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Wind erosion resistance of steppe soils of Ukraine

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Aim. The study of direct (wind erosion resistance) and indirect (lumpiness, mechanical durability, etc) indices of current wind erosion resistance of steppe soils in Ukraine. **Methods.** The following methods were used: field, laboratory, mathematical and statistical, analytical and comparative methods. Wind resistance of soils was studied using the elaborated method in the aerodynamic unit. **Results.** The studies revealed that the highest resistance to soil blowing due to strong winds is demonstrated by light loamy chernozem, somewhat lower resistance – by southern and dark-chestnut heavy loamy chernozem, light loamy, sandy loamy and sandy turf soil. It was demonstrated that the irrigation with mineralized water enhances the indices of wind erosion resistance of dark-chestnut soil and southern chernozem. The granulometric analysis of soil revealed quantitative dependence between the wind erosion resistance, humus content and physical clay content. **Conclusions.** The studies on wind erosion resistance of dry steppe and southern steppe soils of Ukraine and the classification of soil types regarding their capability of resisting strong winds allow implementing the measures of preventing wind erosion.

Keywords: wind erosion resistance of soil, chernozem, dark-chestnut soil, mechanical durability of aggregates, lumpiness.

INTRODUCTION

The phenomenon of deflation (wind erosion) is rather common for the steppe zone of Ukraine [8]. The consequences of this process are the decrease in the productivity of soil, related to the fact that strong winds blow out the top and most productive layer of soil. There are also such hazardous "adverse events" as the failure of crops due to blowing out and abrasion with soil, filling the reclamation canals with soil, deterioration of human health due to more dust-loaded air, etc.

A relevant deflation factor is the ability of soil of the region to resist being blown out during the most hazardous season regarding wind erosion (February-April). This factor is called "wind erosion resistance of soil" or "wind resistance of soil".

The works of domestic and foreign authors [2, 4, 5, 8, 10, 11] present the studies on the main principles of the deflation process development and the formation of wind erosion resistance of soil. The abovementioned works state that the important factors of the formation of wind erosion resistance of soil are the indices of their lumpiness, mechanical durability of soil aggregates, soil humidity and the humus content in the soil of <0.001 and <0.01 mm (according to the granulometric analysis data) and the content of calcium carbonate. It is also highlighted that the soil of light granulometric composition are the most susceptible to wind erosion as they contain many particles of 0.1−0.5 mm and insufficient amount of silt particles with high capability of forming wind-resistant micro- and macroaggregates [4]. According to the observations of some authors [4, 5] the deflation on the types of soils, different in their granulometric composition, starts at the following wind velocity: sand soil – under 3 m per s; sandy loamy – 3–4 m per s; light loamy – 4–5 m per s; heavy loamy – 5–7 m per s; loamy – 7–9 m per s.

As for the macrostructure indices, the experiments demonstrated that the soils of agronomically valuable structure usually are very susceptible to deflation, as the aggregates in them tend to be too tiny to resist strong winds. Therefore, the content of large-size aggregates is proposed as the criterion of wind erosion resistance.

Laboratory aerodynamic unit for the study of wind erosion resistance of soil

In particular, the experiments in the USA demonstrated that this size of aggregates is over 0.84 mm. The marginal value is their content of over 50–60 % [10, 11]. Thus, if the content of such aggregates is under the mentioned percentage, the soil is not wind-resistant. The Ukrainian authors often define the degree of soil surface susceptibility to deflation as the ratio of large and small structural constituents [2, 6]. Their studies reveal that the resistance to wind erosion increases rapidly for soil aggregates of over 1 mm. Thus, the aggregates of <1 mm were called hazardous in terms of deflation, and the ones of > 1 mm – deflation-resistant [2, 6]. The content of > 1 mm aggregates is defined with a special term – "lumpiness". Some authors deem the wind erosion resistance of soil to be the only criterion. If the content of aggregates of > 1 mm is over 50–60 %, the soil is resistant to wind erosion [2, 6].

MATERIALS AND METHODS

The wind erosion resistance of chernozem and dark chestnut soil of Ukrainian steppe was studied using the previously built system of key areas – upland and slope land plots.

The experiments in investigating the wind erosion resistance were conducted both on arable land and grassland. Some key land plots were made on irrigated land. The objects of research were also turf soil and soil-like substrates of the most dangerous zone of the region in terms of deflation – Oleshky sands. The samples were taken from the top (0–3 cm) layer of soil in the most dangerous season in terms of deflation (February–April).

The laboratory aerodynamic unit, designed by us, allowed determining the wind erosion resistance using the previously prepared soil sample in the air-dust flow with the velocity of 15 m per s [7]. The abrasive material (sand) was introduced into the artificial air flow via the loading bin and accelerated therein; then it got to the surface of the soil sample, which was destroyed on being hit by this material (Figure).

The resistance of soil to destruction in the air-dust flow (*VS*) was determined as the ratio of the soil weight after the exposition for 3 min (a) and its initial weight, which equaled 180 g of soil [7]:

$$VS = (a/180) \cdot 100\ \%. \qquad (1)$$

The higher the share of the soil, left after the blowing-out of the sample for the fixed time period, is, the higher the wind erosion resistance is. If the sample was destroyed completely, i.e. a = 0, it meant complete absence of soil resistance to wind erosion.

Another index of the soil resistance to wind erosion is the force (*F*), applied to destroy the soil sample, which is measured in newtons (N). This value is calculated using the following equation:

$$F = 0.69 \cdot (T/l) \cdot (a/180), \qquad (2)$$

where T – time of the standard experiment of destroying the abovementioned soil sample (T = 180 s), sample length = 5 cm (l = 0.05 m). After the reduction the final equation is as follows:

$$F = 13.8 \cdot a \qquad (3)$$

The equation (3) follows that in case of complete destruction of the sample (a = 0), F = 0 N. If such destruction was not observed in the air-dust flow during the 3 min exposition completely (a = 180), then F = 2484 N. It is probable that the determination of the wind erosion resistance of all the Ukrainian steppe soils using the abovementioned method would demonstrate some fluctuations in the same range (0–2484 N).

Besides the wind erosion resistance, the same approach was used to determine the macroaggregate composition of the soil aggregates according to Savinov (DSTU 4744-2007) [12], the mechanical durability of the aggregates of over 1 mm [9] and the granulometric composition of the soil (DSTU 4730-2007) [13]. The content of elementary soil particles was registered using direct microscopy [1], the total content of humus – according to Turin-Kononova (DSTU 4289:2004) [14], the exchangeable cations – using the acetate method: Ca^{2+} and Mg^{2+} in the extract – by complexometry (industrial standard 4649-76), Na^{+}– using the flamephotometer (industrial standard 4651-76). All the measurements were repeated four times.

RESULTS AND DISCUSSION

The immediate determination of the wind erosion of soil demonstrated (Table 1) that the highest index of wind erosion resistance corresponded to normal light loamy chernozem (fallow) – 65.2 % (900 N). The following large group of soils has approximately similar indices of wind erosion resistance (tilled soil): dark-chestnut light loamy soil – 62.8 % (867 N), southern light loamy chernozem – 61.5 % (849 N), normal light loamy chernozem – 59.9 % (827 N), dark chestnut sandy soil – 58.5 % (806 N), dark-chestnut heavy loamy soil – 47.4 % (654 N) and southern heavy loamy chernozem with the wind erosion resistance index in the range of 25.1–44.8 % (346–559 N). The least wind erosion resistance indices are those of friable and cohesive sands (fallow) where this index is from 0 to 4 % (0–58 N) and sandy turf soils (tilled soil) with the wind erosion resistance index of 19.5 % (265 N). As seen from the abovementioned, the wind erosion resistance of soils of the region is defined by a complicated combination of granulometric, chemical, physical and chemical factors. The sandy soils and soil-like substrates of the Oleshky sands are of interest in this respect, as they demonstrate very poor wind erosion resistance which

Table 1. The main anti-erosion characteristics of soils of the southern and dry steppe of Ukraine

No of the key plot	Coordinates		Character of soil usage	Wind erosion resistance		Content of aggregates, %		Mechanical durability, %	Content of particles < 0.01, %	Content of humus, %
	Northern latitude	Eastern longitude		%	N	> 1 mm	< 0.25 mm			
Normal light loamy chernozem										
1.	47°51.050	31°34.67	tilled soil	54.7	755	68.8	8.9	81.1	60.2	3.7
6.	47°53.429	31°33.819	tilled soil	33.9	468	56.5	9.3	66.4	64.7	4.3
8.	47°51.050	31°34.67	tilled soil	59.9	827	78.1	6.1	93.4	63.4	3.7
7.	47°53.431	31°33.255	fallow	65.2	900	83.2	3.4	94.0	70.7	4.2
Southern light loamy chernozem										
10.	46°50.766	32°13.83	tilled soil	61.5	849	80.2	3.1	91.5	61.2	2.6
Southern heavy loamy chernozem										
12.	46°58.702	32°10.118	tilled soil	25.1	346	62.4	6.6	77.0	56.5	2.5
13.	46°56.504	31°40.607	tilled soil	44.8	618	76.5	3.5	88.7	58.7	2.7
14.	46°56.441	31°40.348	tilled soil	40.5	559	57.4	8.9	68.2	56.7	2.4
Dark-chestnut heavy loamy										
19.	46°53.913	31°40.397	tilled soil	47.4	654	69.4	6.3	85.4	53.3	2.6
Dark-chestnut sandy										
25.	46°41.189	31°52.421	tilled soil	58.4	806	76.7	7.0	71.1	17.3	1.0
Dark-chestnut light loamy										
24.	46°23.774	33°06.91	tilled soil	62.8	867	80.6	6.2	92.2	23.9	1.5
Dark-chestnut medium loamy										
20.	46°41.197	31°50.471	tilled soil	41.5	573	54.9	19.7	81.4	43.8	2.4
Sandy turf soil										
26.	46°31.453	32°56.928	tilled soil	19.5	269	54.7	12.3	44.8	9.2	0.9
Sand (cohesive sand)										
27.	46°31.571	32°57.220	fallow	4.2	58	32.8	20.2	24.6	6.8	0.5
Sand (friable sand)										
28.	46°31.606	32°58.026	fallow	0.0	0	1.4	65.4	0.0	1.4	0.4

makes this region one of the most deflation-hazardous in Ukraine.

The study of the effect of irrigation on the wind erosion resistance of steppe soil of Ukraine was conducted on dark-chestnut soils and southern chernozem. The irrigated soils were compared against the same non-irrigated ones. The main key land plots were selected in the area of Ingulets irrigation system, where the irrigation is performed with the mineralized water (the total mineralization: 1.1−3.0 g/l, pH 7.5−8, Na^{+} content – 8.3 mg·eq/l). The analysis of the data obtained (Table 2) demonstrated that the irrigation with the mineralized water increases the wind erosion resistance index. According to the Student's criterion, the difference (with 95 % reliability) between the dark-chestnut soils and southern chernozem is significant.

At the same time the situation proved to be opposite on the southern chernozem, irrigated with the non-mineralized water from the Southern Bug, – the wind erosion resistance on the dry land proved to be higher compared against the irrigated soil.

As for "indirect" indices of the wind erosion resistance, they are primarily related to the macroaggregate composition of the soil. The study of the indirect indices of the wind erosion resistance indices, namely, the content of aggregates > 1 mm and < 0.25 mm and the mechanical durability of aggregates of > 1 mm (Table 1) demonstrated that normal light loamy chernozem (fallow) has the highest content of aggregates of over 1 mm – 83 % and the highest index of mechanical durability – 94 %, while the content of fraction of < 0.25 mm is only 3.4 %. The next large group of soils is nor-

Table 2. The effect of irrigation on the indices of wind erosion resistance of soils

No of the key plots	Character of soil usage, coordinates	Wind erosion resistance			Content of aggregates, > 1 mm, %	t_{actual} according to Student	Content of aggregates, > 0.25 mm, %	t_{actual} according to Student	Mechanical durability		Na content in the soil-biotic complex, %
		Index		t_{actual} according to Student					index, %	t_{actual} according to Student	
		N	%								
Dark-chestnut heavy loamy											
18.	Tilled soil (irrigation) 46° 53.940 N 31° 40.628 E	854	61.9	6.65	89.6	22.3	1.7	11.12	95.5	16.67	4.3
19.	Tilled soil 46°53.913 N 31°40.397 E	654	47.4		69.4		6.3		85.4		1.3
Southern heavy loamy chernozem											
11.	Tilled soil (irrigation) 46° 58.635 N 32° 09.966 E	403	29.2	2.55	55.8	4.2	8.6	2.90	72.7	3.57	2.4
12.	Tilled soil 46°53.913 N 31°40.397 E	346	25.1		62.4		6.6		77		1.7
Southern light loamy chernozem											
9.	Tilled soil (irrigation) 46° 50.312 N 32° 12.145 E	559	40.5	11.29	63.2	11.8	7.5	5.95	86	6.11	2.6
10.	Tilled soil 46°53.913 N 31°40.397 E	849	61.5		80.2		3.1		91.5		2.6

Note: $t_{theor.}$ according to Student = 2.31 (95 % reliability) N – northern latitude; E – eastern longitude.

mal light loamy chernozem, southern light loamy and heavy loamy chernozem, dark-chestnut (heavy loamy, medium loamy, light loamy and sandy) chernozem. The content of aggregates of over 1 mm therein is in the range of 54–80 %, the content of fraction of < 0.25 mm – from 3 to 20 %, and the mechanical durability index – from 66 to 92 %. The lowest indices of wind erosion resistance were determined on friable and cohesive sands (fallow) and sandy turf soils (tilled soil), where the content of aggregates of over 1 mm was in the range of 2–55 %, the index of mechanically durable aggregates was in the range from 0 to 45 %, and the content of the fraction of < 0.25 mm – from 12 to 65 %.

The macrostructural analysis demonstrates the increase in the content of fraction of > 1 mm and in the mechanical durability in the areas, irrigated with mineralized water, and the decrease in the content of fraction of < 0.25 mm compared to the dry land (Table 2). The increase in the “lumpiness” of soils, irrigated with mineralized waters is explained by the enhancement in the process of alkalization. The enrichment of the soil-biotic complex with Na^+ and Mg^{2+} promotes the compaction of plasma in micro- and macroaggregates, which become really solid on drying [3].

The quantitative analysis of the initial data demonstrated that the wind erosion resistance of the soil, defined by the immediate determination in the aerodynamic unit correlates with “indirect” indices, in particular, with mechanical durability of aggregates (determination coefficient $r^2 = 0.97$), content of aggregates > 1 mm (“lumpiness”) ($r^2 = 0.96$) and the content of deflation-hazardous fraction in the soils < 0.25 mm ($r^2 = 0.82$).

In analytic terms, the relation between the wind erosion resistance (VS, %) and the content of aggregates of > 1 mm (G, %) in the soil is defined by the equation:

$$G = 16.8 \cdot VS^{0.35} \qquad (4)$$

As for the effect of other (non-macrostructural) soil indices, the calculations demonstrated some connection between the values of wind erosion resistance and the content of elementary soil particles (ESP) to the correlation coefficient – 0.69.

It should be noted that the evaluation of ESP content by the method of soil microscopy is unique, requiring specific qualification of laboratory analysts. Thus, large-scale evaluation of wind erosion resistance using soil indices requires standard analyses.

Further calculations demonstrated the presence of statistical connection between the content of ESP and humus (r = 0.73) and ESP and physical clay during the granulometric analysis of soil (r = −0.87). The statistical dependence between ESP and the content in the soils will be presented as follows:

$$ESP = \exp(4.57 – 0.48 \cdot \ln FG – 0.80 \cdot \ln G) \qquad (5)$$

The multiple correlation coefficient is 0.91; standard deviation of the equation is 0.43.

At the same time the dependence of the wind erosion resistance index (VS, %) of soils, obtained in the aerodynamic unit, on ESP content in the soil, %, was found:

$$VS = 73.9 \cdot \exp(0.06 \cdot ESP) \qquad (6)$$

The multiple correlation coefficient is 0.73, and standard deviation of the equation is 0.63.

Table 3. The dependence of the wind erosion resistance of soils (%) on the content of humus and physical clay

		Content of humus, %								
Content of physical clay, %		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	0.0	–	–	–	–	–	–	–	–	–
	5.0	–	0.7	5.1	10.7	15.9	20.4	24.3	27.7	30.6
	10.0	–	2.6	10.9	18.5	24.6	29.4	33.3	36.5	39.3
	15.0	–	4.7	15.2	23.6	29.8	34.6	38.4	41.4	43.9
	20.0	–	6.7	18.7	27.3	33.5	38.2	41.7	44.6	46.9
	25.0	–	8.6	21.5	30.2	36.3	40.8	44.2	47.0	49.2
	30.0	–	10.3	23.8	32.6	38.6	42.9	46.2	48.8	**50.9**
	35.0	–	11.8	25.8	34.6	40.4	44.6	47.8	**50.2**	**52.2**
	40.0	–	13.3	27.6	36.2	41.9	46.0	49.1	**51.5**	**53.4**
	45.0	–	14.6	29.1	37.7	43.3	47.2	**50.2**	**52.5**	**54.3**
	50.0	–	15.8	30.5	38.9	44.4	48.3	**51.2**	**53.4**	**55.2**
	55.0	–	16.9	31.7	40.1	45.5	49.2	**52.0**	**54.2**	**55.9**
	60.0	–	18.0	32.8	41.1	46.4	**50.0**	**52.8**	**54.9**	**56.5**

Substituting the equation (6) with the equation (5), we get the index of the wind erosion resistance of soils (VS, %) as a function from the content of only physical clay and humus therein:

$$VS = 73.9 \cdot \exp[0.06 \cdot \exp(4.57–0.48 \cdot \ln FG–0.80 \cdot \ln G)] \quad (7)$$

where FG – content of physical clay, %, G – content of humus, %.

The calculations for the equation (7) allowed determining several groups of soils by the index of wind erosion resistance depending on the content of physical clay and humus therein (Table 3). The first most wind-resistant group of soils with the index of wind erosion resistance of 50 % and more (or 690 N and more) comprises the soils, where the content of physical clay is 30–60 % and the content of humus is 2.5–4.0 %.

The second group of soils (with poor wind erosion resistance) comprises the soils, where the index of wind erosion resistance is 20–50 % (or 276–690 N). The content of physical clay in these soils fluctuates in rather a wide range of 5–60 %, while the content of humus is in the range of 1.0–2.5 %. The third group of non-wind-resistant soils with the index of wind erosion resistance of 0–20 % (or 0–276 N) comprises soils where the content of physical clay is 5–15 %, and the content of humus – 0.15–1.5 %.

The abovementioned classification of the soils of dry and southern steppe of Ukraine according to the index of wind erosion resistance allows using only two standard soil indices (the content of physical clay and humus) to simplify the process of identifying the value of wind erosion resistance of soils, which facilitates the introduction of soil protective measures.

CONCLUSIONS

The highest resistance to strong winds is demonstrated by normal light loamy chernozem with the index of wind erosion resistance of 65.2 % (or 900 N), followed by dark-chestnut light loamy chernozem (62.8 % or 867 N), southern light loamy chernozem (61.5 % or 849 N), normal light loamy chernozem (59.9 % or 827 N), dark-chestnut sandy chernozem (58.5 % or 806 N), dark-chestnut heavy loamy chernozem 47.4 % or 654 N) and southern heavy loamy chernozem (25.1–44.8 % or 346–559 N). The poorest wind erosion resistance was shown for friable and cohesive Oleshky sands (0–4 % or 0–58 N) and sandy turf soils – 19.5 % or 264 N.

The irrigation with mineralized water of the Ingulets river increases the index of wind erosion resistance of dark-chestnut soils and southern chernozem. The irrigation of southern chernozem with non-mineralized water of the Southern Bug decreases the wind erosion resistance.

The quantitative analysis of the initial data demonstrated that the wind erosion resistance of the soil, defined by the immediate determination in the aerodynamic unit correlates with the mechanical durability of aggregates (determination coefficient $r^2 = 0.97$), content of aggregates > 1 mm (“lumpiness”) ($r^2 = 0.96$) and the content of deflation-hazardous fraction in the soils < 0.25 mm ($r^2 = 0.82$).

The granulometric analysis of soil demonstrated the dependence between the wind erosion resistance of soil and the content of humus and physical clay. The classification of wind erosion resistance of the soils of the dry and southern steppe of Ukraine using the abovementioned indices allows simplifying the determination of the quantitative characteristics of the wind erosion resistance of soils, which facilitates the introduction of measures, preventing wind erosion.

Протидефляційна стійкість ґрунтів степу України

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Мета. Вивчення прямих (протидефляційна стійкість) і непрямих (грудкуватість, механічна міцність тощо) показників сучасної протидефляційної стійкості ґрунтів степу України. **Методи.** Використано такі методи: польовий, лабораторний, математично-статистичний і розрахунково-порівняльний. Вітростійкість ґрунтів вивчали за оригінальною методикою в аеродинамічній установці. **Результати.** Дослідженнями встановлено, що найбільшу стійкість до видування сильними вітрами мають чорноземи звичайні легкоглинисті, меншу – чорноземи південні і темно-каштанові важкосуглинкові, легкосуглинкові, супіщані і дерново-піщані ґрунти. Показано, що зрошення мінералізованими водами збільшує показники протидефляційної стійкості темно-каштанових ґрунтів і чорноземів південних. При гранулометричному аналізі ґрунту виявлено кількісну залежність між протидефляційною стійкістю, вмістом гумусу і вмістом фізичної глини. **Висновки.** Проведені дослідження протидефляційної стійкості ґрунтів сухого та південного степу України та їхня класифікація за здатністю протистояти сильним вітрам дають змогу запровадити заходи, що запобігають вітровій ерозії.

Ключові слова: протидефляційна стійкість ґрунту, чорнозем, темно-каштановий ґрунт, механічна міцність агрегатів, грудкуватість.

Противодефляционная стойкость почв степи Украины

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Цель. Изучение прямых (показатель противодефляционной устойчивости) и косвенных (комковатости, механической прочности и т.д.) показателей современной противодефляционной устойчивости почв степи Украины. **Методы.** При обработке материалов были использованы следующие методы: полевой, лабораторный, математически-статистический и расчетно-сравнительный. Исследования ветроустойчивости почв были проведены по оригинальной методике в аэродинамической установке. **Результаты.** Исследованиями установлено, что наибольшую устойчивость к выдуванию сильными ветрами имеют черноземы обыкновенные легкоглинистые, затем черноземы южные и темно-каштановые тяжелосуглинистые, легкосуглинистые, супесчаные и дерново-песчаные почвы. Установлено, что орошение минерализованными водами увеличивает показатели противодефляционной устойчивости темно-каштановых почв и черноземов южных. Обнаружена количественная зависимость между противодефляционной стойкостью, содержанием гумуса и содержанием физической глины при гранулометрическом анализе почвы. **Выводы.** Проведенные исследования противодефляционной устойчивости почв сухой и южной степи Украины и их классификация по способности противостоять сильным ветрам позволяет разработать внедрение мероприятий, которые предотвращают ветровую эрозию.

Ключевые слова: противодефляционная устойчивость почвы, чернозем, темно-каштановый грунт, механическая прочность агрегатов, комковатость.

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