ECOLOGICAL AND ECONOMIC CONSEQUENCES OF THE DEFLATIONARY DESTRUCTION OF THE UKRAINIAN STEPPE SOILS

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ABSTRACT
The decrease in the efficiency of agriculture is associated with the impact of wind erosion, the consequences of which are a decrease in soil fertility. Significant manifestations of wind erosion are characteristic of arid and semiarid zones, which have a small amount of precipitation, high air temperature and evaporation rates, enhanced by strong winds and low differentiation of plant protection. It has been proven that the intensity of the deflationary process' manifestations depend on the physical and geographical conditions of agricultural land location, the systematicity of soil protection measures and the presence of vegetation. It was established that the acceleration of deflationary processes occurs in territories with increased anthropogenic load, which lead to an ecological disturbance of territorial ecosystems natural balance. During the conducted research, it was found that the natural processes of wind erosion are greatly aggravated by the lack of a scientifically based and ecologically remedial system of agriculture, which leads to the destruction of the soil cover, a decrease in soil fertility, damage to agricultural crops and, as a result, economic losses. As a result of GIS and ERS technologies application, as well as an empirical and statistical model of possible soil loss in the territory of the Ukrainian Steppe zone due to wind erosion, it was determined that because of deflation processes in the territory occupied by pure steam in the absence of anti-deflation measures conditions, the value of soil loss in the epicenter of dust windstorms can reach about 600 t/ha. Research has proven the importance of the anti-deflation effect of vegetation, which causes an increase in erosion-dangerous (favorable) areas of agricultural land by 1.7 times, which reduces soil loss by 5.62 times. In accordance with the intensity of deflationary processes manifestations and the excess of soil losses, contour-ameliorative anti-deflation measures with the elements of soil protection agriculture are proposed.
Ke words*: wind erosion, soil loss, ecological and economic consequences, modeling, GIS, ERS*

INTRODUCTION

The spread of wind erosion influence zone leads to a decrease in the efficiency of agriculture, as the deflationary-spatial redistribution of soil parts reduces the level of soil fertility, which is the main factor of influence on agricultural crop yield. The intensity of the deflationary process depends on the physical and geographical conditions of agricultural land allocation, the systematic nature of soil protection measures, and the presence of plant cover [1]. Significant manifestations of wind erosion are typical for arid and semiarid zones, which have a small number of precipitations, high air temperature, and evaporation rates, reinforced by strong winds and low differentiation of plant protection.

As a result of the conducted research, it was determined that the acceleration of deflationary processes takes place on territories with the increased anthropogenic load, which leads to ecological violation of territorial ecosystems' natural balance [2, 3, 4]. Therefore, determining the influence of factors and processes of wind erosion, their occurrence frequency, and inhomogeneity of spatial distribution on the economic efficiency of agriculture is a relevant research direction in the context of ensuring conditions for sustainable land use.

It has been established that the increase in the amplitude of air and soil temperature fluctuations, a decrease in the amount of annual precipitation, the hydrothermal coefficient, a reduction of frost-free period, and an increase of wind activity led to the development of deflationary processes, which is determined by the manifestations of an erosion-dangerous climate, which is determined by continentality [5, 6]. First, in the zone of increased wind-erosion processes, there are soils of the Steppe zone, which are characterized by a light granulometric composition, a low speed of soil formation, a medium and low level of humus content, weak cohesion and strength of the soil clod. On the steppe, mainly flat relief, the wind gains a high speed, which causes an increase in the shock force of particle transport. The main factors of the degree of manifestation of deflationary destruction of the soil cover are the characteristics of the wind (speed, frequency of repetition, its force, and duration), the ground surface (vegetation, its height, and density of the cover, surface roughness, the presence of soil moisture), soils (the size of particles, their connection density, distribution of aggregates and amount of organic matter). Soils with a ratio of 20–30% clay, 40–50% dust, and 20–40% sand have the highest degree of anti-deflation resistance [7, 8].

Thus, erosive degradation of land causes a deterioration of the natural soil properties to decrease of soil fertility, a reduction in biodiversity, a deterioration of surface and groundwater quality, and a decrease in agroecosystems productivity. It has been proven that deflation losses of 10 cm of the fertile soil layer are equal to the displacement of more than 1 thousand t / ha of soil [2, 3], and if the average high degree of erosion is determined, there are lands with a loss of up to 5 thousand t/ha of soil. In full profile chernozems (black earth), the humus reserve is 216 t/ha, as a result of erosion, losses reach 114 t/ha.

In this context, solving the problem of rational use and protection of agricultural land should become a priority direction of state policy in the sphere of land relations and ensuring sustainable land use.

It was determined that there was a steady trend towards an uncontrolled intensification of the erosion degradation processes, dehumidification, acidification, and a decrease in soil fertility. In the conditions of climate change, the negative processes of soil degradation are a significant factor in the intensification of land degradation processes and the negative impact on the productivity of agroecosystems, which reduces the efficiency of agricultural production.

RECENT RESEARCH AND PUBLICATIONS ANALYSIS

In particular, the determination of the ecological and economic consequences of the deflationary destruction of the steppe soils of Ukraine is reflected in the publications of A.B. Achasov [9], S.A. Balyuk [7], S.Yu. Bulygin [10], M.D. Voloshchuk [11], E.G. Degodyuk [12], F.M. Lisetskii [1], O.S. Sytnyk [8], A. Sameni [13], O.G. Tararika [14], S.G. Chornyi [15], G.V. Schwebs [16, 17]. To establish the level of danger of deflationary processes, to determine the level of damages from their manifestations, contour-and-meliorative anti-deflationary measures with elements of soil protection agriculture were proposed, and the system of estimation of losses by socio-cultural component has been expanded.

The influence of wind erosion manifestations processes in the Steppe zone of Ukraine on the efficiency of agriculture actualizes the need for spatial differentiation modeling and forecasting of potential soil erosion losses. Currently, a functioning system for forecasting potential soil erosion losses requires the creation of spatial models of soil deflation losses, which are the basis for determining adaptive anti-erosion-soil protection and contour-melioration measures, it is necessary to apply geostatistical and mathematical models with elements of Earth’s remote sensing.

The aim of the work is geomodeling of potential deflationary losses of soils in the Steppe zone of Ukraine, aimed at determining the ecological state of agrolandscapes, designing an adaptive complex of anti-erosion and soil protection, and contour-meliorating measures aimed at increasing the efficiency of agricultural production.

RESEARCH METHODS

In the process of research, the possibility of using different approaches to calculating deflationary soil losses was analyzed. In particular, the researcher Bagnold [18] proposed the equation of sand movement depending on the wind speed over the eroded surface. A modified form of this equation was proposed by Zingg [19], but it was not widely used. Chepil [20] noted that the method proposed by the authors excludes Spatio-temporal differences of certain factors, so it was proposed to calculate potential wind erosion using a method similar to the equation of soil loss from water-erosion processes. We believe that the proposed method is universal, but due to the existing significant metric differences of the fields, it complicates the

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process of obtaining an accurate spatial model of the average protection of the field length, which causes errors in soil loss calculations [21].

In this regard, in the process of determining possible soil losses on the territory of the Ukrainian Steppe, the model of wind erosion of the NSC "Institute of Soil Science and Agrochemistry named after the name of O.N. Sokolovsky", which is adapted to different physical and geographical conditions of the country [9, 10, 22]:

$$\mathrm{E_p} = \frac{10^{a-bk} \cdot 0.1 K_s \cdot V^3_{av\_\max} \cdot t \cdot K_{spe}}{V^3_{aer}}, \tag{1}$$

when Ep is potentially possible deflationary soil losses, t/ha per year; a, b – power coefficients that depend on the genesis, granulometric composition, density and some other properties of soils (calculated experimentally); k – lumpiness of the surface (0-3 cm) layer of the soil (content of aggregates or particles larger than 1 mm), %; Ks is the coefficient of destruction of aggregates of the surface layer of the soil under the influence of impacts of soil particles and their abrasion by air-dust flow; Vav_max is the average maximum wind speed during dust storms of the 20th reliability, m/s (20% reliability shows that this indicator, determined on the basis of long-term data, is correct in 80 cases out of 100, that is, only in 20% of cases the wind speed during dust storms will be greater); t - the average number of hours of wind erosion per year based on long-term data; Kspe – coefficient of soil protection efficiency of anti-deflation measures; Vaer is the basic flow speed in the aerodynamic installation, which is equal to 23 m/s in terms of vane height (10 m); 0.1 – conversion from g/m2 in 5 minutes to t/ha per year.

The calculation of soil deflation losses was carried out in the GIS environment of the licensed software product ArcGIS 10.1, for this purpose raster models (cell size 30 × 30 m) of the distribution of individual factors in the territory of the Steppe zone of Ukraine (Fig. 1) with a total area of 167.4 thousand km2 were created, including the area of agricultural land is 131.6 thousand km2. The agricultural development of the research region varies between 20–97%.

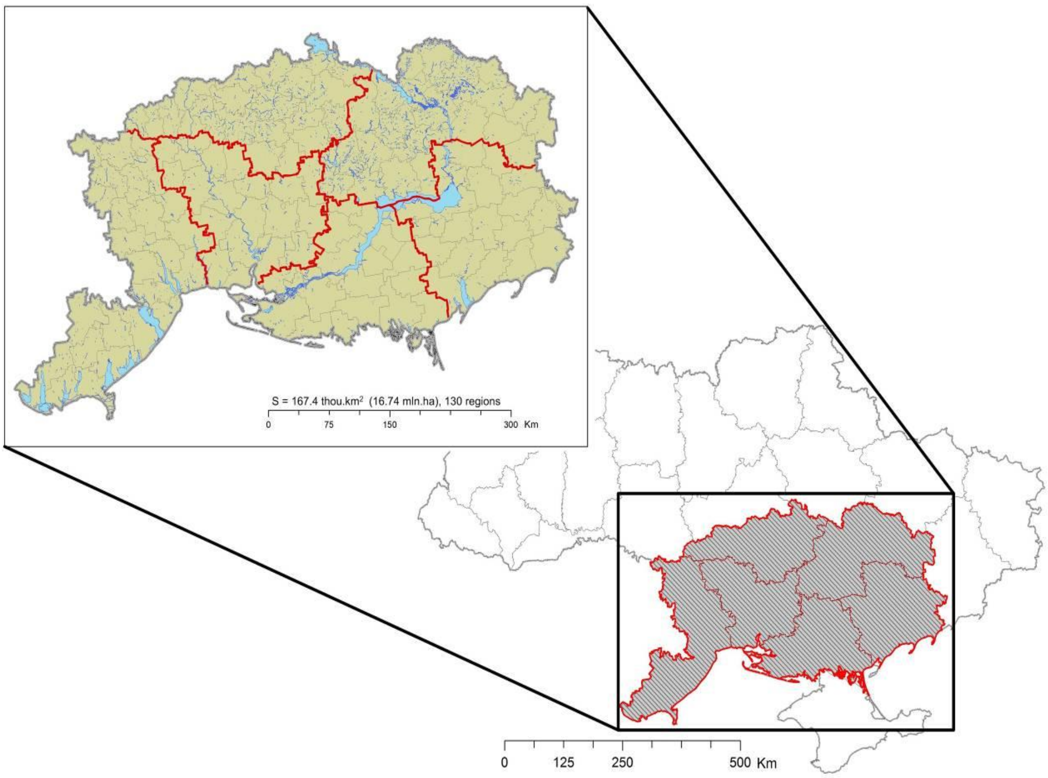

Fig. 1. Spatial characteristic of studied territory

Spatial models of the distribution of regression coefficients (a, b), lumpiness (k) and destruction coefficients *(K_s)* were created based on assigning the corresponding values to each soil variety of the Steppe zone of Ukraine (Fig. 2). Raster models of the spatial distribution of the average maximum wind speed during dust storms (V_{av_max}), as well as the average number of hours with the manifestation of wind erosion per year (t) on the territory of the steppe soils, were obtained based on the extrapolation of decompositions of meteorological map data based on the averaged data of 1990–2018.

The coefficient of soil protection efficiency of anti-deflation measures (K_{spe}) is calculated according to the modified erosion index of crop or the coefficient of crop cover (C`), which reflects the level of efficiency of growing agricultural crops, as well as the effectiveness of the natural plant cover (trees, grasses) of the territory of the land in reducing soil loss. It has been proven that the increase in vegetation leads to a decrease in soil loss. The coefficient of vegetation cover (C`) is the most sensitive to soil loss [23, 24].

To determine the factor C`, the data of the remote sensing of the earth (RSE) of the correctly calibrated Landsat-8 satellite image with a geometric resolution (spatial resolution) of ~ 30x30 m as of March and August 2018 were used. The factor values were generated based on the dimensionless NDVI (normalized differential vegetation index), using a modified formula [25]:

$$C = \exp(-\alpha((NDVI)/(\beta - NDVI))) \quad (2)$$

$$C' = C/\max(C) \quad (3)$$

where α and β are dimensionless parameters that determine the shape of the curve related to NDVI and C factor. Parameters α and β have values of 2 and 1, respectively. The value ranges from 0 (maximum anti-deflation effect of vegetation cover) to 1 (minimum or no anti-deflation vegetation).

The proposed method of calculating soil deflation losses is the main component of environmental assessment, which allows us to offer the assessment of losses from soil degradation. Cost, income, and comparative methods are used in the evaluation process. To preserve land for future generations, as the main productive resource that is a component of national wealth, it is necessary to determine the amount of social losses from degradation. Social losses, in addition to direct losses of agricultural products and a decrease in the level of economic indicators of production, should include the costs of restoring the fertility of soils and their condition. Researchers [26] suggested calculating losses from soil degradation and depletion, we supplemented the calculation system with an indicator of socio-cultural losses:

$$P_{losses} = B_{evaluation} + B_{restoration} + B_{damage} + B_{economic\ services} + B_{sociocultural} \quad (4)$$

This method includes the costs for research and assessment of damage, as a rule, it consists of laboratory tests cost and analytical processing; costs for elimination of the negative consequences of erosion processes, and costs for soil restoration (anti-erosion measures to improve and preserve soils); cost of lost and damaged natural objects; the cost of lost ecosystem services in relation to the environmental protection functions of soil ecosystems; socio-cultural losses, which reflect the lost society's capacity based on its perception of information about losses of this kind of resource.

RESULTS AND DISCUSSION

13.4 million hectares are under the influence of water erosion, which is 31.4% of the total area of rural, areas of land (42.7 million hectares). The impact of wind erosion is 6 million hectares (14.0% of the area of agricultural lands), and in the years of dust storms – 20 million hectares, of which 75% are slightly eroded, and 25% are moderately and strongly eroded. It should also be noted that more than 500,000 hectares of fertile land have been disturbed by ravines. Thus, it was determined that in the absence of ecologically justified anti-erosion measures, there is an intensive transition of lands from the category of weakly eroded to the category of moderately eroded and heavily eroded, which significantly affects the decrease in soil fertility.

It was determined that over the past 40 years, the area of eroded land on the territory of Ukraine has increased by 2.5 million hectares, with an annual increase of 60-80 thousand hectares of eroded arable land.

Soil erosion losses on the territory of Ukraine are on average 10-15 t/ha per year, and the total average annual soil losses, according to various data, range from 260 million tons to 500 million tons of soil [27, 28]. In the period 1960–2015, the area of eroded soils occupied by agricultural land increased by 30–35%, the area of strongly eroded soils increased by 20%, weakly and moderately eroded soils by 2 and 12%, respectively [29].

According to the research results, it was established that Ukraine ranks 9th among European countries in terms of the intensity of erosion processes. Up to 24 million tons of humus from agricultural land, as well as 0.96 million tons of nitrogen, 0.68 million tons of phosphorus, and 9.40 million tons of potassium are removed with erosion products. In this regard, the yield of agricultural crops on eroded soils decreases by 20-60%.

Therefore, losses of agricultural products due to erosion exceed 9-12 million tons of grain units per year, and economic losses under such conditions reach $6.0 billion [30].

The reason for negative erosion manifestations is the high degree of plowing of the territory of Ukraine, more than 80% of agricultural land is plowed, of which 53.8% is arable land. In recent years, the lands of the hydrographic fund, steep slopes, water protection zones, floodplains, and riverbeds have been intensively plowed. This is the result of an uncontrolled process of land use in the conditions of incomplete land reforms, which is exacerbated by the lack of clear state, regional, and local soil protection programs, the development of effective mechanisms for economic stimulation of agricultural producers to protect soils from erosion, and the lack of a system of scientifically based ecological norms for the assessment of land resources.

If it is necessary to develop a system of soil protection anti-erosion contour-ameliorative measures, it should be taken into account that sloping arable land is erosively dangerous, and about 80% of them are classified as weakly and moderately erosively dangerous; 20% of lands are at increased erosion risk, which require fundamental changes in the anti-erosion organization of the territory based on a soil-protective, resource-saving, biologically clean, ecologically safe farming system. An important component of the process of optimizing the structure of agrolandscapes and land use systems is their agroecological typification and zoning according to the resources of heat, moisture, soil fertility, and risks of erosion processes, which are the main factors of degradation and desertification of agrolandscapes [21].

It was determined that the increase in row crops in crop rotations is accompanied by the intensification of erosion processes and soil dehumification. As well as the increase in the intensity of torrential rainfall and the wind regime against the background of the increase in row crops and the actual cessation of the introduction of anti-erosion measures, causes the acceleration of soil erosion degradation in all soil and climate zones of Ukraine.

During the conducted research, it was established that the natural processes of wind erosion are greatly exacerbated by the lack of a scientifically based and ecologically remedial system of agriculture, which leads to the destruction of the soil cover, a decrease in soil fertility, damage to agricultural crops and, as a result, economic losses (Fig. 2)

To establish the cause-and-effect relationships of the development of wind erosion, it was determined that the increase in arable land occurs mainly due to the reduction of pastures, the vegetation cover of which performs the function of restoring soil fertility. This, in turn, led to an increase in deflationary dangerous areas and the frequency of periods of negative effects of wind erosion. Also, the lack of ecologically justified crop rotations and manifestations of monoculture cultivation caused a decrease in the natural stability and fertility of the soil.

The systematic use of old methods of removing plant residues (burning stubble and straw) leads to a decrease in the soil protective effect and the supply of organic matter in the soil, necessary for maintaining the soil structure and fertility. The lack of ecological justification for the use of mineral fertilizers leads to a decrease in the density of soil aggregates, and the improvement of weed control methods reduces their anti-deflationary role. Cutting of protective forest strips increases the impact force of the wind, which leads to a

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violation of the water-holding and infiltration properties of the soil, causing washout and spring erosion, which causes a redistribution of soil material, causing the formation of a complex soil profile.

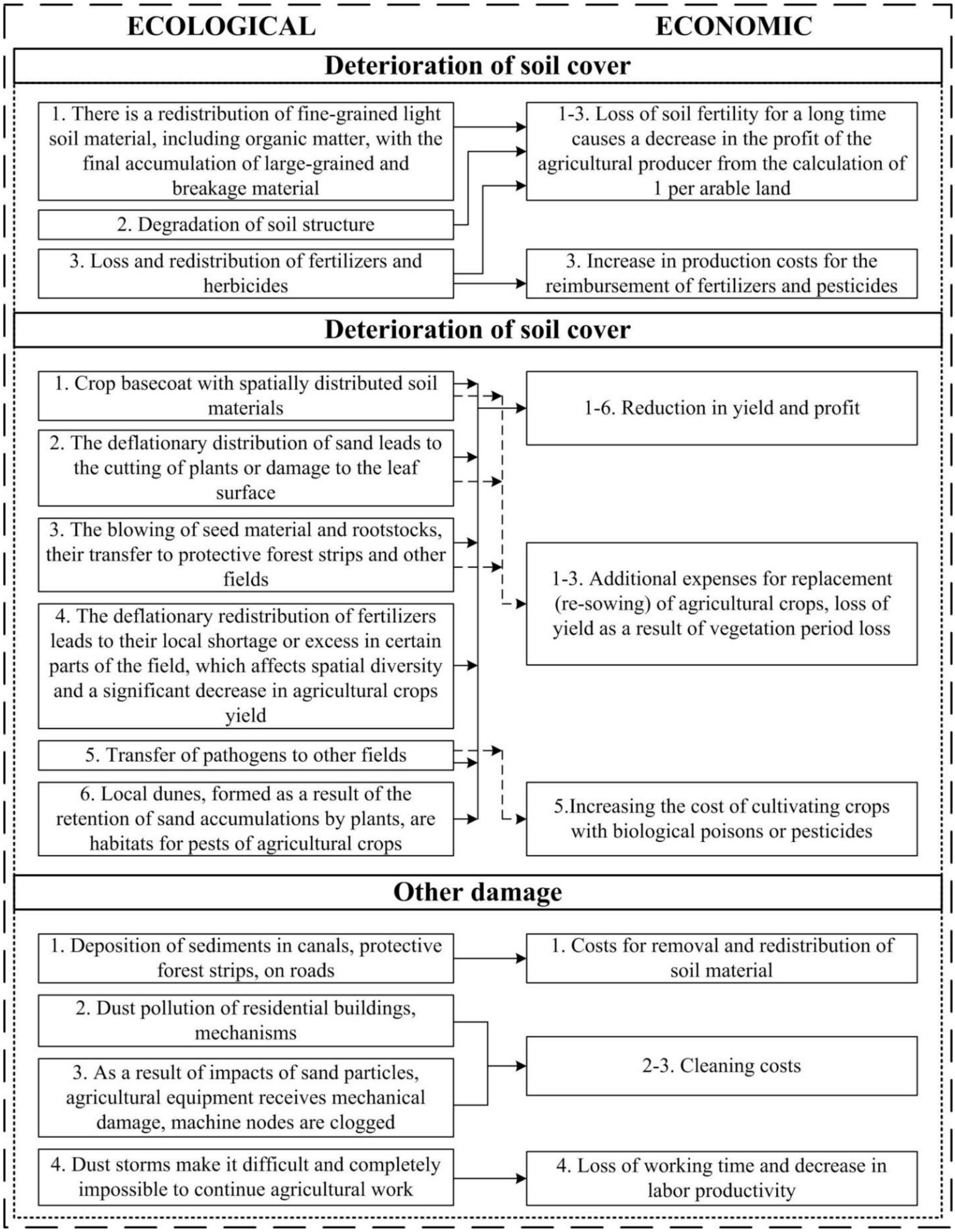

Fig.2. Ecological and economic consequences of wind erosion

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The researchers established that the low effectiveness of the existing contour-and-meliorative anti-deflation measures in the Steppe zone of Ukraine caused a large-scale disaster in 2007, when about 20% of agricultural land was at the epicenter of dust storms. In this regard, soil losses ranged from 10 to 400 t/ha [15]. Therefore, the problem of soil protection from degradation processes, especially in the steppe regions of Ukraine, has become particularly urgent and requires detailed comprehensive research in the direction of developing scientifically based regional soil protection systems of agriculture, finding new reproducing methods of eroded lands fertility.

For this purpose, as a result of spatial modeling, raster models of spatial differentiation of wind-erosion factors were created and soil deflation losses were calculated on the territory of the Steppe zone of Ukraine. The regression coefficients (*a*, *b*), lumpiness (k), destruction coefficients (Ks) for the main soils of Ukraine were calculated in accordance with the method of potential soil losses [9]. Studies have determined that the coefficients of the characteristics of genesis, particle size composition, density and other properties of the soils of the steppe region vary by factor-a (Fig. 3*a*) from 2.3497 (turf-podzolic, turf-podzolized, gleyed, podzolized sandy, clay-sandy and sandy soils soils) up to 4.3060 (chernozem (black soils) typical and ordinary medium and strongly eroded soils), factor-b (Fig. 3*b*) from 0.020 (chernozem (black soils) southern saline soils) to 0.058 (chernozem (black soils) typical and ordinary medium and strongly eroded soils). The average value of the k factor (Fig. 3*c*) varies from 17.5% (turf-podzolic, sod podzolized, gleyed, podzolized sandy soils, clayey-sandy and sandy soils) to 50.0% (gray podzolized, chernozems (black soils) with podzol and saline, chestnut saline, saline loam and clay soils), Ks factor (Fig. 3*d*) from 0.5 (chernozems (black soils), typical and ordinary medium and strongly eroded soils) to 0.83 (sod-podzolic, sod podzolized, gleyed, sandy soils, clay-sandy and sandy loam soils). Average maximum wind speeds during dust storms with 20% probability ($V_{av.max}$) decrease from the southeastern part of the research region to the northeastern from 26.1 to 13.7 m/sec. (Fig. 3*e*), the average number of hours per year with dust storms (*t*) in the Steppe zone of Ukraine also varies in this direction from 0 to 37.8 hours. (Fig. 3*f*).

The modified factor-C' – is the crop erosion index or vegetation cover factor, which determines the soil protection effectiveness of anti-deflation measures (*Kspe*) on the territory of steppe soils. This index determines the influence of agricultural culture (crop rotation or plant cover) and natural vegetation on deflationary processes. To establish the influence of the modified factor-C' on deflation processes, a correctly calibrated Landsat-8 satellite image was deciphered and a raster model of the spatial distribution of the factor-C' was obtained on the research steppe region territory as of March and August 2018 (Fig. 3*g*). Spatial differentiation of the factor-C' deflationary impact depends on the distribution of land areas occupied by natural vegetation and agricultural crops, and its seasonal value varies from 0 to 1. As a result of GIS modeling using a model of potentially possible soil losses because of deflation processes on the territory occupied by pure steam, in the absence of anti-erosion measures (Fig. 4*a*), soil losses in the epicenter of dust storms will range from 0.02 t/ha to 598.3 t/ha.

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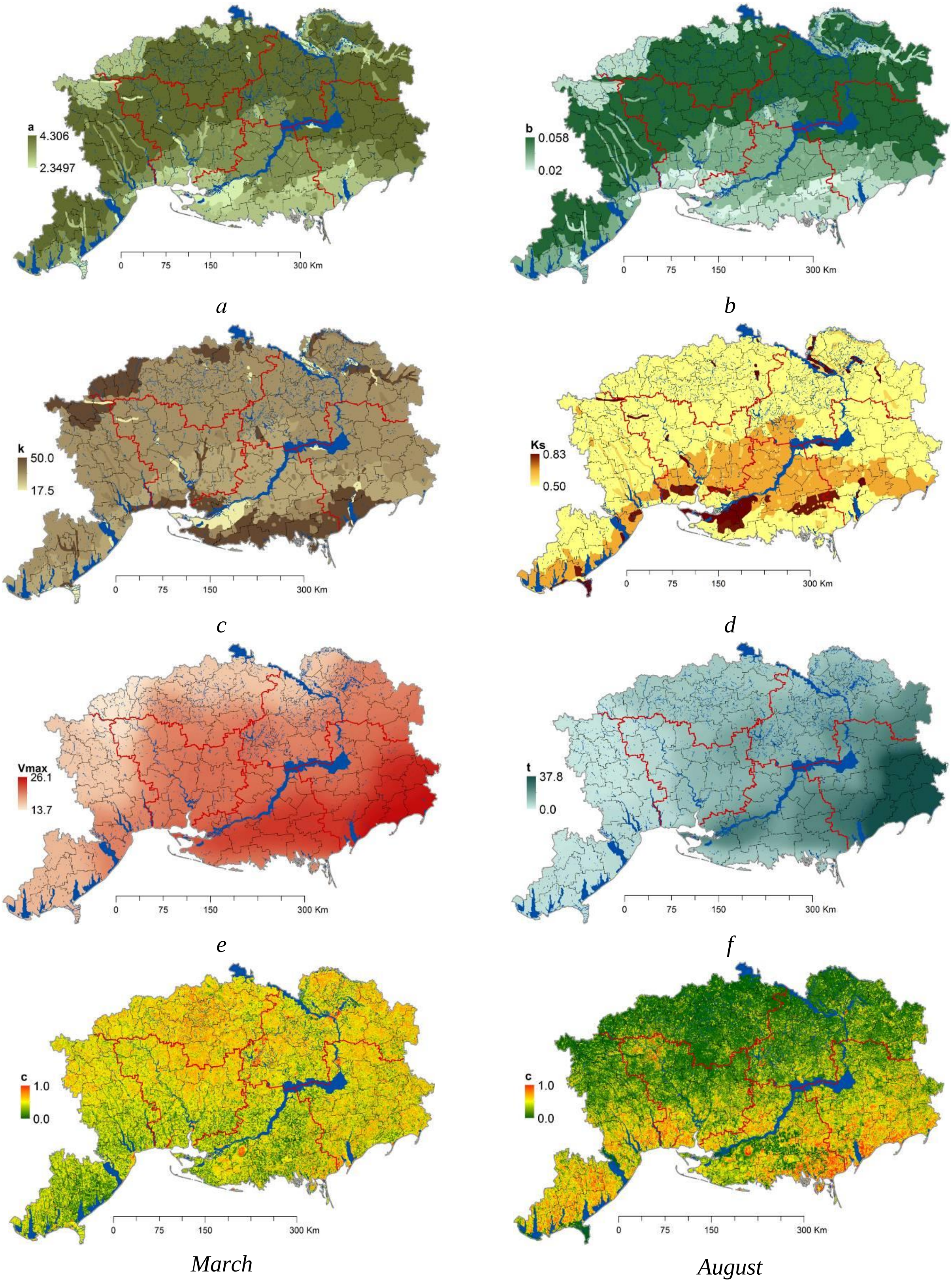

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a, b – coefficients that depend on the genesis, grain size composition, density, and other properties of the soil; c – lumpiness of the surface layer of the soil, %; d – coefficient of the destruction of aggregates of the surface layer of the soil; e – average maximum wind speed during dust storms of the 20th security, m/sec.; f – the average number of hours with the manifestation of wind erosion per year; g – coefficient of anti-deflationary effectiveness of culture or crop rotation

Fig. 4. Spatial distribution of the deflation process factors in the Steppe zone of Ukraine

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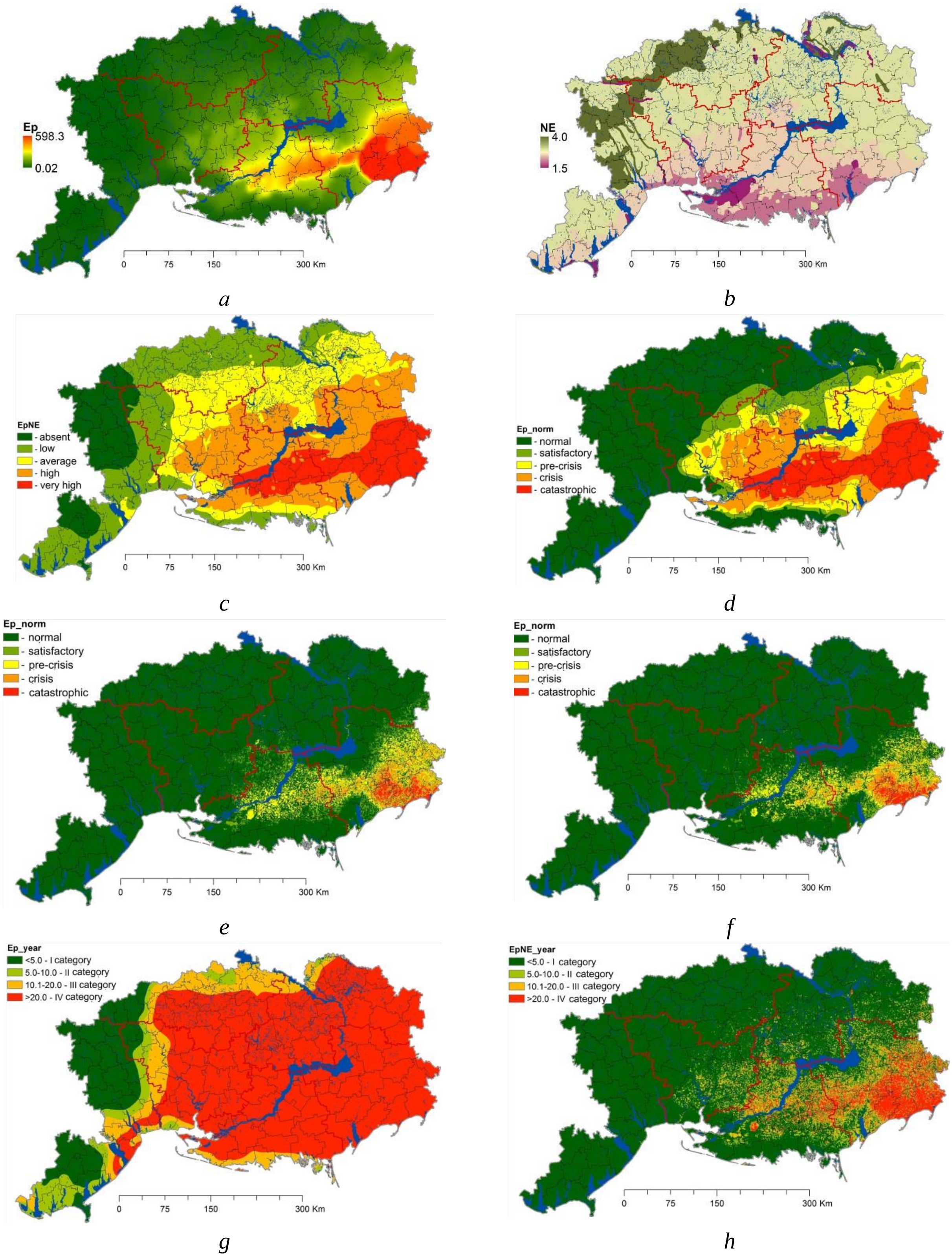

a – potentially possible deflationary soil losses from areas occupied by pure steam; b – annual rates of soil erosion; c – degree of wind erosion processes danger according to soil differences; d – the degree of wind erosion processes development in accordance with their standards; degree of seasonal wind erosion processes danger taking into account the c-coefficient: e – March; f - August; distribution of the territory by categories of deflationary soil losses: g – in the absence of anti-deflationary measures; h – taking into account the coefficient of anti-deflationary effectiveness of culture or crop rotation.

Fig. 5. Modeling of the spatial distribution of potential deflationary soil losses (t/ha) in the Steppe zone of Ukraine

 ISBN 978-9984-891-26-2

In order to determine the dangerous degree of wind erosion for the main soils of the flat territory of Ukraine, the norms of wind erosion processes were taken into account (Fig. 4*b*): turf-podzolic: turf and glee, their types, sandy and sandy, the rate of erosion is 1.5 t/ha; silted soils, glaciated and regraded types thereof, ordinary chernozems (black soils) of all types – 3.0 t/ha; typical chernozems (black soils) of all types, meadow-chernozem(black soils), meadow and chernozem(black soils) -meadow soils of all types on loess, alluvial and deluvial rocks – 4.0 t/ha; southern chernozems(black soils) of all types, clay-sandy chernozems(black soils), saline chernozems(black soils) on non-forest rocks – 2.5 t/ha; dark chestnut, chestnut salt marsh, meadow-chestnut salt marsh, glaciated salt marsh and sweetened soils of pods, salt marshes and salt marshes, meadow-marsh, swamp – 2.0 t/ha.

There are no deflationary soil losses in the territories (Fig. 4*c*) without exceeding their normative value (about 11.80% of the area of agricultural land (Table 1); weak erosion is manifested on 26.56% of the area with an excess of the soil loss rate up to 10 times; average – an excess of 10–30 times with an area of 23.5% of agricultural land; strong – from 30 to 100 times, the area of action is 25.96%; very strong – from 100 to 300 times, about 12.19% of lands; catastrophic – more than 300 times with the possibility of abnormal phenomena.

Table 1. Distribution of arable land areas according to the degree of wind erosion processes danger manifestations

Degree of wind erosion processes development	Excess soil loss over the standard of erosions, times	Area, thousand hectares	Specific gravity, %
The danger degree of wind erosion processes based on soil differences from the territories occupied by pure steam in the absence of anti-deflation measures			
Missing	0-1	1552.7	11.80
Weak	1-10	3495.5	26.56
Average	10-30	3092.5	23.50
Strong	30-100	3416.5	25.96
Very strong	100-300	1604.8	12.19
The degree of wind erosion processes development in accordance with their standard losses			
Normal (favorable)	1-20	6924.6	52.61
Satisfactory	20-30	1216.2	9.24
Pre-crisis	30-50	1623.5	12.33
Crisis	50-100	1792.9	13.62
Disastrous	> 100	1604.8	12.19
The seasonal danger degree of wind erosion processes, considering the ratio of anti-deflationary effectiveness of culture or crop rotation			
March			
Normal (favorable)	1-20	11404.9	86.65
Satisfactory	20-30	664.8	5.05
Pre-crisis	30-50	585.8	4.45
Crisis	50-100	374.4	2.84
Disastrous	> 100	132.1	1.00
August			
Normal (favorable)	1-20	11715.4	89.01
Satisfactory	20-30	535.9	4.07
Pre-crisis	30-50	475.0	3.61

Crisis	50-100	303.4	2.31
Disastrous	> 100	132.2	1.00
Distribution of the territory by categories of deflationary soil losses in the absence of anti-deflation measures, t/ha			
I category	< 5.0	1864.6	14.17
II category	5.0-10.0	840.4	6.39
III category	10.1-20.0	1581.5	12.02
IV category	> 20.0	8875.4	67.43
Distribution of the territory by categories of deflationary soil losses considering the ratio of anti-deflationary effectiveness of culture or crop rotation, t/ha			
I category	< 5.0	10482.4	79.64
II category	5.0-10.0	1102.8	8.38
III category	10.1-20.0	798l.9	6.07
IV category	> 20.0	777.9	5.91
	Total:	13162	100

In accordance with the excess of potential soil losses from deflation processes (Fig. 4*d*), it is recommended to implement appropriate anti-erosion measures. In particular, in the territories of the Steppe zone of Ukraine with a normal (favorable) degree of manifestation of wind erosion processes with an allowable excess of soil loss above the erosion rate up to 20 times, it is worth implementing conventional soil protection measures on 52.61% of agricultural land; in territories with a satisfactory degree of exceeding the norm from 20 to 30 times on 9.24% of land, it is necessary to carry out additional detailed calculations of soil losses, to implement minimal or "zero" soil cultivation technologies, the design distances between the main forest strips should not be more than 15-20- multiple height of plantings; in territories with a pre-crisis degree of deflationary soil loss (exceeding the norm by 30–50 times) with an area of 12.33% of land, it is necessary to implement soil protection systems of tillage, to carry out additional engineering calculations of soil losses and calculations of optimal distances between the main forest strips; in territories with crisis deflation processes (exceeding the norm by 50-100 times), the area of agricultural land is 13.62%, the frequency of droughts is 1.5-3.5 years with a hydrothermal coefficient of 0.2-0.3, a minimum system needs to be implemented soil protective tillage, mandatory seasonal calculation of soil losses and adjustment of optimal distances between forest strips, in addition, it is necessary to adjust the ratio of the main lands, moderate moistening during irrigation; the catastrophic degree of manifestation of wind erosion processes has territories of steppe soils with an area of 12.19% with an excess of soil loss norms more than 100 times, the frequency of manifestations of droughts is 1.5-2.0 years with a hydrothermal coefficient of 0.2-0.3, according to the data territories, scientific substantiation of soil protection optimization of the structure of the main land areas, implementation of special land reclamations, measures against salinization, soil salinization, and desertification of territories is necessary.

According to the intensity of deflationary destruction of soils manifestations, agricultural lands of the Ukrainian Steppe zone are divided into IV categories of erosion danger, in accordance with which contour-meliorating anti-deflation measures are implemented: I - lands that are not subject to wind erosion, soil loss is less than 6 t/ha; II – lands with weak wind erosion, soil losses of 6–10 t/ha; III – lands with average wind erosion, soil losses of 11–20 t/ha; IV – land with strong wind erosion, soil loss of more than 20 t/ha. Potential soil losses under the conditions of the anti-deflation effectiveness of culture or crop rotation (Fig. 4*h*) compared to the model of anti-deflation measures absence (Fig. 4*g*) are reduced by 5.62 times, which allows to optimize additional monetary expenditures for the implementation of anti-deflation measures: 1st category of agricultural land with a specific area of 79.64%, it is recommended to apply zonal agrotechnical measures with preservation and restoration of field protection forest strips; II with an area of 8.38%, the simplest anti-erosion measures are recommended - the optimal timing of soil treatment, fertilizer application, snow retention, no-till cultivation and sowing with the preservation of stubble on the soil surface, placement of crops and pairs in alternating strips 100–200 m wide and perpendicular to the direction erosive winds, additional creation of field protection forest strips; III-rd category of lands with a specific area of 6.07%, the same measures are carried out as on lands of II category, with the additional implementation of no-throw processing and sowing with maximum preservation of stubble, the creation of curtains from high-stemmed crops, strip placement of crops and pairs in combination with buffer strips of perennial grasses, creation of a system of field protection forest strips; IV-th category of land with an area of 5.91%, the entire complex of anti-erosion measures is recommended, including the introduction of soil-protective crop rotations with a predominant share in the crop rotation of perennial grasses, tillage and sowing with maximum preservation of stubble on the surface of the soil, continuous liming of wind-impacted slopes, placement of crops, steams and buffer strips with perennial grasses in strips 50–100 m wide perpendicular to the direction of erosive winds, creating a thickened network of forest strips.

To reduce the impact of temperature rise, drought phenomena, and water and wind erosion, it is necessary to develop and gradually implement anti-erosion soil protection measures aimed at the rational use of moisture resources. In conditions of high potential danger of erosive processes, it is effective to improve the management of surface runoff in the catchment basins of rivers by implementing a soil-, water-conservation contour and meliorative system of land use, which provide environmental protection and agro-economic efficiency.

The basis of the anti-erosion system is the contour organization of the agricultural land territory, differentiated in accordance with the topography of arable land, the use of hydro technical, forestry, and light improvement measures and the achievement of humus balance as a result of adjusting crop rotations.

In this context, it is necessary to implement the contour-ameliorative organization of the territory, subject to the implementation of the basin principles of land and water use [31, 32], which involves the development of appropriate national and regional soil protection programs from erosion degradation and desertification, adaptation of land use to new climatic conditions.

CONCLUSIONS

As a result of GIS and ERS technologies application, as well as an empirical and statistical model of possible soil loss from wind erosion in the territory of the Ukrainian Steppe zone, it was established that because of deflation processes in the territory occupied by pure steam in the absence of anti-deflation measures conditions, the value of soil loss in the epicenter of dusty windstorms can reach about 600 t/ha. In accordance with the norms of soil differentiation, about 40% of agricultural lands have a strong and very strong degree of deflationary processes manifestation. Research has proven the importance of the vegetation anti-deflation effect, which causes an increase in erosion-dangerous (favorable) areas of agricultural land by 1.7 times, which reduces soil loss by 5.62 times. According to the intensity of the deflationary process’s manifestations and the excess of soil losses, contour-ameliorative anti-deflation measures with elements of soil protection agriculture are proposed. Emphasis is placed on the importance of implementing a scientifically based and ecologically remedial system of agricultural management since its absence contributes to the negative consequences manifestation of soil cover destruction, a decrease in soil fertility, damage to agricultural crops, and, accordingly, economic losses. The conducted research should be used as a basis for the development of soil protection anti-erosion and contour-melioration measures, which will allow an economic assessment of the damage amount from erosion processes using the cost method, which will become the basis for the formation of the sustainable land use concept in the Steppe zone of Ukraine.

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