute of the Albert-Ludwigs University Freiburg (Matzarakis et al. 2007, 2010; Matzarakis and Rutz 2010; Röckle et al. 2010). The input data used were hourly measurements from meteorological stations operating in the area of the city of Prague (Karlov, Ruzyně, Kbely, Klementinum and Libuše; fig. 1). The parameters used for calculation were air temperature, air humidity, wind speed and radiation or cloudiness.

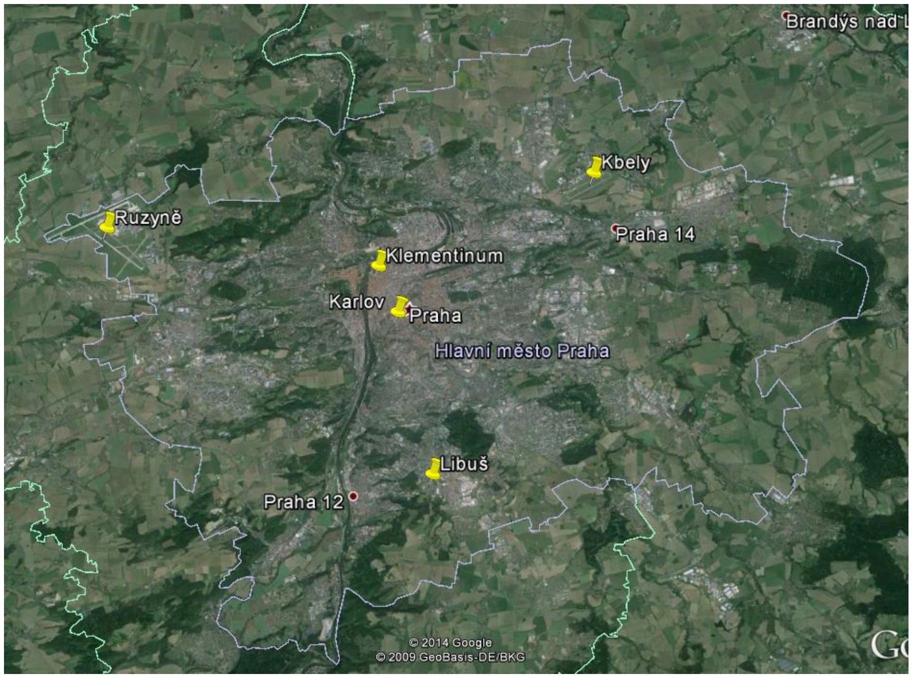


Fig. 1. Map of Prague showing the meteorological stations for which the physiological equivalent temperature has been calculated

RESULTS

Physiological equivalent temperature has the same annual pattern as the average air temperature, its actual values being on average lower. Particularly during winter months, this temperature index decreases significantly lower compared to the standard air temperature. The maximum values of both characteristics show different behavior. PET, just like the average values, is lower during winter, but during the summer, the maximal values are substantially higher than the air temperature. The standard deviation is higher for PET compared to air temperature in both cases (fig. 2).

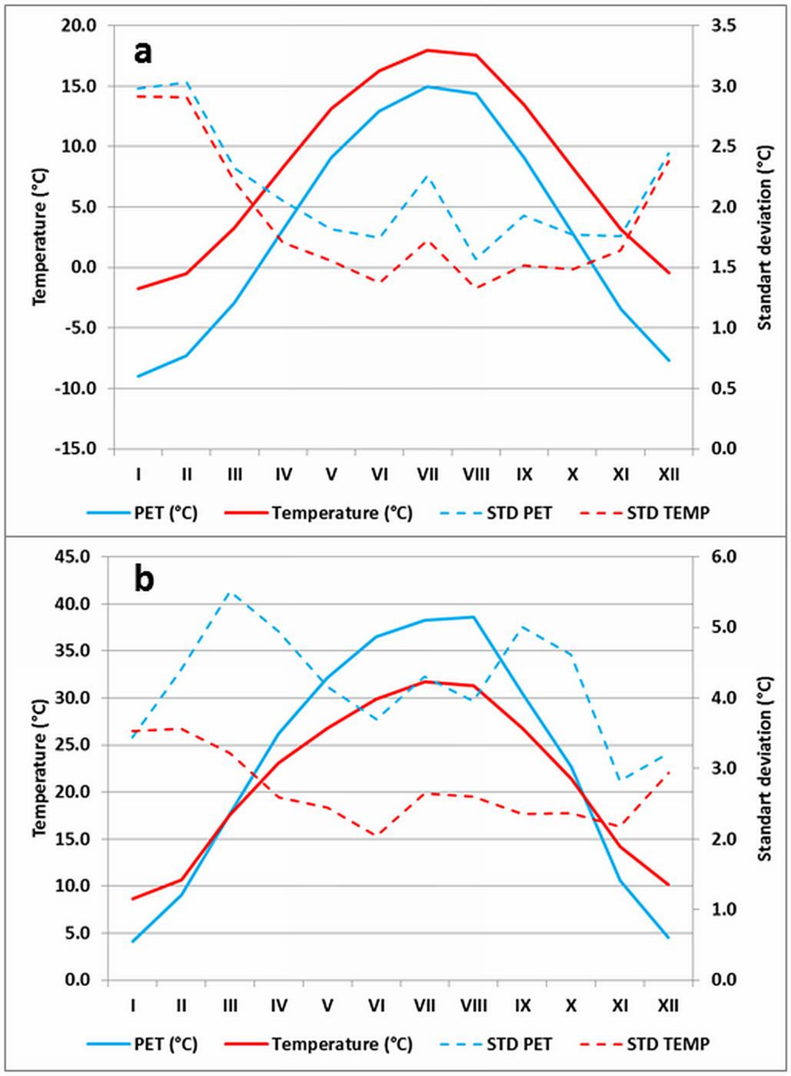


Fig. 2. Annual cycle of average (a) and maximal (b) values of PET (°C) and air temperature (°C) including standard deviations for the station in Prague-Ruzyně during 1961-2013.

In order to compare the behavior of physiological equivalent temperature, two stations were chosen – Prague Karlov representing a typical urban station, and Prague Ruzyne, which is located in the city suburb. The period for which there are equivalent hourly measurements of the individual meteorological parameters is from 2005 to 2013. As figure 3a shows, the highest values of PET are reached in Prague Karlov at the turn of July and August between 10 AM and 4 PM and the average value for the period between 2005 and 2013 exceeds 30 °C. Conversely, the lowest PET values are observed at the end of January from 0 AM to 9 AM, where the average values for the period between 2005 and 2013 decrease below -10 °C.

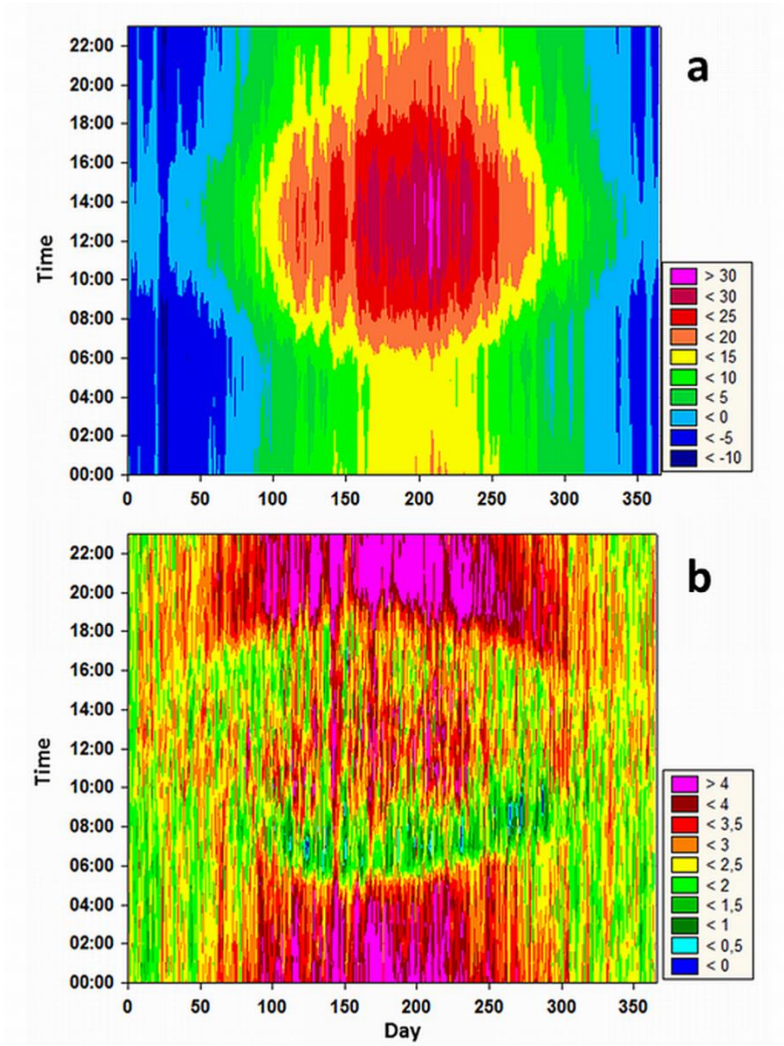


Fig. 3. The course of physiological equivalent temperature, PET (°C) at the Prague Karlov station (a) compared to the Prague Ruzyně station in the period 2005-2013

The largest difference between the PET determined in Prague Karlov and Ruzyně was just after sunset during the summer half-year. At this time, the feel-like temperature in Karlov was more than 4 °C higher than in Ruzyně (fig 3b). Another case where there is a larger difference between PET of the city center and the PET of the suburbs occurs around noon and in the afternoon, again in the summer half-year. Here, however, the difference is not so significant. The smallest difference was determined around the time of sunrise in the summer half-year, the actual value of this difference being less than 1.5 °C. For the rest of the year and hours the difference between feel-like temperature of the city center and the city suburb is usually about 2 to 3 °C.

The physiological equivalent temperature was used to calculate the same temperature characteristics that exist for air temperature, such as the number of summer and tropical days, including the number of hours with PET above 30 °C. The number of summer days is defined as days with maximum temperature of at least 25 °C and a tropical day is a day with maximum temperature of at least 30 °C. These characteristics were calculated for Prague Ruzyne and Prague Karlov. Only values since 2005 can be compared.

For the station in Prague Ruzyně, there is on average 50 PET summer days. As can be seen from figure 4a, the number of PET summer days in Karlov is 40 % higher than in Ruzyně during the period between 2005 and 2013. The largest difference was in 2005, the smallest the year after. The number of tropical days in Prague determined using the standard air temperature is around 10, for the PET however, this number increases to approximately 25 per year. During 2005 and 2013 the difference in the number of these days in the city center and city suburbs (Karlov vs Ruzyně) was very variable. In 2006 and 2007, the difference was just a few days. In contrast, during 2005 and 2011, the number of these days was 2.5 times higher in the city center than in the suburbs (fig 4b). When comparing the number of hours where PET is above 30 °C, the difference between city center and suburbs is even more apparent. In 2011 there was 3 times more of these tropical hours in Karlov compared to Ruzyně (fig 4c).

Discussion

To understand the city climate, it is more convenient to study how citizens really perceive the environment rather than studying the individual meteorological parameters, which when analyzed separately usually only provide understandable information to climatologists. In order to better utilize climatological results in practice, it is more convenient to use bioclimatological characteristics. As can be seen from the results of this work, the difference between physiological equivalent temperature in the center and suburbs of the city of Prague can be at some situations substantial. The goal should be to use the cooperation of climatologists, architects and urban designers in order to mitigate the negative effects of living in cities using new types of materials or by increasing the green areas. Large difference between the feel-like temperature is observed at night during the summer half-year, where one can see that the city center retains more heat accumulated during the day and cools down slower. This of course reduces the quality of sleep and it is difficult to ventilate homes enough (sometimes due to noise or pollution), which increases health problems of the citizens or can decrease work efficiency the next day. Therefore, also the economical results of that particular region can worsen.

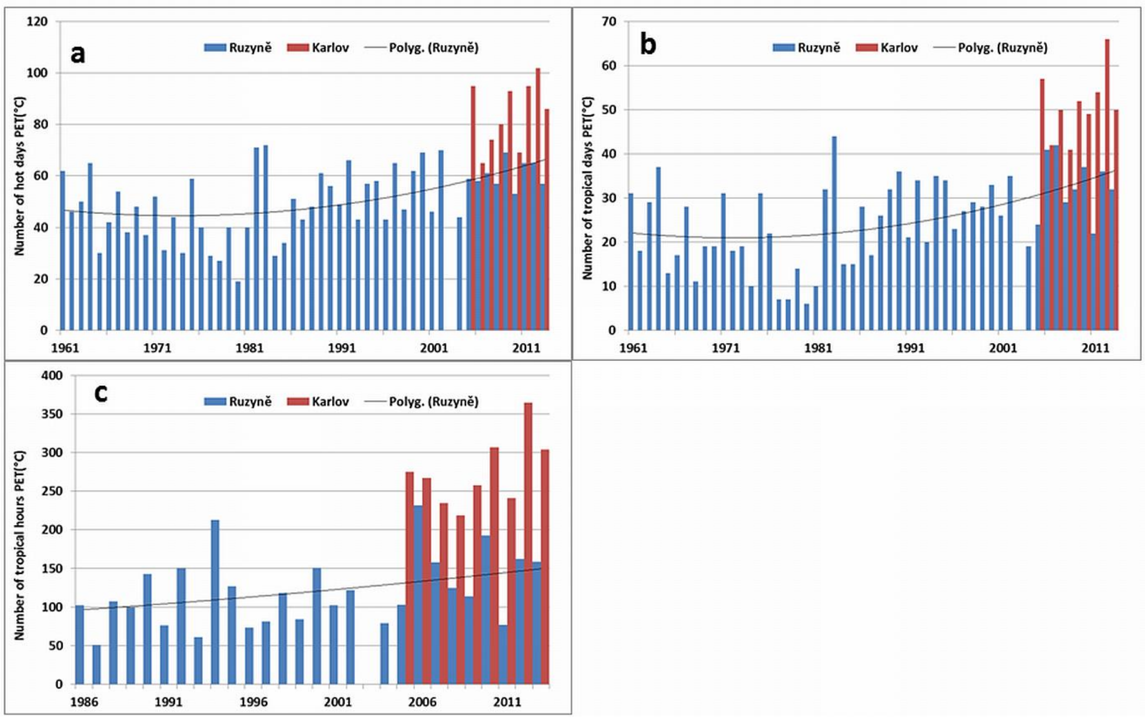
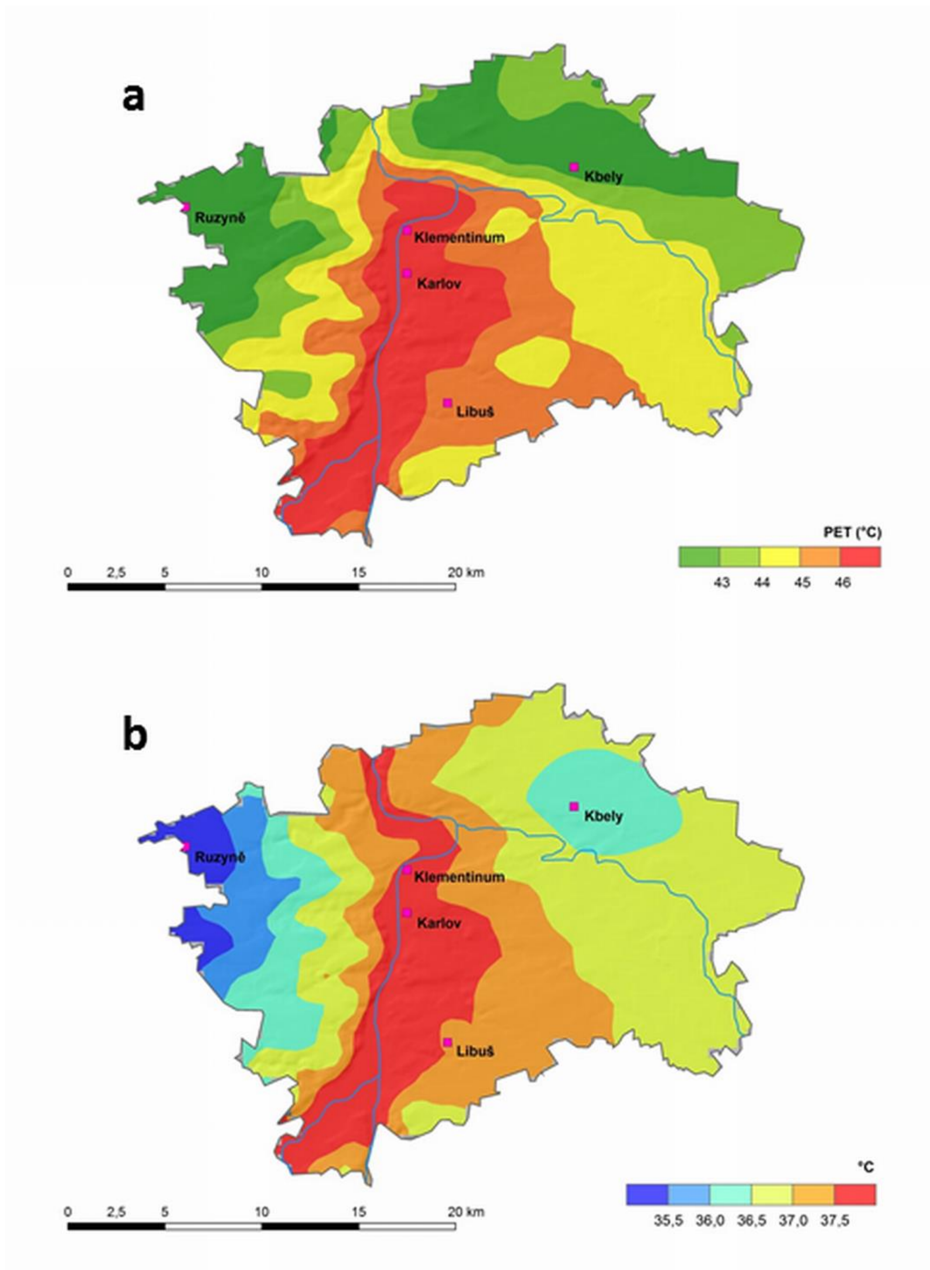


Fig. 4. Number of PET summer days (a); tropical days (b) and number of hours with temperature above 30 °C (c) at the stations in Prague Ruzyně and Prague Karlov

The city overheats substantially during warm summer days. Because Prague is a popular tourist destination, especially during summer months, worsening of temperature conditions can lead to decrease of tourism and tourists aiming for destinations where the feel-like temperature is lower. For example on 28th July 2013, the maximum air temperature at many places in Prague exceeded 35 °C (Karlov 37 °C; fig 5a). Physiological equivalent air temperature even reached 48.1 °C (Karlov; fig 5b). For the maximum air temperature, the difference between Karlov and Ruzyně was 3 °C, but using the PET, the temperature in the suburbs was 7 °C lower than in the city center.



Obr. 5. PET - Physiological equivalent temperature (a) and maximum air temperature (b) on 28th July 2013 in Prague

CONCLUSION

This work presents the less known bioclimatological characteristic called the physiological equivalent temperature (PET), which is used especially to study the urban heat islands. The calculation of this temperature indicator does not include just one meteorological parameter, but rather takes into account the combined effect of temperature, humidity, radiation and other non-meteorological parameters such as surface, human radiation and clothing etc. Physiological equivalent temperature was calculated for the region of Prague. A substantial difference between the city center and suburbs was determined. The largest differences were during night hours during the summer half-year when the Prague city center retains heat accumulated during the day much more. If the temperature comfort of the city center worsens, it could also negatively influence health of the citizens, economy and tourism. An interdisciplinary cooperation of climatologists, architects and other institutions responsible for city planning is therefore necessary.

REFERENCES

Dobrovolný et al (2012): Klima Brna. Víceúrovňová analýza městského klimatu. Masarykova univerzita. Brno 2012.200 p.

Fanger PO (1972) Thermal comfort. McGraw-Hill, New York

Höppe PR (1984) Die Energiebilanz des Menschen (dissertation). Wissenschaftliche Mitteilungen des Meteorologischen Instituts der Universität München 49

Höppe, P. (1999). The physiological equivalent temperature – A uni-versal index for the biometeorological assessment of the thermalenvironment. International Journal of Biometeorology, 43(2), 71–75.http://dx.doi.org/10.1007/s004840050118

Lambin, E., Geist, H., eds. (2006): Land-Use and Land-Cover Change. Local Processes and Global Impacts. Súringer, Berlin, Heidelberg, 222.p

Lin TP, Matzarakis A, Hwand RL (2010a) Shading effect on long-term outdoor thermal comfort. Build Environ 45:863–870

Lin TP, Matzarakis A, Hwang RL, Huang YC (2010b) Effect of pavements albedo on long-term outdoor thermal comfort. In: Matzarakis A, Mayer H, Chmielewski F-M (eds) Proceedings of the 7th Conference on Biometeorology. Ber Meteorol Inst Univ Freiburg 20:498–504

Lopes A, Lopes S, Matzarakis A, Alcoforado MJ (2011) Summer sea breeze influence on human comfort during hot periods in Funchal(Madeira Island). Meteorologische Zeitschrift 20:553–564

Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxesin simple and complex environments – Application of the Ray-Man model. International Journal of Biometeorology, 51(4), 323–334.http://dx.doi.org/10.1007/s00484-006-0061-8

Matzarakis, A., Rutz, F., & Mayer, H. (2010). Modelling radiation fluxes in simple andcomplex environments: Basics of the RayMan model. International Journal ofBiometeorology, 54(2), 131–139. http://dx.doi.org/10.1007/s00484-009-

Matzarakis, A., & Endler, C. (2010). Climate change and thermal bioclimate in cities:Impacts and options for adaptation in Freiburg, Germany. International Journal ofBiometeorology, 54(4), 479–483. http://dx.doi.org/10.1007/s00484-009-0296-2

Oke, T. R. (1981): Canyon geometry and the nocturnal heat island: comparisons of scale model and field observations. Journal of Climatology, 1, č. 3, s. 237-254

Röckle R, Hermsdörfer K, Richter CJ (2010) Mikroklimatische Untersuchung Platz der Alten Synagoge im Zuge der Stadtbahnplanung mit Umgestaltung Kronenstrasse, Werthmannstrasse, Rotteckring und Friedrichring. iMA Richter & Röckle GmbH & Co. KG, 09-12- 05-FR II

VDI (1998) Environmental meteorology, methods for the humanbiometeorological evaluation of climate and air quality for the urban and regional planning at regional level: Part I. Climate.

VDI/DIN—Handbuch Reinhaltung der Luft. Band 1b, Düsseldorf

ACKNOWLEDGEMENT

We would like to thank the project "UHI – Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon" (number 3CE292P3). This project is implemented through the CENTRAL EUROPE Programme co-financed by the ERDF

Pavel Zahradníček would like to thank the project InterDrought (no. CZ.1.07/2.3.00/20.0248) for its support.

SUMMARY

Popis tepelného ostrova města (UHI) pomocí rozdílu mezi teplotou vzduchu sice patří mezi celosvětově nejvíce studované charakteristiky, pokud ale chceme vyjádřit tepelné vnímání člověka, musíme uvažovat celkový účinek teploty vzduchu, rychlosti větru, vlhkosti vzduchu a toků radiace, které je vyjádřeno pomocí tepelných bioklimatologických indexů. Jedním z nich tzv. fyziologicky ekvivalentní teplota (PET), která se používá pro kvantifikaci celkového účinku

meteorologických parametrů kombinovaných s energetickou bilancí člověka a vnímanou lidmi. K simulaci biometeorologických podmínek popisujících vliv na člověka pomocí PET byly použity mikroměřítkové modely RayMan (Matzarakis et al 2007,2010) pro oblast města Prahy.

CONTACT

Mgr. Pavel Zahradníček, Ph.D.,

Czech Hydrometeorological Institute, Brno

Kroftova 43, Brno

+420775417215, zahradnicek@chmi.cz

DROUGHT PERIODS IN 2014

PAVEL ZAHRADNÍČEK[1,2], MIREK TRNKA[2,3], PETR ŠTĚPÁNEK[1,2], DANIELA SEMERADOVA[2,3], ALEŠ FARDA[2]

1) *Czech hydrometeorological Institute*
2) *Czechglobe – Global Change Research Centre AS CR, v.v.i.*
3) *Department of Agrosystems and Bioclimatology, Mendel University in Brno*

ABSTRACT

The first half of year 2014 was characterized by the occurrence of extreme weather. Episode without precipitation were alternated with thunderstorms, temperature were mostly above normal and was occurred first heat wave. The year began with a very mild winter, when amount of snow was only 27 % of long term average and in agricultural region South Moravia only about 10 %. The winter temperature was more than 2°C higher than normal. March and April were characterized by low sum of precipitation mainly again in South Moravia, both months were about 70% of long term average. March and April temperature were significantly above normal (March about more than about 4°C and April more than 2°C). In contrast May was cold and rainy. In the middle of the month there were persistent rainfall, which caused an increase of river levels and flooding several areas. June was again very dry. These weather conditions led to the strong dry episodes during first half of the year.

Key words: Drought, Czech Republic, year 2014, precipitation, temperature

INTRODUCTION

Drought is an essential part of climatic conditions and significantly influences many human activities. Drought in the Czech Republic occurs irregularly in a form of drought periods lasting from several days up to months, characterized by below-average precipitation. These drought periods are usually also accompanied by above-average temperatures. Although there is no unanimous definition of a drought, most authors divide it into four types – meteorological, agricultural, hydrological and socioeconomical drought (Heim 2002). Despite the fact that these are different types of drought, they come in a particular time order or they can appear later simultaneously. Meteorological drought could be defined as a period with negative deviation of precipitation from the normal value, subsequently causing agricultural, hydrological and socioeconomical drought (Brázdil et al 2007).

The weather conditions in 2014 began with a very mild winter with abnormally little snow cover and overall higher air temperatures. This trend continued with a very warm March and April and also the rainfall amount was very small and longer periods with no precipitation occurred. In contrast, the following month, May, was rather cold and after a period of heavier precipitation, higher water levels were observed at many rivers causing flooding. The next month was again dry. A lot of precipitation events in May were associated with thunderstorms, so they had a substantial spatial variability. Tropical days and first heat waves of the year 2014 were observed relatively early.

MATERIALS AND METHODS

Weather conditions in 2014 were first analyzed especially from the perspective of standard meteorological parameters such as air temperature (T), precipitation (SRA), amount of new snow (SNO) and snow cover depth (SCE). The data for 2014 come from the CHMI database. As a reference period, the so-called technical series were used – in case of air temperature from climatological stations (268), for precipitation from rain gauging stations (787). These series underwent quality control, homogenization and all the missing values from 1961-2013 were added (Štěpánek et al., 2011a, 2011b, 2013). No technical series exist for the snow parameters, so as a reference, stations measuring in the period from 1961 to 2000 were used. The rain-gauging station network is quite extensive so the number of such stations is sufficient. The meteorological data were visualized on a map using orographic interpolation with a resolution of 500 m.

A more detailed analysis of air temperature and precipitation during the first half of 2014 was performed for four selected stations (Kroměříž, Kuchařovice, Hradec Králové and

Doksany). In case of temperature, daily deviations from a long-term average value from 1961-2000 were used and the total sum of precipitation since the beginning of the year was also compared with the long-term average.

The outputs from drought monitoring (www.intersucho.cz) operated within the Intersucho project were used for illustration of the progression of agricultural drought in the Czech Republic in the first half of 2014.

Because of the close relationship between an agricultural drought and soil water content, information regarding the daily, root-zone soil moisture content (up to 1.3 m or to the maximum rooting depth) is used to estimate the intensity of agricultural drought. The soil moisture content in two soil layers was calculated for all growing seasons between 1961 and 2012 in a 500 m grid using the SoilClim model (Hlavinka et al., 2011). This model is based on the Penman-Monteith method to estimate reference evapotranspiration and also takes into account other factors affecting soil moisture such as the soil water holding capacity, phenology development, root growth or snow cover accumulation/melting (Trnka et al., 2010, 2014). The SoilClim model also accounts for the interception by vegetation as well as for the soil water percolation to the deeper soil layer and its performance was evaluated by an array of observed data from Hlavinka et al. (2011).

RESULTS

The year 2014 began with a very mild winter characterized by above-average temperatures and below-average precipitation. The western part of the republic was colder, with temperatures 2 to 3 °C above the long-term average from 1961-2000. Moravia and northern part of Bohemia was more than 3 °C above average and the eastern end of the republic even 3.5 °C above the long-term average from 1961-2000. The spatial distribution of precipitation was opposite. In western and southern Bohemia the precipitation amount was 50 % of the long-term average, in some places even less than 30 % (Fig. 1a). Moravia was also below-average in terms of precipitation, but not so significantly. Here, the precipitation amount was usually between 50 to 70 % of the long-term average. Little precipitation and high air temperatures of course also had an effect on the amount of snow. The average spatial amount of new snow for the entire Czech Republic was just 27 % in comparison to the long-term average from 1961-2000 (Fig. 1b). The least amount of new snow was observed in southern Moravia (around 12 %). In western Bohemia the percentage was higher, but usually not more than 50 %. For example, in southern Moravia, the maximum depth of snow cover did not exceed 3 cm. The spatial average for the Czech Republic was 8.6 cm, which is 30 % of the long-term average.

March 2014 was again quite warm in the region of the Czech Republic. The average air temperature for the Czech Republic was 3.7 °C higher than the long-term average. The regions with highest deviation included eastern Bohemia and central Moravia (more than 4 °C), the least difference was observed in western and southern Bohemia (around 2.5 °C). The spatial distribution of precipitation in March 2014 was very variable. In southern Bohemia, the observed precipitation was just 37 % of the long-term average, in the region of Pohořelicko, Znojemsko, Břeclavsko and Hodoninsko even below 30 %. On the other hand, precipitation in central and eastern Bohemia corresponded to or was slightly above the long-term average.

In April 2014 the high temperatures continued. This time, the deviation from the long-term average was smaller in Moravia, especially in its southern and eastern part (1.5 to 2.5 °C). In contrast, the largest difference was measured in western and northern Bohemia (more than 3.2 °C). The average deviation for the Czech Republic as a whole was 2.6 °C. The precipitation showed a very big spatial variability due to rather changeable weather. In the southern part of the republic (Znojemsko, Jindřichohradecko, Domažlicko, Třebíčsko) there were places with less than 50 %, while in Vsetínsko, Rokycansko and other local places, the precipitation amount was more than 130 % of the long-term average.

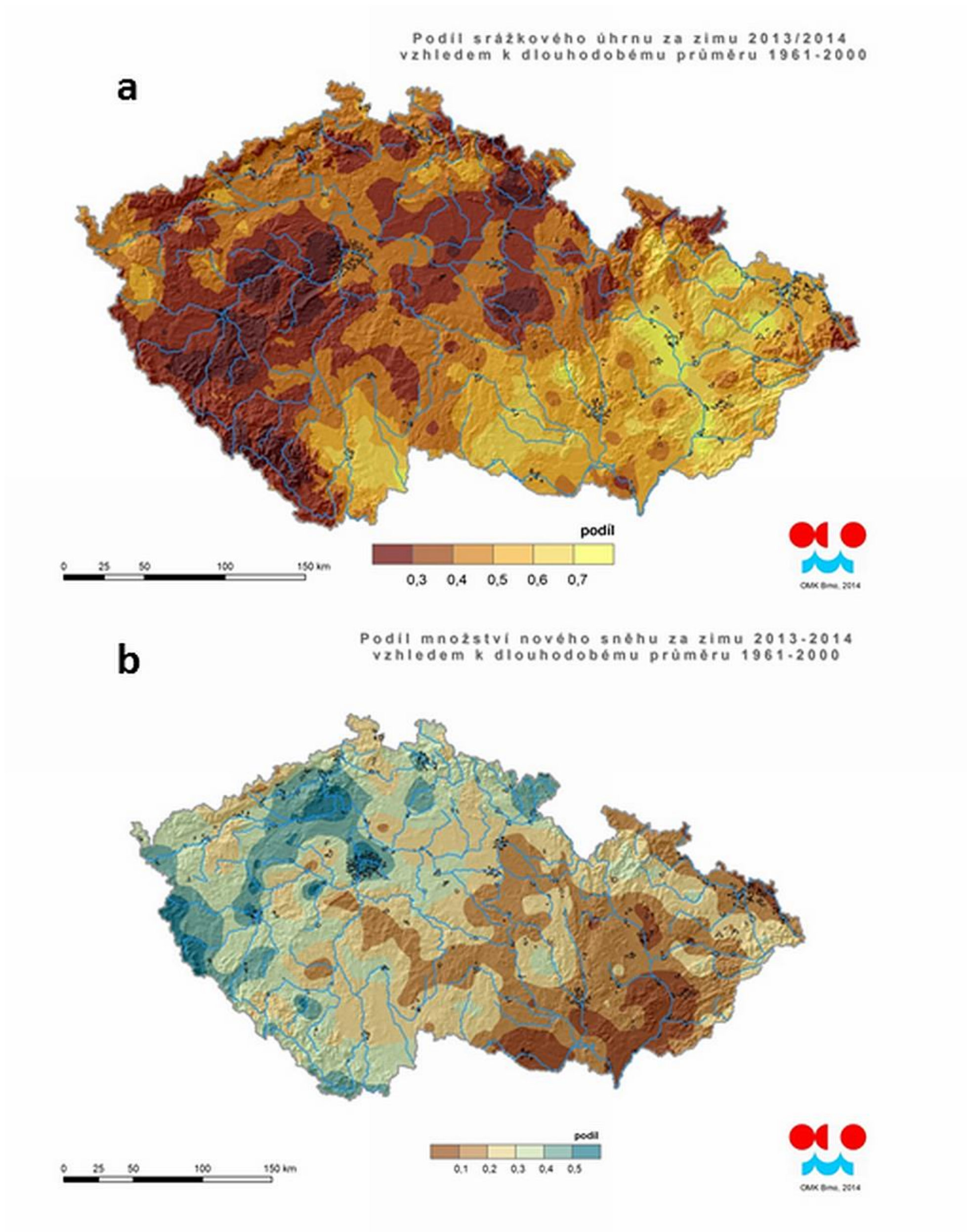


Figure. 1. The ratio of precipitation (a) and amount of new snow during the winter 2013/2014 with respect to the long-term average

The following month, May, was in fact the exact opposite of the previous spring months. In terms of temperatures it was normal for most parts of the republic, with average deviation from the long-term average for the whole Czech Republic of -0.2 °C. Bohemia was slightly colder, with deviations smaller than -0.4°C. The amount of rainfall in May 2014 was relatively high, especially in the western part of the republic. On average, there was 57 % higher precipitation than the long-term average, but for example in Jeseníky, central Bohemia or western Bohemia, the amount of precipitation was even more than double the average. On the other hand in Moravia there were locations, where the precipitation amount corresponded to the average, or was even slightly below it. With exception of 21st and 22nd, precipitation was observed in the Czech Republic on each day of May and quite common were intense thunderstorms. The situation culminated at the end of the month from 27th to 29th May, when flesh floods rose rivers leading to locally even third flood degree. Highest precipitation (Fig. 2) for this period was observed in the region of Jeseníky (maximal daily precipitation of 86 mm), Mladoboleslavsko (64 mm), Klatovsko (40 mm) and Novohradsko (31 mm). The most significant change in discharge was in the affected basins, i.e. in Černý potok basin in Jesenicko in Velká Kraš (location of monitoring), where the third flood degree was exceeded for a short period of time. The third flood degree on 28th May was also reached in Klabava in Hrádek and Nová Huť and for the Úslava River in Koterov, for a period of 17 hours (28th May 2014 from 3 AM to 8 PM). The maximum flow rate was 39.4 m^3/s and water level 183 cm. State of emergency in Nová Huť lasted for 21 hours (28th May 2014 from 10 AM to 5 AM on 29th May 2014), with maximum flow rate of 101 m^3/s and water level 236 cm. In Červený potok basin in Jesenicko, third flood degree was shortly reached in Velký Kraš profile (Internet Source 1).

Overall the spring could be characterized as above-average in terms of temperature, with average deviation for the entire Czech Republic being 2.1 °C. The highest deviation was observed in central and eastern Bohemia, i.e. in the so-called Polabské lowlands (Fig. 3a). Surprisingly the smallest difference compared to the long-term average was in Břeclavsko and Hodonínsko (+ 1.7 °C). Due to heavy rains in May, this month the territory of the Czech Republic as a whole was on average normal or above-average (116 %). This number, however, does not reflect the spatial differences. The highest precipitation was measured in an area stretching from southern to northern Bohemia and Jeseníky. On the contrary, in terms of precipitation average or below-average was most of Moravia (Fig. 3b). The precipitation in the agricultural county Břeclavsko was 83 % of the long-term average.

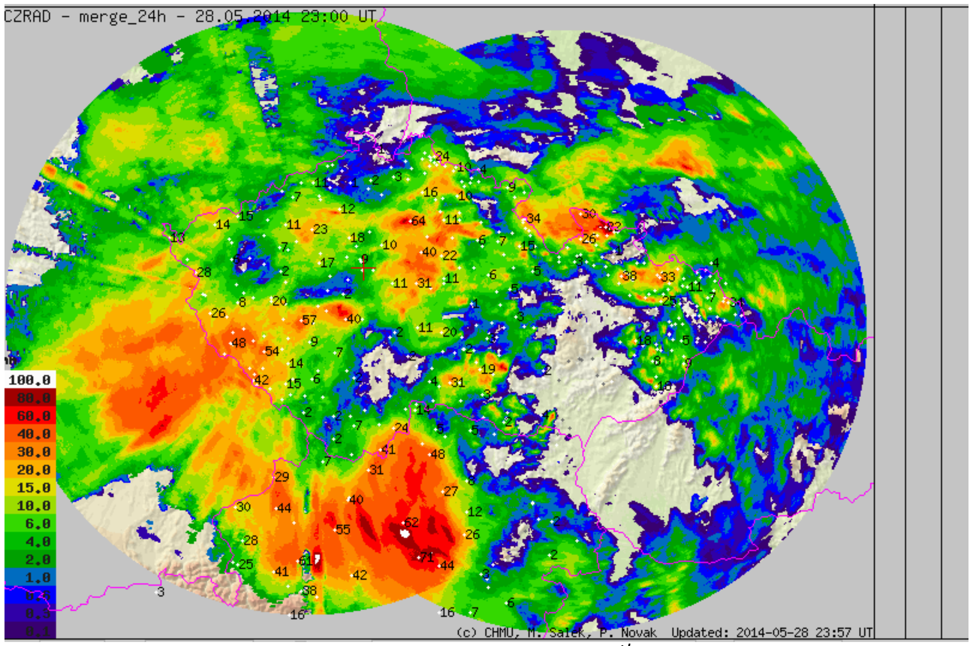


Figure 2. Radar 24h precipitation estimate for 28th May 2014 (www.chmu.cz)

June 2014 was again above-average in terms of temperature and below-average in terms of precipitation. The average air temperature deviation was 0.7 °C. The southern part of the republic was warmer, especially the regions of southern Moravia and southern Bohemia (+ 1.1 °C). On the contrary, average or below-average air-temperature was observed in northern Moravia. Less precipitation was in the western part of the republic. The amount of precipitation in comparison to the long-term average was smallest in southern and central Bohemia (35 %), the average for the whole Czech Republic was 44 %. Smaller deviation from the average was in northern Moravia (60 to 75 % of the long-term average).

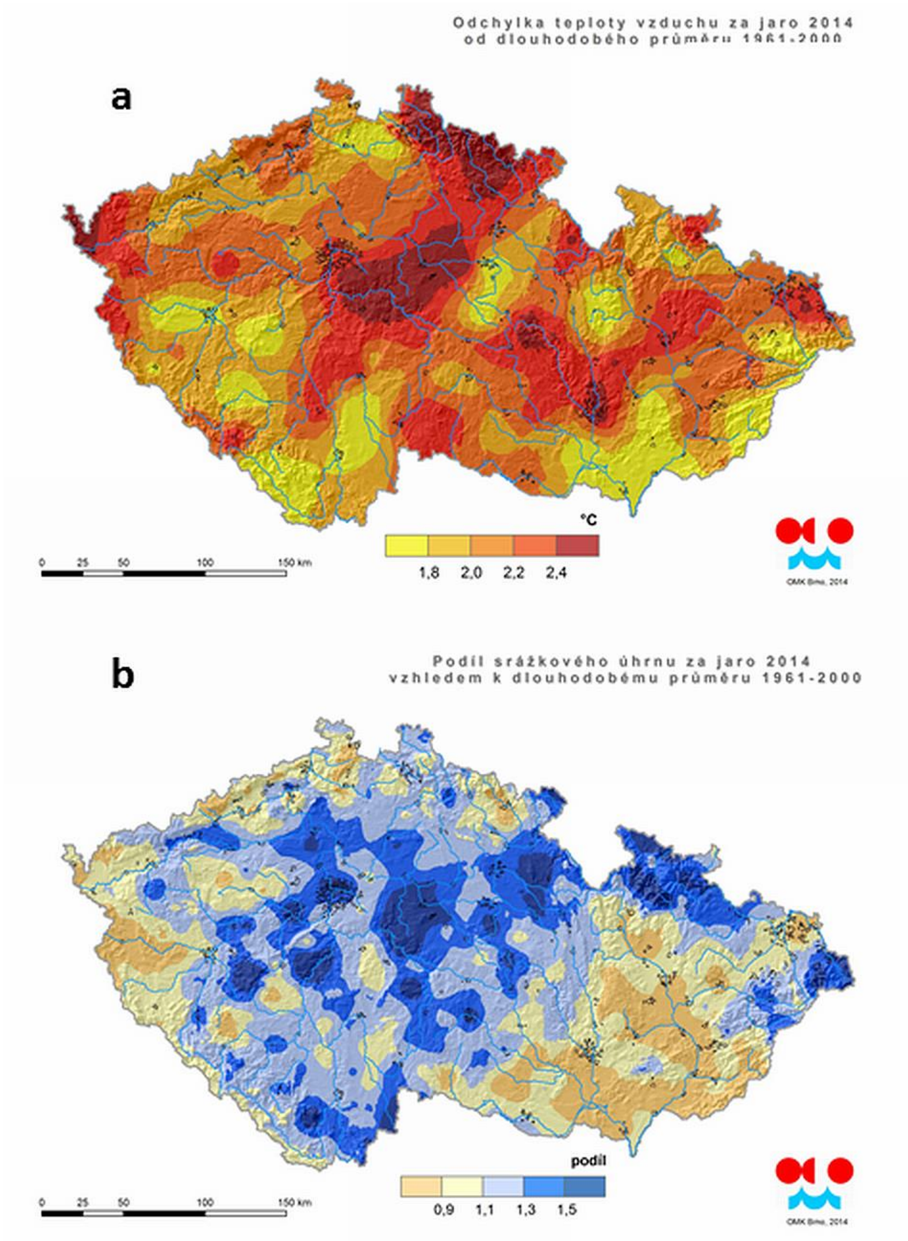


Fig. 3. Deviations in air temperature (a) and precipitation (b) for the spring 2014 from the long-term average of 1961-2000

For the four selected stations, which represent agriculturally important regions, were calculated cumulative values of precipitation for the first half-year of 2014 and these were subsequently compared to the long-term average for 1961-2000 (Fig. 4). The same comparison was also performed for air temperature. As can be seen on figure 4, the difference in total precipitation from the long-term average keeps getting bigger since the beginning of the year. A change occurs in the middle of May 2014, when due to heavy and frequent thunderstorms there is a rapid shift close to the average. In June, the deficit again becomes larger. In case of the station in Kroměříž, a sudden shift can be seen at the end of June, caused by a local thunderstorm. Such a large deficit and deviation from the average is not observed at stations in Bohemia and the initial precipitation deficit started decreasing earlier. As of the last day in June, the precipitation was smaller compared to the long-term average by 27 % in Kroměříž, 25 % in Kuchařovice, 11 % in Hradec Králové and only 4 % in Doksany. For all the four selected stations one can see a large number of days with above-average temperature. The percentage of such days ranged from 70 % (Doksany) to 75 % (Kroměříž). The first half of 2014 was 2.2 to 2.3 °C warmer in Kroměříž, Hradec Králové and Kuchařovice, a slightly smaller difference (+1.8 °C) was measured in Doksany.

DISCUSSION

The above described weather conditions during the first half of 2014 of course also reflected in the intensity of drought and its spatial distribution. The drought intensities came in various waves depending on the current precipitation at that particular area. As can be seen from figure 5, at the beginning of March drought was observed especially in southern and southwestern Bohemia, which exactly corresponds to the precipitation during the winter of 2013-2014 (fig 1a), when the precipitation percentage was even less than 30 % of the long-term average.

By the end of April, more intense drought began to appear in the western part of southern Moravia, where very low precipitation was observed in both March and April. Due to very wet May, however, the risk of soil drought was practically almost completely eliminated and the drought in fact did not occur. However, just 20 dry and warm days in June led to the return of drought situation, this time much more intense compared to the entire preceding period. In particular the region of southern and central Moravia was affected by the highest degree of drought (category S5 – extreme drought). This shows that if there is a longer period of drought, one wetter month can significantly reduce the risk of drought, but subsequent, even just a short, period without precipitation can very quickly and very intensively lead to drought again.

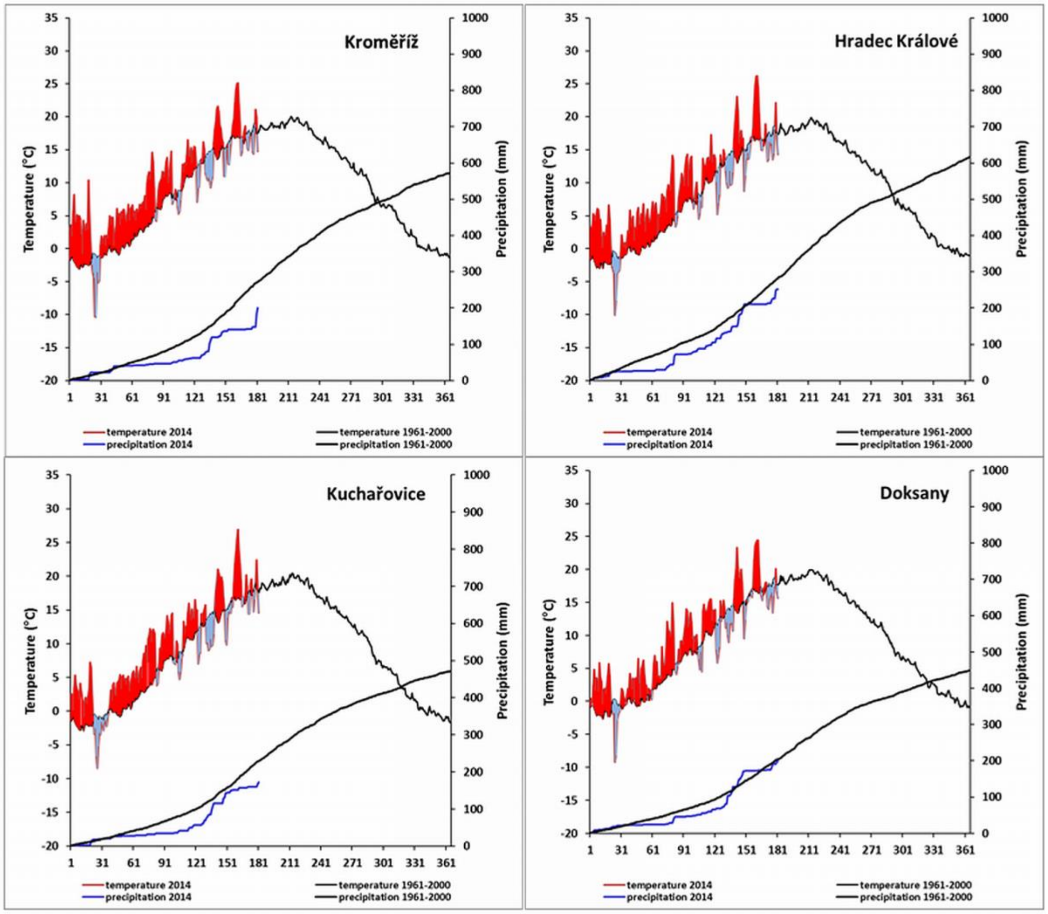


Figure 4. Variations in the daily mean temperatures and precipitation totals for Kroměříž, Hradec Králové, Kuchařovice and Doksany stations from January 2014 to June 2014; blue line – measured cumulative precipitation, black thick line – cumulative precipitation for 1961–2000, red and blue shaded area – measured daily mean temperatures and black thin line – daily mean temperatures for 1961–2000

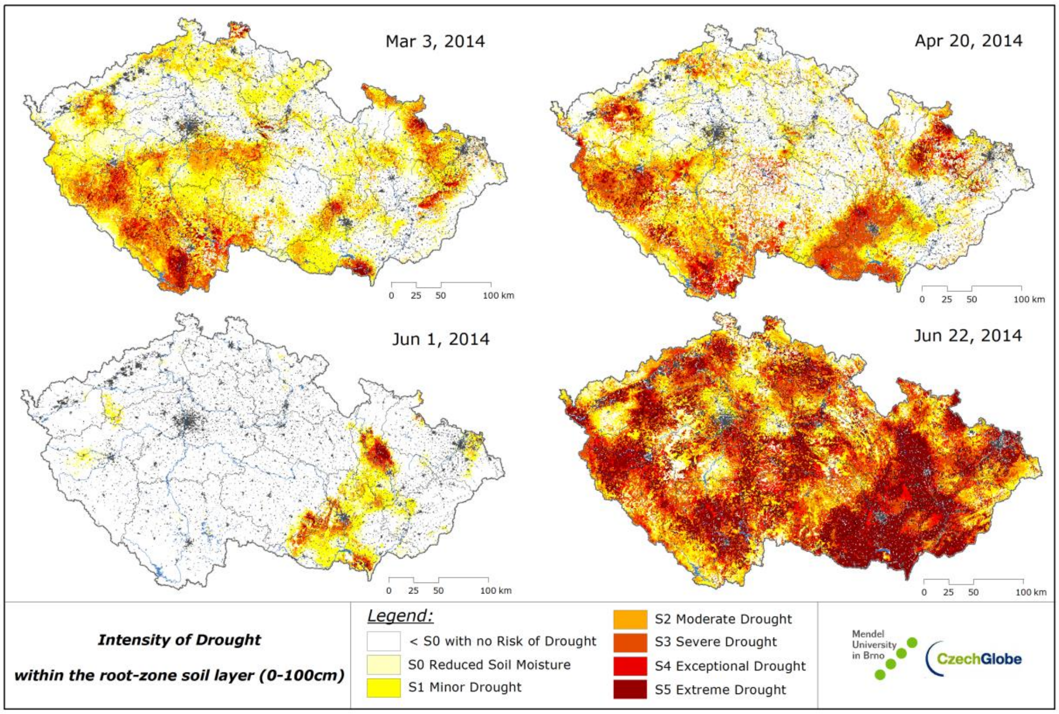


Figure 5. Drought intensity within the rooting zone (0–100 cm) expressed using a six-point scale for selected days from March 2014 to June 2014 for the Czech Republic: S0 – soil moisture level between the 20th and 30th percentile for the given period, S1 – 10th to 20th percentile, S2 – 5th to 10th percentile, S3 – 2nd to 5th percentile, S4 – 1st to 2nd percentile and S5 – less than or equal to the first percentile and for relative soil saturations less than 50% of the maximum water holding capacity for more than one month

There were several drought periods in the last 15 years. Significant were the years 2000, 2003, 2007 and the last episode occurred in 2012. This last one began already in autumn 2011 and lasted for 10 months until the end of May 2012, when the situation got better thanks to rainy summer of 2012. The drought in 2012 was important in terms of its variable spatial distribution – no drought was observed in Bohemia, but in Moravia it was very intense. The drought period began already in autumn 2011, for example in November there was no precipitation at all, or just minimal. The winter was, just like this year, mild, precipitation was, in particular in Moravia, below-average, in Bohemia thanks to wetter January, the precipitation was normal. Spring 2012 was again very warm and with very little precipitation during all months. The precipitation deficit in spring 2012 was significant over the entire region of the Czech Republic, especially in Moravia. This was reflected in poor grain yields, one of the worst in the last decade, and also in an increased number of wildfires. Despite the fact that the course of weather was different this year, it will be interesting to compare the effects with the year 2012. An interesting point is that drought this year is observed more intensively in Moravia than in Bohemia, though this difference is so far not so pronounced as in 2012.

Conclusion

The article summarizes weather conditions during the first half of 2014, which was characterized by high variability leading to episodes of drought. The year began with a very mild winter with above-average temperatures and significantly below-average amount of rainfall and snow. At many locations, snow was a rather an exception. The spring therefore began with a precipitation deficit, which further increased due to very warm and in terms of precipitation below-average March and April. From April the amount of precipitation increased during frequent thunderstorms and this culminated in May, which was very wet and at some places even third degree floods were observed. Rainy May ended the first episode of drought. However, due to very dry June, a second drought episode began, which within just a few weeks became even more intense than the first one. By the end of June it can be said that drought was more intense in the region of Moravia compared to Bohemia. As this study shows, it can be seen that the weather in the Czech Republic is very variable, with a tendency towards fast development of drought episodes.

References

Brázdil R, Kirchner K, Březina L, Dobrovolný P, Dubrovský M, Halásová O, Hostýnek J, Chromá K, Janderková J, Kaláb Z, Keprtová K, Kotyza O, Krejčí O, Kunc J, Lacina J, Lepka Z, Létal A, Macková J, Máčka Z, Mulíček O, Roštínský P, Řehánek T, Seidenglanz D, Semerádová D, Sokol Z, Soukalová E, Štekl J, Trnka M, Valášek H, Věžník A, Voženílek V, Žalud Z. 2007. Selected Natural Extremes and Their Impacts in Moravia and Silesia (in Czech). Masarykova univerzita: Brno.

Heim RR. 2002. A review of twentieth-century drought indices used in the United States. Bulletin of the American Meteorological Society 83: 1149–1165.

Hlavinka P, Trnka M, Balek J, Semerádová D, Hayes M, Svoboda M, Eitzinger J, Možný M, Fischer M, Hunt E, Žalud Z. 2011. Development and evaluation of the SoilClim model for water balance and soil climate estimates. Agriculture and Water Management 98: 1249–1261. DOI: 10.1016/j.agwat.2011.03.011.

Štěpánek P, Zahradníček P, Brázdil R, Tolasz R. 2011a. Methodology of Data Quality Control and Homogenisation of Time Series in Climatology (in Czech). Český hydrometeorologický ústav: Praha.

Štěpánek P, Zahradníček P, Farda A. 2013. Experiences with data quality control and homogenization of daily records of various meteorological elements in the Czech Republic in the period 1961–2010. Idöjárás 117: 123–141.

Štěpánek P, Zahradníček P, Huth R. 2011b. Interpolation techniques used for data quality control and calculation of technical series: an example of Central European daily time series. Idöjárás 115: 87–98.

Trnka M, Brázdil R, Možný M, Štěpánek P, Dobrovolný P, Zahradníček P, Balek J, Semerádová D, Dubrovský M, Hlavinka P, Eitzinger J, Wardlow B, Svoboda M, Hayes M, Žalud Z. 2014. Soil moisture trends in the Czech Republic between 1961 and 2012. International Journal of Climatology (in review).

Trnka M, Kocmánková E, Balek J, Eitzinger J, Ruget F, Formayer H, Hlavinka P, Schaumberger A, Horáková V, Možný M, Žalud Z. 2010. Simple snow cover model for agrometeorological applications. Agricultural and Forest Meteorology 150: 1115–1127. DOI: 10.1016/j.agrformet.2010.04.012.

Internet sources
(S1) http://www.mzp.cz/cz/news_140530_povodne_kveten2014

ACKNOWLEDGEMENT

We would like to thank the project InterSucho (no. CZ.1.07/2.3.00/20.0248) for support.

Pavel Zahradníček was supported by the “Hydrometeorological extremes in Southern Moravia derived from documentary evidence” project (Czech Science Foundation, no. 13-19831S)

SUMMARY

První půlka roku 2014 byla charakterizována výskytem velké variability počasí. Bezsrážkové epizody byly střídány bouřkami, teploty vzduchu byly většinou nadprůměrné a vyskytovaly se jak tropické dny, tak i první horké vlny. Rok začal velmi mírnou zimou, kdy

množství sněhu odpovídal pouze 27 % dlouhodobého průměru a v zemědělské oblasti jižní Moravy jen 10 %. Teploty vzduchu byly více než o 2°C vyšší než dlouhodobý průměr. Taktéž březen a duben se vyznačoval podobným rysem počasí, kdy byla teplota výrazněji nad svým průměrem a srážky byly podnormální. Zcela opačný byl měsíc květen, který byl značně vlhký a teplotně průměrný. Na některých místech spadlo i více než dvojnásobek obvyklých srážek. To se projevilo koncem měsíce, že na řadě míst stoupla hladina řek až na 3. SPA. Červen byl poté opět teplý a srážkově chudý. To se projevilo i v intenzitě sucha, kdy první epizoda trvala právě do května, kdy díky vydatným srážkám byla ukončena, ale v červnu začala druhá epizoda, ještě více intenzivnější než ta první.

CONTACT

Mgr. Pavel Zahradníček, Ph.D.,

Czech Hydrometeorological Institute, Brno

Kroftova 43, Brno

+420775417215, zahradnicek@chmi.cz

DROUGHT MONITOR FOR THE CZECH REPUBLIC - WWW.INTERSUCHO.CZ

MIROSLAV TRNKA[1,2], PETR HLAVINKA[1,2], DANIELA SEMERÁDOVÁ[1,2], JAN BALEK[1,2], MARTIN MOŽNÝ[1,3], PETR ŠTĚPÁNEK[2,4], PAVEL ZAHRADNÍČEK[2,4], MICHAEL HAYES[5], JOSEF EITZINGER[6], ZDENĚK ŽALUD[1,2]

1) *Department of Agrosystems and Bioclimatology, Mendel University in Brno, Zemědělská 1, 613 00, Czech Republic*
2) *Global Change Research Centre, Czech Academy of Sciences,, Bělidla 986, 4a, 603 00 Brno, Czech Republic*
3) *Czech Hydrometeorological Institute, Doksany Observatory, 411 82 Doksany 105, Czech Republic*
4) *Czech Hydrometeorological Institute, Brno Regional Office, Kroftova 43, 616 67 Brno, Czech Republic*
5) *National Drought Mitigation Center, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA*
6) *Institute for Meteorology, University of Life Sciences in Vienna (BOKU), Austria*

ABSTRACT

Because drought and its impacts are among the worst hydrometeorological extremes (including also Central European conditions), the aim of this paper is to describe the core and use of the *Integrated drought monitoring system* for the Czech Republic. Land-use, information about soil, vegetation characteristics and meteorological data are used as inputs to validated water balance SoilClim model, which is applied for estimates of actual and reference evapotranspiration and water saturation of the soil profile in % or soil moisture content in mm. Moreover the prognosis of expected soil moisture (based on probabilistic analysis) is calculated for next 1, 2, 4 and 8 weeks. Main results are weekly updated in form of drought occurrence maps, which are published in spatial resolution 500 m for whole territory of the Czech Republic and for all its 76

districts separately. Final maps with detail comments are available at drought topic dedicated web page (www.intersucho.cz).

Key words: soil moisture, land use, evapotranspiration, drought assessment

INTRODUCTION

Drought is natural phenomena, which belongs to hydrometeteorological extremes with strong impacts on life, economy and generally on most of human activities. It must be emphasized that drought is a common feature of any climate (Smith et al., 1996). Central Europe is not at the moment frequently thought of as being a particularly drought-prone region not even in the European context, where much more emphasis concentrates on the Mediterranean area. As the vegetation in general as well as agriculture systems in Central Europe profited from the advantage of evenly distributed precipitation (e.g. Tolazs et al., 2007), the region is susceptible to even short-term droughts (e.g. Brázdil et al., 2008; Hlavinka et al., 2009). The Central Europe including the Czech Republic, however, experienced substantial (in terms of extend and impact) drought events of various intensity in the past several years including those in the years 2000, 2003 and 2011-2012 or 2013-2014. According to Wilhite (2005) we can distinguish meteorological, agricultural, hydrological and socio-economic drought. These four drought types can be monitored, checked or described on various ways. There are drought systems (monitors or portals) which are more or less successful and used. The most well-known drought systems seems to be drought monitor provided by The National Drought Mitigation Center (http://drought.unl.edu/) in Nebraska, USA or The European Drought Centre (http://www.geo.uio.no/edc/) which is a virtual centre of European drought research and drought management organizations. This contribution offers look inside to Czech national drought monitor (such called: Integrated drought monitoring systems) which has been built for agriculture purposes and his stakeholder group consist of farmers, rural experts and decion-makers primary in agricultural sector. The trigger for development of drought monitor were recent scientific work concerning changing soil moisture and expected higher amount of drought spells occurrence in the Central Europe due to expected patterns of climate change

(Trnka et al., 2013; Hlavinka et al., 2009; Žalud et al., 2009; Trnka et al., 2009a; Trnka et al., 2009b; Brázdil et al., 2008).

MATERIALS AND METHODS

Drought is assessed using water balance model SoilClim. Its structure and validation was published by Hlavinka et al., (2011) and Trnka et al., (2013). This model is based on the work of Allen et al. (1998 and 2005), but includes many modifications and adaptations to follow the conditions of the Czech Republic. The current version of the model can estimate the value of a reference and actual evapotranspiration, and soil moisture content in two layers of the root profile (0-40 cm and 40-100 cm) for the 11 vegetation types. For this purpose also dynamic growth and phenological model or algorithm for snow cover accumulation and melting (Trnka et al., 2010) are included within SoilClim. Integrated Drought Monitoring System uses several databases which are interpolated to 500m grid. For each grid description and actual stage of vegetation cover, land use, land steepness and exposition, interception, underground water level (not for all grids are data available) and basic soil physical properties are taken into account. Actual meteorological data in daily time step (i.e. minimum and maximum air temperature, global solar radiation, precipitation, air humidity and wind speed) are taken from Czech Hydrometeorological Institute. The model provides for each grid information about the actual and reference evapotranspiration, the water content in the soil in both layers, expressed either as proportion of water soil profile saturation in % (in maps 0-1) or as soil moisture content in mm. The final product is a map of the intensity of dryness. This is for each grid determined by comparing the current value of soil moisture content at a given day with the values of soil moisture distribution achieved during the 1961-2010 time period ± 10 days from the date considered. The value expresses the probability of repetition of soil moisture in the given day and is used to assign the appropriate intensity of droughts (<S0, S0, S1, S2, S3, S4, S5) according to this simple 7 step color scale. Every color (= drought level) responds to certain year drought probability. For instance S1 (= drought level 1) responds to occurrence of 3-year drought. Moreover the probabilistic analysis (based on 50 years of meteorological measurements) is used to forecast the probable soil moisture development from the actual state for next 1, 2, 4 and 8 weeks. Drought parameters and forecast are computed weekly on

Sundays (for whole territory of the Czech Republic and for each of its 76 districts) and final maps with relevant comments (www.intersucho.cz) are upgraded on Mondays.

RESULTS

Results of Integrated drought monitoring system are maps showing actual drought over the Czech Republic territory in 500 m grids for rooting zone layers 0-100 cm (Fig. 1-3). In addition two districts (Fig. 4 – Znojmo, and Fig.5 – Přerov), has been selected as outputs for drought monitoring on local level. All examples are for real date 29th June 2014 (maps were published one date later).

CONCLUSION

According to Czech farmers experience (especially in middle and south Moravian region) drought becomes one of the most adverse factor influencing soil structure, erosion and finally crop yield. Development of drought detection tools is crucial condition for mitigation and adaptation processes. Recently developed and weekly updated drought monitor should help for decision processes concerning long term impacts but also actual situations. That is why we work on improving of our *Integrated drought monitoring system*. Drought monitor will be improved by integration of another two methodologies in the near future. First approach is based on satellite observations (as independent source of information), when seasonal greenness deviations will be compared with drought monitor outputs. Second new approach will be connected with soil moisture measurements network (observed data).

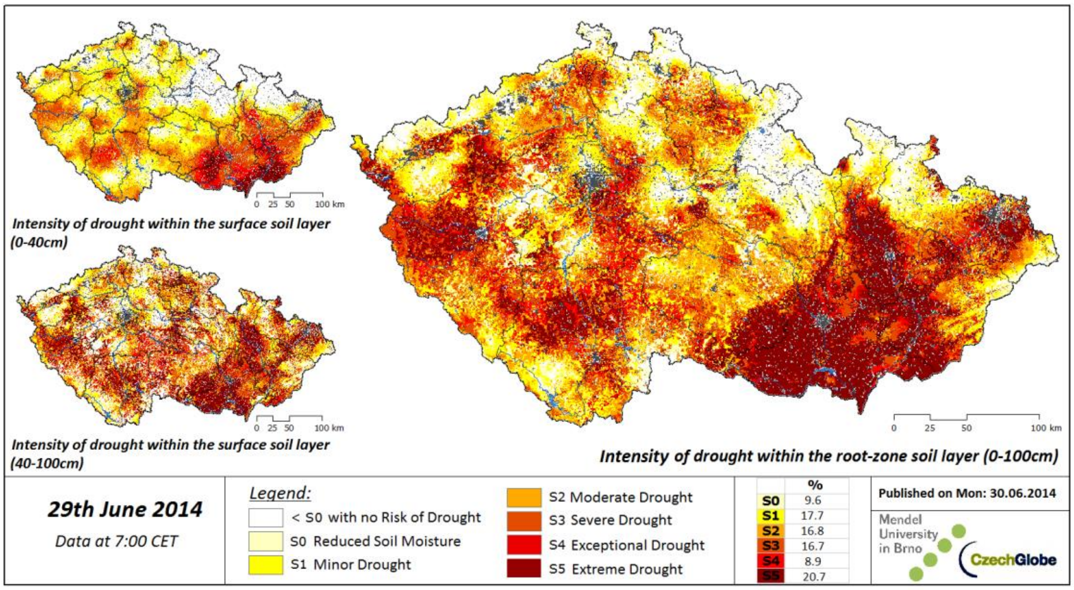


Fig 1: Intensity of drought within the surface layer for whole area of the Czech Republic

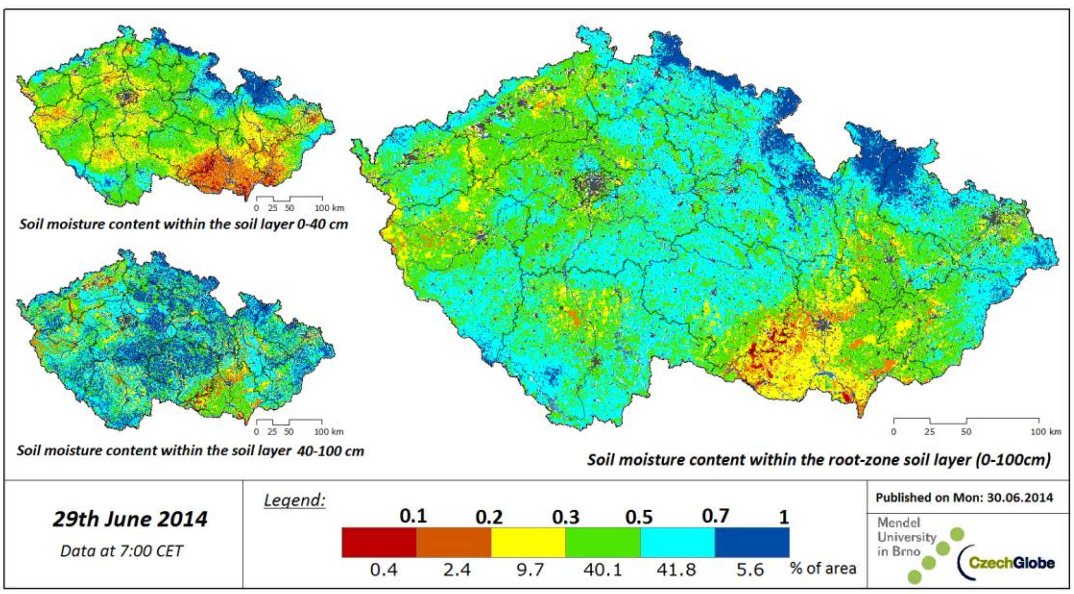


Fig 2: Soil moisture content (x 100 = % of saturation) within the surface layer for whole area of the Czech Republic

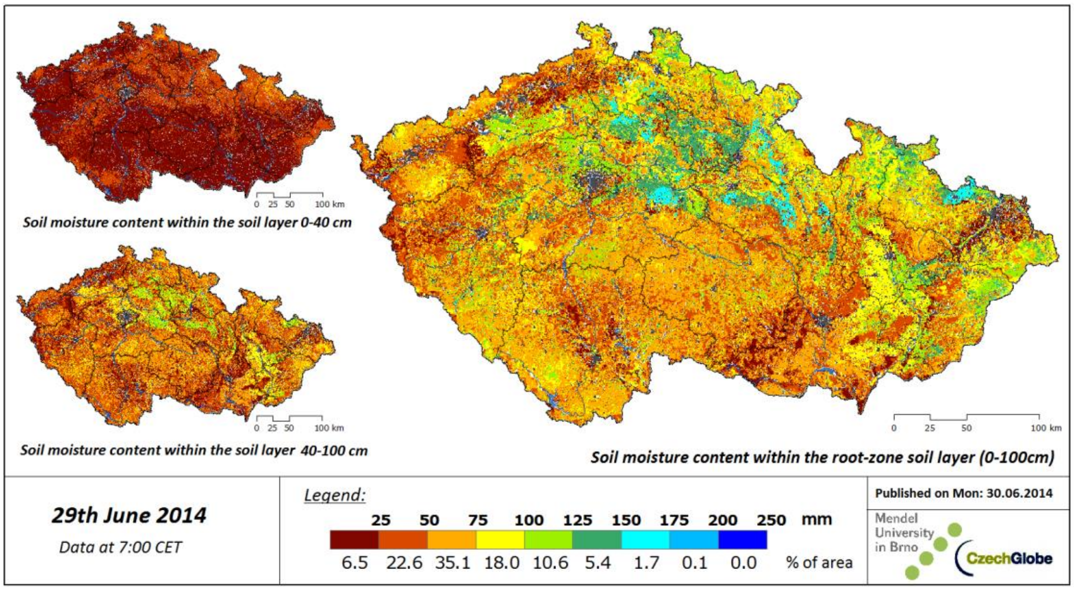


Fig 3: Soil moisture content in soil profile (mm) within the surface layer for whole area of the Czech Republic

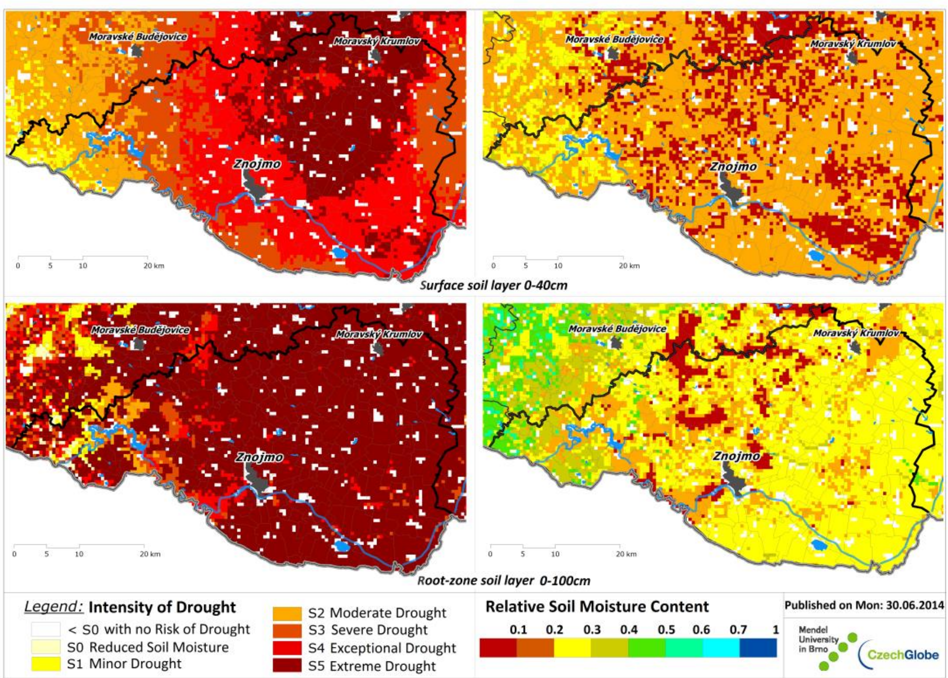


Fig 4: Intensity of drought (left) and soil moisture content (right) for Znojmo district (one square = 500 m x 500 m)

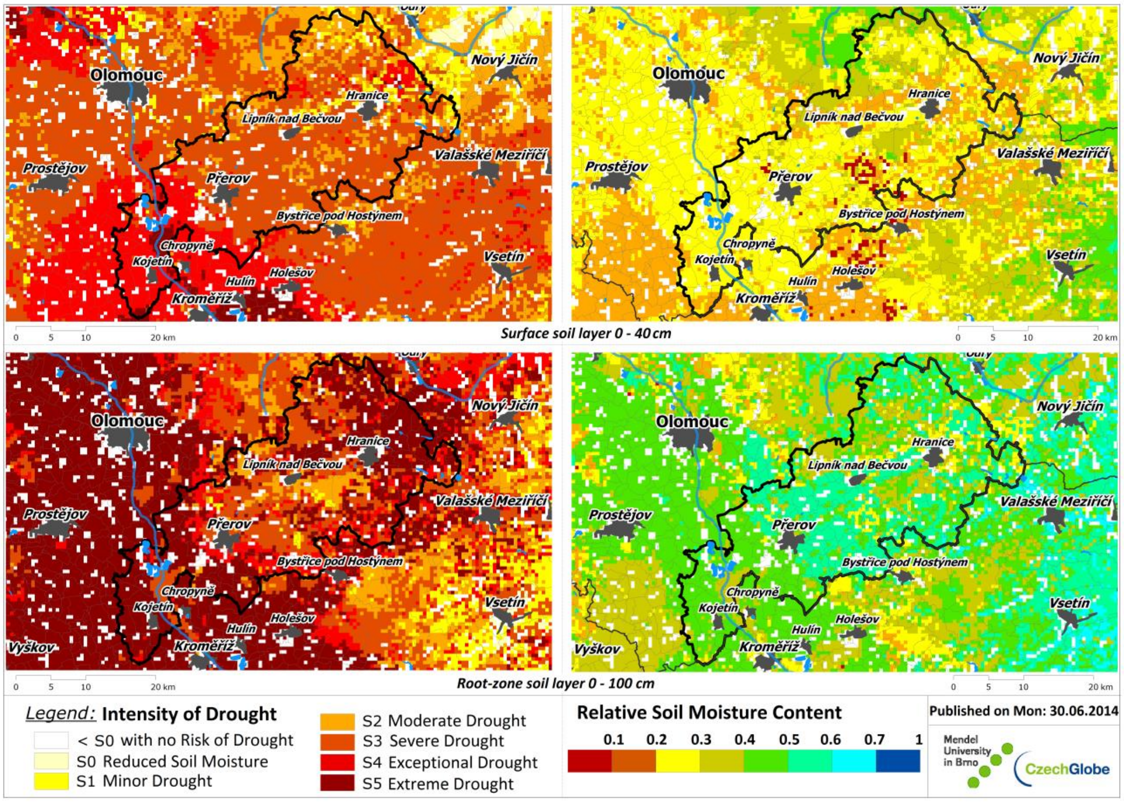


Fig 5: Intensity of drought (left) and soil moisture content (right) for Přerov district (one square = 500 m x 500 m)

REFERENCES

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Guidelines for computingcrop water requirements. FAO Irrigation and Drainage Paper No. 56.

Allen, R.G., Walter, I.A., Elliot, R.L., Howell, T.A., 2005. ASCE standardized reference evapotranspiration equation. American Society of Civil Engineers, 216.

Brázdil, R., Trnka, M., Dobrovolný, P., Chromá, K., Hlavinka, P., Žalud, Z., 2008. Variability of droughts in the Czech Republic, 1881–2006. Theoretical and Applied Climatology, 97: 297-315

Hlavinka P, Trnka M, Balek J, Semerádová D, Hayes M, Svoboda M, Eitzinger J, Možný M, Fischer M, Hunt E, Žalud Z. 2011. Development and evaluation of the SoilClim model for water balance and soil climate estimates. Agriculture and Water Management 98: 1249–1261

Hlavinka, P., Trnka, M., Semerádová, D., Dubrovský, M., Žalud, Z., Možný, M., 2009. Effect of drought on yield variability of key crops in Czech Republic. Agric. For. Meteorol. 149, 431–442.

Smith J.B., Huq S., Lenhart S., Mata L.J., Nemesova I., Toure S., 1996: Vulnerability and Adaptation to Climate Change: Interim Results from the U.S. Country Studies Program. Kluwer AP, 366 pp.

Tolasz R., Míková T., Valeriánová A. (eds). 2007. Climatic Atlas of Czechia, Czech Hydrometeorological Institute and Palacky University Olomouc, Prague, 256

Trnka, M., Kyselý, J., Možný, M., Dubrovský, M., 2009a. Changes in Central-European soil-moisture availability and circulation patterns in 1881–2005. Int. J. Climatol. 29: 655–672.

Trnka, M., Dubrovsky, M., Svoboda, M., Semerádová, D., Hayes, M., Žalud, Z., Wilhite, D., 2009b. Developing a regional drought climatology for the Czech Republic. Int. J. Climatol. 29: 863–883.

Trnka, M., Kocmánková, E., Balek, J., Eitzinger, J., Ruget, F., Formayer, H., Hlavinka, P., Schaumberger, A., Horáková, V., Možný, M., Žalud,Z., 2010. Simple snow cover model for agrometeorological applications. Agricultural and Forest Meteorology 150: 1115–1127.

Trnka M., Kersebaum KC, Eitzinger J., Hayes M., Hlavinka P., Svoboda M., Dubrovský M., Semerádová D., Wardlow B., Pokorný E., Možný M., Wilhite D., Žalud Z. 2013, Consequences of climate change for the soil climate in Central Europe and the central plains of the United States, Climatic Change,120, 1-2: 405-418

Wilhite, D. A. (ed.) 2005. Drought and Water Crisis: Science, Technology and Management Issues. CRC Press, Boca Raton, FL, p.431

Žalud, Z. et al.. 2009. Změna klimatu a české zemědělství – dopady a adaptace, Folia Universitas Agriculturae et Silviculturae Mendeliana Brunensis, Brno, vědecká monografie, MZLU v Brně, Roč. II, Čís.10, s. 154.

ACKNOWLEDGEMENT

This contribution was supported by Czech National Agency for Agricultural Research (NAZV) project reg. No. QJ1310123 “Crop modelling as a tool for increasing the production potential and food security of the Czech Republic under climate change“ and by the Operational Program of Education for Competitiveness of Ministry of Education, Youth and Sports of the Czech Republic, project reg. No. CZ.1.07/2.3.00/20.0248. “Building up a multidisciplinary scientific team focused on drought“.

SUMMARY

Cílem příspěvku bylo objasnit podstatu a využití *Integrovaného systému sledování sucha* (ISSS) pro území České republiky. Vysvětlena byla základní metodika jeho vzniku, ocitovány kalibrace a evaluace systému a naznačeno jeho praktické využití se zaměřením na zemědělství. Mezi základní atributy ISSS patří jeho podrobné prostorové rozlišení v gridu 500 m, které zahrnuje interpolovaná meteorologická data ze sítě ČHMÚ, detailní půdní údaje vycházející z několika zdrojů (např. VÚMOP - Výzkumný ústav meliorací a ochrany půd, KPP - Komplexního průzkumu půd, ČGS - Česká geologická služba) a land use (CORINE). Jádrem ISSS je validovaný model vodní bilance SoilClim počítající hodnotu aktuální/referenční evapotranspirace a obsah půdní vláhy ve dvou vrstvách kořenového profilu (0 - 0,4 m a 0,4 - 1,0 m) pro jedenáct vegetačních typů. Výstupy jsou buď jako míra nasycení půdního profilu (%) nebo jako obsah půdní vláhy (mm). Finálním produktem (= www.intersucho.cz) je mapa intenzity sucha, která je pro každý grid a pro úroveň ČR a současně úroveň každého ze 76 okresů ČR stanovena porovnáním aktuální hodnoty obsahu půdní vláhy v daný den (vždy neděle) s průměrnými hodnotami půdní vláhy dosaženými v období 1961-2010 v časovém úseku ± 10 dní od posuzovaného dne. Součástí uvedeného webu jsou i mapy pravděpodobnostní prognózy sucha pro 1, 2, 4 a 8 týdnů.

CONTACT

prof. Ing. Zdeněk Žalud, Ph.D.

Institute of Agrosystems and Bioclimatology

Faculty of Agronomy

Mendel University in Brno

Zemědělská 1, Brno, 613 00 Czech Republic

Tel.: +420 54513 3083, Email: zalud@mendelu.cz

Early onset of spring phenological phases in the period 2007-2012 compared to the period 1931-1960 as a potential bioindicator of environmental changes in The National Nature Reserve Boky (Slovakia)

Jozef Zverko[1], Jaroslav Vido[1], Jana Škvareninová[2], Jaroslav Škvarenina[1]

1) Department of Natural Environment, Faculty of Forestry, Technical university in Zvolen, ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

2) Department of Applied Ecolog, Faculty of Ecology and Environmental Sciences, Technical university in Zvolen, ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

Abstract

Plants phenology responses is a reliable marker of the climate conditions. Since we see significant changes of regional climate patterns, serious question of phenological responses to this change is in the place. Because of this, our case study aims on comparison of spring phenophases onset in The National Nature Reserve (NPR) Boky in the period 2007 – 2012 with the historical records of the surrounding areas between years 1931 – 1960. We evaluate four woody plant species i.e. European cornel – *Cornus mas L*., Blackthorn – *Prunus spinosa L*., Hawthorn – *Crataegus monogyna L*., European hazel – *Corylus avellana L*. and two phenological phases: flowering and unfolding. Our findings show significant shifts of spring phenophases onset to earlier dates. Thus the result imply significant influence of changed climate conditions on earlier onset of spring phenophases of above mentioned woody plants in the NPR Boky.

Key words: Phenology, climate change, old-growth forest, NPR Boky, Slovakia

Introduction

Phenological response of plants is a reliable marker of changing climate conditions (Chmielewski et Rötzer 2001). It is because of the physiological reaction of plants to seasonal and inter-annual changes of climatological factors i.e. air temperature represents as sum of daily temperature, insolation, precipitation and many others (White et al. 1997). Long-term systematic observation of the phenophases gives a possibility to estimate shifts in phenophases onset or end, what allows to assess an influence of changing climate conditions on the nature especially on the nature reservations (Bauer et al. 2014, Schwartz et al. 2003). However long-term phenological observations in natural reservations were previously carried out relatively rare. Therefore we have relatively weak information from many unique natural reservation i.e. NPR (National Nature Reservation) Boky located in the Kremnické vrchy mountains (Central Slovakia).

To fill this gap, phenological observations has started in the last decade (since 2007) in the NPR Boky (Pálešová 2009). However, although the phenological observations has been established, until now only six years of phenological observation were carried out. In addition, no reference phenological historical records from this specific natural reservations are available. The present paper try to solve this challenge with comparison of the available historical phenological observations around the area to our relatively short-term phenological records in the NPR Boky. Although we understand that the phenological observations in the NPR Boky has been carried out only for few years what is methodically imprecise, comparison with historical records brings scientific interesting findings regarding to plants phenological responses to changing climate conditions in this very unique piece of central European wild nature.

MATERIALS AND METHODS

Characteristics of the NPR (National Nature Reservation) Boky.

NPR Boky (area 176.49 hectares) is located on south oriented steep slopes of the Kremnické Vrchy Mountains near village Budča. Altitude range is between 280 – 589 m a. s. l. The NPR was declared in 1964 in order to protect one of the northernmost sites of thermophilic and xerophilous plant and animal species with the occurrence of interesting geomorphological formations: sea stone, rubble and Devil's Rock Mushroom Rock. The most valuable forests with Turkey oak (Quercus cerris L.) and other concomitant tree species have character of the old-growth forest (Korpeľ 1989). Illustration of the NPR Boky is depicted on Fig. 1

Fig. 1 *Typical aspect of the old-growth forest ecosystem in the NPR Boky. In the middle of the figure is depicted our automatic weather station*

Phenological observations

Phenological observations were carried out during the period 2007-2012 on research spot in NPR Boky located in the Kremnické vrchy mountains (central Slovakia). The research was carried out on forest trees of the following species: European cornel – Cornus mas L., Blackthorn – Prunus spinosa L., Hawthorn – Crataegus monogyna L., European hazel – Corylus avellana. Phenological observations were written down according to the guideline (Kolektív 1984) prepared by SHMU (Slovak Hydrometeorological Institute). This methodology is currently used for phenological monitoring of forest tree species in Slovakia.

Although observations were conducted during the entire growing season, we used only spring phenological phases (flowering and leaf unfolding) as average onset date within the period 2007-2012. It is because of the stronger influence of air temperature on plants spring phenological responses, comparing with remaining seasons. (Chmielewski et al. 2004, Sparks et Menzel 2002).

Historical phenological records were used from the study of Kurpelová (1972a,b). This study includes both phenological and climatological observations performed in Central Slovakia during the period 1931 – 1960. From the study we used average onset date of the phenophases between 1931 – 1960.

Climatological observations

Climatological observations at the locality Boky (512 m a. s. l.) were performed by automatic weather station EMS. Although the standard set of meteorological units (i.e. air temperature, precipitation, soil temperature, global radiation), only the air temperature was used because of the above mentioned major correlation of spring phenophases with air temperature. Also the findings of Zverko (2013) aimed on correlation between various meteorological units to the spring phenological responses of plants at the locality Boky indicates the major role of air temperature. As a reference station was used station Sliač (Slovak Hydrometeorological Institute) located 10 km northeast of our research stationary in Zvolenská kotlina walley (312 m a. s. l.).

RESULTS

Historical temperature comparison

Since only 6 years of climatological and phenological observations carried out by our institution are available, we need to confirm suitability of reference station Sliač to our climatological observations at the station Boky by three steps. This comparison is also necessary because of the south oriented slope of the NPR Boky comparing to the reference station Sliač located in flatland area and also because of the different altitude.

First step aims to compare correlation of measured temperature between years 2007 – 2012 on the research spot Boky with reference station Sliač.

This comparison showed that measured temperature on our research spot Boky strongly correlates (R2=0,9989) with measured temperature at the station Sliač (Tab. 1, Fig. 2)

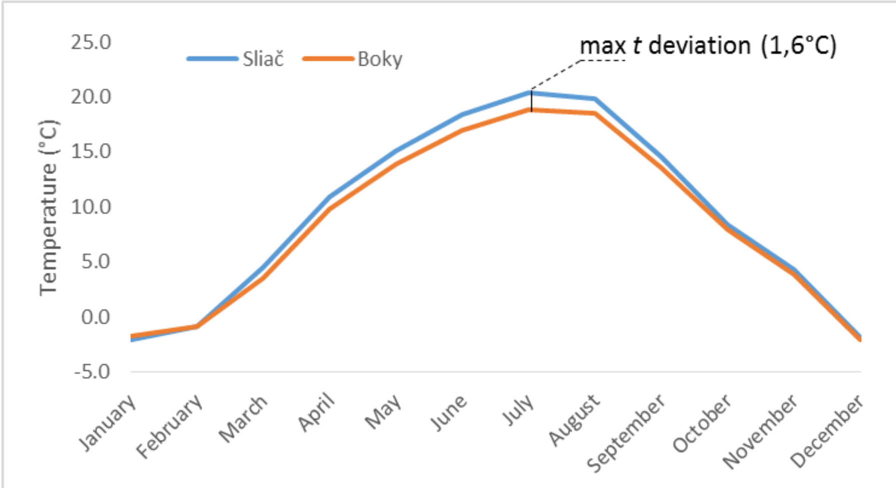


Fig. 2 *Comparison between temperatures measured at the reference station Sliač and station at the research spot Boky (2007-2012)*

Tab. 1 *Average temperature at reference meteorological station Sliač and measured temperature at research spot Boky between years 2007 – 2012.*

Station	Jan.	Feb.	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sliač	-2.1	-0.9	4.6	10.9	15.1	18.4	20.4	19.8	14.6	8.4	4.3	-1.9
Boky	-1.7	-0.8	3.5	9.8	13.9	17	18.8	18.5	13.6	8	3.9	-2.1
Deviation	+0,4	+0,1	-1,1	-0,9	-1,2	-1,4	-1,6	-1,3	-1,0	-0,4	-0,4	-0,2

Correlation between these two stations allows to use historical records from the station Sliač for comparison of the two periods (1931 – 1960 and 1983 – 2012) in terms of discussion of increased temperature also in the area of our research spot Boky.

Thus the second step focuses on estimation of temperature increase comparing two periods 1931 – 1960 and 1983 – 2012 at the reference station Sliač. Relatively strong temperature increase at the reference station Sliač has been found comparing this two periods (Tab. 2).

***Tab. 2** Deviations of average monthly temperature at Sliač between the periods 1931 – 1960 and 1983 – 2012*

Periods	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1931 - 1960	-4.4	-2	2.6	8.5	13.6	16.9	18.8	17.8	13.7	8.2	3.4	-1.1
1983 - 2012	-2.8	-1.3	3.4	9.5	14.5	17.4	19.5	18.8	13.9	8.5	3.2	-1.9
Deviation	1.6	0.7	0.8	1	0.9	0.5	0.7	1	0.2	0.3	-0.2	-0.8

Only during cold months November and December has temperature decreased. However comparison of the average monthly temperature within this two periods showed increase in temperature, especially significant during the months of spring phenophases (February to May). The last step is to control whether the temperature during 2007 – 2012 is within the normal of 1983 – 2012 or whether the period 2007 – 2012 deviates from this long-term normal respectively. We see that the period 2007 – 2012 is not significantly deviated from the long – term normal of the period 1983 – 2012 (R2=0.998728) (Fig. 3). Thus our meteorological observations are not deviating from the long-term normal.

Based on the above presented three step test we argue, that our relatively short-term observations of climatological and phenological data from the locality Boky could be used in argumentation about the shift of spring phenological phases due to temperature increase in the previous decades.

Comparison of present phenological observations with historical records

As a source of historical phenological observation we used the publication of Kurpelová (1972 a,b). Because of the strong correlation in temperature values at the Sliač meteorological station (reference) with our station at Boky, we have used phenological observation from the Zvolen (2 km from Sliač station) as historical reference for our purpose. Phenological observations in Zvolen was carried out during the period 1931 – 1960.

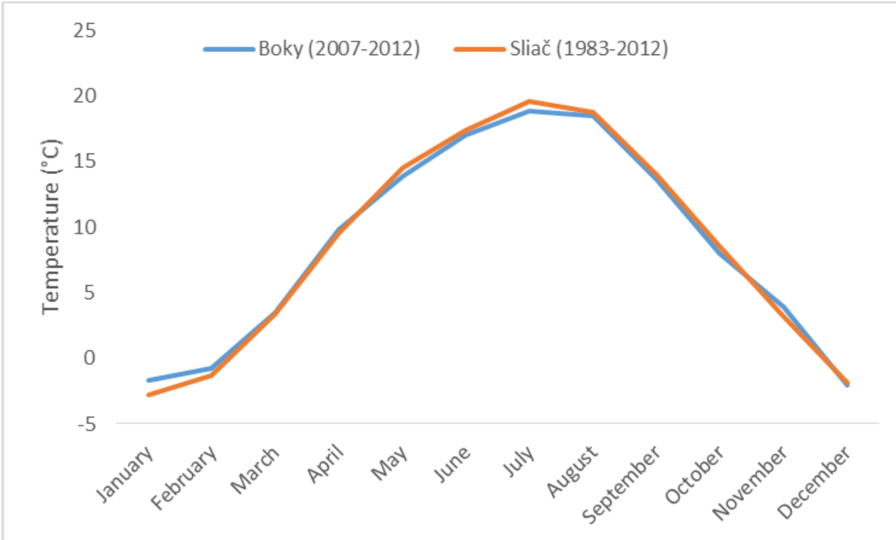


Fig. 3 *Comparison between average monthly temperatures of the period 2007 – 2012 measured at the station Boky and long-term average temperature at the station Sliač (1983 – 2012).*

Kurpelová et al. (1972) have detected average start day of the phase unfolding in Zvolen on April 18 for European Hazel and on May 4 for Blackthorn. Our findings from the locality Boky show that the average start day for European Hazel is on April 14 and for Blackthorn on April 17. This is a significant date shift what shows that the temperature increase in the last decades has strong influence on earlier onset of the unfolding in the area (Tab. 3)

Tab. 3 *Detected average start day for phase unfolding at Boky within 2007 – 2012 and Zvolen 1931 – 1960*

Locality	Hawthorn *Crataegus monogyna*	European hazel *Corrylus avellana*	Blackthorn *Prunus spinosa*	European cornel *Cornus mas*
Boky (2007 – 2012)	April 9	April 14	April 17	April 21
Zvolen (1931 – 1960)	N/A	April 18	May 4	N/A

Significant shifts have also been detected comparing of the historical and present phenological observation of the flowering. Kurpelová (1972 a,b) found that the average start day of flowering in Zvolen in the period 1931 – 1960 was May 13 for Hawthorn, March 13 for European hazel, April 22 for Blackthorn and April 2 for European cornel. Our findings show that the flowering as well as the previously mentioned phase of unfolding started earlier in the period 2007 – 2012. On May 6 by Hawthorn, March 3 by European hazel, on April 13 by Blackthorn and on March 27 by European cornel (Tab 4).

Tab. 4 *Detected average start day for phase flowering at Boky within 2007 – 2012 and Zvolen 1931 – 1960*

Locality	Hawthorn *Crataegus monogyna*	European hazel *Corrylus avellana*	Blackthorn *Prunus spinosa*	European cornel *Cornus mas*
Boky (2007 – 2012)	May 6	March 3	April 13	March 27
Zvolen (1931 – 1960)	May 13	March 13	April 22	April 2

Discussion

Our findings indicate that the temperature increase has a significant influence on earlier onset of spring phenological phases of all the above discussed species. This facts correspond with findings of authors over the Europe. Sparks et al. 2005 indicate that in Sussex UK was the average start day of the flowering by Hawthorn on May 27 in the period 1980 – 1989 whereas in the period 1990 – 2000 flowering appeared on May 15. The same trend has been observed in Suffolk UK where the first flowering date of Hawthorn was observed on May 11 in the period 1930 – 1940, while in the period 1998 – 2005 shifted this date on April 28 (Sparks et al. 2006). The same trend is observed also on the continental Europe. Ahas et al. (2002) indicate significant speed up in spring phenological phases over the whole Europe in the last fifty years. The same situation has been detected in Swiss by spring phenophases of European hazel (Defila et Clot 2001). The most recent research of Pálešová et Snopková (2010) from the central Slovakia also confirmed that increased temperature in the last decades has significant influence on earlier onset of spring phenophases. Thus higher air temperature in spring months lead in earlier onset of spring phenological phases. Although we understand that our findings based only on six years of continual measurements and observations should be used in discussion of the climate change influence only very carefully, we see that the same trends are observed over the whole Europe. Therefore we argue, that if the temperature increase will continue in the area (Lapin et Melo 2004), early onset of phenophases comparing to the previous records will be a fact. This could bring problems and devastation to the ecosystems of the NPR Boky due to e.g. late frost situations (Dittmar et al. 2006).

CONCLUSION

Our findings confirm that the temperature increase has significant impact on earlier onset of spring phenological phases in all the discussed woody plant species. We understand that our climatological measurements were carried out only during six years what limits our findings as a significant signal of climate change impact. However our case study shows that increased temperature significantly speed up the onset of spring phenological phases. This facts with anticipated air temperature increase gives evidence that ecosystems in our study area will probably face this problem in the future. Thus our contribution show that early onset of spring phenological phases in the NPR Boky in the period 2007 - 2012 could be carefully discussed as a potential indicator of changing climate conditions. However to be sure we need to continue in climate and phenological observations in ecosystems of the NPR Boky.

REFERENCES

Ahas, R., Aasa, A., Menzel, A., Fedotova, V. G., & Scheifinger, H. (2002). Changes in European spring phenology. International Journal of Climatology, 22(14), 1727-1738.

Bauer, Z., Bartošová, L. et al. (2014). Observed phenological response of ecosystems to the climate: Pat I. Flood-plain forest. Mendel university in Brno, Brno, 128 p.

Defila, C., & Clot, B. (2001). Phytophenological trends in Switzerland. International Journal of Biometeorology, 45(4), 203-207.

Dittmar, C., Fricke, W., & Elling, W. (2006). Impact of late frost events on radial growth of common beech (Fagus sylvatica L.) in Southern Germany. European Journal of Forest Research, 125(3), 249-259.

Chmielewski, F. M., & Rötzer, T. (2001). Response of tree phenology to climate change across Europe. Agricultural and Forest Meteorology, 108(2), 101-112.

Chmielewski, F. M., Müller, A., & Bruns, E. (2004). Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. Agricultural and Forest Meteorology, 121(1), 69-78.

Kolektív, (1984). Návod pre fenologické pozorovanie lesných rastlín. SHMÚ, Bratislava, 23 p.

Korpel, Š. (1989). Pralesy Slovenska. (Old-growth forests of Slovakia) Bratislava: Veda.

Kurpelová, M. (1972a). Fenologické pomery. In: LUKNIŠ, M. et al. (ed.) Slovensko. [zv.] 2 Príroda. 1.vyd. Bratislava: Obzor, 1972. p. 275-282.

Kurpelová M. (1972b). Fenologické pomery kraja. In: Petrovič, Š. (ed.): Klimatické a fenologické pomery Stredoslovenského kraja. HMÚ Bratislava, p. 325–414.

Lapin, M., & Melo, M. (2004). Methods of climate change scenarios projection in Slovakia and selected results. Journal of Hydrology and Hydromechanics,52(4), 224-238.

Pálešová, I. (2009). Phenological observations of the European hornbeam, the European hazel and the English oak in the area of National Natural Reservation Boky in 2007-2009. In: Transport vody, chemikálií a energie v systéme pôda-rastlina-atmosféra : 17. Posterový deň s medzinárodnou účasťou a Deň otvorených dverí na ÚH SAV, 12. november 2009, Bratislava : zborník recenzovaných príspevkov, 481-488.

Pálešová, I., & Snopková, Z. (2010). Bozk pod rozkvitnutou čerešňou na 1. Mája? Realita alebo minulosť, In: Kožnarová, V., Sulovská, S. (eds): Medzinárodní vědecká konference Bioklima 2010, Praha.

Schwartz, M. D. (Ed.). (2003). Phenology: an integrative environmental science (Vol. 346). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Sparks, T. H., & Menzel, A. (2002). Observed changes in seasons: an overview.International Journal of Climatology, 22(14), 1715-1725.

Sparks, T. H., Croxton, P. J., Collinson, N., & Taylor, P. W. (2005). Examples of phenological change, past and present, in UK farming. Annals of applied biology, 146(4), 531-537.

Sparks, T., Croxton, P. H. I. L., & Collinson, N. I. C. K. (2006). Phenology in a changing climate. Suffolk Natural History, 42, 6-14.

White, M. A., Thornton, P. E., & Running, S. W. (1997). A continental phenology model for monitoring vegetation responses to interannual climatic variability. Global biogeochemical cycles, 11(2), 217-234.

Zverko, J. (2013). Fenologické prejavy drevín v južnej časti Kremnických vrchov ako potenciálny bioindikátor zmien prostredia (Phenological responses of the woody platns in south parts of the Kremnické Vrchy Mountains as a potential bioindicator of the environmental changes). Zvolen: Technical University in Zvolen, Dissertation thesis.

ACKNOWLEDGEMENT

This contribution was supported by research grants of The Ministry of Education, Science, Research and Sport of the Slovak Republic: VEGA 2/0101/14, VEGA 1/1130/12,VEGA 1/0281/11, VEGA 1/0463/14 and by grant of the Slovak Research and Development Agency APVV 0423-10, APVV 0303-11 and APVV 0480-12.

SUMMARY

Predkladaný príspevok sa zameriava na zhodnotenie posunu jarných fenologických fáz (kvitnutie a zalisťovanie) lesných drevín (drieň obyčajný – *Cornus mas L.*, trnka obyčajná – *Prunus spinosa L.*, hloh obyčajný – *Crataegus monogyna L.*, lieska obyčajná – *Corylus avellana L.*) v národnej prírodnej rezervácií Boky (Kremnické vrchy) ako potenciálny bioindikátor zmien prostredia vo vzťahu ku klimatickej zmene. Výsledky poukázali na otepľujúci sa charakter klímy porovnaním období 1931 – 1960 a 2007 – 2012 resp. v prípade referenčnej stanice Sliač 1983 – 2012. To viedlo k skoršiemu nástupu vyššie spomenutých fenologických fáz všetkých lesných drevín signifikantne do skorších termínov u oboch sledovaných fenofáz. Aj keď si uvedomujeme, že naše pozorovania sú relatívne krátkodobé, dokazovanie vzťahov medzi referenčnou stanicou na Sliači a našou automatickou meteorologickou stanicou v NPR Boky nám dávajú silný argument, že zistené posuvy nie sú iba náhodilou fluktuáciou, ale náznakom trendu posunu jarných fenofáz vo vzťahu k neustále rastúcej teplote vzduchu v regióne. Avšak pre definitívne a štatisticky preukazné tvrdenie bude potrebné naďalej pokračovať vo fenologickom výskume v NPR Boky.

CONTACT

Ing. Jaroslav Vido, PhD.

Department of Natural Environment, Faculty of Forestry, Technical university in Zvolen, ul. T. G. Masaryka 24, 960 53 Zvolen, Slovakia

+421 (45) 520 6215, email: vido@tuzvo.sk