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Environment-forming and stabilizing role of the soil-protective agroforestry landscape complex on slopes

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Abstract. This study examines the effects of forest belts on erosion and hydrological conditions, soil moisture reserves, and cellulolytic activity, as well as their influence on agricultural crop yields on slopes. The research reveals that forest belts lead to increased snow depth and even distribution, reduced soil freezing, and decreased water erosion risk in catchment areas. Additionally, forest belts enhance moisture reserves in the middle slope by reducing lateral water flow. In comparison to upland areas, the lower and middle parts of the slope typically exhibit greater snow depth, reduced soil freezing, and increased soil moisture. Forest belts also promote higher cellulolytic activity in adjacent areas. The study finds that barley yields increase on slopes with forest belts, but buckwheat yields decrease due to excessive vegetative growth.

1 Introduction

A feature of agricultural landscapes with complex relief is the high spatial heterogeneity of the soil cover, which creates different abiotic and biotic conditions for the growth and development of cultivated crops according to the relief elements. Depending on the shape of the relief and the exposure of the slopes, the snow cover and insolation are unevenly distributed; accordingly, different regimes of soil profile moistening and thermal conditions are formed. Slopes of southern and southwestern exposure warm up better than slopes of northern and northeastern exposure. In concave landforms, the temperature is lower than the temperature in convex landforms. On slopes of northern and northeastern exposure, as a rule, moisture reserves are higher than on slopes of southern and southwestern exposure [1]. Changes in temperature and moisture regime inevitably affect the microbiological activity of the soil, the processes of humification and mineralization of organic matter. Accordingly, across relief elements their intensity and direction are ambiguous, since unequal conditions are created for the active life of soil microorganisms [2]. Thus, the listed features, characteristic of agricultural landscapes with hilly terrain, explain the mechanism for the formation of higher diversity of soil fertility in a given area, in comparison with flat terrain.

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The instability of parameters characterizing the properties of soils in agricultural landscapes with complex topography complicates the management of the production process during the cultivation of agricultural crops [3] and increases the costs of optimizing the conditions for plant growth and development. Unlike flat areas, conditions are created on slopes for water erosion of soils, which is considered the most large-scale and harmful factor in soil degradation. Melt water or rainfall with a high concentration does not have time to seep into the soil on the slopes, resulting in the formation of surface runoff, which, in turn, leads to the washout of the most fertile top layer of soil [4, 5]. Therefore, hilly agricultural landscapes, as a rule, are characterized by the presence of washed away (eroded) and reclaimed soils, which differ radically in fertility. On slopes of different exposures, there is a different intensity of water erosion processes and different rates of accumulation and mineralization of organic matter. It has been established that the highest losses of organic matter, including due to erosion processes, occur on slopes of southern exposure, and less on slopes of northern exposure [6]. On washed away soils, a higher mineralization of organic matter is observed in comparison with non-eroded soils, which indicates that water erosion has a destabilizing effect on soil properties [7]. Thus, water-erosion processes also contribute to an increase in the diversity of soil fertility. The listed features of agricultural landscapes with complex topography necessitate the need to find ways and techniques that allow optimizing water-physical, biological and production processes in them at the optimal level, ensuring stable and resource-saving management of the crop growing sector of agricultural production.

On slopes, soil protection from water erosion is implemented in the form of anti-erosion complexes. They include various complementary measures aimed at preventing or at least reducing surface runoff of melt and storm water that causes soil loss. Anti-erosion complexes involve the use in agricultural landscapes with complex topography of the correct organization of the territory, soil protection forest belts and crop rotations, various hydraulic structures and agrotechnical techniques. In combination with other anti-erosion measures, soil protection forest strips are highly effective in combating water erosion of soils. They are nature-like (natural) objects that have a multifaceted impact on natural processes in the surrounding environment, forming a special microclimate that differs from treeless space [8, 9].

2 Materials and methods

The influence of forest strips as an element of the soil-protective agroforestry landscape complex on erosion-hydrological conditions, moisture reserves in the soil, cellulosic activity of the soil and crop yields was determined in 2022-2023. in a stationary field experiment on contour-reclamation farming, which has been conducted since 1982 on the territory of the Kursk region of the Russian Federation. The objects of the study were two catchment areas with complex hollow-beam topography, which differed in the degree of saturation with erosion control elements. In the control catchment area, which has an area of 44.3 hectares, there are no erosion control elements. In another catchment area, the area of which is 46.6 hectares, since 1985, narrow-row runoff-regulating forest strips have been growing, the tree composition of which is represented by poplar. Forest strips are located in rows along the diagonals of the slopes. There are only three rows of forest belts, the distance between them is 216 m. Each forest belt consists of two rows of trees, between which a water-retaining ditch 1.5 m deep is cut to enhance the anti-erosion effect. At the lower edge of each forest belt, also to enhance the anti-erosion effect, a water-retaining shaft is formed. In 2022, arable land on all relief elements within the catchment areas was used for barley; in 2023, buckwheat was sown. To assess the influence of relief elements on the studied indicators, studies were carried out on the upland, in the middle and lower part of the slope with western exposure.

Weather conditions during the growing season of cultivated crops (from April to August) during the years of research were assessed using data from the Kursk meteorological station. The height and distribution of snow cover according to the experimental options, as well as water reserves in the snow, were determined during the snow survey, in accordance with the regulations established in the governing document. Moisture reserves in the soil were determined at the beginning of the growing season of the crop and after harvesting. We used the calculation method, having previously determined the soil moisture. The cellulolytic activity of the soil was determined by the application method using linen fabric. The yield of cultivated crops was taken into account using a grain harvester. The experimental data were processed using the statistical method of analysis of variance.

3 Results and discussion

The growing conditions and productivity of agricultural crops are largely determined by meteorological conditions during their growing season, and depend on temperature conditions and precipitation. In 2022, in April and May, the growing season of barley took place at a reduced temperature; in June the air temperature was above normal, and in July it was within the long-term normal (Fig. 1).

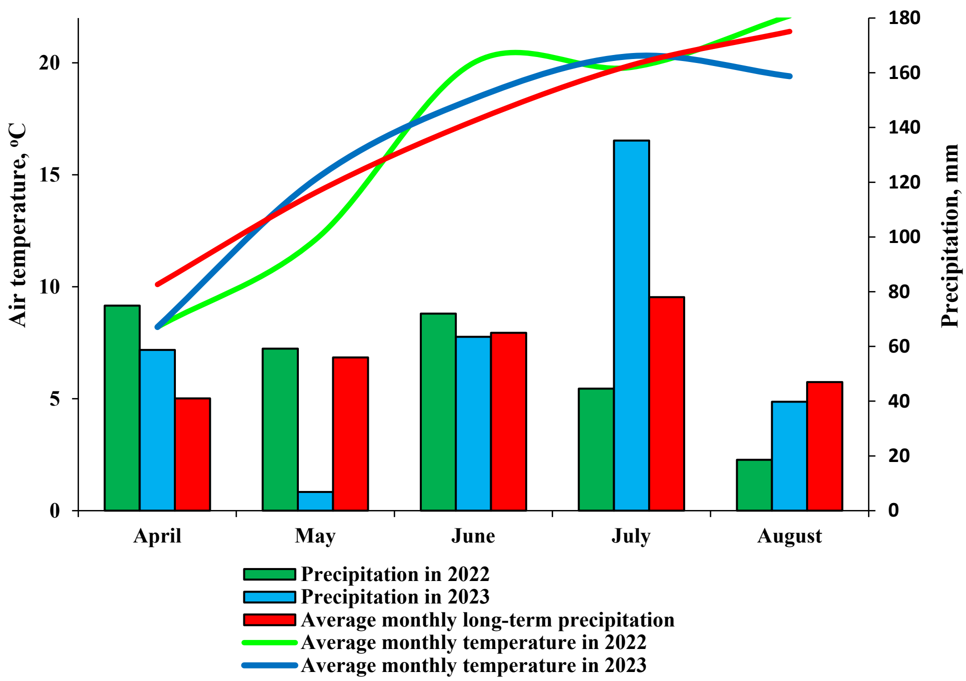

Fig. 1. Meteorological conditions during the research.

The amount of precipitation that fell during the barley growing season under the conditions of 2022 was 11 mm higher than the long-term norm. In 2023, in April the air temperature was above the long-term norm, but in May, June and July it was below the norm. Precipitation fell 24 mm more than the long-term norm.

Forest strips as elements of a soil-protective agroforestry landscape complex in all years of the study contributed to greater accumulation of snow in the interstrip space on the slopes of the catchment area, compared to the catchment area without erosion protection elements.

In 2022, in a catchment area without erosion control elements before snowmelt, the average snow cover height across relief elements was 21.7 cm, and in a catchment area with forest strips it was 30.2 cm, which is 8.5 cm more (Table 1).

Table 1. The influence of the soil-protective agroforestry complex and relief elements on the height of snow cover.

Watersheds (factor A)	Relief elements (factor B)	Snow depth, cm	
		2022	**2023**
Without anti-erosion protection	Plakor	22.4	7.2
	Middle of the slope	18.0	6.6
	Bottom of the slope	24.6	9.4
With forest stripes	Plakor	28.4	12.6
	Middle of the slope	31.8	15.2
	Bottom of the slope	30.4	14.4
HCP_{05} of A factor		0.4	0.4
HCP_{05} of B factor		0.6	0.5
HCP_{05} for private differences		0.8	0.7

Under the conditions of 2023, the snow depth in the catchment areas before snowmelt was less than in 2023, but the same pattern of influence of forest belts on this indicator remained. On average, for the relief elements in the catchment area without erosion control elements, the snow cover height was 7.7 cm and in the catchment area with forest strips it was 14.1 cm. Of particular interest is the distribution of snow cover among the relief elements in the studied catchment areas. It was found that in all years in the catchment without erosion protection elements, the highest snow depth was recorded in the lower part of the slope, and the minimum in the middle part of the slope. The results obtained indicate that in areas without forest belts, snow was blown by wind flow from the middle of the slope to its lower part. In a catchment with a soil-protective agroforestry landscape complex, forest strips contributed to the retention of snow on the slope in the space between the strips. The highest snow depth in all years of the study was noted in the middle part of the slope, and the lowest on the upland. Plumes with the maximum height of snow cover formed near forest belts. The accumulation of snow in the fields provides additional moisture to the soil, which is a factor in plant life. In 2022, in the catchment with a soil-protective agroforestry complex in the snow, water reserves were 25.6 mm higher, and in 2023, respectively, 12.6 mm higher, compared to water reserves in snow in the catchment without erosion protection elements.

The depth of snow cover has a direct impact on the depth of soil freezing, which, in turn, affects the likelihood of meltwater runoff and soil washout. The greater the height of the snow cover, the shallower the depth the soil freezes [10]. The probability of the formation of melt water runoff and soil washout occurs when the soil freezing depth is more than 50 cm [11]. It was found that in the conditions of 2022, which was characterized by a higher snow cover, the depth of soil freezing was much less than in the conditions of 2023 with a relatively low snow cover (Table 2).

Table 2. The influence of the soil-protective agroforestry complex and relief elements on the depth of soil freezing.

Watersheds (factor A)	Relief elements (factor B)	Snow depth, cm		
		2022	**2023**	**Average**
Without anti-erosion protection	Plakor	16.7	29.7	23.2
	Middle of the slope	22.7	33.0	27.8
	Bottom of the slope	15.3	27.3	21.3
With forest stripes	Plakor	11.7	22.0	16.8
	Middle of the slope	7.3	17.3	12.3

	Bottom of the slope	9.7	19.7	14.7
HCP_{05} of A factor		0.6	0.6	-
HCP_{05} of B factor		0.8	0.7	-
HCP_{05} for private differences		1.1	1.0	-

On average, based on relief elements in 2022, in a catchment without erosion protection elements, the soil freezing depth was 18.2 cm, and in 2023, the soil froze to a depth of 30.0 cm. Accordingly, in a catchment with forest belts in 2022, the soil froze to a depth of 9.6 cm, and in 2023 – to a depth of 19.7 cm.

Assessing the influence of relief elements on the depth of soil freezing, it can be noted that an inversely proportional dependence of the freezing depth on the depth of snow cover has emerged. In 2022, in the catchment without erosion protection elements in the middle part of the slope, the depth of soil freezing was 6.0 cm greater, and in the lower part of the slope - 1.4 cm less, compared to the depth of freezing on the upland. In a catchment with forest strips, under the conditions of this year, in the middle part of the slope, the depth of soil freezing was 4.4 cm less, and in the lower part of the slope - 2.0 cm less than the depth of soil freezing on the upland. The same pattern in the influence of relief elements on the depth of soil freezing in the conditions of various watersheds appeared in 2023. In the watershed without erosion protection elements in the middle part of the slope, the depth of soil freezing was 3.3 cm greater, and in the lower part of the slope - 2.4 cm less than the depth of soil freezing on the platform. Accordingly, in the catchment with forest strips in the middle part of the slope, the depth of soil freezing was 4.7 cm less, and in the lower part of the slope - 2.3 cm less, in comparison with the depth of soil freezing on the upland. The results obtained indicate that the anti-erosion agroforestry landscape complex, due to greater accumulation of snow in the fields, ensures a shallower depth of soil freezing, reducing the likelihood of the formation of surface meltwater runoff and the manifestation of water erosion of soils on slopes.

For the normal growth and development of agricultural crops, the formation of their high yields, it is necessary to ensure sufficient reserves of moisture available to plants in the soil. On slopes in regions of the country with insufficient and unstable moisture, this problem becomes particularly relevant, since moisture loss occurs due to surface runoff of melt water and storm precipitation [12], as well as due to lateral intrasoil runoff of water seeped into the soil column down the slope [13]. During the years of study, the amount of precipitation far exceeded its long-term annual norm, and moisture did not limit the growth and development of agricultural crops. With an annual norm of 632 mm, in the conditions of 2022 the actual amount of precipitation was 884 mm, and in 2023, accordingly, 863 mm of precipitation fell. Moisture reserves in the soil were determined at the beginning of the growing season and after harvesting barley under conditions of 2022, and at the beginning of the growing season and after harvesting buckwheat under conditions of 2023. It was established that in 2022, in a catchment with forest strips, the reserves of available moisture in a meter layer of soil were 8.8 mm larger than in the catchment area without erosion protection elements. In the conditions of 2023, there was only a tendency for moisture reserves to exceed in the catchment area with forest strips, in comparison with the catchment area without erosion protection elements (excess by 2.0 mm) (Table 3).

When assessing the influence of relief elements on the reserves of available moisture in watersheds with different saturation with elements of erosion protection, it was found that in all years in the middle part of the slope, the reserves of available moisture in all watersheds were significantly less than in the upland. This difference was especially noticeable in the catchment without erosion protection elements. In 2022, in the middle part of the slope, moisture reserves in this catchment were 12.6 mm less, and in 2023 - 13.2 mm less than in the upland. In a catchment with forest strips, under the conditions of 2022, in the middle part of the slope, moisture reserves were 5.1 mm less, and in 2023, correspondingly, 6.6 mm less, compared to the upland.

Table 3. The influence of the soil-protective agroforestry landscape complex and relief elements on the reserves of available moisture in the soil layer of 0-100 cm.

Watersheds (factor A)	Relief elements (factor B)	The period for determining the indicator (factor C)	Available moisture reserves, mm		
			2022	2023	Average
Without anti-erosion protection	Plakor	Beginning of the growing season	307.5	273.6	290.6
		After harvest	194.3	233.8	214.0
	Middle of the slope	Beginning of the growing season	287.8	255.9	271.8
		After harvest	188.7	225.1	206.9
	Bottom of the slope	Beginning of the growing season	305.3	290.1	297.6
		After harvest	209.9	246.2	228.0
With forest stripes	Plakor	Beginning of the growing season	302.1	288.9	295.5
		After harvest	223.8	226.0	224.9
	Middle of the slope	Beginning of the growing season	296.1	274.5	285.3
		After harvest	219.6	227.2	223.4
	Bottom of the slope	Beginning of the growing season	292.3	291.1	291.7
		After harvest	212.0	228.8	220.4
HCP_{05} of A factor			1.5	3.5	-
HCP_{05} of B factor			1.8	4.3	-
HCP_{05} of C factor			1.5	3.5	-
HCP_{05} for private differences			3.6	8.6	-

It is characteristic that in all years of study in the catchment area without erosion protection elements, the highest moisture reserves were in the lower part of the slope. Under the conditions of 2022, in the lower part of the slope in this catchment they were 6.7 mm larger, and in 2023, correspondingly, 14.5 mm larger, compared to the upland. The results obtained can be explained by the unimpeded lateral intrasoil flow of moisture that seeped into the soil column down the slope. In a catchment with forest belts, only in the conditions of 2023, an insignificant (by 2.5 mm) excess of the reserves of available moisture in the lower part of the slope appeared, in comparison with the upland. In 2022, in the catchment with forest strips, moisture reserves were 10.8 mm less than in the plain. The results obtained indicate that forest strips with a water catchment ditch, placed diagonally across the slope, are a natural obstacle to the lateral intrasoil flow of the bulk of the moisture that has seeped into the soil into the lower part of the slope. In a catchment area with forest strips, moisture reserves on the upland and in the middle part of the slope are significantly greater compared to similar elements of the catchment topography without erosion protection elements. It was established that in all years of the study, after harvesting of cultivated crops, the moisture reserves in the soil in all variants of the experiment were significantly less than the moisture reserves at the beginning of their growing season. The difference in moisture reserves after harvesting and at the beginning of the barley growing season in the conditions of 2022 was in the range of 76.5-113.2 mm, and in the conditions of 2023, respectively, in the range of 30.8-62.9 mm. If there is a sufficient amount of precipitation during the growing season of cultivated crops, the results obtained are explained by the consumption of moisture to form their yield.

The environment-forming role of forest strips as an element of a soil-protective agroforestry landscape complex was revealed when assessing their influence on the cellulolytic activity of the soil, which characterizes the representativeness and activity of soil microorganisms that take part in the destruction of post-harvest plant residues in the soil [14]. It was found that under the conditions of 2023, after two months of exposure, the highest intensity of cellulose decomposition, which amounted to 60.7%, was observed directly in the forest belt (Fig. 2).

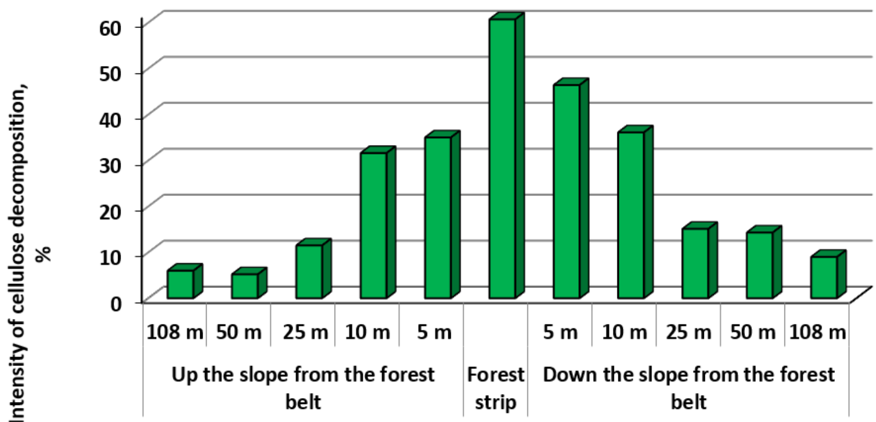

Fig. 2. The influence of distance from the forest belt on the intensity of cellulose decomposition.

With increasing distance from the central forest belt up and down the slope, a decrease in the intensity of decomposition of flax was noted. It is characteristic that the cellulolytic activity of the soil on the slope area below the forest line was slightly higher in comparison with the area located above the forest line. The high cellulolytic activity of the soil in the forest belt and in areas adjacent to it is explained by the higher moisture supply of the soil, as well as the presence of leaf litter, which is an additional source of undecomposed organic matter necessary to feed soil microorganisms.

Abiotic and biotic environmental conditions are the background that directly affects the formation of the level of productivity of cultivated crops. It was previously noted that forest strips, as elements of an anti-erosion agroforestry landscape complex in the corresponding catchment, contribute to greater accumulation of moisture on slopes in the interstrip space, compared to a catchment without erosion protection elements. In the immediate vicinity of the forest belt, the microbiological activity of the soil increases significantly and, in general, a certain microclimate is formed on the slope in the space between the belts, different from areas not protected by forest belts. Changes in plant growth conditions under the influence of forest belts also affected the yield of cultivated crops. It was found that under the conditions of 2022, on average, according to relief elements in a catchment area with forest strips, the barley yield was significantly (1.05 t/ha) higher in comparison with the crop yield obtained in a catchment area without erosion protection elements (Table 4).

Table 4. The influence of the soil-protective agroforestry complex and relief elements on the productivity of agricultural crops.

Watersheds (factor A)	**Relief elements (factor B)**	Harvest, t/ha	
		2022 г.	2023 г.
Without anti-erosion protection	Plakor	4.46	1.25
	Middle of the slope	4.21	1.34
	Bottom of the slope	3.90	1.63
With forest stripes	Plakor	5.29	1.20
	Middle of the slope	5.71	0.93
	Bottom of the slope	4.71	1.65
HCP_{05} of A factor		0.07	0.04
HCP_{05} of B factor		0.08	0.05
HCP_{05} for private differences		0.12	0.07

It is characteristic that in a catchment area without erosion protection elements, the maximum barley yield was obtained in the flat area; in the middle part of the slope, the yield was 0.25 t/ha less, and in the lower part of the slope, correspondingly, less by 0.56 t/ha. In the catchment area with forest strips, the highest barley yield, which is 0.42 t/ha more than on the upland, was obtained in the middle part of the slope. The minimum yield level is 0.58 t/ha less than on the upland, in the lower part of the slope. The results obtained indicate that forest belts not only generally increase the level of barley yield, but also allow more efficient use of soils on slopes as a source of high crop productivity.

In 2023, the buckwheat yield in the catchment area without erosion protection elements, on average across relief elements, was higher than in the catchment area with an anti-erosion agroforestry complex by 0.15 t/ha. A detailed analysis of the influence of relief elements on buckwheat yield in this catchment shows that the minimum level of crop yield was in the middle part of the slope. It is obvious that in the space between the strips, with sufficient moisture supply to the crops, there was stagnation of humid air, and under conditions of shading from forest strips, the vegetative mass of plants intensively developed due to a decrease in generative productivity. However, in the lower part of the slope the yield of the moisture-loving buckwheat crop was maximum. In the conditions of a catchment with forest strips, the buckwheat yield in the middle part of the slope was 0.27 t/ha less, and in the lower part of the slope 0.45 t/ha more, compared to the upland.

4 Conclusion

The environment-forming and stabilizing role of forest strips as an element of a soil-protective agroforestry landscape complex on slopes consists in the accumulation and uniform distribution of snow mass on the slope between the strips and in reducing the depth of soil freezing. As a result, additional moisture enters the soil during snowmelt and the likelihood of water-erosion processes is reduced. In a catchment area without erosion protection elements, the greatest height of snow is formed in the lower part of the slope due to its blowing by the wind from the middle part of the slope. In a catchment with a soil-protective agroforestry landscape complex, the highest depth of snow cover is formed in the middle part of the slope between forest belts. As the depth of snow cover increases, the depth of soil freezing decreases. Forest strips increase the reserves of moisture available for plants on the slopes by reducing the lateral intrasoil flow of water that has seeped into the soil column down the slope. Forest strips increase the microbiological activity of the soil in the areas adjacent to them by increasing the moisture content of the soil profile and leaf litter, as a source of additional organic matter for feeding microorganisms. In watersheds with forest strips, higher barley yields are formed, but buckwheat grain yields are reduced due to the intensive development of vegetative mass.

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