AGRO-ECOLOGICAL AND TOXICO-ECOLOGICAL INDICATORS OF CORN AND SUNFLOWER AGRO-ECOSYSTEMS ON SLOPING LANDS

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Abstract. On weakly washed ashed black soil of heavy loams, the humus content decreases by 12.9%, compared to unwashed soils. Weakly washed ashed black soil had a content of easily hydrolyzed nitrogen by 13.3% less than unwashed ones. The content of mobile forms of phosphorus in poorly washed soils decreased by 51.1%. The content of mobile potassium on the unwashed heavy loam was 34.9% higher than on the slightly washed soil.

Result. Observation of medium-washed ashed heavy loam black soil showed that the humus content decreased by 8.8%, compared to lightly washed. The content of easily hydrolyzed nitrogen decreased by 14.3%. The content of mobile forms of phosphorus increased by 15.3%. The content of mobile forms of potassium increased by 42.9%. Hydrolytic acidity of slightly washed soil increased by 4.9%. The reaction of the soil solution is 1.8%. The amount of absorbed bases increased by 11.4%. Medium-washed heavy loamy black soil had 11.3% higher hydrolytic acidity than lightly washed black soil. The reaction of the soil solution was 1.7% lower. The amount of absorbed bases was the same. Changes in the indicators of the agrochemical composition of ashed heavy loam black soil on unwashed and slightly washed lands showed that weak soil washing leads to a decrease in the content of humus, easily hydrolyzed nitrogen, mobile forms of phosphorus and potassium, an increase in the value of hydrolytic acidity, the amount of absorbed bases, and optimization of the pH reaction of the soil solution. The largest decrease in the content of mobile forms of phosphorus was revealed – by 51.1%, and the smallest and almost identical decrease in the content of humus and easily hydrolyzed nitrogen – by 12.9-13.3%. Among the indicators

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of acidity of the slightly washed black soil, the amount of absorbed bases increased by 11.4%, compared to the unwashed one, and the least – the reaction of the pH of the soil solution – by 1.8%.

From an agro-ecological point of view, weak soil leaching leads to the deterioration of such indicators of soil fertility as a decrease in the content of humus, easily hydrolyzed nitrogen, mobile forms of phosphorus and potassium, and an increase in the hydrolytic acidity of the soil. At the same time, the indicators of the reaction of the soil pH saline solution improve in the neutral direction, and the amount of absorbed bases increases.

A similar dependence is observed when comparing the agrochemical parameters of weakly and moderately washed ashed black soil heavy loam. In particular, a decrease in the content of humus, easily hydrolyzed nitrogen, a decrease in the reaction value of the soil solution pH, and an increase in hydrolytic acidity, which are negative factors, were revealed. The largest negative manifestation was observed in the decrease in the value of the hydrolytic acidity of the medium-washed soil – by 14.3%, and the smallest – in the value of the reaction of the soil solution pH – by 1.7%.

At the same time, the increase in the degree of soil erosion from weakly washed to moderately washed caused an increase in the content of mobile forms of phosphorus and especially potassium in medium-washed ashed black soil in heavy loam, the content of which increased by 42.9 %. A comparison of the changes in the agrochemical state of ashed black soil heavy loam lightly washed with medium washed showed that the humus content decreases more intensively in lightly washed soil, compared to medium washed, by 4.1%; the content of easily hydrolyzed nitrogen decreased more intensively in moderately washed soil, compared to lightly washed soil, by 1%. Hydrolytic acidity increased by 6.4% more intensively on moderately washed soil, compared to slightly washed soil.

Value/originality. In Ukraine, about a third of all arable land is exposed to water erosion. The reasons for the development of erosion processes are the plowing of sloping lands with a steepness of more than 3°, the cultivation of row crops on them, mainly corn and sunflower, and intensive tillage with overturning of the soil.When agricultural crops are grown on such lands, their productivity is significantly reduced, but the question of changes in the indicators of nutrition and ecological safety of the products obtained on power lands has not been investigated.

Research was carried out by establishing field experiments on sloping lands with the spread of weakly and moderately washed erosion processes and growing corn and sunflower on them. Laboratory studies were carried out in the certified Scientific and Measuring Agrochemical Laboratory of the Vinnytsia National Agrarian University. The change in the content of protein and nitrates in plant products was determined depending on the slope.

When corn and sunflower are grown on sloping lands, the highest content of protein and nitrates is observed in their products from the lower part of the slope. The lowest protein content in sunflower seeds was found in the middle part of the slope, which was 4.0% less than in the bottom part of the slope. The lowest corn grain protein content was observed in the upper part of the slope, which was 0.3% less than in the lower part of the slope. The lowest nitrate content in corn grain was found in the upper part of the slope, which was 21.0% less than in the lower part of the slope. The lowest nitrate content in sunflower seeds was found in the middle part of the slope and was 20.0% lower than at the bottom of the slope.

1. Introduction

The current crisis state of Ukraine's land resources, the decrease in soil fertility and the large-scale spread of degradation processes lead to the need for significant changes in economic activity and nature management. The development and implementation of measures to increase soil fertility on agricultural lands, their protection and reproduction primarily require information on the agrochemical state of soils [1; 34; 40–43].

The development of intensive farming technologies has caused many problems and changes in soil cover. In this regard, the issue of studying the dynamics of soil processes and their agrochemical indicators under the influence of economic activity is gaining special relevance [2; 33].

Land resources and favorable climatic conditions of Ukraine create adequate potential for highly efficient farming and other branches of agriculture, but an extensive approach to the use of the main means of agricultural production – soil – has led to its degradation on large areas. For many years, the expansion of the area of agricultural land and arable land was almost the only measure to increase production. In pursuit of additional centners of production, everything was plowed up: steep slopes, protective zones along reservoirs and pastures, roadsides [3; 35; 44].

In the 90s of the last century, the deterioration of the country's land was especially rapid due to the aggravation of crisis phenomena in the economy of Ukraine. Due to the lack of funds, the implementation of the system of agriculture with the contour-reclamation organization of the territory was stopped, the irrigated lands became abandoned, no reclamation measures were carried out on them; agriculture was conducted according to a sharply negative balance of organic matter, the main biogenic elements, which led to the loss of about 10% of its energy potential [4; 36].

A decrease in humus reserves and a decrease in the content of mobile forms of phosphorus and potassium in the soil became characteristic for all regions of Ukraine, since for many years the amount of fertilizers applied to the soil was much less than what was carried with cultivated plants [5; 37].

2. Analysis of recent research and publications

Erosion processes cause irreparable damage to the land cover of Ukraine. Thus, the annual loss of soil in the country reaches about 600 million tons, which is equivalent to the loss of almost 120,000 hectares of land with a humus horizon 50 cm thick. In the Forest Steppe, 23.4% of the territory was damaged by erosion (mostly Kharkiv, Vinnytsia, Khmelnytsky, Ternopil and Cherkasy region) [6; 50–53].

Erosion processes on sloping lands with light loamy black soil, in the absence of agrotechnical measures, are manifested already at a steepness of 1°. As a result of the comparison of the morphometric indicators of the relief and the materials of the soil survey, a direct relationship between the area of washed soils and the steepness of the slopes was established (the correlation coefficient is 0.90–0.95). This pattern is observed only on slopes occupied by agricultural land [7; 45–50].

The tendency to increase the area of eroded soils was found on slopes with a length of 500 to 800 m. As the length increases, the area of washed soils decreases, which is associated with the steepness and reduction of run off [7; 30–32].

Erosion processes lead to the transformation of the soil cover, changes in soil fertility indicators. Thus, the loss of 10 cm of the humus layer means that more than 1,000 tons of soil is moved from 1 ha, and up to 5,000 tons from a medium and strong degree of erosion [4; 27–29; 38].

According to Yablokova A.V., with modern application technologies, 97-99% of insecticides and fungicides and 80-95% of herbicides fall into the soil, water bodies, and air. The negative effect of mineral fertilizers is that when they are systematically applied to the soil, harmful stationary substances accumulate – heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, vanadium, zinc, etc.). With each ton of phosphorus applied to the fields, up to 160 kg of fluorine enters the soil, the high concentration of which changes the direction of biological processes in the soil [8].

The development of erosion processes on sloping lands leads to the formation of washed-out soils. The washed soil is characterized by the violation of the upper humus horizon, as a result of which its fertility decreases and agro-ecological characteristics deteriorate. According to the degree of washing, unwashed, slightly washed, medium and strongly washed soils are distinguished. The degree of soil washout is determined by comparing the profile of the reference (unwashed) soil with the washed-out profile. No more than half of the H humus horizon was washed away in weakly washed soils, more than half of the humus horizon was washed away in moderately washed soils, and the upper part of the transitional (illuvial) horizon was washed away in strongly washed out soils. In eroded soils, the entire profile is destroyed by erosion, and soil-forming rocks come to the surface [9; 20–24; 39–40].

Long-term use of intensive farming measures on sloping lands leads to powerful degradation processes, strong soil erosion and changes in their ecological and agrochemical characteristics. A similar trend is characteristic of the agricultural lands of the Tomashpil district in Vinnytsia region, the soils of which are located within the Volyn-Podilsky upland, are characterized by significant hilliness, complex undulating topography, and heavy mechanical composition.

Arable land in Ukraine occupies 57% of the country's area, which is more than in all other EU countries. A large part of these lands is located on slopes. One of the most dangerous factors of soil degradation on sloping lands is water erosion. Its intensity increases with a high level of land plowing, with the placement of row crops on slopes, tillage with the rotation of the plow, a decrease in the share of perennial grasses in the structure of sown areas, rectilinear placement of field borders, and a low level of afforestation of the agrolandscape. Water erosion of the soil is characterized by plane washing or surface erosion and linear or furrow water erosion [10; 25; 28].

The materials of scientific research testify that the degree of soil erosion increases with the increase in the steepness of the slopes. On slopes with a steepness of up to 1º, weakly eroded soils prevail, occupying approximately 16% of the entire slope area. As the steepness of the slopes increases, both the total area of washed away soils and the degree of their washing away increases sharply. On slopes of 1-3º, the area of eroded soils occupies more than 60% of the slope, but weakly eroded soils also prevail here [11].

Weakly eroded soils also prevail on slopes with a steepness of 3-5º, but here the share of moderately eroded soils is increasing, accounting for more than 20%. The washing away of soils on slopes of more than 5º, where medium and strongly eroded lands make up more than 60%, is especially sharply increased. Based on this, slopes that have a steepness of more than 5º must be taken out of cultivation and transferred to permanent afforestation and afforestation [12].

Differentiation of the relief of different agricultural regions of Ukraine determines the distribution of arable land according to the steepness of the slopes. In Ukraine, slopes with a steepness of up to 3° prevail. They make up 88.5% of the entire area of arable land in our country. Arable land on slopes with a steepness of more than 3° is the most dangerous for agricultural use. Their share is 11.5%, and in some regions of Ukraine – up to 20%, which indicates significant potential prerequisites for the development of degradation, in particular, erosion processes [13].

In Ukraine, the area of eroded and erosion-dangerous soils is about 17 million hectares. The most washed-out soils are in Luhansk, Vinnytsia, Dnipropetrovsk, and Odesa regions, where the share of washed-out soils is 53-66% of the total arable land area [14]. The total area of agricultural lands of Ukraine, which are constantly affected by water erosion, is 13.4 million hectares, of which 10.6 million hectares are arable land (32% of the total area of these lands). Eroded lands include 4.5 million hectares with moderately and severely eroded soils, including 68,000 hectares of those that have completely lost the humus horizon [15].

In the Vinnytsia region, 851,100 ha were damaged by water erosion, of which 743,800 ha were agricultural land or 30% of the total area of such land, including 628,000 ha of arable land (36%), which is a third of the total arable land [16].

The emergence and development of erosion processes in soils is associated with many reasons. One of them is the irrational use of soils, which is facilitated by the intensive plowing of sloping lands with a slope of more than 3º and the cultivation of row crops on them (especially sugar beets, corn, sunflower); lack of a comprehensive approach in carrying out anti-erosion measures; oversaturation of the structure of sown areas with row crops [17].

The highest percentage of eroded land is in the Bar, Kryzhopol, Tomashpil, Murovano-Kurilovets, Chechelnytsky, and Shargorod districts (60–67%), the lowest is in the Lypovetsky, Kalynovsky, and Vinnytsia districts (9–14%) of the Vinnytsia region [18].

Studies of the influence of the degree of soil erosion on the efficiency of their use show that depending on the increase in the specific gravity of the areas, which are subject to water erosion, the efficiency of land use is significantly reduced. Oversaturation of the structure of sown areas with row crops – mainly corn and sunflower, significant plowing of sloping lands and mass cultivation of row crops on them leads not only to a decrease in their productivity on such lands, but also to a deterioration in the nutritional value and ecological safety of the products obtained. If the issue of reducing the yield of agricultural crops when growing them on slopes with the manifestation of erosive processes has been sufficiently studied, then the change in indicators of the nutritional value and ecological quality of such products has not been studied enough, which determines the need for conducting research.

3. Conditions and methods of research

The research was carried out on the basis of the processing of Materials for monitoring and ecological and agrochemical certification of agricultural lands of the FG "August V.A." Markivka village of Tomashpil district, which were developed by the Vinnytsia branch of the State Institution "Institute of Soil Protection of Ukraine" [19]. The soil of the experimental site is black soil, gold-plated heavy loam with different degrees of washability: unwashed, slightly washed, medium washed.

The following ecological and agrochemical indicators of the soil were analyzed: humus – according to Tyurin [11]; hydrolytic and exchange (pH) acidity [12]; base saturation; the content of nutrients available to plants:

phosphorus and potassium – by the Chirikov method [13], nitrogen – by the Kornfield method [14].

Agrochemical survey of farm soils was conducted on a total area of 740.5 hectares. The selection of samples was carried out in accordance with the methodical instructions for large-scale agrochemical examination of soils in the system of the agrochemical service of Ukraine.

Field research was conducted during 2018-2021 on the lands of the FG "August V.A." Markivka village, Tomashpil district, Vinnytsia region. The soil of the experimental site is black soil, gold-plated, heavy loam with different degrees of washability: unwashed, slightly washed, and moderately washed, which also depended on the steepness of the slopes.

Two crops were grown: corn and sunflower, with sowing on the slope plots in such a way that the experimental plots covered the top, middle part and bottom of the slope. The content of protein, nitrates and moisture in corn and sunflower seeds was determined depending on the location of the experimental plot at the top, middle part and bottom of the slope. Experiments are repeated four times, placement of options is systematic multi-tiered. The sown area of the plot is 30 m^2, the accounting area is 25 m^2.

In the experimental plots, the average content of humus was 2.94%, the content of easily hydrolyzed nitrogen – 113 mg/kg, mobile forms of phosphorus – 137 mg/kg, mobile potassium – 152 mg/kg. The hydrolytic acidity was 2.34 mg-equiv./100 g. The reaction of the soil solution was 5.5 pH. The amount of absorbed bases was 25.6 mg-equiv./100 g.

Laboratory studies were conducted in the certified Scientific and Measuring Agrochemical Laboratory of the Department of Ecology and Environmental Protection of the Vinnytsia National Agrarian University. The content of protein in sunflower seeds and corn grains was determined by the Kjeldahl method [10], nitrates by the spectrometric method of molecular absorption [10], and moisture by the method of drying a weight of plant mass by the thermostatic weight method in accordance with DSTU 29144:2009 ISO 711-85 [10]. Grain and seed samples were taken in accordance with the requirements of DSTU 4117:2007 [11]. We carried out mathematical and statistical processes of the obtained research results with the determination of the average deviation, correlation coefficients, determination, construction of the equation and regression diagram.

Only mineral fertilizers were used when growing sunflowers. In particular, when sowing, N16P16K16 was applied in the form of a complex mineral fertilizer, nitroammophos. Nitrogen mineral fertilizers in the total amount of N70 were applied before sowing. Nitrogen mineral fertilizer ammonium nitrate was used. When growing corn, only mineral fertilizers were also used. In particular, during sowing, N16P16K16 was applied in the form of a complex mineral fertilizer, nitroammophos. Nitrogen mineral fertilizers in the total amount of N100 were applied before sowing. Nitrogen mineral fertilizer ammonium nitrate was used. Sowing of corn and sunflower, as well as soil cultivation, was carried out across the slope.

4. Changes in soil fertility indicators depending on the degree of soil erosion

The main indicators of soil fertility are the content of humus, easily hydrolyzable nitrogen, mobile forms of phosphorus and potassium, hydrolytic acidity, the pH reaction of the soil solution, and the amount of absorbed bases. Under the conditions of the development of soil erosion processes and varying degrees of their washing away, a change in soil fertility indicators is possible.

The humus content was 2.94% on the unwashed black soil of ashed heavy loam by mechanical composition. On weakly washed soils, the humus content decreases by 12.9% and amounts to 2.56%. The content of easily hydrolyzed nitrogen in unwashed soils was 113 mg/kg. The analysis of lightly washed ashed black soil established the content of easily hydrolyzed nitrogen at 98 mg/kg, which was 13.3% less than in unwashed soils. The content of mobile forms of phosphorus in unwashed soils was 137 mg/kg, and in weakly washed soils it decreased by 51.1% and amounted to 67 mg/kg. The content of mobile potassium on unwashed ashed black soil heavy loam was 152 mg/kg. This was 34.9% more than on lightly washed soil, where the content of mobile potassium was 99 mg/kg (Table 1).

Observation of a site of ashed heavy loam black soil with slightly and moderately washed-out degrees showed that the humus content on slightly washed-out soil was 2.94%, and on moderately washed-out soil it decreased by 8.8% and amounted to 2.68%. The content of lightly hydrolyzed nitrogen on slightly washed ashed black soil heavy loam amounted to 112 mg/kg, and on medium washed it decreased by 14.3% and was 96 mg/kg. The content

Table 1

Changes in soil fertility indicators depending on the degree of soil erosion

Type of soil	Mechanical componants	Degree of washing	Humus content, %	Content of easily hydrolyzed nitrogen, mg/kg	The content of mobile phosphorus, mg/kg	The content of mobile potassium, mg/kg
Ashed black soil	Heavy loam	unwashed	2,94	113	137	152
		Weak washed	2,56	98	67	99
Ashed black soil	Heavy loam	Weak washed	2,94	112	50	89
		Medium washed	2,68	96	59	156

of mobile forms of phosphorus on lightly washed soil was 50 mg/kg, and on moderately washed soil it increased by 15.3% and amounted to 59 mg/kg. The content of mobile forms of potassium on slightly washed ashed black soil heavy loam amounted to 89 mg/kg, and on medium washed soil it increased by 42.9% and amounted to 156 mg/kg.

5. Changes in soil acidity indicators depending on the degree of soil erosion

The degree of leaching of ashed heavy loamy black soil had a direct effect on soil acidity indicators – hydrolytic, the reaction of the soil pH solution, the amount of absorbed bases. In particular, the hydrolytic acidity of the unwashed soil was 2.34 mg-eq./100 g, and the slightly washed soil increased by 4.9% and amounted to 2.46 mg/100 g. The reaction of the soil solution on the unwashed soil was 5.5 pH, and on slightly washed – increased by 1.8% and amounted to 5.6 pH (Table 2).

The amount of absorbed bases in unwashed heavy loamy black soil was 25.6 mg-equiv./100 g, and in weakly washed black soil it increased by 11.4% and amounted to 28.9 mg-equiv./100 g.

Observations of the acidity indicators of another soil area, where the degree of washing was greater, revealed the hydrolytic acidity of

Table 2

Changes in soil acidity indicators depending on the degree of soil erosion

Type of soil	Mechanical components	Degree of washing	Hydrolytic acidity, mg-equiv./ 100 g	The reaction of the soil solution, saline pH	The amount of absorbed bases, mg-equiv./ 100 g
Ashed black soil	Heavy loam	unwashed	2,34	5,5	25,6
		Weak washed	2,46	5,6	28,9
Ashed black soil	Heavy loam	Weak washed	1,72	5,8	29,2
		Medium washed	1,94	5,7	29,2

slightly washed soil of 1.72 mg-eq./100 g. The medium-washed black soil, gold-plated heavy loam, had a hydrolytic acidity 11.3% higher – 1.94 mg-eq./100 g. The reaction of the soil solution of weakly washed soil was 5.8 pH, and that of moderately washed soil was 1.7% lower – 5.7 pH. The amount of absorbed bases of weakly and moderately washed soils was the same and amounted to 29.2 mg-eq./100 g.

The analysis of the changes in the agrochemical composition of ashed heavy loam black soil on unwashed and slightly washed lands showed that weak soil washing leads to a decrease in the content of humus and nitrogen of easily hydrolyzable, mobile forms of phosphorus and potassium, increasing the value of hydrolytic acidity, the amount of absorbed bases, and optimizing the reaction of the pH of the soil solution. In particular, the largest decrease in the content of mobile forms of phosphorus was found – by 51.1%, and the smallest and almost identical decrease in the content of humus and easily hydrolyzed nitrogen – by 12.9-13.3%.

Compared to the unwashed soil, the amount of absorbed bases increased the most among the indicators of the acidity of the slightly washed black soil, by 11.4%, and the reaction of the pH of the soil solution – by 1.8%. From an agro-ecological point of view, weak soil leaching leads to the deterioration of such indicators of soil fertility as a decrease in the content of humus, easily hydrolyzed nitrogen, mobile forms of phosphorus and potassium, and an increase in the hydrolytic acidity of the soil. At the same time, the indicators of the reaction of the soil pH saline solution improve in

the neutral direction, and the amount of absorbed bases increases. A similar dependence is observed when comparing the agrochemical parameters of weakly and moderately washed ashed black soil heavy loam. In particular, a decrease in the content of humus, easily hydrolyzed nitrogen, a decrease in the reaction value of the soil solution pH, and an increase in hydrolytic acidity, which are negative factors, were revealed.

The greatest negative manifestation was observed in the reduction of the value hydrolytic acidity of medium-washed soil – by 14.3%, and the smallest – on the value of the reaction of the pH soil solution – by 1.7%. At the same time, the increase in the degree of soil washing from slightly washed to medium-washed caused an increase in the medium-washed black soil, ashed heavy loam content of mobile forms of phosphorus and especially potassium, the content of which increased by 42.9%. A comparison of the changes in the agrochemical state of ashed black soil heavy loam lightly washed with medium washed showed that the humus content decreases more intensively in lightly washed soil, compared to medium washed, by 4.1%; the content of easily hydrolyzed nitrogen decreased more intensively in moderately washed soil, compared to lightly washed soil, by 1%.

Hydrolytic acidity increased by 6.4% more intensively on moderately washed soil, compared to slightly washed soil.

6. The content of protein, nitrates and moisture in corn grain grown on sloping lands

The protein content of corn grain grown in the upper part of the slope was 5.8%. In the middle part of the slope, the protein content in grain decreased by 0.2% and amounted to 5.6%. In the lower part of the slope, the protein content, relative to its upper part, increased by 0.1% and amounted to 5.9%. The highest protein content in corn grain was established when it was grown in the lower part of the slope – 5.9%, and the lowest – 5.6%, in the middle part of the slope (Table 3).

The content of nitrates in corn grain grown in the upper part of the slope was 600 mg/kg. In the middle part of the slope, the nitrate content increased by 6.3% and amounted to 640 mg/kg. At the bottom of the slope, the nitrate content, relative to its upper part, increased by 21.1% and amounted to 760 mg/kg. Thus, it was found that the highest content of nitrates

Table 3

The content of protein, nitrates and moisture in corn grain grown on sloping lands, M±m

Placement of crops relative to the slope	Contents		
	protein, %	nitrates, mg/kg	moisture, %
Upper of the slope	5,8±0,1	600±11	12,9±0,1
Middle of the slope	5,6±0,1	640±10	13,7±0,2
Bottom of the slope	5,9±0,1	760±13	12,8±0,1

was established in the grain of corn grown at the bottom of the slope – 760 mg/kg, and the lowest – at the top of the slope – 600 mg/kg.

The moisture content of corn grain grown at the top of the slope was 12.9%. In the middle part of the slope, the grain moisture content increased by 0.8% and amounted to 13.7%. In the lower part of the slope, the moisture content, relative to the upper part of the slope, decreased by 0.1% and amounted to 12.8%. Thus, the highest moisture content in corn grain was established when it was grown in the middle part of the slope – 13.7%, and at the bottom and top of the slope, the moisture content in corn grain was the same – 12.8-12.9%.

7. Protein, nitrate and moisture content of sunflower seeds grown on sloping lands

Observation of the protein content in sunflower seeds grown in the upper part of the slope revealed its 21.3%. In the middle part of the slope, the protein content in sunflower seeds decreased by 4.6% and amounted to 16.7%. At the bottom of the slope, compared to its upper part, the protein content in sunflower seeds increased by 0.4% and amounted to 21.7%. Thus, it was established that the highest protein content was observed in sunflower seeds grown at the bottom of the slope – 21.7%, and the lowest – in the middle part of the slope – 16.7% (Table 4).

The nitrate content in sunflower seeds grown at the top of the slope was 1960 mg/kg. In the middle part of the slope, it decreased by 18.4% and amounted to 1600 mg/kg. In the lower part of the slope, relative to the upper one, the nitrate content in sunflower seeds increased by 2.0% and amounted to 2000 mg/kg. That is, the highest content of nitrates in sunflower seeds was found when it was grown at the bottom of the slope – 2000 mg/kg, and the lowest – in the middle part of the slope – 1600 mg/kg.

Table 4

Protein, nitrate and moisture content of sunflower seeds grown on sloping lands, M±m

Placement of crops relative to the slope	Contents		
	protein, %	nitrate, mg/kg	moisture, %
Upper of the slope	21,3±0,2	1960±14	14,1±0,3
Middle of the slope	16,7±0,1	1600±12	15,0±0,2
Bottom of the slope	21,7±0,2	2000±15	12,5±0,2

The moisture content of sunflower seeds grown in the upper part of the slope was 14.1%. In the middle part of the slope, it increased by 0.9% and amounted to 15.0%. In the lower part of the slope, the moisture content of sunflower seeds, compared to the upper part of the slope, decreased by 1.6% and amounted to 12.5%. Therefore, the highest moisture content in sunflower seeds was found when it was grown in the middle part of the slope – 15.0%, and the lowest – in the lower part of the slope – 12.5%.

Correlation-regression analysis of changes in the quality indicators of corn grain grown on different parts of the slope showed the presence of an average positive correlation between protein content and nitrates (r = 0.577), a strong negative correlation between protein content and grain moisture (r = – 0.973). This indicates that with a decrease in the moisture content of corn grown on sloping lands, its protein content increases, and also with an increase in the protein content of corn grown on sloping lands, its nitrate content increases. Based on the fact that protein is formed at the expense of nitrogenous substances during nitrogen mineral nutrition of crops, then, accordingly, when the content of protein in grain increases, the content of nitrates also increases in it.

A strong positive correlation was established between the content of protein and nitrates in sunflower seeds grown on different parts of the slope (r = 0.999), and a strong negative correlation was found between the content of protein and moisture in sunflower seeds grown on sloping lands (r = – 0.819), a strong negative correlation was also found between the content of nitrates and moisture in sunflower seeds grown on sloping lands (r = – 0.829). In addition to the revealed correlation-regression dependences on the example of corn grain, a strong dependence was also established for

sunflower seeds between the increase in nitrate content and the decrease in moisture content in its seeds.

The coefficient of determination $R^2 = 0.8415$ shows that when the protein content in sunflower seeds changes by 1%, the nitrate content in it changes directly proportionally by 0.84%.

The coefficient of determination $R^2 = 0.3804$ shows that when the moisture content in sunflower seeds changes by 1%, the protein content in it changes inversely proportionally by 0.38%.

The coefficient of determination $R^2 = 0.2033$ shows that when the moisture content in sunflower seeds changes by 1%, the nitrate content in it changes inversely proportionally by 0.20%.

Justifying the change in the protein content of sunflower seeds and corn grains in different parts of the slope, it should be noted that the processes of soil washing are just beginning in the upper part of the slope, so there is still a certain supply of humus and nutrient minerals.

In the middle part of the slope, there is a strong washout of the soil both from the upper part of the slope and from its middle part. Therefore, the lowest protein content in sunflower seeds and corn grains was found here. In the lower part of the slope, there is deposition, accumulation and accumulation of humus and nutritious mineral parts of the soil that moved from the upper and middle part of the slope. Because of this, the highest protein content was found in sunflower seeds and corn grains in the lower part of the slope.

A similar dependence is observed in the change of nitrate content in sunflower seeds and corn grain, in particular, the highest nitrate content was found in sunflower seeds and corn grain grown in the lower part of the slope. The lowest content of nitrates in sunflower seeds was found in the middle part of the slope, and in corn grains – in the upper part of the slope.

8. Nitrate content in corn grains and sunflower seeds relative to the maximum permissible concentration

Nitrates in seeds and grains of agricultural crops are an ecological factor of product safety. Their content in seeds and grains is regulated by the maximum permissible concentration (MPC), which for the studied crops is 500 mg/kg (Table 5).

An excess of nitrate content relative to MPC was found in corn grain by 1.2-1.5 times in all studied points, and in sunflower seeds by 3.2-4.0 times.

Table 5

Nitrate content in corn grains and sunflower seeds relative to the maximum permissible concentration

Placement of crops relative to the slope	MPC of nitrates for corn grain and sunflower seeds, mg/kg	Nitrate content in corn grain, mg/kg	Exceeding the content of nitrates in corn grain relative to MPC, times	Nitrate content in sunflower seeds, mg/kg	Exceeding the content of nitrates in sunflower seeds relative to MPC, times
Upper of the slope	500	600±11	1,2	1960±14	3,9
Middle of the slope	500	640±10	1,3	1600±12	3,2
Bottom of the slope	500	760±13	1,5	2000±15	4,0

The lowest nitrate content was observed in corn grain grown in the upper part of the slope and in sunflower seeds grown in the middle part of the slope. A significant excess of the permissible limits of nitrates in sunflower seeds, compared to corn grain, is caused by a shorter growing season of sunflower and a much lower level of yield of its seeds.

9. Conclusions

The development of erosion, which leads to the formation of washed ashed black soil heavy loam, leads to a decrease in the content of humus, easily hydrolyzed nitrogen, mobile forms of phosphorus and potassium, and an increase in hydrolytic acidity. The further development of erosion, which leads to the formation of moderately washed soils, leads to acidification of the reaction of the soil solution.

When corn and sunflower are grown on sloping lands, the highest content of protein and nitrates is observed in their products from the lower part of the slope. The lowest protein content in sunflower seeds was found in the middle part of the slope, which was 4.0% less than in the bottom part of the slope. The lowest corn grain protein content was observed in the upper part of the slope, which was 0.3% less than in the lower part of the slope. The lowest nitrate content in corn grain was found in the upper part of the slope, which was 21.0% less than in the lower part of the slope. The

lowest nitrate content in sunflower seeds was found in the middle part of the slope and was 20.0% lower than at the bottom of the slope.

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