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ECONOMICS OF SOIL DEGRADATION AND SUSTAINABLE USE OF LAND IN DANGER OF WIND EROSION

Soil degradation has been identified as one of the major threats to European soils. This article describes the conditions under which wind erosion of soils occurs in Ukraine and the potential soil loss caused by this problem. The purpose of this paper is to find the best option, from both an economic and an environmental point of view, to conserve and restore soil productivity on the land suffering from and at risk of wind erosion. Losses of humus and nutrients from the soil through deflation have been calculated for the districts of Volyn in 1999–2009, and ecological and economic damage from the loss of soil through deflation has been identified for Volyn district and the village of Pichcha. Three options to mitigate and compensate for the losses of organic matter and nutrients on the affected lands are assessed for the comparative effectiveness of the measures in the Pichcha village, Shatsky district, Volyn region during 2008–2012. In these sites, the research identified that the best measure against soil deflation as changing the economic use of lands at risk of soil erosion by wind. In particular, the halting of cattle grazing and the creation of overseeding grass meadows. This options has a number of advantages, including: the cultivation of perennial grasses generates income from the sale of seed clover in the first year and hay for following four years; through nitrogen fixing bacteria associated with the annual grasses improving nitrogen levels in the soil; and, through halting the deflationary processes in the different soil types in the investigated areas and allowing for the steady build up of a fertile humus layer.

Key words: *wind erosion, areas at risk of erosion, losses of organic matter and nutrients, efficiency, anti-deflationary measures.*

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ЕКОНОМІКА ДЕГРАДАЦІЇ ҐРУНТІВ І СТАЛЕ ВИКОРИСТАННЯ ДЕФЛЯЦІЙНО НЕБЕЗПЕЧНИХ ЗЕМЕЛЬ

Проаналізовано потенційні втрати ґрунту від вітрової ерозії в Україні. Визначено еколого-економічний збиток від втрати ґрунту через дефляцію на прикладі районів Волинської області. Обґрунтовано ефективність протидефляційних заходів і запропоновано перспективні варіанти сталого використання дефляційно небезпечних земель.

Ключові слова: *вітрова ерозія, райони, схильні до ризику ерозії, втрати органічної речовини й поживних речовин, ефективність, протидефляційні заходи.*

Introduction and review of literature. The EU Thematic Strategy for Soil Protection identifies soil degradation caused by erosion as one of the major threats to European soils. A thorough literature review revealed important gaps in research on soil erosion processes in Europe. These gaps are particularly wide for wind erosion processes. The current state of the knowledge in erosion research lacks a thorough understanding about where and when wind erosion occurs in Europe, and the distribution and intensity of erosion that poses a threat to agricultural productivity [1, p. 232].

Wind erosion is a widespread phenomenon causing serious soil degradation. It is estimated that about 28 % of the global land area experiences land degradation from wind-driven soil erosion processes. In agricultural lands, soil erosion by wind mainly results from the removal of the finest, richest in organic matter and nutrients, and most biological active part of the soil. Repeated exposure to wind erosion can have long term and permanent effects on the condition and productivity of agricultural soils, which can be difficult or impossible to rectify.

Wind erosion is also a European phenomenon. According to the European Environment Agency, about 42 million ha of European agricultural land may be affected by wind erosion. Local studies have reported that wind erosion can affect both the semi-arid areas of the Mediterranean region and the temperate climate areas of the northern European countries. However, little is known about the extent and magnitude of wind erosion throughout Europe [2].

The wind induced movement of soil occurs when three environmental conditions coincide: i) the wind is strong enough to mobilize soil particles; ii) the characteristics of the soil make it susceptible to wind erosion (soil texture, organic matter and moisture content); and iii) the surface is mostly devoid of vegetation, stones, snow or other cover. Wind erosion has always occurred as a natural land-forming process but, today, the geomorphic effects of wind are locally accelerated by anthropogenic pressures (e.g. leaving cultivated lands fallow for extended periods of time, overgrazing and, to a lesser extent, over-harvesting of vegetation [1]. Soil erosion also influences desertification processes at all scales [3].

Wind erosion poses serious threats to agricultural production in the affected areas and these losses lead to lower incomes for farmers and decreases in food security locally and, cumulatively, the whole region. So, it is very important to design effective management strategies to control this form of land degradation.

The purpose of the article is to determinate the potential soil loss from wind erosion in Ukraine, to calculate of humus losses and nutrients, to evaluate ecological and economic damage from the loss of soil through deflation in the districts of Volyn region and to identify the best option, from both an economic and an environmental point of view, for restoring and protecting soil productivity on the land with risk of wind erosion.

Results and discussion. Ukraine is located in South-Eastern Europe and borders Hungary, Slovakia and Poland in the West, Belarus in the North, Russia in the North and East, Romania and Moldova in the South, and the Black and Azov Seas in Southern Part. The total area of the country is 603.7 thousand km^2. The territory of the Ukraine is mostly flat, with nearly 90 % of the whole area is plain and the average elevation of the flat area is 170 m. The mountains and uplands of the Carpathians in the West and Crimean in the South occupy near 5 % of the country. Approximately 70 % of Ukraine occupied by agricultural lands, most of them involved in extensive agriculture production systems. There is a very strong need to mitigate the scale and impacts of wind erosion and, where possible, to prevent it through optimizing agricultural activity and improving conditions for the preservation and renewal of soil [4]. In the Southeast and Southern parts of Ukraine there are droughts, dry winds (25–30 days per year), and occasional dust storms (3–8 days per year) during spring and autumn. The duration of dust storms varies from a few minutes to a few days. Climate change has resulted in dust storms even in regions that previously had a «low» soil erosion risk status. Even in Polissya (Forest Area), the most part of which is covered by woodland, trees and shrubs, and where portion of cultivated lands is relatively small, dust is being lifted from dry turfs with wind velocities as low as 2–3 m/s [5]. Dust emission by wind erosion is the largest source of aerosols, which directly and indirectly influence the atmospheric radiation balance and hence global climatic variations [6].

The annual manifestations of wind erosion take place in south-eastern and eastern districts of Ukraine and cover the territory up to 5 millions ha, which are the main districts of grain crop production [7] (Fig. 1). According to average annual data, wind erosion processes appear once per 1.5–2.0 years as dust storms, while local processes appears annually.

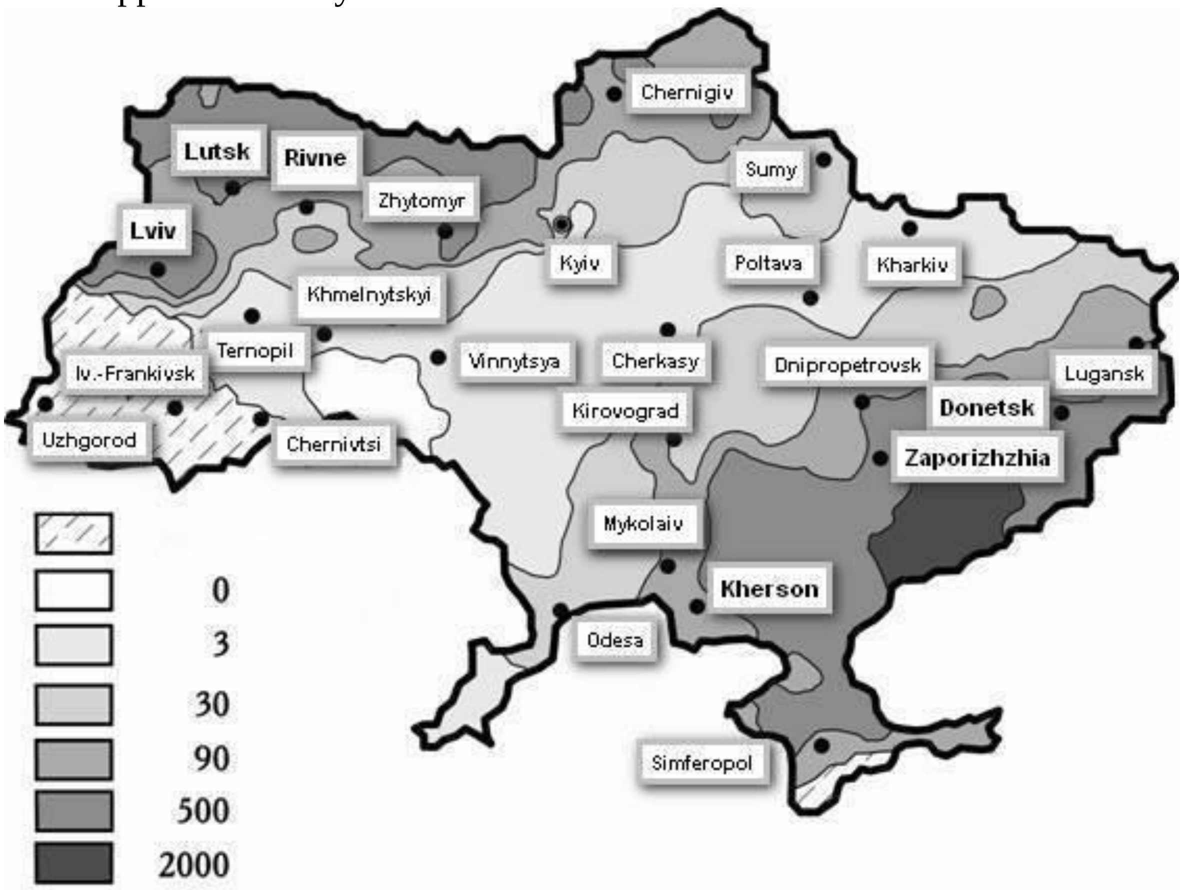

Fig. 1. Possible soil loss from wind erosion on plain lands of Ukraine, (t/ha per year)

Source: [8].

Continuing climate change has the potential to make the situation considerably worse. Increases in average temperatures, the seasonal and spatial redistribution of rainfall, and the increased frequency and intensity of extreme weather events, including drought, wind and rain, are all likely to result in further soil erosion if not mitigated or adapted to [9]. In light of this, we need to ensure that we act now to overcome or at least minimize erosion while the problem is still manageable. Earlier (in 1999–2009) losses of soil due to wind erosion in Volyn region ranged from 32.8 t/ha to 261.7 t/ha and losses of humus were in the range of 508–3952 kg/ha, of which 6.0–33.5 kg nutrients/ha was available phosphorus and 3.4–22.8 kg nutrients/ha was exchangeable potassium (Table 1). These already considerable impacts are only going to be significantly exacerbated by future climate change if they are not addressed promptly.

Based on data on the loss of humus and nutrients, ecological and economic damage from the loss of soil through deflation (Table 2) was found to have a total value in Volyn region of 1231–9023 UAH/ha.

Table 1

The calculation of humus losses and nutrients from the soil through deflation in the districts of Volyn region

Districts	Losses of soil, t/ha for 1999–2009*	Average rate of content**			Average losses for 1999–2009		
		humus, %	available phosphorus, mg/kg	exchan-geable potassium, mg/kg	humus, т/ha	available phosphorus, kg/ha	exchan-geable potassium, kg/ha
Volodymyr-Volyn	58.3	1.81	161	107	1.055	9.4	6.2
Gorokhiv	45.5	1.83	132	103	0.833	6.0	4.7
Ivanuchivsk	32.8	1.55	258	104	0.508	8.5	3.4
Kamin-Kashyrsk	77.1	1.63	94	75	1.257	7.2	5.8
Kivetsivsk	97.1	1.40	114	76	1.359	11.1	7.4
Kovelsk	126.9	1.54	109	75	1.954	13.8	9.5
Lokachynsk	61.0	1.54	128	106	0.939	7.8	6.5
Lutsk	100.4	1.73	139	94	1.737	14.0	9.4
Kubeshivsk	102.1	1.48	87	77	1.511	8.9	7.9
Lyabomsk	261.7	1.51	128	87	3.952	33.5	22.8
Manevytsk	133.6	1.56	94	69	2.084	12.6	9.2
Ratnivsk	157.7	1.76	98	75	2.776	15.5	11.8
Rozchishensk	108.5	1.55	98	83	1.682	10.6	9.0
Starovyzchsk	189.9	1.56	105	83	2.962	19.9	15.8
Turiysk	83.9	1.53	108	84	1.284	9.1	7.0

Remarks. * Data of Erosion Control Laboratory of NSC «ISSAR» [10, p. 26].
** Data of agrochemical passportization [11].
Source: author’s calculations.

Analysis of the structure of ecological and economic damage from the loss of soil through deflation identifies that it is mostly caused by loss of humus, which accounts for 86.4–94.2 % of the losses, as well as 4.1–11.2 % of the available phosphorus and 1.7–2.6 % of the exchangeable potassium. It is clear that the amount calculated for ecological and economic damage resulting from the loss of soil through deflation is largely shaped by the cost factors of the organic matter and nutrition elements. If, to illustrate the sensitivity of figures economic damage done to the values used, we accept the cost of 1 ton of humus as 144 USD [12], which at current exchange rates represents 3168 UAH rather than the 2095 UAH/t used in Table 2, the value of damage from loss of humus increases by 51.2 % and the range to 1609–12520 UAH/ha.

The degradation processes that occur in this region are due to the heterogeneity and diversity of soil within agricultural landscapes. The main climatic factors of deflation that determine intensity of these processes are the speed of the air, the duration of dust storms and the nature of the use of soils (the degree of plant cover and protection by woodland belts). Generalized indicators of soil characteristics, such as rate of destruction of aggregates and connectivity, were collected by the laboratory of Soil Erosion Control Laboratory of National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky» for the Volyn region in the years 2000–2012, based on 1:10,000 topographic maps. Soil connectivity did not exceed 35 % and the resulting coefficient of destruction was 65 %.

Table 2

Evaluation of ecological and economic damage from the loss of soil through deflation in the districts of Volyn region

Districts	Damages from losses of soil, t/ha for 1999–2009*	Including damage from loss, UAH/ha			Structure of damage for 1999–2009, %		
		humus	available phosphorus	exchan-geable potassium	humus	available phosphorus	exchan-geable potassium
Volodymyr-Volyn	2417	2210	152	55	91,4	6.3	2.3
Gorokhiv	1883	1745	97	41	92.7	5.1	2.2
Ivanuchivsk	1231	1064	137	30	86.4	11.2	2.4
Kamin-Kashyrsk	2802	2633	118	51	94.0	4.2	1.8
Kivetsivsk	3092	2847	180	65	92.1	5.8	2.1
Kovelsk	4402	4094	224	84	93.0	5.1	1.9
Lokachynsk	2151	1967	127	57	91.4	6.0	2.6
Lutsk	3948	3639	226	83	92.2	5.7	2.1
Kubeshivsk	3379	3166	144	69	93.7	4.3	2.0
Lyabomsk	9023	8279	544	200	91.8	6.0	2.2
Manevytsk	4651	4366	204	81	93.9	4.4	1.7
Ratnivsk	6171	5816	251	104	94.2	4.1	1.7
Rozchishensk	3776	3524	173	79	93.3	4.6	2.1
Starovyzchsk	6668	6205	324	139	93.1	4.8	2.1
Turiysk	2899	2690	147	62	92.8	5.1	2.1

Source: author's calculations.

The average maximum wind speed for Shatsk district according to data from long-term research was 18 m/s at ground level, with the speed at height of weathervanes at 23 m/s. The average number of hours with dust storms during the year was 15. As sod gley soil occupies 80 % of the research land area and sod light loamy carbonate 20 %, it was calculated that the potential loss for soil is 120–150 tons/ha per year for fields with missing vegetation [4].

Considering the average equilibrium density for turf-podzolic sandy soils of light loamy composition of 1.5 g/cm^3 (750 m^3 · 1.5 g/cm^3 = 1125 tons for five years) [13], the total loss is calculated as 225 tons of soil per year (for the whole territory) or 45 tons of soil from 1 ha per year. The limiting losses to these soils is 10 times smaller.

The content of humus and nutrients in the soil was determined from the results of the agrochemical survey and research data. The share of humus in sod gley soil was 5.22 % and 1.67 % in sod carbonate. The loss of organic matter in the period of study was 2.3 t/ha per year or 11.5 tons for the entire period from the sod gley soil, and 0.752 t/ha per year or 3.76 t/ha for five years from the sod carbonate soil. Taking into account the amount of nutrients in the soil top layer, for sod gley soil there was 117 mg/kg or 26.3 kg/ha of phosphorus (P) and 78 mg/kg or 17.55 kg/ha of potassium (K) lost, while sod carbonate soils lost 27.5 mg/kg or 6.19 kg/ha of phosphorus and 44.0 mg/kg or 9.9 kg/ha of potassium. It should be noted that the loss of nutrients in the soil top layer is relatively small in comparison with the main losses, which, according to the study, are of humus [13]. If land management methods are not adapted to meet the challenge of preserving the organic matter in the soils these losses will reduce the fertility and productivity of agricultural land in the short term and, increasingly, in the long run, as well as further increasing the risk of soil erosion.

To compensate for the losses of organic matter and nutrients resulting from soil deflation on the affected lands, several options were identified and investigated:

1) organic fertilizers in the form of mixed manure and straw;

2) fertilization using ammophos for raising phosphorus levels and kalimag-30 for restoring potassium;

3) changing the economic use of land - replacing the grazing of grasslands with overseeding creation of perennial grass meadows.

Among the studied options, the lowest cost (environmental price) for restoring soil losses was found to be using fertilizers with costs for the application of fertilizers at 663.27 UAH/ha over the 5 years (Table 3). This options provides full compensation for the loss of phosphorus and potassium, and partially for nitrogen.

Table 3

Comparative effectiveness of anti-deflationary measures in the Pishcha village, Shatsky district, Volyn region during 2008–2012

Name of measure	The environmental cost (expenses), UAH/ha	Effect / loss		
		economic, UAH/ha	environmental (abstract loss / recovery)	
			sod gley soils	sod carbonate soils
1 option. Use of organic fertilizers	5808.00	x	Humus – 11.5 t/ha; N – 250 kg/ha; P – 125 kg/ha; K – 300 kg/ha	Humus – 3.76 t/ha; N – 80 kg/ha; P – 40 kg/ha; K – 96 kg/ha
2 option. The use of mineral fertilizers	663.27	x	N – 5.26 kg/ha; P – 26.3 kg/ha; K – 17 kg/ha	N – 1.24 kg/ha; P – 6.19 kg/ha; K – 9.9 kg/ha
3 option. Growing perennial grasses	2649.60	1523.90 UAH/ha from sales of products	termination of deflation; 15.9 c/ha biological nitrogen annually	

Source: [13].

The highest environmental price was the application of organic fertilizers at 5808.00 UAH/ha for five years, although, compared to the use of ammophos and kalimag-30, this had the significant advantage directly restoring the humus while also compensating for the losses of nutrients and increasing their content in the soil.

Conclusions. As in the main grain producing areas of the Steppe in the south-eastern and eastern districts of Ukraine, where soil loss from wind erosion can be up to 2000 tons/ha, wind erosion is in the process of degrading the soils of the country's Forest regions. Despite the passionate interest of scientists and affected landowners, effective action to address the issues raised in this paper will only happen with the timely and sufficient investment of public resources. Necessary soil protecting techniques, such as No-Till farming or GIS-based technologies, have, to date, had very limited impact and in order to harness their positive effect in the future proper investment in and scientific approaches to land and soil management are required. If the targeting of activities to prevent soil erosion is only based on current soil erosion data, the main efforts will be in regions with already highly eroded soils (Steppe Area). However, in regions that are currently only suffering comparatively moderate erosion (Forest Area) further intensification of agriculture is planned with the use of 5–10 year old data. Using such an unconnected and poorly informed approach, where actual erosion and action frequently does not coincide with the potential danger of the wind erosion, risks not addressing the dynamics of the spread of wind-driven soil erosion in a timely and effective manner. In Polissya (Forest) Zone it is recommended that in order to reduce the area that is prone to soil deflation that those areas with fine-textured soils be used for hayfields or pastures and that woodland coverage is increased to 40–50 % of the total area.

The options and recommendations put forward in this paper to effectively manage the sustainable use of soil resources that are exposed to wind erosion potentially involve a wide range of actors and stakeholders. Research on the identification and engagement of these stakeholders was performed and will be presented in a further paper.

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