DE GRUYTER OPEN

Contributions to Geophysics and Geodesy Vol. 44/3, 2014 (241–252)

Spatial expression of potential wind erosion threats to arable soils in the Czech Republic

Bronislava SPÁČILOVÁ[1], Tomáš STŘEDA[2,3], Pavlína THONNOVÁ[1]

[1] Department of Applied and Landscape Ecology, Mendel University in Brno
Zemědělská 1, 613 00 Brno, Czech Republic;
e-mail: bronislava.spacilova@mendelu.cz

[2] Department of Crop Science, Breeding and Plant Medicine, Mendel University in Brno
Zemědělská 1, 613 00 Brno, Czech Republic,
e-mail: streda@mendelu.cz

[3] Czech Hydrometeorological Institute, branch office Brno
Kroftova 43, 616 67 Brno, Czech Republic;
e-mail: tomas.streda@chmi.cz

Abstract: Wind erosion risk strongly depends on soil surface conditions. Aridity or dryness of the climate in the Czech Republic is a typical property for Southern Moravia and Central Bohemia. The study aims to map and assess qualitatively the areas vulnerable to wind erosion using available data and intelligible methodology. The evaluation is based on the number of days when at least once a day dry condition of bare soil surface was recorded. Daily data of soil surface state from 70 climatological stations to 500 m altitude from 1981 to 2010 are used. First, soil conditions from 1st March to 30th April and from 1st September to 31st October were evaluated. Evaluation of erosion risk in May is presented separately in the second phase, because only thermophilous crops (late-sowing crops) can be affected in that time. The results show that mainly in the South and Southeast Moravia, there are areas where up to 60 days with dry soil surface in the spring and autumn occurred. Occurrence of such conditions may represent potential risk of wind erosion for arable soils and therefore potential risk for sown crops and loss of fertile soil surface which is irreplaceable for agricultural activities. The results are applicable for preparation of a concept of wind erosion control measures in the threatened regions.

Key words: soil moisture, soil surface state, meteorological conditions, drought, soil erodibility

1. Introduction

Erodibility of soil by wind depends primarily on soil texture or relative proportion of sand, silt and clay, water stable structure and degree of dis-

doi: 10.1515/congeo-2015-0004

persion in water (*Chepil, 1953*). Other factors such as surface roughness, fetch distances and wind speeds (*Bullock, 1999*), size and stability of soil aggregates (*Skidmore and Powers, 1982; Colazo et al., 2010; Amézketa et al., 2003*) and crusting (*Singer et al., 2004*) are also important for the soil susceptibility to wind erosion.

Within Central Europe wind erosion prevails on light, sandy soils (*Bolte et al., 2011*). Potential susceptibility of soil to wind erosion is mainly due to soil conditions, but also climatic conditions of the area. Wind erosion occurs mainly in areas where the weather is characterized by low and variable rainfall, variable and high wind speeds, the frequent occurrence of drought, rapid and extreme changes in temperature and high evaporation.

A typical characteristic of precipitation in the Czech Republic (further CR) is a large variability in time and a high dependency on altitude and exposure. The occurrence of drought is therefore important feature of the climate of the CR. It is usually evaluated using various indicators, indices (*Alley, 1984*), in particular in relation to crop yields mainly in the vegetation period. For the occurrence of erosion, however, rainfall distribution during the year and occurrence of dry periods outside the growing season are important. Rainfall alone is not an indicator of soil moisture, which is, however, in terms of data availability and length of series a questionable characteristic.

Long-term measuring of soil moisture within the network of the Czech Hydrometeorological Institute (further CHMI) stations has been performed in long term only on Doksany Observatory (since 1970). Since 1991, measurement has been fully automatic using sensors VIRRIB and after 1998, the measurement has been gradually introduced to other stations of CHMI. Soil moisture is monitored under standard grass surface using sensors placed horizontally in the layer of 0–10 cm and two vertically placed sensors in layers of 11–40 cm and 51–90 cm. However, in terms of wind erosion incidence, moisture conditions of the soil surface are crucial. Dry soil surface is more affected by erosive wind because of slight cohesion among erodible soil particles which can be blown away. It is well known that erodibility by wind is a function of the cohesive force of adsorbed water films surrounding the soil particles (*Chepil, 1956*).

For the evaluation of surface soil moisture data from remote sensing since the seventies of the 20th century are of limited utility. With regard to spatial resolution and frequency of imaging is not possible to use them for the assessment of soil erosion hazard in the country. A specific feature in the CR and Slovakia is the evaluation of the state of the soil surface at stations. This indicator is not exactly measured, but it is replaced by observing the state of the soil surface, which observers record each day in terms of 7, 14 and 21 h of local solar time each day. At many stations beyond the observation period exceeds 50–60 years and therefore long-term averages can be used. It is easily accessible characteristics recorded at climatological stations, which often remains aloof interest. In Slovakia *Tekušová et al. (2013)* and in the CR *Mužíková et al. (2013)* used soil surface condition to evaluate drought period. The number of days with dry condition of soil in the period 1961–2010 in the CR has no significant upward or downward trend. However last years (2002, 2003, 2007 and 2009) have been evaluated as dry. Causality of this is in increased evapotranspiration demand due to rising air temperature (*Takáč, 2013*).

In principle, the wind erosion may occur throughout the year. The most significant is the spring that follows below normal winter precipitation. The incidence of wind erosion also increases the autumn when, like in the spring, the soil is not protected by vegetation.

2. Material and methods

State of soil is defined as consistency of the bare soil surface. Observation of the soil is done on the station plots and its vicinity at all observation times (at 7 am, at 2 pm, at 9 pm). State of soil is registered using the defined code numbers (*Žídek and Lipina, 2003; Slabá et al., 1972*). Dry soil surface (not frozen) code is number 0 (Table 1).

Daily data from the seventy CHMI network stations to an altitude of 500 m, i.e. in areas with intensive crop production and a higher probability of drought in thirty years from 1981 to 2010 were used (Fig. 1).

The evaluation is based on the number of days when at least once a day (one observation term) soil surface state "0" was recorded. The average number of days with the "0" state of soil for the period was calculated for each station. Given that this is the element influenced by a certain degree

Table 1. Classification of soil surface states

0	Dry soil surface
1	Wet soil surface
2	Wet (soaked) soil surface (water is present in puddles)
3	Soil surface is bare and frozen
4	Soil covered by ice, without snow or thawing snow
5	Snow or thawing snow (with or without ice) covers less than half of soil surface
6	Snow or thawing snow (with or without ice) covers more than half of soil surface, but not completely
7	Snow or thawing snow (with or without ice) covers soil surface completely
8	Dry, loose snow covers more than half of soil surface, but not completely
9	Dry, loose snow covers soil surface completely

of subjectivity, correlation between the number of days with the state "0" across selected stations was verified to eliminate inhomogeneities. For most stations statistically significant to statistically highly significant relationship was found. Number of days with dry soil surface state and stations altitude also shows statistically highly significant relationship (correlation coefficient $r = -0.33$, $n = 70$, $\alpha = 0.01$). Inhomogeneities of raw data are taken into account so the stations with non-standard soil surface regime are not used for analysis (three per cent of cases).

In the first phase, data of soil surface states from 1st March to 30th April and from 1st September to 31st October (periods of greatest risk of wind erosion) were evaluated. The first period does not include crucial conditions of late sown or planted crops in May (corn, sunflower, soya, vegetables). Evaluation of erosion risk in this term was done separately in the second phase (due to erosion specifics in the May term).

The maps of potential vulnerability of areas to wind erosion under dry soil conditions were created. The values for each station represented by a point GIS layer were interpolated in the area of the CR, using the method of local linear regression depending on the altitude with correction of estimated value by variation in order to preserve the value corresponding to the location of the station. The resulting raster model was then processed in the ArcGIS 10.0 software environment and leveling was done by the

Fig. 1. Location of the stations.

method of the nearest neighbors. The map was then covered with a layer of estimated pedological ecological units (EPEU) because of the exclusion of non-agricultural land. The maps of soil potential threat by wind erosion based on drought risk were created.

Based on the average number of days with dry soil surface, the territory of the CR is divided into 5 categories. Territory at altitudes above 500 m a.s.l. and the area of non-agricultural land were classified into sixth category – not evaluated.

3. Results and discussion

The maps of potential threats to soil wind erosion (Figs. 2–6) show average number of days with potential risk based on dry soil surface conditions in different parts of the year. With increasing altitude, the number of days with dry soil conditions decreases statistically significantly.

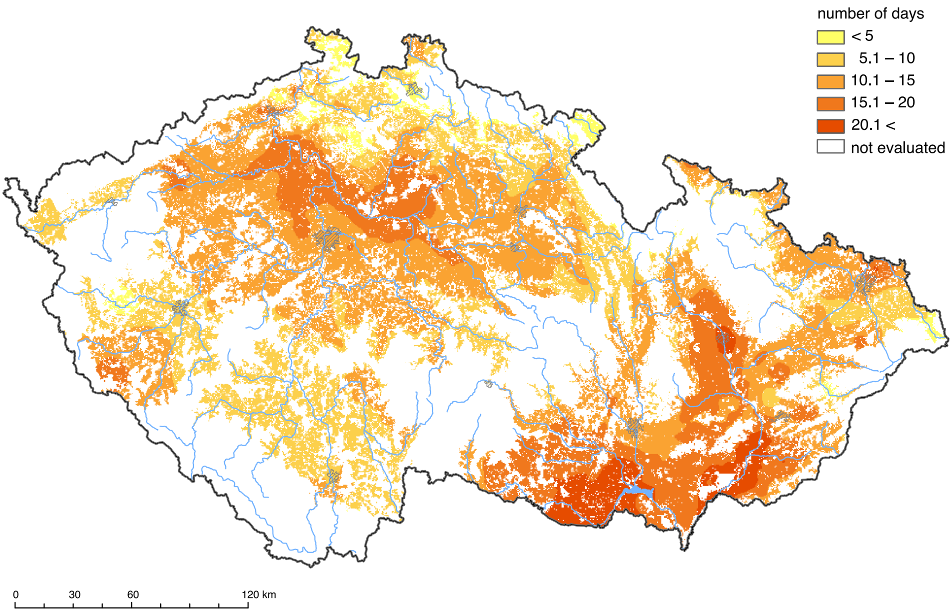

Fig. 2. Average number of days with dry soil surface conditions from 1st March to 30th April for the period 1981–2010.

a) without taking the thermophilous crops into account

Figure 2 presents situation in spring months. There are areas mainly in the South and Southeast Moravia, where more than 20 days (average) with dry soil surface occurred in March and April.

Figure 3 presents situation in autumn months. The potential wind erosion vulnerability conditions in the CR are worse than in the spring. There are areas mainly in the South, Southeast and Central Moravia, where more than 25 days (average) with dry soil surface occurred in September and October.

Figure 4 presents summary results for the spring and autumn periods. Relative risk (risk areas in the CR) remains essentially identical, changing the absolute value of the number of days with risk conditions. Mainly in the Moravia, areas with more than 40 days with dry soil surface in the spring and autumn occurred. It means, one of the areas, most

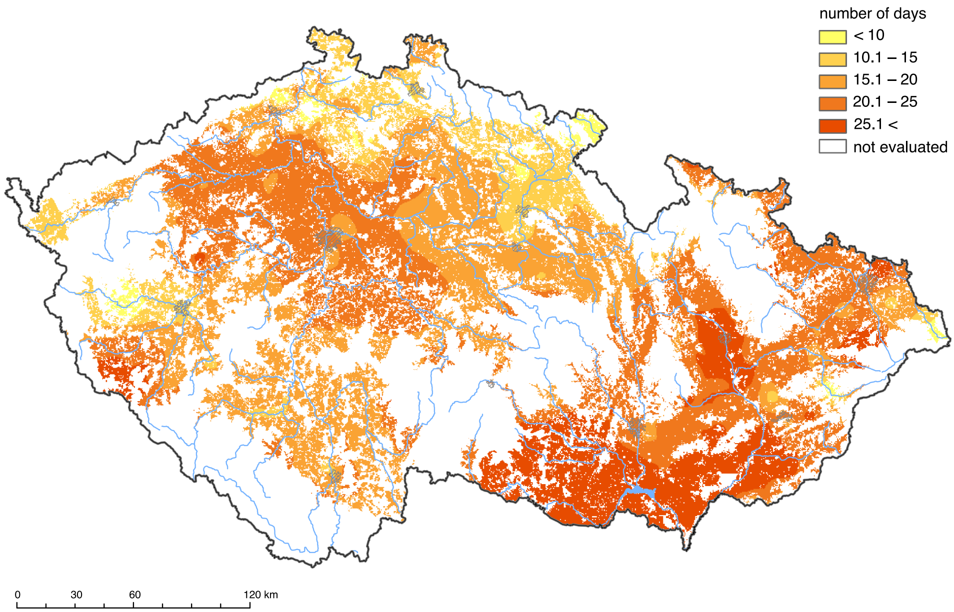

Fig. 3. Average number of days with dry soil surface conditions from 1st September to 31st October for the period 1981–2010.

endangered by wind erosion in the Czech Republic, is South Moravia. Those results correspond with *Podhrázská et al. (2013)*.

b) including thermophilous crops

Maps of potential threats to wind erosion after adding the values of May are presented below (Figs. 5 and 6). Figure 5 presents results for the spring period. Number of days with dry soil surface increased significantly. There are localities with more than 40 such days in the spring – Southeast Moravia. Summary results for the spring and autumn period are presented in Fig. 6. Relative risk (risk areas in the CR) remains essentially identical, changing the absolute value of the number of days with risk conditions. Mainly in the south and Southeast Moravia, areas with more than 45 days with dry soil surface in the spring and autumn occurred.

Effects of water and drought on the stability of aggregates and soil

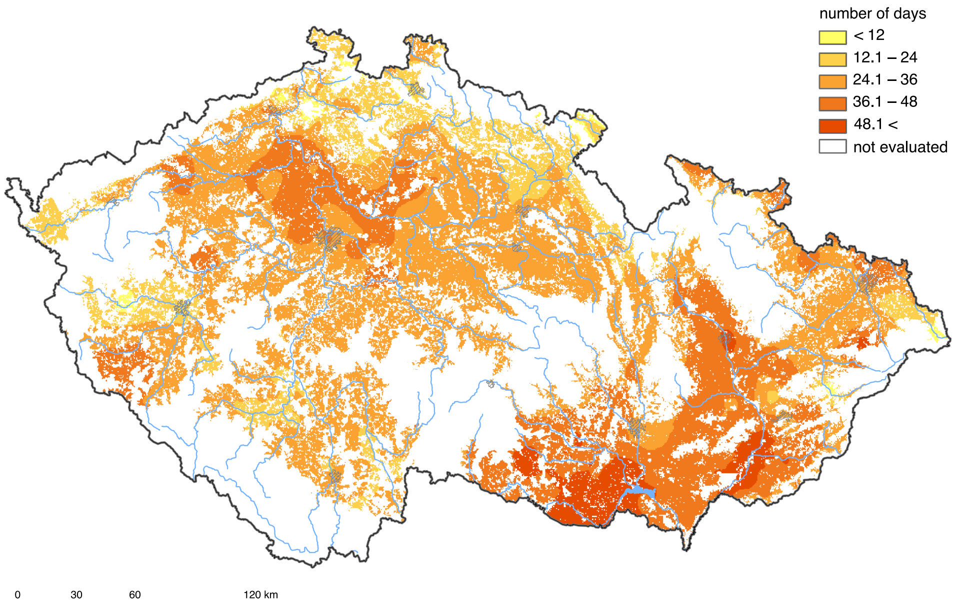

Fig. 4. Average number of days with dry soil surface conditions from 1st March to 30th April and from 1st September to 31st October for the period 1981–2010.

erosion were studied and their principles were described in the scientific literature in the forties to the sixties (*Yoder, 1936; Chepil, 1953; 1956; 1958* and others). In the present the outputs of these classic experiments can be applied using automated measurements of (agro) meteorological variables and surface-expressed by GIS methods. Maps of soil erosion risk or factors influencing the erosion occurrence have been published for different parts of the world (e.g. *Gournellos et al., 2004; Afifi and Gad, 2011*).

Occurrence of drought is a significant characteristic of Czech climate. Scenario calculations of potential evapotranspiration predict a significant increase in aridity of climate in the CR. From the estimated values of moisture indices it is evident that parts of Central and Southern Moravia, Central and Northwestern Bohemia, the lower and middle Elbe and Vltava will be increasingly vulnerable to drought (*Kalvová et*

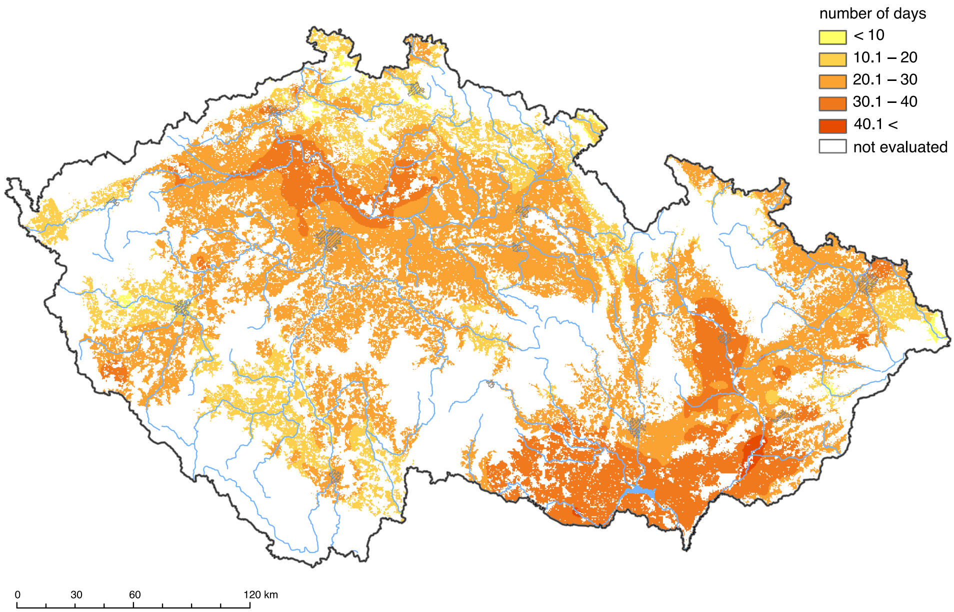

Fig. 5. Average number of days with dry soil surface conditions from 1st March to 31st May for the period 1981–2010.

al., 2002). *Kohut et al. (2010)* analyzed moisture conditions in the CR for the period 1961–2000. The analysis revealed a decreasing trend of soil water reserves. *Středová et al. (2013)* compared average values of two 50-year periods (1901–1950 and 1961–2010). The results of these analyses confirmed long-term change in precipitation distribution within the year and deterioration in the moisture situation. The most serious impact can be detected in arid lowland areas (Central Bohemia – Polabí Lowland, Southeast Moravia). If the number of days with dry soil surface increases, potential erodibility will also increase and wind erosion might endanger more agricultural areas. Increasing drought, predicted by climate models (*Fukalová et al., 2014*), presents major problem for the agriculture of CR. It is necessary to adapt to these anticipated changes not only in the agricultural activities but also in the landscape management in general.

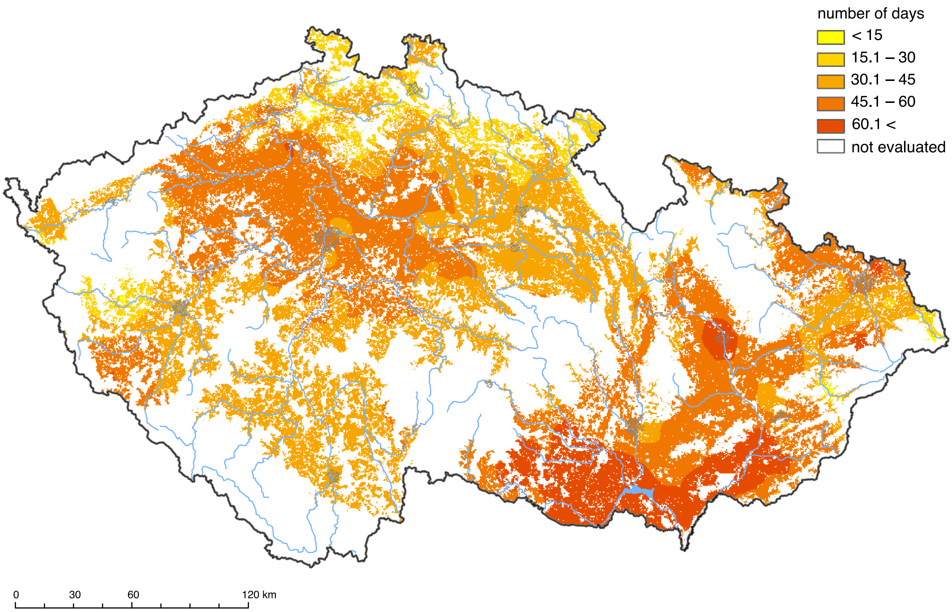

Fig. 6. Average number of days with dry soil surface conditions from 1st March to 31st May and from 1st September to 31st October for the period 1981–2010.

4. Conclusion

The paper aims to map and assess qualitatively the areas vulnerable to wind erosion using available data and intelligible methodology. Climatological data from climatological stations across the CR allowed a spatial characterization of spring and autumn soil surface state which may lead to wind erosion events on agricultural soils. The results presented in maps show the regional differences in potential soil erodibility. There are areas mainly in the South and Southeast Moravia, where more than 20 days (average) with dry soil surface occurred in March and April. In the autumn the potential wind erosion vulnerability conditions in the CR are worse than in the spring. At many localities in the South, Southeast and Central Moravia, more than 25 days (average) with dry soil surface occurred in September and October. When the May conditions were also evaluated, relative risk (risk areas in the CR) remains essentially identical. Changing the absolute value of the number of days with risk conditions were detected. There are localities with more than 40 such days in the spring – Southeast Moravia. Summary results show that mainly in the South and Southeast Moravia, areas with more than 45 days with dry soil surface in the spring and autumn occurred.

Acknowledgments. This work was supported by project of the Ministry of Agriculture of the Czech Republic QJ1220054 "Impact of a change of climatic factors on the development of wind erosion processes, conceptual solution through the land adjustment measures".

References

Afifi A., Gad A., 2011: Assessment and mapping areas affected by soil erosion and desertification in the north coastal part of Egypt. International Journal of Water Resources and Arid Environments, **1**, 2, 83–91.

Alley W. M., 1984: The Palmer drought severity index: limitations and assumptions. Journal of Climate and Applied Meteorology, **23**, 7, 1100–1109.

Amézketa E., Aragüés R., Carranza R., Urgel B., 2003: Macro- and micro-aggregate stability on soils determined by a combination of wet-sieving and laser-ray diffraction. Spanish Journal of Agricultural Research, **1**, 4, 83–94.

Bolte K., Hartmann P., Fleige H., Horn R., 2011: Determination of critical soil water content and matric potential for wind erosion. Journal of Soils and Sediments, **11**, 2, 209–220.

Bullock M. S., Larney F. J., McGinn S. M., Izaurralde R. C., 1999: Freeze-drying processes and wind erodibility of a clay loam soil in southern Alberta. Canadian Journal of Soil Science, **79**, 1, 127–135.

Colazo J. C., Buschiazzo D. E., 2010: Soil dry aggregate stability and wind erodible fraction in a semiarid environment of Argentina. Geoderma, **159**, 1–2, 228–236.

Fukalová P., Středová H., Vejtasová K., 2014: Development and prediction of selected temperature and precipitation characteristics in Southern Moravia. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, **62**, 1, 91–98.

Gournellos T. H., Evelpidou N., Vassilopoulos A., 2004: Developing an erosion risk map using soft computing methods (case study at Sifnos Island). Natural Hazards, **31**, 63–83.

Chepil W. S., 1953: Factors that influence clod structure and erodibility of soil by wind: I. Soil texture. Soil Science, **75**, 6, 473–484.

Chepil W. S., 1956: Influence of moisture on erodibility of soil by wind. Soil Science Society of America Proceedings, **20**, 288–292.

Chepil W. S., 1958: Soil conditions that influence wind erosion. Technical Bulletin No. 1185. U.S. Department of Agriculture, Washington, D. C. 40 p.

Kalvová J., Kašpárek L., Janouš D., Žalud Z., Kazmarová H., 2002: Climate change induced impacts on water regime, agriculture, forestry and human health in the Czech Republic (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). National Climatic Program of the Czech Republic, Prague: 151 p. (in Czech)

Kohut M., Rožnovský J., Chuchma F., 2010: Long-term available soil water resource and its varaibility in the Czech Republic (Dlouhodobá zásoba využitelné půdní vody a její variabilita na území České republiky). In: Voda v krajině, Lednice 31.5. – 1.6.2010, 35–46. (in Czech)

Mužíková B., Středa T., Středová H., 2013: State of bare soil surface as a spring drought indicator. Contrib. Geophys. Geod., **43**, 3, 197–207.

Podhrázská J., Kučera J., Chuchma F., Středa T., Středová H., 2013: Effect of changes in some climatic factors on wind erosion risks – the case study of South Moravia. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, **61**, 6, 1829–1837.

Singer M. J., Shainberg I., 2004: Mineral soil surface crusts and wind and water erosion. Earth Surface Processes and Landforms, **29**, 9, 1065–1075.

Skidmore E. L., Powers D. H., 1982: Dry soil-aggregate stability: energy-based index. Soil Science Society of America Journal, **46**, 6, 1274–1279.

Slabá N., 1972: Manual for observers at the meteorological stations in Czechoslovakia (Návod pro pozorovatele meteorologických stanic ČSSR). 2nd revised edition, Hydrometeorologický ústav, Sborníky předpisů Hydrometeorologického ústavu v Praze, 7, Praha, 222 p. (in Czech).

Středová H., Středa T., Rožnovský J., 2013: Long-term comparison of climatological variables used for agricultural land appraisement. Contrib. Geophys. Geod., **43**, 3, 179–195.

Takáč J., 2013: Assessment of drought in agricultural regions of Slovakia using soil water dynamics simulation. Agriculture (Poľnohospodárstvo), **59**, 2, 74–87.

Tekušová M., Horecká V., Jančovičová Ľ., 2013: State of ground in relation to precipitation characteristics during the vegetation seasons in Hurbanovo (Stav povrchu pôdy vo vzťahu k zrážkomerným charakteristikám počas vegetačných období v Hurbanove). In: Rostliny v podmínkách měnícího se klimatu. Lednice 20.–21.10.2011, Úroda, vědecká příloha, 2011, 629–639, (in Czech).

Yoder R. E., 1936: A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Journal of American Society of Agronomy, **28**, 5, 337–351.

Žídek D., Lipina P., 2003: Manual for observers at the meteorological stations CHMI. Metodological guide of CHMI No. 13. (Návod pro pozorovatele meteorologických stanic ČHMÚ. Metodický předpis), 13, CHMI, Ostrava, 90 p. (in Czech).