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Wind erosion intensity determination using soil particle catcher devices

Určovanie intensity veternej erózie pomocou deflametrov

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Abstract

To analyze wind erosion events in the real terrain conditions, we proposed to construct a prototype of soil particle catcher devices to trap soil particles. With these devices we are able to measure the intensity of wind erosion at six different heights above the soil surface in one location or at three different heights in two places. It is possible to use them for six different places at the same time as well. We performed field measurements to determine the amount of soil particles transported by the wind between 26th – 31st March 2012. Each measuring took 60 minutes. After this time the soil particle catchers were emptied and further measurements carried out. At the beginning we selected two places for measurement (soil HPJ 16 and 37) at two heights, one above the other. Then we used two measuring systems 40 m apart at two sites (D2 and D4) and the soil captured at two heights (0, 1). The maximum weight of soil particles trapped in measuring system D2 at height (0) was 1242.7 g at a wind speed of 9.6 ms^{-1}. At measurement height (1) the maximum weight was 72.7 g trapped at the same average hourly rate, but during different measurement events. The measuring system at D4 trapped the highest amount of soil at a wind speed of 8.9 ms^{-1} (1141.7 g) at height (0) and at a speed of 9.3 ms^{-1} (22.3 g) at height (1). During the measurements with the two basic measuring systems D4 and D2, we measured the wind erosion intensity together with soil particle catchers D1 and D3. D3 was placed between devices D4 and D2, D1 was 20 m ahead D2. Soil particle catchers were placed on the soil surface at height position (0). We measured increasing soil erosion downwind on four locations spaced at 20 m. The results show that with there is an increasing quantity of particles collected as the erosive surface length increases, due to the so-called snowball effect. We analyzed selected trapped soil samples in order to determine the size of the soil particles and their proportion in the sample at different wind speeds. Samples were subjected to aggregate analysis (laser soil particle analyzer FRITSCH ANALYSETTE 22) in order to set the size and percentage of soil particles.

Key words:
wind erosion, soil particles catcher devices, aggregate analysis

Abstrakt

Na analýzu veternej erózie v reálnych terénnych podmienkach sme navrhli skonštruovať lapače pôdnych častíc – deflametre. S týmito zariadeniami dokážeme merať intenzitu veternej erózie v šiestich výškach nad pôdnym povrchom na jednom mieste alebo v troch výškach na dvoch miestach. Urobili sme poľné merania na určenie množstva erodovaných pôdnych častíc v čase 26-31. marec 2012. Dĺžka každého merania bola 60 minút. Po uplynutí tohto času boli deflametre vyprázdnené a pokračovalo sa v ďalšom meraní. Na začiatku sme si vybrali dve miesta na meranie (s HPJ 16 a 37) v dvoch výškach. Potom sme merali pomocou dvoch meracích zostáv vo vzdialenosti 40 m (D2 a D4) a častice sme zachytávali v dvoch výškach (0,1). Maximálne množstvo zachytených častíc v deflametri D2 vo výške (0) bolo 1242,7 g pri rýchlosti vetra 9.6 ms^{-1}. Vo výške (1) maximálne množstvo zachytených častíc bolo 72,7 g pri rovnakej rýchlosti vetra, ale pri inom meraní. V deflametri D4 bolo najväčšie množstvo zachytených častíc 1141.7 g, pri rýchlosti vetra 8.9 ms^{-1} vo výške (0) a 22.3 g pri rýchlosti 9.3 ms^{-1}, vo výške (1). Spolu s meraním pomocou meracích zostáv D4 a D2 sme merali aj s deflametrami D1 a D3. Deflameter D3 bol umiestnený medzi zostavami D4 a D2, D1 bol umiestnený 20 m pred D2. Deflametre boli umiestnené vo výške (0). Merali sme intenzitu veternej erózie v smere prevládajúceho vetra na štyroch miestach vzdialených medzi sebou 20 metrov. Výsledky ukazujú, že množstvo zachytených pôdnych častíc narastá s dĺžkou erózneho povrchu v dôsledku takzvaného efektu snehovej gule. Zachytené pôdne častice sme podrobili analýze, na zistenie ich veľkosti pri rôznej rýchlosti vetra. Vzorky sme podrobili agregátovej analýze pomocou laserového analyzátora FRITSCH ANALYSETTE 22 na zistenie veľkosti a percentuálneho podielu zachytených častíc.

Kľúčové slová:
veterná erózia, deflameter, agregátová analýza

Introduction

The process of wind erosion (aeolian) is via the loss of the soil surface by mechanical wind forces (abrasion), moving and transporting the soil particles (aggregates) by wind (deflation) and depositing them elsewhere (accumulation). Wind erosion is a physical phenomenon and it is directly influenced by the physical properties of the soil, by kinetic energy, and by many other factors (Streďanský, 1993).
When wind erosion occurs its action is selective dependent upon soil particle size. Finer particles either remain suspended and are carried long distance or move by bouncing to other locations and leave only resistant particles to erosion in place - a coarse stone layer (Morgan, 2005).
The control and limitation of soil erosion in Slovakia is regulated by Act 220/2004 (Collection of Laws on the Protection and Use of Agricultural Land) (Varga, Streďanský, 2012) and amending Act 245/2003 (Integrated Pollution Prevention and Control of the Environment) and certain other additional amendments (Jurík, Palšová, 2012). I soil erosion. For wind erosion the limit is 40 tons per 1 ha per year.
According to Slovak Technical Norm STN 75 4501 (2000) Hydromelioration, erosion

protection of agricultural land, the maximum allowable value for single soil erosion is 0.014 tons per hectare. The movement of soil particles is caused by wind forces affecting the soil surface. The average wind speed increases exponentially with height above the soil surface. The movement of soil particles begins with uplifting forces in the turbulent flow. If the particles are large enough or are grouped with other particles they can resist the effects of the wind forces. If this is not the case soil particles may be lifted from the soil surface and start to move (Vrána, 1977).

Material and Methods

We proposed to construct a prototype of soil particle catcher devices to trap soil particles. With these devices we are able to measure the intensity of wind erosion at six different heights above the soil surface in one location (fig. 1), 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 5 x 5 cm.

Figure 1. The prototype of soil particles catcher

Obrázok 1. Prototyp deflametra

We performed field measurements to determine the amount of soil particles transported by the wind between 26th – 31st March 2012. We chose field in the Močenok, Slovakia region. Although according the BPEJ – evaluated soil-ecological units maps analysis there are no soils vulnerable to wind erosion, we evaluated the soils with a pedologist and identified a vulnerable soil type like black chernozem; easy drying (HPJ 16), formed from non-carbonate aeolian sands with silicate humus, A horizon ($CaCO_3$ content < 0.3%). In the horizon up to 100 cm from the surface with rust - brown stains caused by oxidation of Fe^{3+}.
The Močenok regional area lies in the Podunajská lowlands, on the south-western border of the Nitra highlands, in the shallow valley in the Long Channel. The selected area is characterized by the dominant soil type chernozem, which covers the northern, central and eastern part of the region (Varga, Halva, 2012). Loam (moderate soil) - 79.35% - represents the largest area in terms of grain size, sandy loam (moderate soil) covers 17.56%, light loam (light soils) covers 1.93%.

Results

On the 26th March this field was underwent pre-sowing soil preparation. There was thus a violation of the soil crust and loosening of the soil surface layer. Initial roughness of the soil surface immediately after the farming operation was calculated at as 0.9. Small furrows occurred performing the soil tillage where black chernozem quickly aligned and the roughness was changed to a value of 1. During the measurement the soil surface was without vegetation cover or crop residues. The top layer, to a depth of about 2 cm, was completely dry. Soil moisture was investigated by the gravimetric method of soil sampling on Kopecky rollers from the upper 0-5 cm. Rainfall activity during the entire measurement period didn´t occur and did not hamper the calculation of total soil erosion.
Each measuring took 60 minutes. After this time the soil particle catchers were emptied and further measurements carried out. At the beginning we selected two places for measurement (soil HPJ 16 and 37) at two heights, one above the other. As the amount of particles trapped at HPJ 37 was minimal after a couple of measurements, we focused on trapping particles from black chernozems. The soil particle catchers were moved successively downwind and soil erosion was measured with increasing lengths of erosive surface. Since we have a limited number of soil particle catchers, we always placed them at four locations downwind at 20 m spacing. A constant measurement location (D4) was located 20 meters ahead of the windbreaks, the others varied depending on wind flow, but the distance between them was always constant. At each station (D1, D2, D3, D4) soil particle catchers were laid on the soil surface (particles being captured from 0-5 cm above the soil surface). At stations D2 and D4 the soil was trapped between 15 to 20 cm above the soil surface (fig. 2).

Figure 2. Soil particles catcher disposition during the terrain measurement

Obrázok 2. Umiestnenie deflametra počas terénneho merania

Two measuring systems D4 and D2

Two measuring systems were used 40 m apart at two sites (D2 and D4) and the soil captured at two heights (0, 1). The wind speed was measured at both sets 1 m above the ground. The variation of the wind flow changed with the length of the erosive surface, for D4 from 135 to 170 m. The length of erosive surface was measured in the direction of the wind flow up to the measuring system. D4 always captured more

soil with three exceptions compared with the measuring system D2. However, the wind speed was always lower. This was caused by the erosive surface length, which was about 40 meters longer. A lower wind speed was measured at D4 due to a windbreak situated close by reducing the wind speed. The maximum weight of soil particles trapped in measuring system D2 at height (0) was 1242.7 g at a wind speed of 9.6 ms^{-1}. At measurement height (1) the maximum weight was 72.7 g trapped at the same average hourly rate, but during different measurement events. The measuring system at D4 trapped the highest amount of soil at a wind speed of 8.9 ms^{-1} (1141.7 g) at height (0) and at a speed of 9.3 ms^{-1} (22.3 g) at height (1).
A graphical display of measured soil erosion from 03/30/2012 is shown in fig. 3. The left side of the Y-axis reflects the measured soil loss at height (0), the right side of this axis expresses soil erosion measured at height (1). Of the five measurements made on this day, we have created a statistical dependence of soil erosion by wind speed for a particular measuring system and height of measurements. The regression equations and coefficients of reliability are shown in the chart.

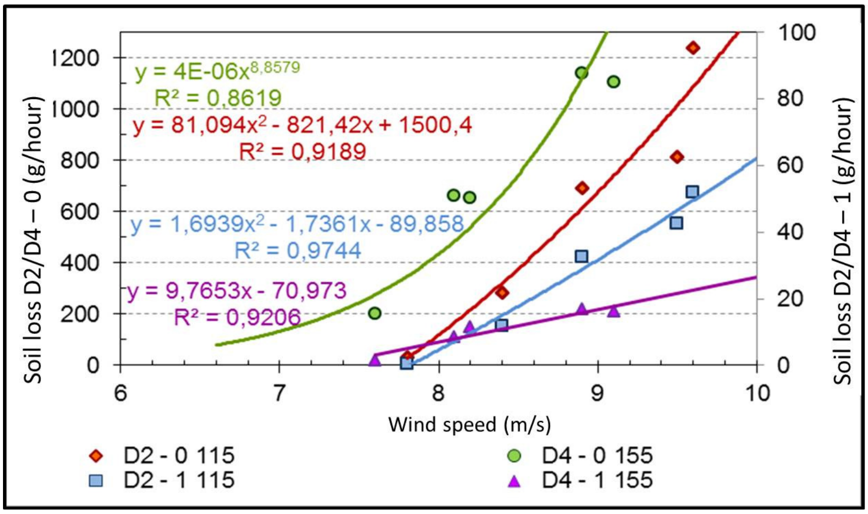

Figure 3. Graph of measured soil erosion in the D2 and D4 from the day 30.3.2012 and their regression equation

Obrázok 3. Graf erózneho odnosu na stanovištiach D2 a D4 zo dňa 30.3.2012 a jeho regresná závislosť

Measuring system with four soil particle catchers
During the measurements with the two basic measuring systems D4 and D2, we measured the wind erosion intensity together with soil particle catchers D1 and D3. D3 was placed between devices D4 and D2, D1 was 20 m ahead D2. Soil particle catchers were placed on the soil surface at height position (0). We measured increasing soil erosion downwind on four locations spaced at 20 m. For comparison, the soil erosion is shown for height measurements (0).
The results show that with there is an increasing quantity of particles collected as the erosive surface length increases, due to the so-called snowball effect. At speeds from 7.0 to 7.3 ms^{-1} the trapped soil loss gradually increased at each station from D1 to D4 (29th March). At higher wind speeds the soil loss gradually increased with length, but at the last station the measured loss had decreased. This was caused by the aforementioned soil accumulation (lower wind transport capacity) due to reduced

wind speed but also in some cases by measurement error. The errors appeared due to the accumulation of soil that occurred near the device entrance and therefore restricted the flow of soil particles causing a blockage (fig. 4).

Figure 4. Reduction of transverse profile of device due to soil accumulation

Obrázok 4. Zmenšenie profilu deflametra v dôsledku nahromadenia pôdnych častíc

A graphical representation of increasing soil erosion dependent on the erosive surface length, at a certain wind direction (that day), and its speed, is shown in fig. 5 and 6. The horizontal axis expresses the measuring system and the erosive surface length in a certain hour. The righthand vertical axis shows the measured soil loss during the measurement period, the left-hand axis expresses the measured average hourly wind speed.

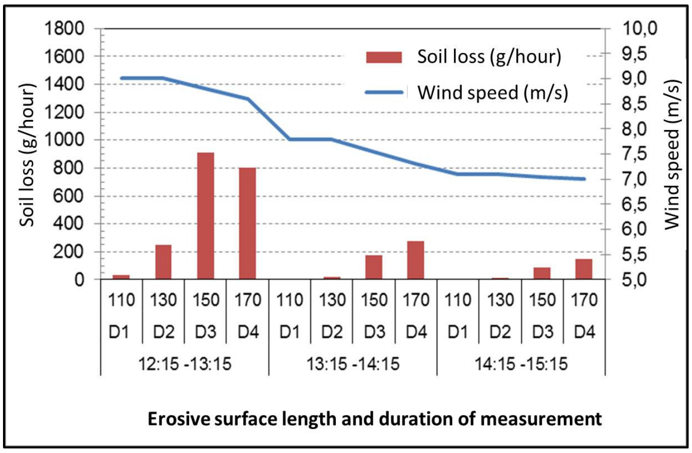

Figure 5. Graph of measured soil loss for devices D1 - D4 at height (0) from 29.3.2012

Obrázok 5. Graf závislosti straty pôdy medzi zostavami D1 – D4 vo výške (0) zo dňa 29.3.2012

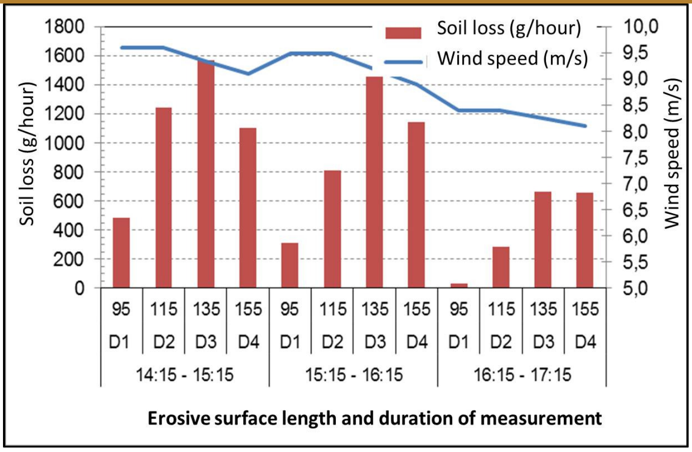

Figure 6. Graph of measured soil loss for devices D1 - D4 at height (0) from 30.3.2012

Obrázok 6. Graf nameranej straty pôdy pre zostavy D1 – D4 vo výške (0) zo dňa 30.3.2012

We analyzed selected trapped soil samples in order to determine the size of the soil particles and their proportion in the sample at different wind speeds. Samples were subjected to aggregate analysis (laser soil particle analyzer FRITSCH ANALYSETTE 22) in order to set the size and percentage of soil particles. Analysis of each sample was carried out in triplicate and the mean calculated. For the same length of erosive surface (150-155 m) but different wind speeds, we analyzed 10 samples. The results of this analysis are presented in Table 1.

Table 1. The results of aggregate analysis of the samples trapped at various wind speeds

Tabuľka 1. Výsledky agregátovej analýzy vzoriek zachytených pri rôznych rýchlostiach vetra

The size of the particles (µm)	% content of the aggregates in the sample (V)									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
< 10	20.5	19.9	25.0	26.6	24.0	21.8	25.0	22.2	26.8	23.3
< 50	25.6	25.8	32.9	34.5	31.1	27.9	32.2	28.5	35.0	30.0
< 100	35.7	35.1	41.5	42.7	38.4	36.9	41.3	37.6	45.4	38.1
< 200	67.0	66.6	70.2	70.2	65.6	67.2	70.5	68.0	75.6	66.7
< 500	99.3	99.5	99.5	99.4	99.0	99.4	99.5	99.5	99.8	99.2

V1 –sample trapped at wind speed 6,0 $m.s^{-1}$ V6 sample trapped at wind speed 8,1 $m.s^{-1}$
V2 – sample trapped at wind speed 7,0 $m.s^{-1}$, V7 – sample trapped at wind speed 8,2 $m.s^{-1}$,
V3 – sample trapped at wind speed 7,2 $m.s^{-1}$, V8 – sample trapped at wind speed 8,8 $m.s^{-1}$,

V4 – sample trapped at wind speed 7,5 $m.s^{-1}$, V9 – sample trapped at wind speed 8,9 $m.s^{-1}$,
V5 – sample trapped at wind speed 7,6 m.s-[1], V10 – sample trapped at wind speed 9,1 $m.s^{-1}$.

Analysis of the trapped samples showed no difference in particle size and the percentage at different hourly average wind speeds. Although the average speed for trapping sample V1 was 6.0 ms^{-1}, the wind erosion occurred in gusts of wind 9 to 10 ms^{-1} and higher. These results showed that in all cases the movement of particles was caused by wind at about the same speed but with different durations. For this reason the proportions of soil particles is approximately the same in each sample.

Conclusion

In this paper we describe the wind erosion event measurement with soil particle catcher devices. Measuring wind erosion intensity directly in the terrain is more expensive and time demanding more than mathematical modeling but provides real results. At first we measured soil loss with two measuring systems 40 m apart at two sites (D2 and D4) and the soil captured at two heights (0, 1). The length of erosive surface was measured in the direction of the wind flow up to the measuring system. D4 always captured more soil with three exceptions compared with the measuring system D2. However, the wind speed was always lower. This was caused by the erosive surface length, which was about 40 meters longer. Then we created 4 stations (D1, D2, D3, D4), where soil particle catchers were laid on the soil surface (particles being captured from 0-5 cm above the soil surface). At stations D2 and D4 the soil was trapped between 15 to 20 cm above the soil. The devices were spaced at 20 m. The results show that with there is an increasing quantity of particles collected as the erosive surface length increases, due to the so-called snowball effect. We analyzed selected trapped soil samples in order to determine the size of the soil particles and their proportion in the sample at different wind speeds. The results showed that in all cases the movement of particles was caused by wind at about the same speed but with different durations. For this reason the proportions of soil particles is approximately the same in each sample.

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