Chapter 29
Verification of the Wind Erosion Equation on the Ukrainian Steppe

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Abstract As a basis for the design of anti-deflationary measures, the Wind Erosion Equation has been verified for the steppe zone of Ukraine. Soils may be classified in eight Wind Erodibility Groups (WEG) according to their resistance to deflation, with the lowest potential annual loss (I-factor) zero and the highest 766 t/ha. Generalization of the data on the anti-deflationary stability of soils showed that most soils of loamy and clay texture fall into Group 7 with an I-factor of 94 t/ha/year; the sandy soils of the Oleshkovsky Sands area can be assigned to groups 1 and 5. Study of intra-annual fluctuations of the I-factor, as well as the effect of soil erosion, irrigation, and various kinds of tillage showed that, in most cases, these factors have little effect on the classification of soils by WEG groups. At the same time, slaking of the soil during unstable winter weather conditions can lead to a short-term increase in the I-factor in spring.

Keywords Soil erosion · Wind erosion equation · Wind erodability groups · Chernozem

Introduction

Deflation decimates soil fertility in Ukraine. Its extreme manifestations are *black storms* that cover hundreds of square kilometers. These were first recorded at the beginning of the nineteenth century when the steppes were converted to arable land. Nowadays, with ploughland at its maximum extent, the area vulnerable to deflation across Ukraine is estimated at about 20million hectares, including 16–18 million ha of the steppe (Chornyy 2018). Local outbreaks of wind erosion are observed almost every year and regional or trans-continental dust storms occur every 5–10 years. In the 20th century, trans-continental dust storms swept the steppes from the Altai to the Carpathians—in 1928, 1960, 1968, 1969, 1972, 1974, and 1984. In this century, the catastrophic black storm of March 23/24, 2007, covered much of the Odesa region, the whole of Mykolayiv, Kherson and Zaporizhzhia regions, the north of Crimea,

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the southern regions of the Kirovograd and Dnipropetrovsk regions, and the western regions of Donetsk—an area of about 125 thousand km^2, about 20% of the country and half of the entire steppe zone; soil losses amounted to 50–400 t/ha (Chornyy et al. 2008).

An objective, quantitative basis is needed to design effective anti-deflationary measures; in particular, a mathematical model to quantify the potential soil loss. These values can be compared with the permissible norm to arrive at a scientifically sound system of soil protection for a particular territory—which should include legal, agricultural, and forest reclamation measures. Equations of wind erosion (Wind Erosion Equation—WEQ) were worked out in the USA in the 1950s–90s for the conditions of the Prairie states of the Mid-West (Woodruff and Siddoway 1965; Skidmore and Woodruff 1968; USDA 2011) with the aim of predicting long-term average annual soil losses from a specific agricultural landscape that has certain plant and soil characteristics, roughness, a specific intra-annual distribution of strong winds, specific farming practices, etc. A modified version (RWEQ) was used in the USA until replaced by the new WEPS (Wind Erosion Prediction System) (Wagner 2013). Given the cost of creating our own national system for quantifying wind erosion, and current financial and scientific constraints, it seems reasonable to adapt this well-proven system for the conditions of the Ukrainian steppe, as scientists from Austria, Hungary, Canada, and the Czech Republic have done for theirs (Klik 2004; Mezosi et al. 2015; Huang et al. 2017; Kozlovsky Dufková et al. 2019).

Results and Discussion

By the end of the 1980s, the WEQ equation had acquired a more-or-less complete form (USDA 2011) and made it possible to calculate annual soil losses (E, tonne per acre) according to the formula:

$$E = I \cdot K \cdot C \cdot L \cdot V \tag{29.1}$$

where

I is the indicator of soil wind-erodibility.
C is the climatic parameter of wind erosion.
K is an indicator of the roughness of the soil surface.
L is the value of the *unprotected distance.*
V is an indicator of soil-protective effectiveness of vegetation cover.

The I-index (or I-factor) is the conditional average annual deflationary soil loss in tons per acre/tonne per ha, provided that this section is:

- isolated from external deflation; i.e. there is no input saltation of soil particles from outside
- absolutely flat

- in the territory where the value of the C (climatic) parameter is 100
- without barriers that inhibit the wind (shelter belts etc.)
- without vegetation
- without a soil crust.

As part of the verification of Eq. (29.1) in the United States, the entire list of soils of the sub-humid and semi-arid regions of the United States was classified by wind erodibility groups (WEG) and the I-factor was determined for each group of soils. This grouping is based on the macrostructure, the content of organic matter and carbonates, and the mineralogical composition of the topsoil. Eight classes of soils were determined by their susceptibility or resistance to deflation (1, 2, 3, 4, 4L, 5, 6, 7, and 8) with the lowest I-factor 0 and the highest I-factor of 310 tons per acre per year (766t/ha/year). The current version of WEG is published in the National Soil Survey Handbook (NRCS 2019). According to Chepil (1958), the value of the I-factor is closely related to the content of the aggregates on the soil surface greater than 0.84 mm diameter under dry dispersion conditions. This size fraction is commonly used as an independent indicator of anti-deflation stability, for example in the spatial hazard assessment of wind erosion in Western Europe developed by Borrelli and others (2014). An analagous *lumpiness* indicator (fraction greater than 1 mm) is widely used in deflation studies in Ukraine and a substantial database on *soil loosening* has been accumulated in the steppe zone (Chornyy and Pismenniy 2006, 2008; Chornyy and others 2012; Chornyy and Voloshenyuk 2017). Recalculation of this indicator, i.e. the content of aggregates of more than 1 mm to the content of fraction in the soil of greater than 0.84 mm is a purely arithmetic issue.

The determination of the soil susceptibility to deflation (I-factor) is obtained either by the method in the National Handbook or by the formula:

$$I = 766.78 \cdot \exp(-0.049 \cdot g) \tag{29.2}$$

where g is the fraction content of greater than 0.84 mm with dry soil dispersion.

Generalization of data on steppe soils of Ukraine (Table 29.1) was made only taking into account the content of fractions greater than 0.84 mm. Most soils of loamy and clay texture fall into WEG 7 although the mineralogy of our soils is different from that of US soils in that group. For this WEG group, the I-factor is 94 t/ha/year. Two samples (10 and 11 of Table 29.1) taken in the Oleshkovsky Sands area (the left-bank part of Kherson), loose and cohesive sands according to NRCS (2019), are assigned to WEG 1 ($I = 310$ t/ha/year) and WEG5 ($I = 766$ t/ha/year). It should be noted that two samples with sandy particle size distribution (12 and 13 of Table 29.1) fell into group 7. In the first case, long-term irrigation with mineralized water affects the content of aggregates greater than 1 mm (and greater than 0.84 m) when the saturation of the cation exchange complex with Na^+ and Mg^{2+} ions promote micro- and macro-units that become stronger when dried. In the second case, the formation of windshield aggregates was probably positively affected by the beneficial accumulation of humus in the upper soil layer associated with a high proportion of legumes in crop rotation and the introduction of organic

Table 29.1 Soil resistance parameters against wind erosion

№.	Coordinates at the middle of the site		Soils	Soil texture	Land use	Aggregate content %		*I* (t/ha/year)	WEG
	Latitude (N)	Longitude (E)							
						<1 mm	<0.84 mm		
1	47° 51.050	31° 34.467	*Ordinary chernozem*	Light clay	Arable	68.8	72.0	22.5	7
2	47° 53.429	31º 33.819	*Ordinary chernozem*	Light clay	Arable	56.5	59.2	42.2	7
3	47° 51.050	31º 34.467	*Ordinary chernozem*	Light clay	Grassland	83.2	87.1	10.7	7
4	47º 53.431	31º 33.000	*Ordinary chernozem*	Light clay	Grassland	78.1	81.8	13.9	7
5	46° 50.766	32º 13.183	*Dark chestnut*	Heavy loam	Arable	69.4	72.7	21.8	7
6	46° 58.702	32º 10.118	*Southern chernozem*	Heavy loam	Arable	62.4	65.3	31.2	7
7	46º 53.966	31º 40.877	*Southern chernozem*	Heavy loam	Grassland	80.2	84.0	12.5	7
8	46° 56.441	31º 40.348	*Southern chernozem*	Heavy loam	Arable	76.5	80.1	15.1	7
9	46º 53.821	31º 39.905	*Southern chernozem*	Heavy loam	Arable	57.4	60.1	40.3	7
10	46° 31.606	32º 58.026	Sandy	Coarse sand	Fallow forest	1.4	1.5	713.6	1
11	46° 31.571	32º 57.220	Sandy	Sandy clay loam	Fallow	32.8	34.3	142.5	5
12	46º 31,453	32º 56.928	Sod- sandy	Sandy clay loam	Irrigated crops	54.7	57.3	46.3	7

(continued)

Table 29.1 (continued)

№.	Coordinates at the middle of the site		Soils	Soil texture	Land use	Aggregate content %		*I* (t/ha/year)	WEG
	Latitude (N)	Longitude (E)				<1 mm	<0.84 mm		
13	46º 24.817	33º 02.355	*Dark chestnut*	Sandy loam	Arable	76.7	80.3	15.0	7
14	46º 23.774	33º 06.191	*Dark chestnut*	Light loam	Arable	80.6	84.4	12.3	7
15	46º 41.189	31º 52.421	*Dark chestnut*	Medium loam	Arable	54.9	57.5	45.9	7

fertilizers. The humus content in these soils was about 1% whereas it is only 0.5% in the sandy parent material.

Given that the sampling was carried out in spring and early summer (March-June), it is necessary to determine how representative the obtained I-factor values are in the local verification of the WEQ equation. Specific local soil conditions can affect the soil deflation resistance, for instance, soil erosion and changing agricultural practices, especially cultivation and irrigation systems, Fig. 29.1 shows the annual fluctuations of the I-factor in the area of lat. 46º 53.821, 31º 39.905 with non-eroded, weakly eroded, and moderately eroded *Southern chernozem*. These fluctuations hardly depend on the soil erosion factor but are determined by other factors—in particular by a sharp drop in the fraction cover greater than 0.84 mm so the growth of the I-factor in spring is associated with the number of freeze–thaw cycles during the winter months. If the number of cycles approaches 50–70, then almost complete destruction of large aggregates is observed.

In other cases, when the winter is persistently cold or warm, there is no such slaking of the soil surface. From the point of view of soil classification in the context of model verification, despite a sharp decrease in the ability of the soil to resist wind erosion in the spring of 2008, *Southern chernozem* were the most wind-resistant over the whole period of observation. Analysis of the I-factor in *Southern chernozem* with irrigation at lat. 46º 56.504, long. 31º 40.607 (Fig. 29.2) shows that the anti-deflation stability

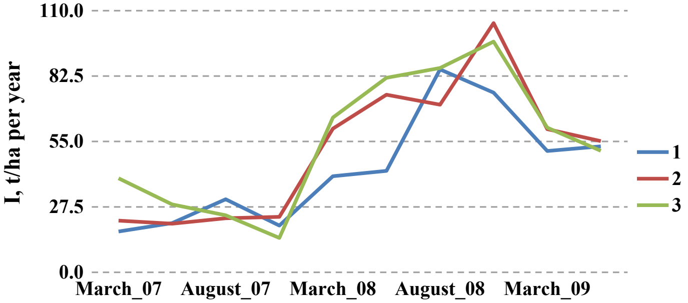

Fig. 29.1 Impact of extant soil erosion on wind-erosion susceptibility (1 non-eroded, 2 weakly eroded, 3 moderately eroded)

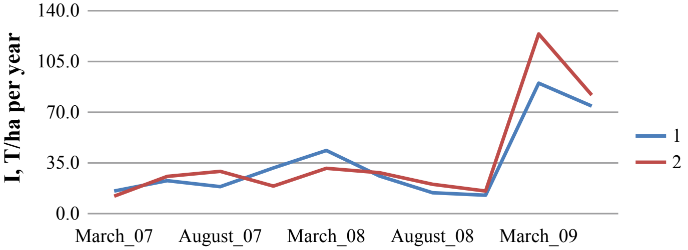

Fig. 29.2 Impact of irrigation on wind erosion susceptibility (1 irrigated soil, 2 non-irrigated soil)

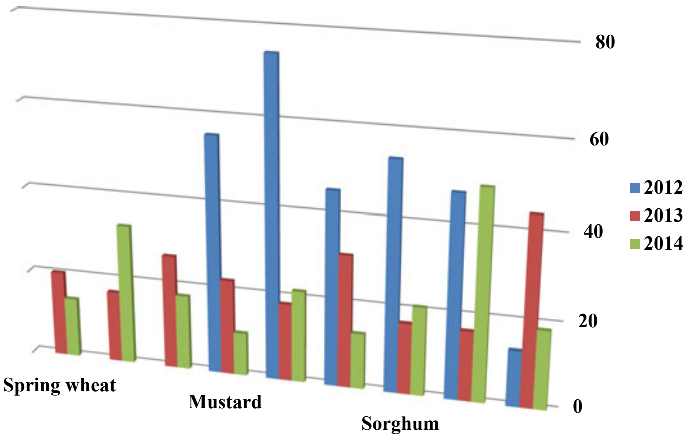

Fig. 29.3 Impact of tillage on wind-erosion susceptibility (left to right: traditional tillage, minimum tillage, no-till)

of these soils does not go beyond WEG 7; the difference of the macrostructure in unstable, short-term winter conditions resulted in an I-factor of 120 t/ha in March 2009 which would indicate WEG 6.

A study of the effect of tillage on the ability of the soil to withstand blowing was carried out 2012–2014 in Askania-Nova, the most erosion-prone part of Ukraine, at lat. 46.549249, long. 33.813563. Chornyy and others (2012) and Chornyy and Voloshenyuk (2017) have shown that under standard and minimal tillage and no-till spring wheat, mustard, and sorghum, the resilience of *Southern chernozem* to wind erosion, determined by the I-factor in the spring, fluctuates between 15 and 65 t/ha per year (Fig. 29.3). These fluctuations are determined not so much by the direct influence of tillage as by the degree of protection of the soil surface by crop residues. In particular, under no-till with the soil surface mulched by crop residues during winter and early spring, the number freeze–thaw cycles is much reduced, so the destruction of structural aggregates on the soil surface is less intense.

Conclusions

1. The design of effective anti-deflation measures is possible only on an objective, quantitative basis. The well-established WEQ technology predicts long-term average annual soil losses while accounting for soil parameters, surface roughness, intra-annual distribution of strong winds, and the effects of agricultural machinery, growing crops, etc.
2. Generalization of the data on the anti-deflation stability of the soils of the region showed that most loamy and clayey soils fall into the WEG group 7 (the I-factor

is 94 t/ha/y). Some sandy soils of the Oleshkovsky Sands region can be assigned to group 1 ($I = 310$ t/ha per year) and group 5 ($I = 766$ t/ha per year).

3. Study of intra-annual fluctuations of the I-factor, as well as the effect of soil erosion, irrigation, and various tillage system reveals no strong relationship with WEG groups. However, there is a clear relationship between susceptibility to blowing and soil cover and structural stability, for instance when unstable winter weather slakes the soil surface causing a short-term increase in the I-factor in spring.

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