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ASSESSMENT OF SOIL LOSSES COSTS IN CROP ROTATION DUE TO WIND AND WATER EROSION RISKS

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Abstract

The results of soil losses management studying due to wind and water soil erosion crops rotations proposed based on methodologies of NSC "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky". The main purpose of our research was to assess the soil losses under influence of wind and water erosion in crop rotation. The works were planned to determine how erosion types correspond to crops or having the same effect on a similar field parts in the crop rotation of Ukrainian Eastern Steppe part. It was also planned to compare soils losses in similar gradations (allowable, slight, moderate, high) with the following analysis of the differences in the manifestation dynamics under different agricultural crops (fallow, winter crops, barley, oat, corn for grain, corn for silage, millet, peas), and different parts of fields. It is proposed when determining the erosion risk of the territory, the areas of such soils must be protected by such crops with minimal losses from the destructive effects of wind erosion and surface runoff. It is possible to state the cumulative manifestation of erosion and deflation on the territory of the region, but it is impossible to separate the contours of eroded and deflated soils in detail, therefore, in erosion situations proposed to obtain separate influence of each erosion (wind and water) on already eroded or erosionally hazardous lands.

Key words**:** *soil runoff, deflation, losses, modeling, management, crop rotations, forest shelterbelts*

INTRODUCTION

The soil surface on agricultural lands is constantly changing. The contours of eroded and deflated soils are created over a long period of time, first of all, on areas of soils that are dangerous for erosion and deflation. Their location in agricultural landscapes has both a natural and a technological basement. Erosion dynamic depends on the relief of the area and the type of land use. The most unprotected areas from deflation are located on open, unobstructed areas, most often on watersheds and on windy slopes. The erosively dangerous soils of Ukraine are not protected from the destructive action of surface runoff, therefore they are located on convex and long slopes, as well as along the thalwegs of the hydrographic network. Accordingly, the interpretation of M.I. Zaslavskyi [16], erosion-dangerous lands are those where the combination of natural conditions creates an opportunity for the manifestation of accelerated erosion during their economic use without the necessary anti-erosion measures. It is appropriate to take into account that the most dangerous method of soil cultivation is continuous tillage. But when considering the territory of agricultural production of Lugansk region, it can be noted that in previous years, in the second half of the 20th century, a system of protective forest plantations (PFP) as shelterbelts was created in the farms, which functions until now. The available PFP have a different level of system organization, but these are long-term anti-erosion plantations that, with age, form a favorable background for the sustainability of agro-landscapes. Because of this, when determining erosion-dangerous soils on working areas of continuous plowing, it is necessary to take into account the specific features of modeling the simultaneous manifestation of both water and wind erosion in the conditions of the Lugansk region. In addition, it should be remembered that the lands of agricultural production included tillage lands, fallow, and sometimes virgin areas. Because of this, it is advisable to apply erosion-hazardous soils on a modern cartographic basis in a differentiated manner, depending on the type of land use and the type of erosion. The materials of methodological approaches that are most suitable for practical implementation, which can be used for mapping eroded soils on agricultural production lands, are presented in the works of I. P. Kovalchuk [4], N. Velickovic, M. Todosijevic, D. Šulic [15], which justified general mapping methods. Much attention was paid to the mapping of eroded lands as a result of water and wind erosion by such scientists as V. O. Bilolipskyi [1], V. O. Bilolipskyi, S. Yu. Bulygin [2], P. V. Bolstad, T. Stowe [3], M. A. Nearing [10]. O. O. Svitlychny, S. G. Chorny. [11]. H. Teng, R. A. Viscarra Rossel, Z. Shi, T. Behrens, A. Chappell, E. Bui [14], C. Zhang, E. A. McBean [17].

The main purpose of our research was to assess the soil losses under influence of wind and water erosion in crop rotation. The works were planned to determine how they (erosion types) correspond to each other or having the joint effect on soil losses in the crop rotation of Ukrainian north-eastern part.

MATERIALS AND METHODS

Research was conducted in 2018 year on the territory of the former state farm near the village of Chuginka, Luhansky district, Luhansk region. In the 70-s of the last century, the farm was an experimental one for the introduction of soil protection technology of agricultural cultivation. crops and the first, regarding the introduction of no-till soil cultivation. On this object, images searches were performed, available cartographic material was studied, and potential soil losses due to erosion and deflation were determined in the section of working areas under agricultural crops with the help of appropriate models, methods and methodologies, whose were used to determine areas with erosion-hazardous soils.

The lower limit of the categories of erosion-dangerous arable soils was determined by the author's calculation method of V. I. Tarasov [12], which states down to establishing isohypsometric points in which the amount of soil erosion on arable land does not exceed the lower values of the regional scale of the corresponding categories: I - the zone of formation of surface runoff and soil erosion, which is compensated by the speed of cultural soil formation; II – soil run off (deflation) up to 5 t/ha; III – soil run of 5-12 t/ha; IV – run of 12-20 t/ha, V – > run of 20 t/ha.

Soils of the 1st category were allocated in the upper part of the slope. It is separated from the upper watershed line by the height of the slope drop of up to 5 m with the steepness of the slope < 0.75º. The soils of other zones were classified as erosion-dangerous. They were calculated depending on the steepness of the slope and soil losses in accordance with this steepness. The soils cover of site was represented by chernozems of various degrees of erosion, sod soils and outcomes of parent materials. Zonal soils are ordinary chernozems, partially-shortened with low-humus content. They situated on the plateau of areas between watersheds. Slightly eroded chernozems are located on the slopes of the watersheds of the northern and western expositions. On the slopes of the southern and eastern expositions, there are medium and highly eroded; on the terraced slopes – chernozem soils are saline. In the ravines, the soil cover is represented by chernozem eroded, ravine and sod eroded soils. Sod eroded soils are located on the southern exposition slopes.

According to quantitative indicators of soil organic matter, the average soils humus content was on the level of 4.11%. Soil quality score points was calculated according to authors results, which determines the level of their fertility and the conditions for planning crop yields in conditions of wind and water erosion. To determine potential soil losses from deflation, we used the Bocharov-Shiyaty model in the modification of the NSC "ISSAR named after O. N. Sokolovsky" (NSC ISSAR) [8]. Calculation of soil losses during wind storm erosion was performed using the mathematical and statistical model of A.B. Lavrovsky [9].

RESULTS AND DISCUSSIONS

According to research data of Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky [9], the norm (Po) of the manifestation of erosion was considered to be the value of the soil lost through erosion for a year, which is equal to 0.1% of the capacity of the upper humus genetic horizon (H) of a full-profile (non-eroded) soil. For example, typical chernozem has a thickness of H = 42 cm. That is, this amount of losses can be compensated in the course of cultural soil formation.

Thus, the definition of contours or zones of erosion-dangerous soils is performed by the calculation method, with the help of existing mathematical models. At the same time, it is necessary to observe the rule that it is not necessary to spread the effect of mathematical models beyond the zone for which they were developed [8].

As mentioned above, to determine the potential soil losses from deflation, we used the Bocharov-Shiyaty model in the modification of the NSC ISSAR, which is presented with detail in the Methodological recommendations for forecasting the occurrence of wind storms in Ukraine, published in 2010 [9] and which has included: conditional potential soil losses; soil lumpiness; amount of stubble or plant residues on the soil surface; coefficients depending on the genesis, physical and physico-chemical properties of the soil and the type and amount of plant residues; coefficient of destruction of aggregates; terrain influence coefficient; coefficient of deflationary stability of rural and urban areas with crops; coefficient expressing the level of the field protection by forest shelterbelts; coefficient of influence of additional soil protection measures; average multi-year number of hours with a dust storm; average maximum wind speed during dust storms of 20% coverage; speed of the air flow in the Air Aerodynamic Installation-3, which is equal to 13.5 m/s (23 m/s on the vane height).

Calculations according to this method were performed separately for each field, taking into account the available agricultural background and the protection of the field by PFP in form of forest shelterbelts (Table 1).

Table 1. Potential wind erosion soil losses on crop rotation fields in experiment

Field	Part	Crop	Field area, ha	Protected with forest belts, %	Potential soil losses	
					t/ha	from field, t
1	2	3	4	5	6	7
I	1	Black fallow	100.40	16.62	12.67	1,272.45
	2	Black fallow	38.50	35.00	9.88	380.38
II	1	Winter crop	70.90	8.18	2.08	147.77
	2	Winter crop	40.60	0.00	2.27	92.16
	3	Winter crop	21.80	0.00	2.27	49.49
III	1	Corn for grain	62.70	38.00	8.62	540.35
	2	Corn for grain	94.20	0.00	13.90	1,309.38
IV	1	Barley	16.30	32.00	1.75	28.49
	2	Oat	65.00	2.97	2.49	162.08
	3	Millet	46.50	38.00	1.59	74.09
	4	Barley	13.60	15.00	2.18	29.71
	5	Barley	20.70	21.00	2.03	42.03
V	1	Corn for silage	109.40	9.10	12.91	1,412.11
	2	Corn for silage	51.20	0.00	14.20	727.04
VI	1	Peas	95.10	9.10	2.18	207.47
	2	Peas	51.40	5.00	2.28	117.19
VII	1	Winter crop	141.30	0.00	2.27	320.75
	2	Winter crop	32.30	15.83	1.91	61.71
VIII	1	Sunflower	123.80	29.23	11.04	1,366.73
	2	Sunflower	23.20	11.90	13.74	318.85
	3	Sunflower	33.90	15.83	13.13	445.10
Total			1,252,80	12,90	7.27	9,105.32

Source: Authors' results.

At the final stage, the calculation of the amount of soil loss from water and wind erosion was carried out with an analysis of the stability of the soil. soil deflation and erosion processes within the limits of crop rotation.

The results of the calculations show that the fields of the existing crop rotation are the most vulnerable to dust storms. Extrusion of soil on them depends on two main factors: agricultural background and protection of the territory by forest shelterbelts, which varies from 0 to 38%. Since in most cases dust storms occur in early spring (from the end of February - beginning of March), soil losses depend on the coverage of its surface. The average calculated protection of land by forest shelterbelts in field crop rotation is 12.9%, while potential soil losses amount to 7.27 t/ha. Based on the data of the given calculations, a corresponding cartogram (Fig. 1) was constructed, which characterizes the deflation risk of the fields.

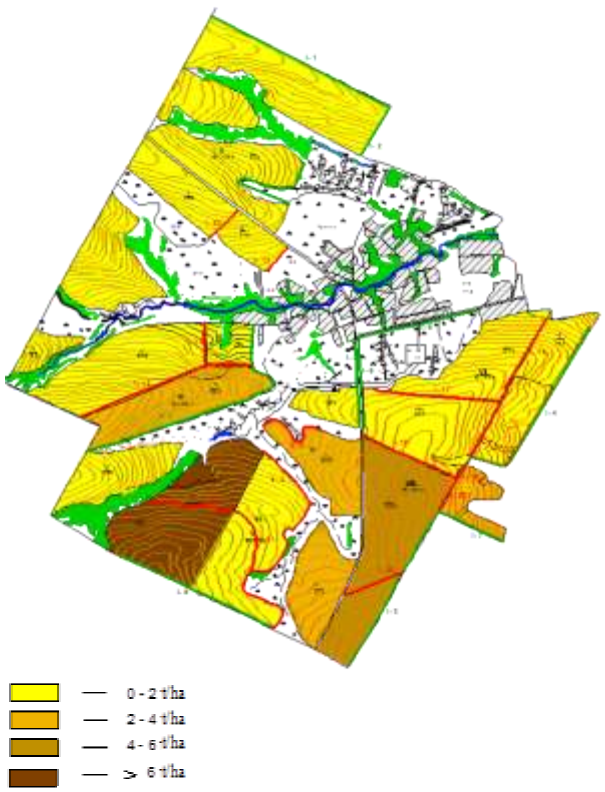

Fig. 1. Wind erosion soil losses cartogram
Source: authors interpretation of results.

According to the Institute for Soil Science and Agrochemistry Research, allowable soil losses from deflation should not exceed 2 t/ha [8]. Since soil losses within field crop rotation significantly exceed permissible limits, they can be classified as erosion-dangerous. This situation requires an increase in the protection of rural areas by applying some agrotechnical measures or additionally created field protection forest shelterbelts.

Calculation of soil losses during rainfall storm erosion was performed using the mathematical and statistical model of A.B. Lavrovsky [7], which has the form:

AR = 10-3 X2,7E (5,0 - 0,04Xc - 0,1 Xh + 0,1Xcc) Xs Xt Xob Xe..........................(1)

where:

AR - amount of soil loss, t/ha; XE – weighted average kinetic energy of the erosive part of heavy rainfall, kJ/m^2; Xc – physical clay content, %; Xh – humus content, %; Xcc – carbonate content ($CaCO_3$), %; Xs – steepness, degree; Xt – terrain factor, м; Xob – openness of the background, %; Xe – efficiency factor of some soil protection measures, %.

The average amount of rainfall energy for the zone for a certain period is determined by adding up the probability-weighted average energy values of the maximum daily precipitation:

$$X_E = \frac{E_1F_1 + E_2F_2 + ... + E_nE_n}{F_1 + F_2 + ... + F_n} \kappa J / m^2$$

....(2)

where:

E1, E2, En – energy of torrential precipitation of a certain security, kJ/m^2; F1….Fn – probability, %.

The energy of the erosive part of heavy rainfall was determined by the equation:

$$E=23.1\, I^{0,21}$$ ....(3)

where:

E – energy of the erosion-dangerous part of heavy rainfall, kJ/m^2; I – average intensity of the erosive part of the rainfall, mm/min.

The influence of soil properties in the models is reflected by three leading factors: the content of physical clay (Xc), humus (Xh) and carbonates (Xcc). The use of basic properties

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makes it possible to quickly take into account the susceptibility to storm erosion of soils.

The models take into account the weighted average steepness of the slopes (Xα):

$$X_a = \frac{\alpha_{11} L_1 + \alpha_2 L_2 + ... + \alpha_n L_n}{L_1 + L_2 + ... + L_n}$$ ....(4)

where:

Xα – weighted average slope (section), degree; α – slope of elementary homogeneous area, degree; L – length of an elementary homogeneous section, m.

The influence of the weighted average value of the slope, corrected by the relief factor (Xri) - the shape of the slope and exposition. The latter are expressed by the corresponding values taking into account the ratio of the length of the slopes (L, m) to the width of the site (B, m). Before determining the amount of soil loss from wind erosion, an information table (field) is compiled for each plot (field) of the crop rotation. However, in order to determine the amount of fine soil carried outside the field, calculations were made of the amount of deposited fine soil in the forest shelterbelts.

Potential soil losses from rainfall under the existing organization of the territory amount to 4.17 t/ha, or 5,213.82 t in total For this purpose, the formula of V.I. Tarasov [7] was used:

W =10 [0.99(Wn + 1/0)0.69 – 1.0] (1.98 – 2.04k) sin β ....(5)

where:

W - mass of fine soil deposited in the forest shelterbelts, t/ha; Wn - mass of fine soil removed from the higher slope, kg/m^2;

Wn = AR Sn / 10·Sл; ....(6)

where:

Sn - field area, ha; Sл - area of the forest shelterbelts, ha; k - flow coefficient in the shelterbelts; sinβ - sine of the angle between the drainage line and the forest shelterbelts. The coefficient of runoff in forest shelterbelts is adopted on the basis of field experiments with manual raining on various elements of the terrain. At the same time, a rain generating device (patent 62336 A) was used [13]. Results of potential soil losses from rainfall presented in Table 2.

Table 2. Potential water erosion soil losses on crop rotation fields in experiment

Field	Part	Crop	Field area, ha	Soil losses, t	
				from 1 ha	from field
1	2	3	4	5	6
I	1	Black fallow	100.40	6.54	656.14
	2	Black fallow	38.50	6.89	265.33
II	1	Winter crop	70.90	3.55	251.56
	2	Winter crop	40.60	1.90	77.30
	3	Winter crop	21.80	4.02	87.54
III	1	Corn for grain	62.70	6.02	377.65
	2	Corn for grain	94.20	4.78	449.99
IV	1	Barley	16.30	3.18	51.91
	2	Oat	65.00	3.35	217.50
	3	Millet	46.50	3.36	156.14
	4	Barley	13.60	2.97	40.41
	5	Barley	20.70	4.05	83.84
V	1	Corn for silage	109.40	5.35	585.09
	2	Corn for silage	51.20	3.59	183.88
VI	1	Peas	95.10	2.77	263.36
	2	Peas	51.40	1.33	68.21
VII	1	Winter crop	141.30	2.61	369.45
	2	Winter crop	32.30	2.87	92.80
VIII	1	Sunflower	123.80	4.31	533.54
	2	Sunflower	23.20	6.30	146.06
	3	Sunflower	33.90	7.55	256.11
Total			1,252.80	4.17	5,213.82

Source: Authors' results.

The results of calculations show that potential soil losses from 1 ha vary from 1.33 to 7.55 t, on average by crop rotation - 4.17 t/ha. It should be noted that the land of field crop rotation is located on a flat surface or on slopes with a steepness of up to 3º. But most of the fields have a slope length of more than 800 m, so the potential soil erosion exceeds the ecologically acceptable limit of 2.0 t/ha. Such crops as fallow and row crops are more susceptible to leaching, where leaching varies from 3.59 to 7.55 t/ha. Based on the results of soil loss calculations, a corresponding cartogram was also constructed (Fig. 2).

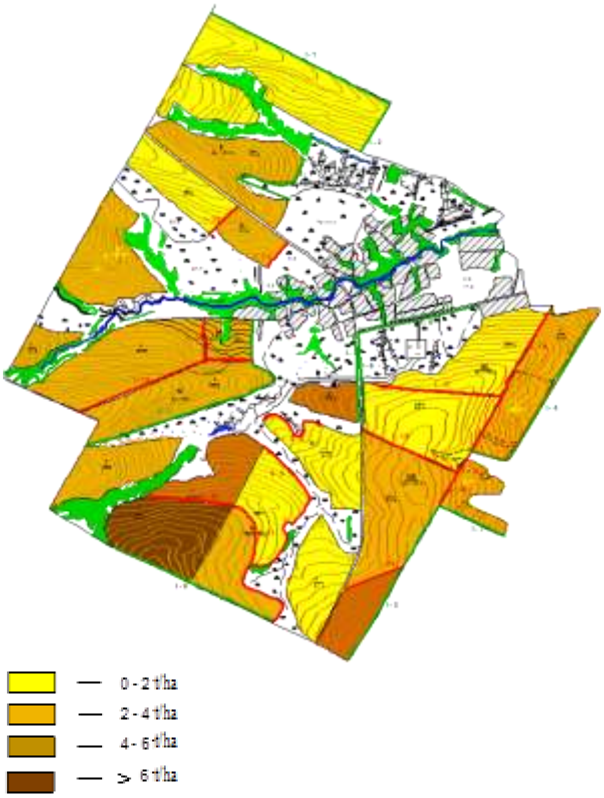

Fig. 2. Water erosion soil losses cartogram.
Source: authors interpretation of results.

The results of the experiments and calculations showed risk of individual fields part both from the point of view of runoff processes and the processes of soil deflation.

Quantitative calculations of soil losses costs restoration for the humus content removed from the soil as a result of water and wind erosion were carried out taking into account the actual costs of organic fertilizers in 2019 year. Based on the fact that 0.08 tons of humus were formed from 1 t of organic manure in the Steppe zone of Ukraine, to restore 1 t of humus, it is necessary to apply about 12.5 tons of manure (1 ton / 0.08 = 12.5 tons). According to the research of Kucher A. I. and the authors, in 2019 [5, 6], at the cost of organic fertilizers 250 UAH/t and the costs of their application 124 UAH/t, the total amount was 374 UAH/t. Taking into account the official inflation, it is possible to determine the estimated actual amount at the present moment - 586 UAH/t or, for example, 5,860 UAH/ha for an application of 10 t/ha. Thus, the cost of restoring of 1 t humus is 7,325 UAH. The information below obtained as the results of calculations of the restoration costs of humus that removed has been presented in Table 3 (water erosion) and Table 4 (wind erosion).

Table 3. Costs of humus losses restoration due to water erosion according to fields parts and crops, UAH

Field	Part	Crop	Soil losses t/ha	Humus losses t/ha	Costs of restoring humus losses (water erosion)	
					UAH/ha	UAH/ field
1	2	3	4	5	6	7
I	1	Black fallow	12.67	0.5207	3,814.40	382,965.61
	2	Black fallow	9.88	0.4061	2,974.45	114,516.25
II	1	Winter crop	2.08	0.0855	626.20	44,397.55
	2	Winter crop	2.27	0.0933	683.40	27,746.06
	3	Winter crop	2.27	0.0933	683.40	14,898.13
III	1	Corn grain	8.62	0.3543	2,595.12	162,713.75
	2	Corn grain	13.90	0.5713	4,184.70	394,198.67
IV	1	Barley	1.75	0.0719	526.85	8,587.67
	2	Oat	2.49	0.1023	749.63	48,726.16
	3	Millet	1.59	0.0653	478.68	22,258.69
	4	Barley	2.18	0.0896	656.31	8,925.75
	5	Barley	2.03	0.0834	611.15	12,650.74
V	1	Corn silage	12.91	0.5306	3,886.65	425,199.76
	2	Corn silage	14.20	0.5836	4,275.02	218,880.84
VI	1	Peas	2.18	0.0896	656.31	62,414.64
	2	Peas	2.28	0.0937	686.41	35,281.53
VII	1	Winter crop	2.27	0.0933	683.40	96,564.49
	2	Winter crop	1.91	0.0785	575.02	18,573.14
VIII	1	Sun-flower	11.04	0.4537	3,323.67	411,470.94
	2	Sun-flower	13.74	0.5647	4,136.53	95,967.50
	3	Sun-flower	13.13	0.5396	3,952.88	134,002.80
Total			7.27	0.2650	1,940.96	2,740,940.68

Source: Authors' results.

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Table 4. Costs of humus losses restoration due to wind erosion according to fields parts and crops, UAH

Field	Part	Crop	Soil losses t/ha	Humus losses t/ha	Costs of restoring humus losses (wind erosion)	
					UAH/ha	UAH/ field
1	2	3	4	5	6	7
I	1	Black fallow	6.54	0.2688	1,968.92	197,679.17
	2	Black fallow	6.89	0.2832	2,074.29	79,860.02
II	1	Winter crop	3.55	0.1459	1,068.75	75,774.67
	2	Winter crop	1.9	0.0781	572.01	23,223.58
	3	Winter crop	4.02	0.1652	1,210.25	26,383.48
III	1	Cor grain	6.02	0.2474	1,812.37	113,635.36
	2	Corn grain	4.78	0.1965	1,439.05	135,558.97
IV	1	Barley	3.18	0.1307	957.36	15,605.01
	2	Oat	3.35	0.1377	1,008.54	65,555.27
	3	Millet	3.36	0.1381	1,011.55	47,037.22
	4	Barley	2.97	0.1221	894.14	12,160.31
	5	Barley	4.05	0.1665	1,219.28	25,239.16
V	1	Corn silage	5.35	0.2199	1,610.66	176,205.94
	2	Corn silage	3.59	0.1475	1,080.80	55,336.78
VI	1	Peas	2.77	0.1138	833.93	79,306.67
	2	Peas	1.33	0.0547	400.41	20,580.89
VII	1	Winter crop	2.61	0.1073	785.76	111,027.90
	2	Winter crop	2.87	0.1180	864.04	27,908.33
VIII	1	Sun-flower	4.31	0.1771	1,297.56	160,637.66
	2	Sun-flower	6.3	0.2589	1,896.66	44,002.56
	3	Sun-flower	7.55	0.3103	2,272.98	77,054.16
Total			4,17	0,1708	1,251.40	1,569,773.11

Source: Authors' results.

The highest losses of soil from wind erosion were on the crops (t/ha): black fallow (9.88-12.67) and sunflower (11.04-13.74), corn (12.91-14.20). Lowest allowable losses (t/ha): millet – 1.59, barley – 1.75, winter wheat – 1.91. The highest soil losses from water erosion were calculated for the crops (t/ha): sunflower (6.30-7.55), black fallow (6.54-6.89) and corn (5.35-6.02). Lowest allowable losses (t/ha): millet – 1.59, peas – 1.33, winter wheat – 1.90.

When analyzing the cost of losses of soil organic matter due to water and wind erosion, a similar trend was maintained. The highest cost of humus losses restoration in soil (UAH/ha) as a result of water erosion was observed on variants with the most open soil surfaces under the cultivation of technical crops - corn (2,595.12-4,275.02), sunflower (3,323.67-4,136.53) and black fallow (2,974.45-3,814.40). The lowest cost of humus losses restoration in soil (UAH/ha) was fixed for millet (478.68) and barley (526.85). In the case of humus losses costs for lands restoration due to wind erosion, this trend was also preserved for some extent. The highest ones humus losses restoration costs (UAH/ha) were observed for variants with black fallow (1,968.92-2,074.29), sunflower (1,297.56-2,272.98) and corn (1,080.80-1,812.37). The lowest value of humus loss restoration cost (UAH/ha) was observed for variants with peas (400.41) and winter wheat crop (572.01). The rest of studied in experiment crops were having average values of soil losses from erosion and required average values of costs for humus content restoration.

CONCLUSIONS

When determining the erosion risk of the territory, the areas of eroded or erosionally hazardous soils must be protected by crops with potentially minimal soil losses from the wind erosion and surface runoff. The highest and lowest values of humus loss restoration costs should also be considered.

For areas with black fallow and technical crops (such as sunflower, corn for grain or corn for silage) some monitoring plots should be organized to observe soil erosion dynamics. The specified features of these crops are suggested to be taken into account when planning crop rotations and soil tillage, assessing the risks of highest costs of humus losses restoration because of erosion processes.

It is also important to state the cumulative manifestation of wind and water erosion on the territory of the region, but it is difficult to separate the contours of eroded and deflated soils in detail, therefore, in cases of erosion situations we propose to obtain separate influence of each erosion on already eroded or erosionally hazardous lands.

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