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Influence Pattern of Forest Strips Complex and Mulched Para-Plowing in Crop Rotations on Erosion in the Volga Region Steppe

Petr Proezdov
Department of Forestry and Landscape Construction
Saratov State Vavilov Agrarian University
Saratov, Russia
proezdovp@mail.ru

Dmitry Eskov
Department of Forestry and Landscape Construction
Saratov State Vavilov Agrarian University
Saratov, Russia
eskovdv@rambler.ru

Dmitry Mashtakov
Department of Forestry and Landscape Construction
Saratov State Vavilov Agrarian University
Saratov, Russia
tor1502@mail.ru

Aleksander Rozanov
Department of Economic Cybernetics
Saratov State Vavilov Agrarian University
Saratov, Russia
arosanov@yandex.ru

Abstract—**The article is devoted to the analysis of long-term data (1964-2019) and mathematical modeling of the impact of the complex of anti-erosion techniques in fodder and field crop rotations on the elements of water balance and soil erosion on the erosion-prone slope of 4,5°. It is established that after full-scale reclamation of the slope (filling of ravines, planting of contour forest strips reinforced by shafts-ditches) it is necessary to develop lands initially with perennial grasses (perennial rye, alfalfa), and then with crops of field crop rotations with the restriction of the use of tilled crops and fallows to 25 %. Fogger crop rotations re-duce the coefficient of surface runoff compared to the field by an average of 1.83 times, and erosion - 2.26 times. Forest strips together with mulched para-plowing reduce the runoff coefficient on average for crop rotations by 3 times, and erosion - by almost one order of magnitude – to an allowable value of 0.3 t/ha for southern chernozem with A+B < 0.5 m. Modeling has shown that soil erosion is 99 % associated with the runoff coefficient and the degree of protection of ploughed field by agrotechnical and forest improvement techniques in crop rotations. The results of the research can be used in digital mapping of eroded lands in modern precision farming systems implemented in the Saratov region in order to improve the efficiency and quality of their use.**

Keywords—erosion, runoff coefficient, crops, crop rotations, forest strips, mulched para-plowing, modeling.

I. Introduction

The problem of soil protection from erosion is the most important in the agricultural sector of the economy of the Eurasian countries [1, 2] including the Russian Federation [3, 4]. According to VNIIALMI (now the Federal Scientific Center for Agroecology), 65 % of ploughed field, 28 % of hayfields and 50 % of pastures are subject to erosion and deflation [3]. In the steppe of the Volga region on erosion-prone slopes 3-8° soil erosion exceeds 3 t/ha, and the growth of ravines is an average of 2.5 m/year with a reduction in land area of 0.2 ha/year per 100 ha [4].

Forest strips are the ecological framework of forest-agrarian landscapes, which is the basis of the modern concept of agricultural afforestation (agroforestry) [3-5]. Plantings, being almost invariable natural objects, provide possibility of creation of uniform steady structure of a forest-agrarian landscape for ecological adaptation of agricultural land use to it [6, 7]. Forest strips on land contribute to an increase in water reserves in snow and soil moisture, reducing surface runoff and erosion [8, 9].

Field and fodder crop rotations with applied crops play a significant role in soil erosion protection. Full-scale reclamation of low-productive erosion-prone lands (with steepness >3°) often involves filling of slope ravines with subsequent development of the first 3-4 years for fodder crop rotations with the participation of perennial grasses 100 % (phytomelioration). Then the slope lands can be developed for field crop rotations with a different combination of crops and the corresponding restriction of the use of the most erosion-hazardous broad-row plants and naked fallows [4, 10].

Long-term practice of application of erosional-preventive methods has shown that their success depends on a considerable number of diverse factors the consideration of the influence of which is impossible without the use of modern methods of mathematical modeling.

II. Purpose and object of research

The purpose of the study is to determine, based on statistical processing of long-term data of field studies and mathematical modeling, optimal parameters and conditions of soil content at the permissible level of erosion in the conditions of application of a complex of forest strips and mulched para-plowing in fodder and field crop rotations.

The object of research is located in the Volga steppe in the farm "Vyazovskoye" of Tatishchevsky district of the Saratov region, which is a scientific and industrial hospital of the Department of forestry and landscape construction of the Saratov State Agrarian University named after N.I. Vavilov. The soil of the object of study on the slope of 4.5° - southern crushed chernozem medium loamy medium washed on the flask with the capacity of soil horizons A+B < 0.5 m and humus content 3.7%.

Erosional-preventive complex at the station includes the following:

- contour-reclamation organization of the slope with a steepness of 4,5°;

- filling of ravines with preservation of fertile soil layer (cutting thickness up to 4 cm) and application of organic fertilizers 100 t/ha;

- planting of two forest strips in 300 m, width 19.5 m, with the main breed of Siberian larch (Larix sibirica);

- application of mulched para-plowing between forest strips in 1.4-2.8 m (mulch - straw shreddings 0.3 m long on depth of a crack 0.2 m for fight against iciness and siltation);

- development of the inter-stripe section: in the first 9 years (1964-1972) - for fodder crop rotations: perennial grasses - 100 %; perennial grasses - 50 %, forage crops - 34%, tilled for silage - 16%, and in subsequent years (1973-2019) - for field crop rotations with the share of tilled crops and fallows 25 % and other crops - 75%.

The scheme of field experiments provided for the study of the influence of the type of crop rotation in the complex of forest strips and mulched para-plowing on the formation of precipitation, surface runoff and erosion in different with water content and moisture years (1964-2019) [4].

III. RESEARCH METHODOLOGY

The methodology and methods of the research are based on the land, forest and water codes of the Russian Federation using the principles of the organization of the theory and practice of classical agricultural afforestation (agroforestry), standard and private methods of planning and conducting experiments

TABLE I.   ELEMENTS OF WATER BALANCE AND SOIL EROSION WITHOUT INFLUENCE OF FOREST STRIPS AND MULCHED PARA-PLOWING (ON AVERAGE FOR 1964-2019)

Crop rotations	Water reserves in snow + rainfall, mm	Spring + storm runoff, mm	Drain ratio k	Degree of protection of ploughed field from erosion by crop rotations C_E	Spring + storm water erosion E_S, t/ha	Runoff turbidity, g/l
Fodder crop rotation: 100 % of crop rotation- perennial grasses	113	13	0.12	0.95	1.49	11.5
Fodder crop rotation: 50% of crop rotation - perennial grasses, 34% - spring crops for fodder, 16% - tilled crops for silage.	104	14	0.15	0.85	1.66	11.8
Field crop rotation: 25% fallows and tilled crops, 75% the rest of crops	101	22	0.22	0.5	3.36	15.3

The study used: a set of methods used in agroforestry, soil science, arable farming, hydrology, hydrometry and others; methods of generalization, observation, comparison, statistical, cartographic, modeling. Field experimental data were processed by methods of variational statistics. Observations and studies were carried out based on GOST standards, methods and recommendations of Russian research institutes, universities and individual scientists [4, 6, 11].

IV. RESULTS

Studies conducted in different with water and moisture content years have shown that forage crop rotations compared with field reduce surface runoff to 69.2 %, and the runoff coefficient - to 83.3 %, indicating a positive hydrological role of perennial grasses, especially for snow deposition.

TABLE II.   ELEMENTS OF WATER BALANCE AND SOIL EROSION FOR FOREST STRIPS AND MULCHED PARA-PLOWING (AVERAGE FOR 1964-2019)

Crop rotations	Water reserves in snow + rainfall, mm	Spring + storm runoff, mm	Drain ratio k	Degree of protection of ploughed field from erosion by crop rotations C_E	Spring + storm water erosion E_S, t/ha	Runoff turbidity, g/l
Fodder crop rotation: 100 % of crop rotation- perennial grasses	132	7	0.05	1.0	0.19	2.7
Fodder crop rotation: 50% of crop rotation - perennial grasses, 34% - spring crops for fodder, 16% - tilled crops for silage.	129	6	0.05	1.0	0.23	3.8
Field crop rotation: 25% fallows and tilled crops, 75% the rest of crops	121	6	0.05	1.0	0.29	4.8

Under the influence of a complex of erosion-preventive techniques, 5% of precipitation is lost to runoff regardless of the type of crop rotation. In field crop rotations compared to fodder rotations soil erosion with runoff coefficient growth increases by almost 2.4 times. Phytomeliorative crop rotations reduce soil erosion by 11.4% compared to fodder ones with a 50% share of perennial grasses. Indicators of turbidity of water flow appropriately decrease with the use of fodder crop rotations (see table 1, 2). The content of southern chernozem with A+B < 0.5 m at the permissible erosion level of 0.3 t/ha is possible regardless of the type of crop rotation in the complex of forest strips and mulched para-plowing [2].

A. Mathematical modeling

Comprehensive accounting of all environmental factors affecting soil erosion (precipitation, surface runoff, soil freezing and infiltration, etc.), due to their diversity, is a very difficult task. The fact is that from a fundamental point of view, the set of environmental factors is a multidimensional hypersurface, the detailed study of which is complicated by the complexity of its structure. Therefore, for practical purposes, it is advisable to use such mathematical models and methods that would allow to consider the impact on the erosion of agricultural land the most significant of these factors and at the same time would allow for a mathematical description available for practical needs. For mathematical processing of materials of 56-year-long observations, covariance analysis was applied using B.A. Dospekhov [11]

methods and professional versions of application software packages.

In this paper, a probabilistic modeling method was used to analyze the influence of environmental factors on erosion, assuming the replacement of a real object with its statistical model [12].

Based on empirical and analytical methods of research from the variety of natural and anthropogenic factors affecting soil erosion and the success of protection against it, the following key factors were identified, namely: type and level of precipitation, amount of runoff, degree of protection of plowed field from erosion by crop rotations and applied erosion control techniques [4, 6, 9]. Regression and correlation analyses revealed that the most significant factors affecting erosion are the runoff coefficient and the level of protection of plowed field by crop rotations in combination with forest strips and mulched para-plowing.

The corresponding multiple regression equation has the form:

$$E_S = b_0 + b_1k + b_2C_E + b_3kC_E, \qquad (1)$$

where E_S - spring and storm erosion, t/ha; k - coefficient of spring + storm runoff; C_E - degree of protection of arable land from erosion by crop rotations using a complex of forest strips and mulched para-plowing, b_0 - b_3 - multiple regression coefficients.

In the process of regression analysis and modeling data the following crop rotations were used:

- pure fodder, which corresponds to the value of CE = 0.95 (100 % - perennial grasses - phytomelioration);

- mixed fodder CE = 0.85 (50 % - perennial grasses, 34 % - forage crops, 16 % – tilled crops);

- field CE = 0.50 (25% –tilled, 75% - fallows and other crops).

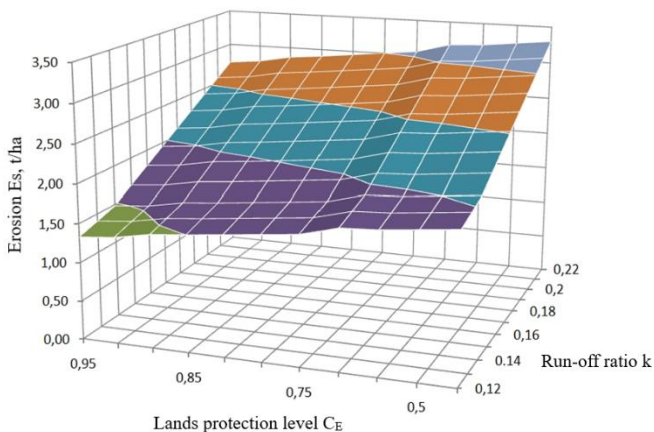$Es = 3,24 + 5,69*k - 3,33*C_E + 4,58*k*C_E$; $R^2 = 0,99$

Fig. 1. Dependence of erosion on the runoff coefficient and the degree of protection of arable land from erosion by crop rotations in combination with forest strips and mulched para-plowing.

The response surface for model (1) is shown in figure 1. Regression analysis showed that soil erosion is 99% determined by the runoff coefficient, reflecting the ratio of runoff to precipitation, and the degree of protection of arable land from erosion by crop rotations in combination with forest strips and mulched para-lowing.

B. *The practical significance of the proposals and the results of the implementation*

The results of the study were implemented according to the developed projects of complexes of anti-erosion techniques in farms located in the steppe zone of the Right bank of the Saratov region, "Lesnoe" of Tatishchevsky district on 13 thousand hectares and "imeni Lenina (n.a. Lenin)" of Balashovsky district on 9 thousand hectares. The created forest strips on the area of 513 hectares with forest cover of 2.3% and the fixed tops of large ravines by hydro-technical utilities (spillway channels) stopped growth of ravines. Filling of slope ravines with preservation of a fertile layer of soil and other conditions of full-scale reclamation [10] on 454 hectares are carried out. Two anti-erosion dams with a catchment area of 1500-2000 hectares were built. Between the forest strips on the slopes, the beardless technology of cultivation in soil-protective crop rotations and mulched para-plowing are used. The implementation of complexes of erosion-protection techniques allowed to increase the productivity of agricultural land by 10-40%, and large values correspond to dry years [4].

V. CONCLUSION

Data processing of more than half a century (1964 – 2019) experience of development of eroded lands of the steppe Volga region and mathematical modeling of soil erosion processes showed that:

- type of crop rotation with different combinations of crops and fallows plays a decisive role in the sequence of application of initially forage and then field crop rotations on erosion-prone slope lands (>3º);

- soil erosion is determined by 99% runoff coefficient and the degree of protection of arable land with the optimal combination of crops in crop rotations, forest strips and mulched para-plowing;

- permissible erosion of 0.3 t/ha on southern chernozems with A + B < 0.5 m is achieved using contour forest strips and mulched para-plowing of inter-stripe fields in the applied crop rotations.

The results obtained can be used to improve the efficiency and quality of agricultural land use in modern precision farming systems.

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