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COMPARISON OF VOLUMETRIC AND DEFLAMETRIC METHOD WITH WIND EROSION EQUATION (WEQ) TO DETERMINE SOIL EROSION BY WIND EVENTS ON SELECTED SOIL UNIT

POROVNANIE VOLUMETRICKEJ A DEFLAMETRICKEJ METÓDY S ROVNICOU VETERNEJ ERÓZIE PRE URČENIE PÔDNEJ ERÓZIE SPÔSOBENEJ ÚČINKAMI VETRA NA VYBRANÝCH PÔDNYCH JEDNOTKÁCH

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Despite the fact that wind erosion seriously affects the sustainable use of land in large part of the world and even though in Slovakia there is not that big percentage of agricultural land influence by wind erosion it still has an effect on the soil. Valid wind erosion model that predicts wind-blown mass transport on regional scale is lacking. The objective of this research was to compare two empiric methods to determine wind erosion. One of them is deflametric method, in which we capture soil units in one hour during wind erosion events. Second method we used was volumetric method where we calculate amount of eroded soil behind the wind barrier. With deflametric method we determined that actual wind speed needed to lift and carry soil unites is 9 – 10 m.s^{-1}. With volumetric calculation we found out that our measurement is 1.7 times higher than in WEQ model. We can say that models can portray certain areas and soil types, but only field measurement can provide precise amount of eroded soil on particular land.

Keywords: wind erosion, volumetric method, deflametric method, WEQ

Wind erosion is a major problem of soil conservation in arid and semi-arid regions worldwide, including about one-sixth of the world's population (Skidmore, 2000). Wind is one of the exogenous factors affecting the earth's surface by mechanical force and evokes a phenomenon that is commonly called eolisation. In this process, we distinguish two forms, depending on what substrate the wind affects. The wind erosion process (aeolian) involves eroding the soil surface by mechanical wind force (abrasion), moving and transporting soil particles (aggregates) by wind (deflation) and depositing them elsewhere (accumulation). Wind erosion is a physical phenomenon and it is directly influenced by soil physical properties, kinetic energy, and many other factors (Streďanský, 1993a). Wind erosion is less dependent on relief areas than water erosion and therefore influences fully plain terrain.

Wind erosion can be researched by a variety of special techniques, of which the primary interest focuses on detecting the nature of wind-transported particles – deflates. By analyzing eroded and transported soil (grain size, texture, nutrient content, etc.) we can detect the influence of wind erosion on the soil (Zachar, 1970).

Material and methods

The research of the process and intensity of wind erosion can be carried out using various methods like water erosion(leveling, volumetric, soil science, morphology, vegetation, photogrammetric, historical), but more appropriate for this purpose are deflametric and tunnel methods. While deflametric methods are appropriate for qualitative research, tunneling methods are used to detect aeolian erodibility of soils (Stred'anský et al., 2005). Švehlík (1996) describes the erosion intensity as level of soil damage, expressed in quantities of soil particles transported by the wind from the unit area in a certain time. Usually it is expressed in m^3.h^{-1}.year^{-1} or t^{-1}.ha^{-1}.year^{-1}. We can also express the erosion intensity in terms of erosion height, it means the depth of the soil removed from certain place in certain time (mm. ha^{-1}.year^{-1}).

The basis of the deflametric method consists in capturing soil particles carried by the wind in different natural conditions, at different heights above the soil surface. Quantitative data of the soil transport allow to determine the wind erosion intensity and its relation to various parameters and

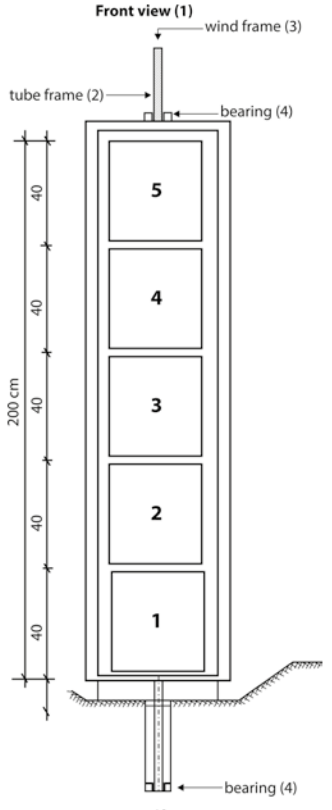

Figure 1 Soil particle catcher
Source: Švehlík, 2007

Obrázok 1 Lapač pôdnych častíc
(1) čelný pohľad, (2) trubkový rám, (3) veterné krídlo, (4) ložisko
Zdroj: Švehlík, 2007

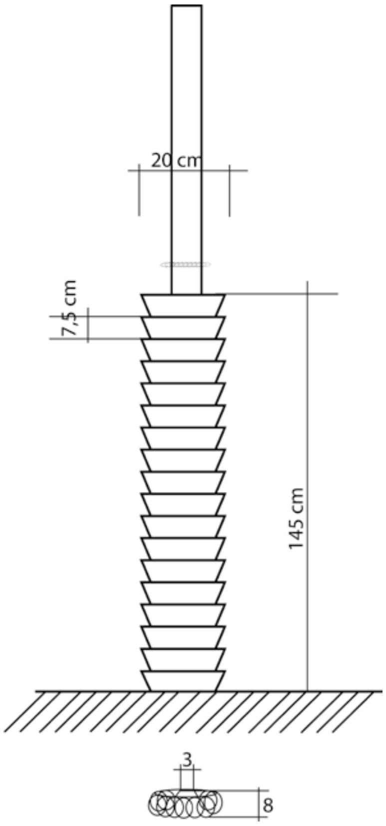

Figure 2 Soil particle catcher of transported soil particles
Source: Streďanský et al., 2005
Obrázok 2 Lapač pohybujúcich sa pôdnych častíc – deflameter
Source: Streďanský et al., 2005

conditions, qualitative data allow to assess the selective effect on the soil. For this purpose we use devices called soil particle catchers (Stred'anský, 1993a).

Figure 4 2nd model of soil particle catcher
Source: Urban, 2011
Obrázok 4 Druhý model deflametra
Source: Urban, 2011

Field nr. 9 in cadastral area Močenok

Evaluated soil – ecological units with the main soil unit nr. 37 (typical chernozems, carbonate in loess, medium), 31 (typical black soils and gley black soils, medium and heavy, the loess slope and clay) and 17 (black chernozems, mainly carbonate, medium) occur in the field nr. 9. However, according to the analysis of the BPEJ maps, soil susceptible to wind erosion does not occur there, there is a more prone soil type of black chernozem (HPJ 16).

Figure 3 1st model of soil particle catcher
Source: Urban, 2011
Obrázok 3 Prvý model deflametra
Source: Urban, 2011

For the soil particles trapped in the field in the first year of research, we designed the first prototype of soil particle catcher (fig. 3) Soil particle catcher consists of tapered entrance part through which the circulating air gets into the body of soil particle catcher, which absorbs kinetic energy of the wind. Inside the soil particle catcher, there are three filters that trap soil particles. Entrance part consists of the holes which are 5 cm wide and 20 cm high. Reduced input section gradually expands and connects to the body of soil particle catcher which is 25 cm wide and 20 cm high. Soil particle catcher is 130 cm long.

Field measurements in which we tried to trap the moving soil particles during the wind through the first prototype of soil particle catcher was performed on 8 and 13 April 2011. The catcher was loosely laid on the soil surface and in the prevailing wind direction and it trapped the moving soil particles up to a height of 20 cm above the soil surface. The duration of each measurement was always 60 minutes. The recalculation of the amount of particles captured per unit area is very simple because the width of the entrance is 5 cm. By multiplying the width and length of erosive surface in the wind direction we get the area of wind erosion surface.

Besides trapping moving soil particles, we verified the intensity of wind erosion by the volumetric

Figure 5 Height of soil accumulation in windbreak measurement
Source: Urban, 2011

Obrázok 5 Meranie výšky akumulácie pôdy pri vetrolame
Source: Urban, 2011

method, which is based on direct surveys of soil deposition volumes and deposition of accumulated soil and the volume is calculated by measuring the transverse profiles and lengths of accumulated products of an erosive activity (fig. 5). We used this method to determine soil loss by wind erosion after occurrence in April 2011, in the soil unit no. 9 in cadastral area Močenok that has been affected by the erosion on the total area of about 8.4 hectares. Transported soil particles were accumulated in areas with rougher soil surface, and in the places where a reduction in wind speed caused by effects of windbreak was. The volume of accumulated soil and deposits that were created in front of windbreaks and in its internal parts in a ditch at the interface between plots and on the nearby field, where corn was planted.

Results and discussion

The results of deflametric method on 8th and 13th April 2011

Field measurements in which we tried to trap the moving soil particles during the wind through the first prototype of soil particle catcher took was performed on 8th and 13th April 2011. Within these measurements, we also tested the efficiency and the ability of soil particle catcher to capture moving particles.

Analyzing data (average minute data on wind speed and direction) provided by SHMÚ (from the nearest meteorological station Nitra – Janíkovce), we found out that in the area in the period from 5th to 15th April 2011 there were five wind erosion events in total. As effective erosive wind in our case we chose the wind speed, which is higher than the critical wind speed for loamy soil by Pasák (1964). Recalculated critical speed at the height in which

Table 1 Analysis of the 1st wind erosion event for meteorological station Nitra-Janíkovce

The beginning of wind erosion event: 7. 4. 2011 at 9:05 a. m. (1)				
The end of wind erosion event: 8. 4. 2011 at 1:15 a. m. (2)				
Hourly average wind speed in m.s^{-1} (3)	4.5–4.9	5.0–5.9	6.0–6.9	7.0–7.9
Erosive wind duration in hours (4)	5	2	4	0

Source: SHMÚ, 2011 Zdroj: SHMÚ, 2011

Tabuľka 1 Analýza 1. veternej udalosti pre meteorologickú stanicu Nitra-Janíkovce
(1) začiatok veternej udalosti: 7. 4. 2011 o 9:05, (2) koniec veternej udalosti: 8. 4. 2011 o 1:15, (3) priemerná hodinová rýchlosť vetra v m.s^{-1}, (4) trvanie vetra v hodinách

Table 2 Analysis of the 2nd wind erosion event for meteorological station Nitra-Janíkovce

The beginning of wind erosion event: 8. 4. 2011 at 1:16 p. m. (1)				
The end of wind erosion event: 9. 4. 2011 at 7:09 p. m. (2)				
Average hourly wind speed in m.s^{-1} (3)	4.5–4.9	5.0–5.9	6.0–6.9	7.0–7.9
Erosive wind duration in hours (4)	4	13	5	2

Source: SHMÚ, 2011 Zdroj: SHMÚ, 2011

Tabuľka 2 Analýza 2. veternej udalosti pre meteorologickú stanicu Nitra-Janíkovce
(1) začiatok veternej udalosti: 8. 4. 2011 o 13:16, (2) koniec veternej udalosti: 9. 4. 2011 o 19:09, (3) priemerná hodinová rýchlosť vetra v m.s^{-1}, (4) trvanie vetra v hodinách

Table 3 Analysis of the 3rd wind erosion event for meteorological station Nitra-Janíkovce

The beginning of wind erosion event: 10. 4. 2011 at 7:05 a. m. (1)				
The end of wind erosion event: 10. 4. 2011 at 6:50 p. m. (2)				
Hourly average wind speed in m.s^{-1} (3)	4.5–4.9	5.0–5.9	6.0–6.9	7.0–7.9
Erosive wind duration in hours (4)	0	3	4	2

Source: SHMÚ, 2011 Zdroj: SHMÚ, 2011

Tabuľka 3 Analýza 3. veternej udalosti pre meteorologickú stanicu Nitra-Janíkovce
(1) začiatok veternej udalosti: 10. 4. 2011 o 7:05, (2) koniec veternej udalosti: 10. 4. 2011 o 18:50, (3) priemerná hodinová rýchlosť vetra v m.s^{-1}, (4) trvanie vetra v hodinách

Table 4 Analysis of the 2nd wind erosion event for meteorological station Nitra-Janíkovce

The beginning of wind erosion event: 8. 4. 2011 at 1:16 p. m. (1)				
The end of wind erosion event: 9. 4. 2011 at 7:09 p. m. (2)				
Average hourly wind speed in m.s^{-1} (3)	4.5–4.9	5.0–5.9	6.0–6.9	7.0–7.9
Erosive wind duration in hours (4)	4	13	5	2

Source: SHMÚ, 2011 Zdroj: SHMÚ, 2011

Tabuľka 4 Analýza 2. veternej udalosti pre meteorologickú stanicu Nitra-Janíkovce
(1) začiatok veternej udalosti: 8. 4. 2011 o 13:16, (2) koniec veternej udalosti: 9. 4. 2011 o 19:09, (3) priemerná hodinová rýchlosť vetra v m.s^{-1}, (4) trvanie vetra v hodinách

Table 5 Analysis of the 2nd wind erosion event for meteorological station Nitra-Janíkovce

The beginning of wind erosion event: 8. 4. 2011 at 1:16 p. m. (1)				
The end of wind erosion event: 9. 4. 2011 at 7:09 p. m. (2)				
Average hourly wind speed in m.s^{-1} (3)	4.5–4.9	5.0–5.9	6.0–6.9	7.0–7.9
Erosive wind duration in hours (4)	4	13	5	2

Source: SHMÚ, 2011 Zdroj: SHMÚ, 2011

Tabuľka 5 Analýza 2. veternej udalosti pre meteorologickú stanicu Nitra-Janíkovce
(1) začiatok veternej udalosti: 8. 4. 2011 o 13:16, (2) koniec veternej udalosti: 9. 4. 2011 o 19:09, (3) priemerná hodinová rýchlosť vetra v m.s^{-1}, (4) trvanie vetra v hodinách

the meteorological station measures is > 4.5 m.s^{-1}. The following tables show the average hourly rate of effective erosive winds and their duration according to different wind erosion events.

On August 4, 2011 during the second wind erosion event between 16:00 and 17:00 o´clock (measurement duration – 60 minutes) at an average wind speed of 5.7 ms^{-1}, 1722 grams of eroded soil were trapped in the soil particle catcher, which after recalculation (soil particle catcher width of 5 cm, the northwest wind erosion surface length of 265 m) is 1299.6 kg.ha^{-1}.hour^{-1} of soil loss.

On April 13, 2011, the second measurement in the same location was made, during the fifth wind erosion event between 10:00 and 11:00 o´clock at an average wind speed 5.6 ms^{-1} 364.4 grams of eroded soil were trapped. After recalculation it is 275.0 kg of eroded soil from one hectare per one hour.

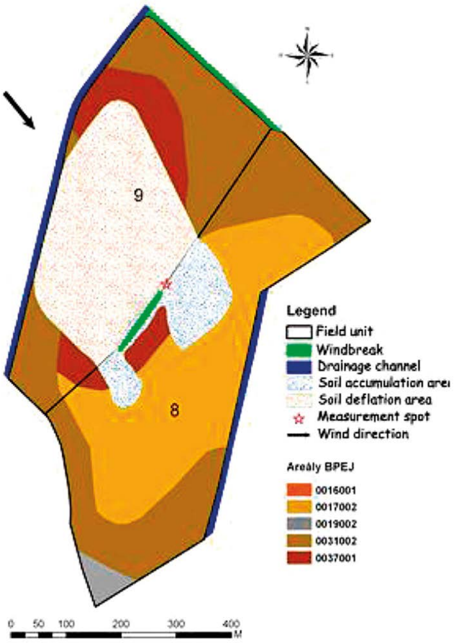

Figure 6 Map of soil deflation and accumulation
Obrázok 6 Mapa deflácie a akumulácie pôdy

Third measurement was performed between 11:00 to 12:00 o´clock the same day in the same place at an average speed of 4.3 m.s^{-1}. 199 grams of soil which represents soil erosion of 150.2 kg.ha^{-1}.hour^{-1}, were trapped in the soil particle catcher. The measurement site is shown in fig. 6.

The results of the wind erosion events analyses is show that during the monitored period effective erosive winds lasted together 58 hours. The most average hourly wind speed ranged from 5.0 to 5.9 m.s^{-1} and the period of occurrence lasted a total of 28 hours. The maximum average minute wind speed reached 12.3 m.s^{-1} and a maximum gust of wind was 17.3 m.s^{-1}.

The results of the volumetric method to determine the intensity of wind erosion

Wind erosion which has occurred on period from 5th to 15th of April 2011 at the whole soil unit no. 9 in cadastral area Močenok affected approximately 8.4 hectares of its area.

Transported soil particles were accumulated in areas with rougher soil surface, and where there has been a reduction in wind speed caused by windbreaks effects. The volume of accumulated soil and deposits that were created in front of windbreaks and in its internal parts in a ditch at the interface between plots and on the nearby field, where corn was planted was calculated by volumetric method (fig. 7, 8). The results are shown in table no. 6.

The sum of all deposits and soil accumulation represents volume of 485.3 m^3 of accumulated soil that has been eroded and transported to another location. At density 1.1 g.cm^3 (mild fever topsoil, 60% porosity) is the weight of eroded material 533.8 t, which represents soil loss of 63.5 t.ha^{-1}. Deflation and accumulation of soil particles areas are shown in figure 6.

Figure 7 Accumulated soil particles in front of the windbreak
Source: Urban, 2011

Obrázok 7 Akumulované častice pôdy pred vetrolamom
Zdroj: Urban, 2011

Figure 8 Soil particles deposition between corn rows
Source: Urban, 2011

Obrázok 8 Nánosy pôdnych častíc medzi radmi kukurice
Zdroj: Urban, 2011

Table 6 Calculated volumes of soil accumulation

Place of soil accumulation (1)	Transverse profile content in m^2 (2)	Length in m (3)	Calculated volume in m^3 (4)
In front of windbreak (5)	0.38	130	49.4
Windbreak (6)	1.35	130	175.5
Ditch between two fields (7)	0.12	160	19.2
Accumulation between rows (8)	1.51 (in number 80)	160	241.2
Total (9)			485.3

Tabuľka 6 Vypočítané objemy akumulácie pôdy
(1) miesto akumulácie pôdy, (2) obsah transverzálneho profilu, (3) dĺžka, (4) vypočítaný objem, (5) pred vetrolamom, (6) vetrolam, (7) priekopa medzi dvomi poľami, (8) akumulácia medzi radmi, (9) spolu

Comparison of soil loss calculated by volumetric method and WEQ equation

The soil loss calculated by volumetric method was compared with the mathematical model WEQ equation according to the USDA (2002) methodology. The factors that enter the equation, we expressed by the values that represents the period (April 5–15, 2011) in the soil unit. Soil erodibility factor was determined on the basis of non-erodible soil particles content, the values were the same as in the previous calculations based on soil loss equation of WEQ. Roughness of the surface soil was minimal, so we choose the value 1. Vegetation covers as well as plant residues were not occurred during wind erosion, so we calculated soil loss excluding this factor. For climatic factor, we calculated the annual value for year 2011.

By modeling of wind erosion on soil unit no.9 we found out that the average annual soil loss by WEQ equation for specified variable factors ranges from 0 to 104.25 t.ha^{-1}.year^{-1}. Maximum value reaches a peak of terrain wave, which occurs on field no. 9 (fig. 6). On the deflation surface, which was estimated at 8.4 ha at the time of erosion, we modeled the average annual soil loss of 36.7 t.ha^{-1}.year^{-1}. Soil loss surface from the deflation area measured by volumetric method was calculated to 63.5 t.ha^{-1}.year^{-1}. Soil loss due to wind within 10 days was at least 1.7 times higher than the modeled yearly average soil loss without vegetative factor, and with the maximum value of K factor.

Conclusion

The intensity of wind erosion was measured under the field conditions using constructed soil particle catchers. We focused on the measurement of increase in soil erosion due to increasing of the length of the erosion surface as well as the measurement of the vertical transport of soil particles. Lyles and Krauss (1971) indicate that wind is considered to be effectively erosive when it reaches a speed of 5.8 m.s^{-1} at 0.3 m height above the soil surface, which is calculated by the height of 1 meter above the surface of 6.9 m.s^{-1}. From observations during field measurements we found out that soil particles of soil type black chernozems were reported to move at the speed of wind 9 to 10 m.s^{-1} and measured at 1 meter above the soil surface. The higher critical wind speed observed in our case was probably due to the higher content of clay particles (13 %) in the soil, where measurements were conducted. Lyles and Krauss indicated the speed for sandy soil (clay particles containing 0 to 10 %). Pasák (1970) provides a critical wind speed for dry loam soil 3.3 ms^{-1}, which is calculated at height of 1 meter above the soil surface of 5.1 m.s^{-1}. This does not associate with this value, because critical speed in our case was about 4 to 5 $m.s^{-1}$ higher.

After that the occurrence of wind erosion (April 5–15, 2011) was calculated by volumetric method on the soil unit no. 9 volume of erosive activity. This volume represented 485.3 m^3 of accumulated soil that has been eroded from the total area of 8.4 ha. After recalculation, the soil erosion represented 63.5$t.ha^{-1}.year^{-1}$. On the deflation surface, which was at the time of erosion estimated at 8.4 ha, we modeled the average annual soil loss of value 36.7 $t.ha^{-1}.year^{-1}$. Soil loss by wind was within 10 days of at least 1.7 times higher than the modeled yearly average soil loss without vegetative factor, and with the maximum value of K factor.

Súhrn

Veterná erózia priamo ovplyvňuje udržateľné využívanie pôdy na celom svete a hoci sa na Slovensku nenachádza vysoké percento ornej pôdy, na ktorom by priamo pôsobila, jej vplyv na našom území nie je zanedbateľný. Absentuje tu platný model veternej erózie, na základe ktorého by sme mohli predvídať pohyb pôdnych častíc spôsobený vetrom v jednotlivých oblastiach. Cieľom našej práce bolo porovnať dve empirické metódy určovania veternej erózie. Prvou je deflametrická metóda, pri ktorej počas veterných udalostí zachytávame pôdne častice v priebehu jednej hodiny. Druhou je volumetrická metóda. Jej základom je určenie množstva zerodovanej pôdy za veternou bariérou. Pomocou deflametrickej metódy sme zistili, že na zdvihnutie a presun pôdnych častíc je potrebný vietor s rýchlosťou 9 – 10 $m.s^{-1}$. Pomocou volumetrického výpočtu sme zistili, že namerané výsledky sú 1,7-násobne vyššie ako pri modeli WEQ. Konštatujeme, že modely erózie nám môžu poskytnúť prehľad o určitých oblastiach a typoch pôdy, no presné informácie o množstve erodovanej pôdy v konkrétnej oblasti nám môže poskytnúť iba terénny prieskum.

Kľúčové slová: veterná erózia, volumetrická metóda, deflametrická metóda, WEQ

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