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# The effectiveness of agrotechnical anti-erosion measures on sloping soils in the conditions of the forest-steppe of Ukraine

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## ABSTRACT

Erosion is one of the most dangerous causes of soil destruction. It leads to soil degradation and reduction of agricultural land, as well as desertification of landscapes as a whole. The article examined the intensity of erosion processes in an anti-erosion organized agricultural landscape. The purpose of the work was to determine the effectiveness of anti-erosion agrotechnical measures on the chernozems of the regraded forest-steppe of Ukraine. The research was conducted in the Kupiansk Rayon of the Kharkiv Oblast, which is characterized by a complex terrain. Experimental data were obtained from a stationary experiment, where two groups of studies were established: 1) traditional rectangular layout of the territory with the length of the drain line over 800.0 m; 2) anti-erosion organized agricultural landscape with a system of embankments-terraces and forest strips (the length of the drainage line does not exceed 200.0 m) and infrastructure for safe drainage in extreme periods of water discharge. In both groups, the effectiveness of such methods of tillage as plowing, flat-cut and chisel tillage, as well as their combination with mole drainage. The results of the experiments confirmed the high protective effectiveness of agro-landscape improvement against erosion processes. It was found that flat-cut and chisel tillage, especially when combined with mole drainage, contributes to a 1.5–15.0-fold reduction in water runoff, which significantly reduces the risk of erosion. The use of protective forest strips and embankment-terraces after 200.0 m helps to reduce the intensity of runoff and minimizes soil erosion. An important aspect of the research was the study of the aggregate composition of the soil and its resistance to destruction by water. It was found that the content of agronomically valuable aggregates (0.25–10.0 mm) did not differ significantly between tillage methods. A comparative analysis showed that moldboard plowing increased the content of the fraction of > 1.0 mm aggregates in the topsoil layer; however, the water stability of these aggregates remained low. The best water resistance indicators were noted in flat-cut tillage, where the average weighted diameter of water-resistant aggregates was 1.40 mm, which increases the erosion resistance of the soil. Special attention is paid to the influence of the terrain on the development of erosion processes. It was found that on gentle slopes (3–4°) soil erosion occurs gradually, while on convex slopes (4–5°) erosion processes are much more intense, because the speed of surface runoff and its eroding speed increases. Thus, the results of the study confirm the need to implement adaptive farming systems based on considering the natural conditions of the region.

**Keywords:** anti-erosion landscape, terraced embankments, regraded chernozem, soil tillage, soil resistance to erosion.

## INTRODUCTION

Erosion processes, their development and impact on landscapes, as well as the ways to limit the negative consequences of erosion have interested mankind since the beginning of intensive land cultivation. Since before human intervention, natural erosion existed, which never reached planetary scales and the magnitude of which did not exceed a critical limit, the balance of substances in landscapes was optimal – erosion was balanced by soil formation. However, the intensity of erosion processes increased significantly with human intervention in the geosystem (Peng and Wang, 2012, Pham et al., 2020).

Erosion processes, which are based on the destruction of soil cover by water flows and wind, as well as its degradation as a result of anthropogenic activity, are the result of a complex interaction of natural and economic factors within the agro-landscape system (Zhu and Xu, 2021). The degree of manifestation of erosion processes depends on many factors, including those independent of humans, such as weather conditions. This makes it necessary to consider the anti-erosion organization of the territory as a system and use a systemic approach to solving problems (Pavlichenko et al., 2023; Litvinova et al., 2023; Voytovyk et al., 2024).

Determining the quantitative regularities of the influence of soil erosion factors on its intensity made it possible to estimate and forecast potential soil washout because of erosion. Significant success in this was achieved by American scientists based on a large amount of experimental data, creating the Universal Soil Loss Equation (Wischmeier and Smith, 1965). An important step was the creation of a logical-mathematical model of erosion (Shwebs, 1974), which, in fact, opened a new direction for mathematical modeling, calculation and forecasting of water erosion of soils in the former USSR.

The country's provision of land resources is the most important economic and political factor in the development of social production. The availability of land resources provides a wide scope for the economic development of regions of the world. The structure of the land fund is constantly changing under the influence of two opposing processes. One is the struggle of mankind for the expansion of lands suitable for habitation and agricultural use (land development, land reclamation, drainage, irrigation, development of coastal areas of the sea); the other is the deterioration of lands, their withdrawal from agricultural use as a result of erosion, desertification, industrial and transport development, open-pit mining of minerals, waterlogging, salinization. The second process occurs faster in time. Thus, the main problem of the world's land fund is the degradation of agricultural lands, as a result of which there is a noticeable reduction in cultivated lands and a constant increase in the load on them (the lowest provision of arable land per capita in China is 0.09 hectares, in Egypt – 0.05 hectares) (Zos-Kior and Sokolova, 2012, Zbarskyi et al., 2020).

It should be noted that cultivated land (arable land, gardens) today occupies 1450 million hectares, or only 11.0% of the inhabited land area. The corresponding figures for meadows and pastures are 3400 million hectares, or 26.0%. The data indicate that not all possible reserves for the expansion of agricultural and livestock cultural landscapes have been used (Searchinger et al., 2023). However, natural factors severely limit the possibilities of such expansion. Such natural factors include steep slopes, climatic dryness or permafrost, and negative soil properties. The territories with various natural limitations for the development of agriculture occupy a total of 78.0% of the entire land area. In turn, 13.0% of lands have low productivity, 6.0% have medium productivity, and only 3.0% have high productivity out of a total of 22.0% of lands without natural limitations (Belkin, 2024).

The area of potentially suitable for agriculture is 3.4 billion hectares, of which 40.3% is currently used (Belolipskii and Bulygin, 2009). The above proves that only a relatively small part of the reserve areas can be brought to economic use at relatively low costs.

Today, the number of areas involved in agricultural circulation of unproductive, washed-out, sloping lands is increasing, especially after the full-scale invasion of Russia into the territory of Ukraine. As of 2023, the area of mined fields was 8 million hectares, of which 6 million hectares are in temporarily occupied territories, and 2 million hectares are in liberated territories. More than 500 thousand hectares of arable land in Ukraine are not used (Bavrovska et al., 2024; Moskalenko and Heryn, 2023). Military activity causes long-term and large-scale soil degradation, as evidenced by the experiences of countries where military operations have taken place or are ongoing. Such operations exert a significant impact on the soil's resistance to pollution and its mechanical or physical integrity, leading to changes in soil structure.

Soil aggregates are destroyed when the humus horizon is mixed with other layers due to trench digging, explosions, and fires. The movement of military equipment also causes mechanical damage – compacting the soil and increasing its aridity. The soil microbiota, which is essential for maintaining soil health and fertility, is also disrupted. It can be destroyed by soil compaction, thermal shock, disruption of soil horizons, and the exposure to explosive toxic substances. These substances contribute to chemical pollution through fuel leaks, the deposition of combustion products from the air, and toxins released from explosive shells.

Blast waves lead to soil erosion, further exacerbating the challenges of climate change and the efforts to adapt to it (Moskalenko and Heryn, 2023). This highlights the urgent need to address land degradation in the post-war period and to assess the ecological condition of the areas affected by military conflict.

Therefore, the current task of the field of soil science is to increase the efficiency and sustainability of agricultural production through adaptation to climate change, preservation and restoration of soil fertility, and improvement of soil protection measures. This task is complicated on the agricultural lands located on the slopes of watersheds. Therefore, the protection of such soils from erosion is an important task of rational nature management.

The main cause of soil destruction and agricultural production shortages is progressive erosion. Soil erosion is more of a social phenomenon. Natural factors can be considered more as a prerequisite, in the presence of which erosion under human influence is possible to occur and develop (Jin et al., 2021; Kucher et al., 2022).

During agricultural development of agricultural landscapes, increased water erosion is observed, because of which the productivity of sloping lands decreases. It is believed that even highly fertile chernozems degrade under the conditions of the temperate humid climate of Central Europe, especially in the areas with intensive cultivation of agricultural crops and hilly terrain (Koshel et al., 2023; Labaz et al., 2022).

Conventional anti-erosion agrotechnical measures can prevent the intensity of erosion processes. However, their actions are not always effective. Modern approaches to solving this problem are associated with the implementation of an adaptive landscape system of agriculture with an anti-erosion ordered agricultural landscape that consider possible terrain, climatic and ground conditions. It contributes to the formation of a high yield and protects the soil from erosion. Thus, an erosion-resistant cultural landscape was created.

Sloping soils are particularly susceptible to erosion. Soil erosion increases along with the slope angle (Yongshan and El-Swaify, 2001). The intensity of erosion depends on many factors, among which the physical properties of the soil are of key importance. All soil aggregates are divided by size into macroaggregates (> 0.25 mm) and microaggregates (< 0.25 mm). In the case of destruction of macroaggregates, the soil becomes more susceptible to erosion (Six et al., 2000). Aggregate stability, as a physical property of the soil, is increasingly considered as the main indicator of soil quality and resistance to water erosion (Nsabimana et al., 2021).

## MATERIALS AND METHODS

The Kharkiv region is in the north-east of Ukraine on the border of the forest-steppe and steppe physiographic zones and occupies the southwestern outskirts of the Central Russian Upland. The research was conducted on a stationary experiment to study the erosion resistance of sloping lands when growing agricultural crops (2017–2022) in the village of Lisna Stinka, Kupiansk Rayon, Kharkiv Oblast, which was established in 1987. On February 27, 2022, the territory of the Kupiansk district was captured by the Armed Forces of the Russian Federation, which led to the suspension of the research.

The soil of the experimental plot is a slightly washed-out, degraded chernozem (Figure 1). Agrochemical indicators in the studied soils were performed according to the National Standard of Ukraine DSTU 4362:2004 (DSTU 4362:2004, 2005). The arable layer of the soil has the following agrochemical indicators: mobile phosphorus – 58 mg kg$^{-1}$, exchangeable potassium – 106 mg kg$^{-1}$ by Chirikov's method, humus content – 3.8% by the Tyurin method, (DSTU 4362:2004, 2005).

Soil washout was determined using the method of S. Sobolev in two experiments: 1) traditional rectangular arrangement of the territory with a drain line length of more than 800.0 m (49°30'43"N 37°33'47"E); 2) anti-erosion arranged agricultural landscape with a runoff line length of no more than 200 m with a system of equipped embankments-terraces (40.0 m wide, 0.4–0.5 m high) and single-row tree and shrub forest strips planted along their crest (49°30'43"N 37°34'30"E,) and infrastructure created along the flanks of the embankment system for safe discharge of runoff during extreme periods of high rainfall (Figure 2). In parallel, erosion processes of gentle and convex slopes on production crops

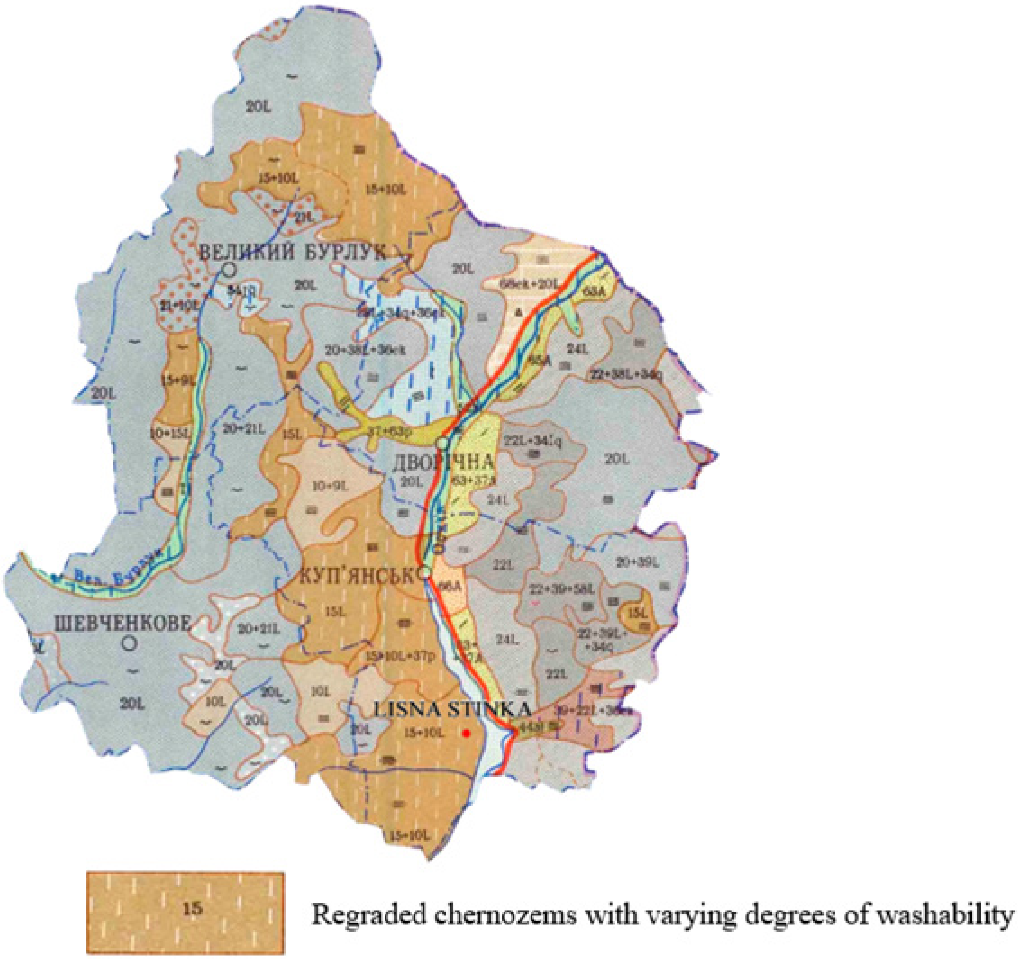


**Figure 1.** Fragment of a soil map of Ukraine. Kupiansk Rayon, Kharkiv Oblast (1972)

were studied. Crop rotation: (1) barley with undersowing of perennial grasses; (2–4) perennial grasses 1–3 years of mowing; (5) winter wheat; (6) corn for silage.

The size of the plots according to the methods of soil cultivation is 50.0 × 200.0 m. Repetition is two-fold. Drainage areas measuring 20.0 × 100.0 m were built on the experimental plots.

**Figure 2.** Location of research fields (Google Earth aerial photos)

Soil cultivation and ameliorative measures were carried out in the direction of the horizontals.

The following methods of soil cultivation were studied in the experimental plots.

Experiment 1:
- plowing for all crops of crop rotation,
- plowing + mole drainage,
- flat-cut tillage to the depth of plowing for the crop,
- flat-cut tillage + mole drainage,
- chisel tillage,
- chisel tillage + mole drainage.

Experiment 2:
- plowing,
- flat-cut tillage,
- chisel tillage.

### Methods to estimate soil erosion resistance

To study soil erosion resistance based on tillage methods, the structural-aggregate composition was determined using dry and wet sieving methods. The soil samples were assessed for their stability and resistance to water jet erosion (Akshalov, 2010). According to Savinov's dry sieving results, the content of agronomically valuable (0.25–10.0 mm) and non-valuable (sum > 10.0 mm and < 0.25 mm) structural aggregates was determined. The structural coefficient (Kstr) was calculated as the ratio of the sum of fractions 0.25–10.0 mm to the sum of fractions < 0.25 mm and > 10.0 mm from dry sieving: Kstr = Σ(0.25–10.0 mm)/ Σ (> 10.0 mm and < 0.25 mm) (DSTU 4744:2007, 2008).

The predicted soil washout was calculated using Mirtskhulava's formula modified by Bulygin (Bulygin and Nearing, 1999). Liquid runoff was measured by flow through a thin-walled weir with a 90° cutout angle (Akshalov 2010). Soil erosion resistance was determined using Bastrakov's method (Bastrakov 1977, 1994). The content of water-stable aggregates > 0.25 mm was determined by wet sieving using Bakheyev's device (Sukhanovsky et al., 2016). The mean weighted diameter of water-stable aggregates was calculated according to Bulygin (Bulygin and Vitvitsky, 2024).

The runoff coefficient was defined as the ratio of the volume of liquid runoff to the amount of precipitation that fell on the catchment area and caused this runoff (Goewin et al, 2024). It shows what part of the precipitation is spent on the formation of runoff. The runoff coefficient varies within 0.05–1.0 and depends on the type of soil, vegetation cover of the soil surface, slope of the terrain, rain intensity, and previous soil moistening.

Statistical analysis of the considered indicators was conducted according to analysis of variance (ANOVA) for a randomized complete block design (RCBD) with a split-plot arrangement. The least significant difference (LSD) test was also used to compare arithmetic means at the 5% probability level.

## RESULTS AND DISCUSSION

### Study area and limiting factors

In the research area, one of the limiting factors for increasing agricultural crop yield is moisture. However, a significant amount of moisture is lost as surface runoff during snowmelt and heavy rainfall. Over the five years of research (2017–2022), early spring soil washout occurred in 2017 and 2022. The studies conducted on runoff plots (20.0 × 100.0 m) demonstrated that during snowmelt, liquid runoff in the soil treated with mole drainage was 1.5–15.0 times lower than without it (Figure 3). The highest liquid runoff was recorded on agricultural background 1 with conventional plowing without mole drainage – 507.4 $m^3$ $ha^{-1}$. For flat-cut tillage, the runoff was 244.0 $m^3$ $ha^{-1}$, and for combined chisel and mole drainage – 0.9 $m^3$ $ha^{-1}$.

The significant reduction in washout on the combined agricultural background can be explained by the looser composition of the arable layer, which led to better soil absorption capacity compared to other agricultural backgrounds. In flat-cut tillage, the stubble residues in the upper 0–10.0 cm layer reduced soil pore clogging, positively affecting rainfall infiltration.

In the anti-erosion arranged agricultural landscape with a runoff line length not exceeding 200.0 meters and a system of equipped embankment terraces, there was minimal soil runoff.

The highest solid soil washout was also noted in variant 1.0–1.19 t $ha^{-1}$ (Figure 4). However, this amount is significantly below the permissible limits (3.0–5.0 t $ha^{-1}$). The soil washout in flat-cut tillage was 8.5–29.7 times lesser than in plowing.

In experiment 1, not only the amount of water runoff increased, but also its velocity, thereby enhancing its erosive and transport capacity, resulting in more noticeable soil washout. This is confirmed by the data obtained when accounting

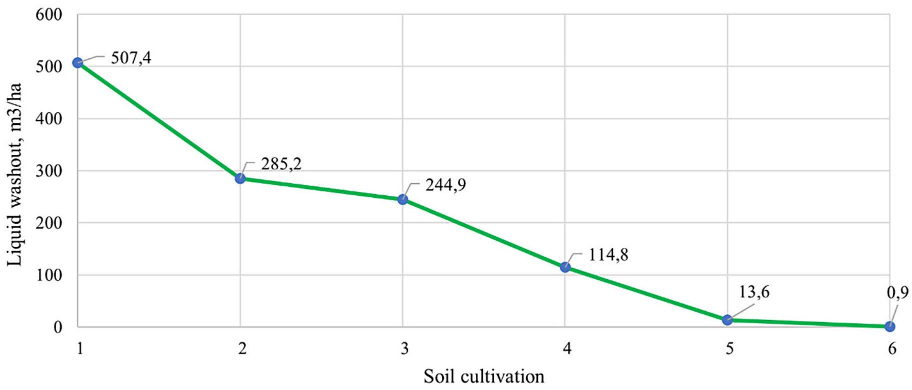


**Figure 3.** Liquid runoff during spring snowmelt depending on the agro-background in experiment 2, m³ ha$^{-1}$

for water rills after intense snowmelt, where soil washout amounted to 4.0–5.0 t ha$^{-1}$.

Calculations of the predicted soil washout in t ha$^{-1}$ using Bulygin's modification of Mirtskhulava's formula (Bulygin and Nearing 1999) show that in early spring, in the absence of anti-erosion measures, it can reach 19.0 t ha$^{-1}$ (Figure 5).

The runoff coefficient decreased from 0.81 for plowing to 0.01 for chisel tillage with mole drainage (Figure 6). The graph shows that the use of chisel tillage significantly reduces surface runoff during precipitation.

In production crops of winter wheat grown after silage corn, significant soil washout was observed, varying from 5.29 to 45.41 t ha$^{-1}$ depending on the slope exposure (Figure 7). The washout data were obtained in April during erosion inspection and water rill accounting using S.S. Sobolev's method (Shein, 2005).

On the southern slope exposure, washout begins at 5.0–7.0 m from the upper embankment, whereas on the northern slope exposure, soil washout is recorded only when retreating 75.0–80.0 m from the embankment, which is explained by the lower intensity of snowmelt on this slope. However, with an increase in the runoff line length to more than 100.0 m, soil washout sharply increased. Thus, at 142.0 m from the upper embankment on the northern slope exposure, soil washout increased more than 4 times, although with further retreat down the slope, this ratio decreased by half. At the same time, the disparity in the number of water rills and the difference in their quantitative characteristics also decreased. It should be noted that on gentle slopes, soil washout increases proportionally with the increase in runoff line length, whereas on convex slopes, it increases sharply.

The convex shape of the southern slope exposure, at 102.0 m from the water-retaining embankment, contributed to an increase in soil washout to 18.24 t ha$^{-1}$, while on the northern slope exposure, soil washout increased more than twofold, reaching 54.6 m³ ha$^{-1}$ (Figure 8).

One of the key factors affecting soil erosion is the distribution of rainfall intensity during showers. Many field and laboratory studies have been conducted to better understand soil erosion and

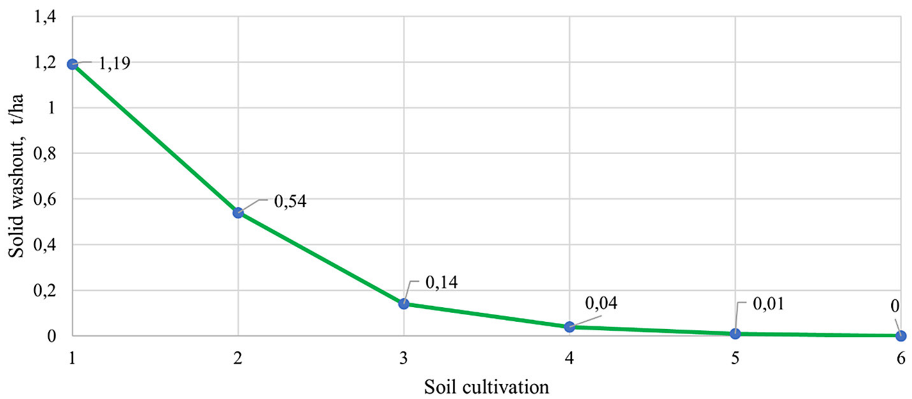


**Figure 4.** Solid soil washout during spring snowmelt depending on the agro-background in experiment 2, t ha$^{-1}$

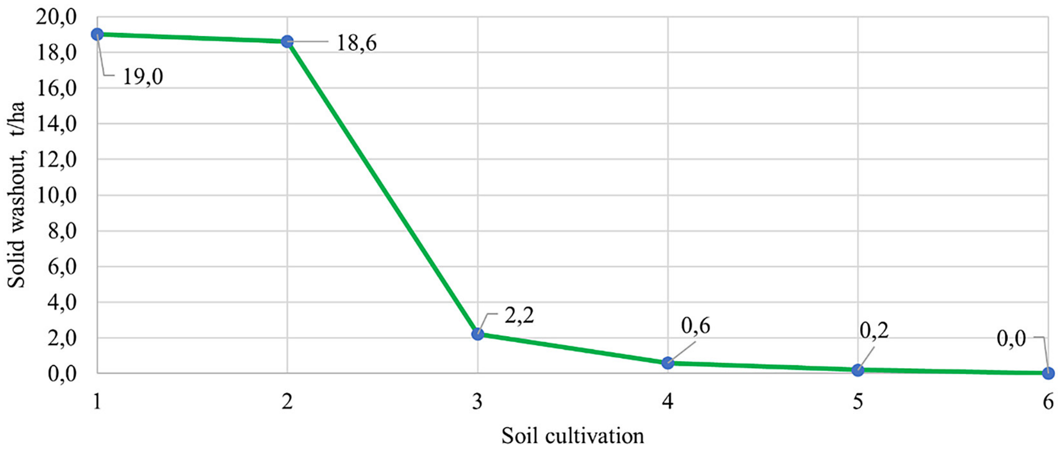


**Figure 5.** Predicted soil washout during spring snowmelt depending on the agro-background, t ha$^{-1}$, using Bulygin's modification of Mirtskhulava's formula (Bulygin and Nearing, 1999)

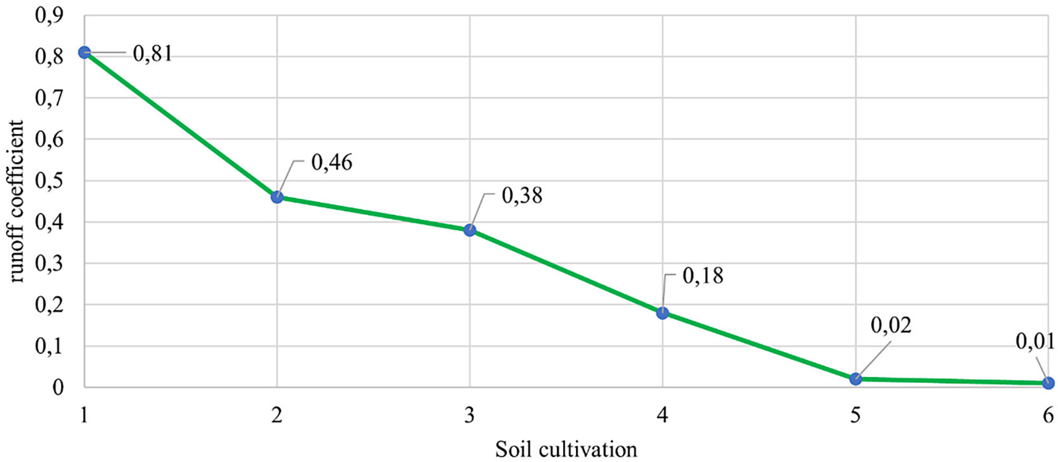


**Figure 6.** Runoff coefficient during spring snowmelt depending on the agricultural background in experiment 2

its relationship with the amount, intensity, as well as structure of precipitation (Truman et al., 2007; Ahmed et al., 2012; Gholami et al., 2018). A rainstorm on one soil type can cause varying erosion intensities depending on the vegetation cover (Lal, 2018). In the system of anti-erosion measures aimed at combating erosion, a crucial role belongs to a complex of meliorative techniques that ensure the formation of a surface resistant to runoff and soil washout. Studies show that reducing the runoff line length is not sufficient for effective erosion control (Figures 9, 10).

Due to the reduction of the runoff line length, the soil losses in winter wheat crops decreased by 1.5–4.5 times, and in row crops (corn) by 6.3–12.0 times (Figures 10). The soil losses on sloping soils when cultivating crops without specialized tillage exceed the permissible limit by 3.9–8.2 times (3.5 t ha$^{-1}$ – permissible loss limit) (Bulygin and Nearing, 1999).

Soil erosion resistance depends on the method of soil tillage, the density of the arable layer, the humus content, as well as the physical and chemical properties (Guo, 2018). One of the main qualitative characteristics of soils is the size of aggregates. Soil mass consists of clods of various shapes and sizes. There are three groups by size: macroaggregates (structural units larger than 10.0 mm), mesoaggregates (from 0.25 to 10.0 mm), and microaggregates (smaller than 0.25 mm). In agronomic terms, soil is considered structured if crumbly-granular water-stable structural units of 10.0–0.25 mm in size constitute more than 55%. These aggregates have water stability, ensuring an optimal water-air regime in the soils (Harvey et al., 2020, Yakovenko, 2019, Shahzad, 2020).

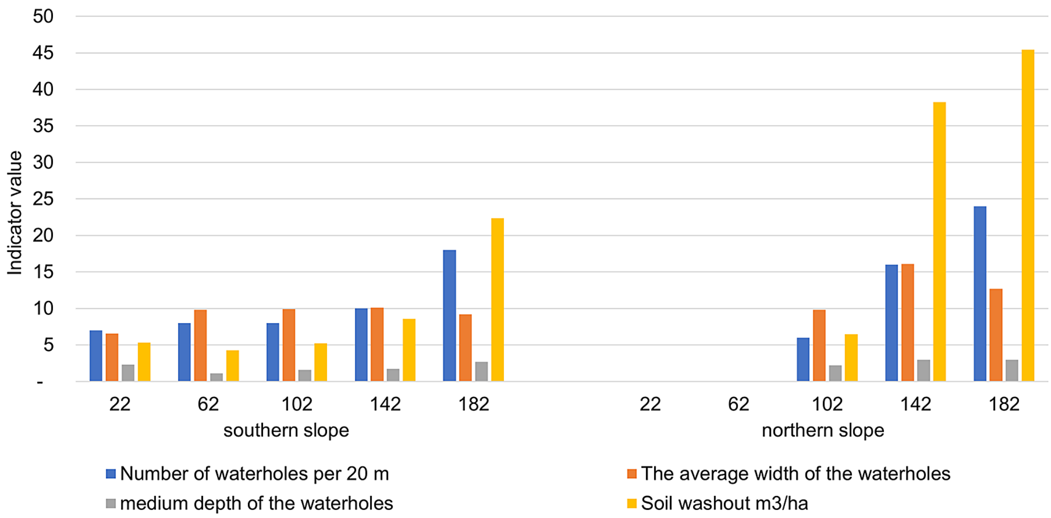


**Figure 7.** Results of soil washout accounting after spring snowmelt on a gentle southern and northern slope (3.0–4.0 degrees) during winter wheat cultivation using the water rill method

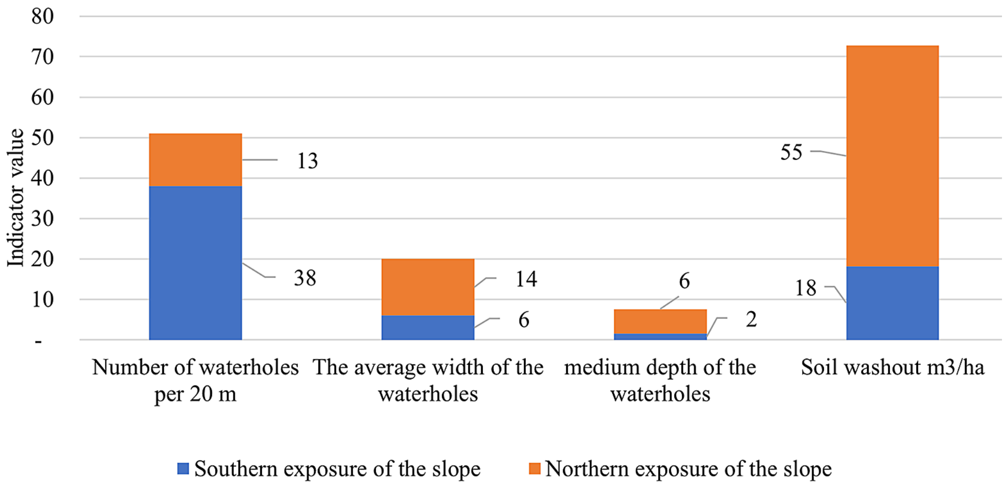


**Figure 8.** Results of soil washout accounting after spring snowmelt on a convex slope (4–5 degrees) at 102 m from the embankment, using the water rill method during winter wheat cultivation

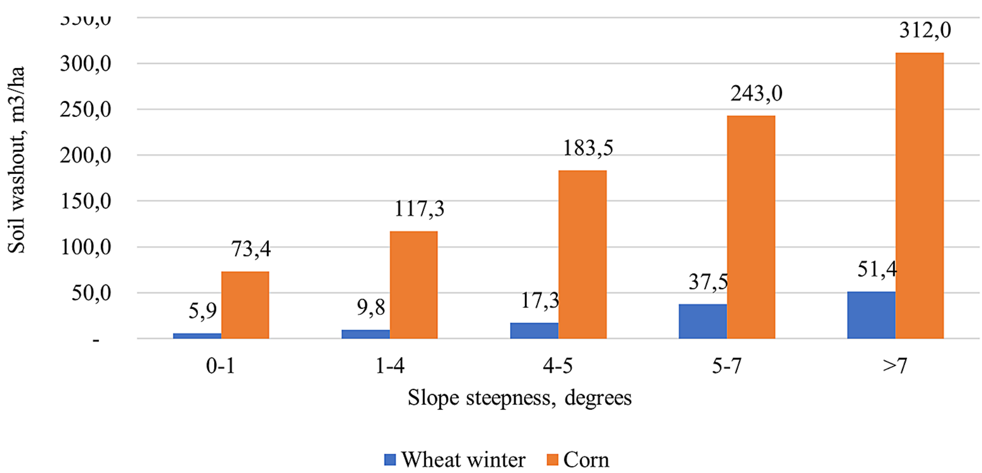


**Figure 9.** The effect of slope steepness on soil washout during the cultivation of agricultural crops with a runoff line length > 800 m on slopes of varying steepness, m³ ha⁻¹

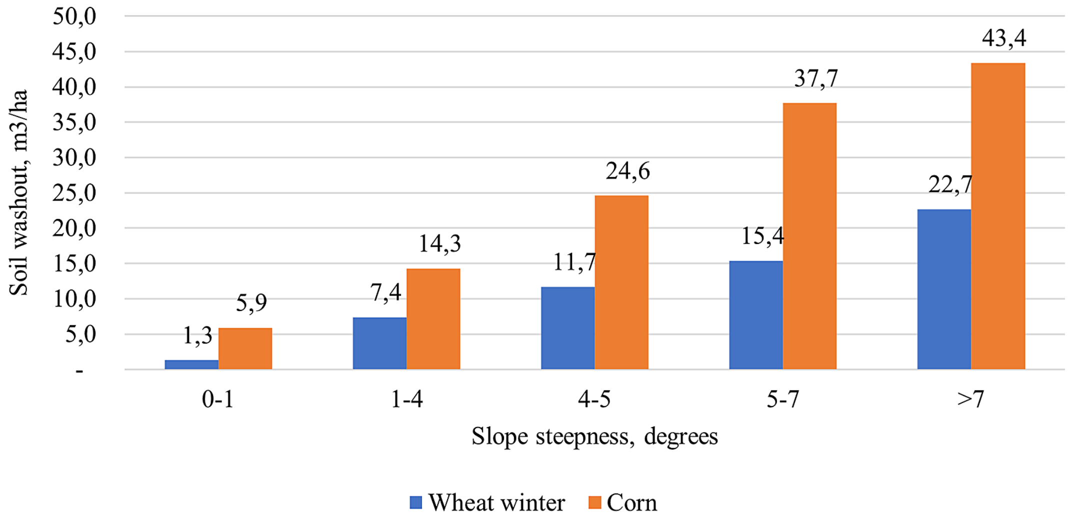


**Figure 10.** The effect of slope steepness on soil washout during the cultivation of agricultural crops in an anti-erosion arranged agricultural landscape with a runoff line length not exceeding 200.0 meters, m³ ha$^{-1}$

The study of the structural-aggregate composition of the arable layer of regraded chernozem was conducted in experiment 1 (Table 1). The content of agronomically valuable fraction (10.0–0.25 mm) determines the quality of soil crumbling during tillage. Of particular importance is the content of water-stable aggregates larger than 1.0 mm in the surface soil layer, which helps reduce the intensity of erosion processes (Thai et al., 2022). If the topsoil has a good aggregate composition, the water entering the soil surface filters into the lower layers through non-capillary pores. Where soil structure quickly deteriorates under the influence of water, individual particles of destroyed aggregates, especially their silt fraction, clog the pores of the lower layers, sharply reducing soil permeability for air and water, leading to surface washout on sloping areas (Fajeriana et al., 2024).

The content of agronomically valuable aggregates (10.0–0.25 mm) in the 0–40 cm layer was practically the same, regardless of the tillage method. However, the content of aggregates larger than 1 mm was slightly higher in the 0–10.0 cm layer with conventional plowing at 87.8%, compared to 79.6% in flat-cut tillage and 84.4% in chisel tillage, showing a statistically significant increase in the coarse fraction with conventional plowing by 8.2% compared to flat-cut tillage (LSD 0.5–3.02%). This is explained by the fact that plowing brings the structured part of the lower horizon to the soil surface, while the pulverized upper horizon is buried.

When loosening the soil with a chisel, significant mixing of soil horizons also occurs. This is confirmed by data on the stability of soil samples to water jet erosion and the water stability of soil aggregates during wet sieving.

The structural coefficient is based on the number of agronomically valuable aggregates. The Kstr. ranges used for qualitative assessment of soil structure are as follows: more than 1.5 – excellent aggregate condition, 1.5–0.67 – good aggregate condition, less than 0.67 – unsatisfactory aggregate condition (Artemjev and Guryanov, 2019). In the variant with plowing, the 0–10 cm soil layer had excellent aggregate condition, which can be explained by the turning of the furrow and the exposure of undestroyed aggregates to the surface, as well as the 30.0–40.0 cm layer. In the variant with flat-cut tillage, the 30.0–40.0 cm soil layer had an excellent aggregate condition. In the variant with chisel tillage, all layers below 0–10.0 cm had excellent aggregate condition. In the most root-containing layer of 0–40 cm, the excellent aggregate condition had a variant with chisel tillage of the soil Kstr. – 1.54, and the unsatisfactory aggregate condition had a variant with flat-cut processing and a structural coefficient of 1.36.

Soil erosion resistance was determined in the soil samples taken from the top layer (0–10.0cm), which is most prone to water erosion processes. It was found that to erode a soil sample with conventional plowing, a water jet force of 130.0 N was required (Table 2), while for flat-cut tillage – 93.0 N, and for chisel tillage – 73.0 N. The data on the lower stability of aggregates under chisel tillage to

**Table 1**. The impact of tillage methods on the structural-aggregate composition of the 0–40 cm soil layer

| Soil layer, cm | Tillage method | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Conventional plowing | | | Flat-cut tillage | | | Chisel tillage | | |
| | 10–0.25 mm | > 1 mm | Kstr. | 10–0.25 mm | > 1 mm | Kstr | 10–0.25 mm | > 1 mm | Kstr. |
| | | | 1.83 | 94.18 | 79.63 | 1.27 | 95.80 | 84.41 | 1.20 |
| | | | 0.89 | 97.44 | 88.98 | 1.13 | 97.14 | 87.43 | 1.56 |
| 20–30 | 98.20 | 90.36 | 1.18 | 97.3 | 88.84 | 1.11 | 96.45 | 86.20 | 1.64 |
| 30–40 | 97.00 | 86.32 | 1.98 | 94.43 | 81.63 | 1.96 | 95.11 | 84.72 | 1.76 |
| $LSD_{05}$ 0–10 | 3.08 | 3.02 | 0.75 | 3.08 | 3.02 | 0.75 | 3.08 | 3.02 | 0.75 |
| $LSD_{05}$ 0–20 | | | 0.50 | | | 0.50 | | | 0.50 |

**Table 2.** Characteristics of water stability of slightly washed-out regraded chernozem depending on the tillage method

| Tillage method | Soil layer, cm | Erosion resistance, N | Mean weighted diameter of water-stable aggregates, mm | Content of water-stable aggregates > 0.25 mm, % |
|---|---|---|---|---|
| Conventional plowing | 0–10 | 130.0 | 1.0 | 18.46 |
| | 10–20 | | 1.14 | 18.58 |
| | 20–30 | | 0.82 | 20.23 |
| | 30–40 | | 0.74 | 17.92 |
| Flat-cut tillage | 0–10 | 93.0 | 1.40 | 17.93 |
| | 10–20 | | 0.96 | 18.95 |
| | 20–30 | | 0.77 | 17.27 |
| | 30–40 | | 0.73 | 18.24 |
| Chisel tillage | 0–10 | 73.0 | 1.17 | 18.41 |
| | 10–20 | | 1.00 | 19.36 |
| | 20–30 | | 0.76 | 17.94 |
| | 30–40 | | 0.69 | 19.20 |

the destructive action of water are confirmed by the results of rainfall and runoff modeling obtained using the MDU laboratory-field rain simulator.

Soil erosion resistance depends on the content of water-stable aggregates > 0.25 mm and the mean weighted diameter of water-stable aggregates, calculated based on "wet" soil sieving (Torri et al., 1998).

Soil erosion resistance was determined in the soil samples taken from the top layer (0–10 cm), which is most prone to water erosion processes. It was found that to erode a soil sample with conventional plowing, a water jet force of 130.0 N was required (Table 2), while for flat-cut tillage – 93.0N, and for chisel tillage – 73.0 N. The data on the lower stability of aggregates under chisel tillage to the destructive action of water are confirmed by the results of rainfall and runoff modeling obtained using the MDU laboratory-field rain simulator.

Soil erosion resistance depends on the content of water-stable aggregates > 0.25 mm and the mean weighted diameter of water-stable aggregates, calculated based on "wet" soil sieving (Torri et al., 1998).

## Aggregate water stability and conclusions

The water stability of aggregates depending on the tillage method changes insignificantly. The highest mean weighted diameter of water-stable aggregates in the 0–10.0 cm layer was observed with flat-cut tillage – 1.40 mm, which is 0.4 mm higher than with conventional plowing. With chisel tillage, the diameter was 0.17 mm. However, by 40.0 cm, the fluctuation of this indicator significantly decreases. The content of water-stable aggregates > 0.25 mm was practically the same for all tillage methods and horizons.

The study covered only a specific time period, which may not fully reflect long-term climatic or landscape changes. In particular, variations in erosion potential may vary significantly from year to year due to anomalous weather conditions or changes in land use. The results may also be partly due to the characteristics of the crop rotations used in the region during the study period. For example, the presence of crops with different degrees of soil protection (winter, row crops, perennial grasses) may have influenced the intensity of erosion processes.

## CONCLUSIONS

The study of erosion process intensity in an anti-erosion arranged agricultural landscape with a runoff line length not exceeding 200.0 m, using a system of equipped embankment-terraces, allowed for evaluating the effectiveness of different soil tillage methods and anti-erosion measures. The results confirm that reducing the runoff line length to 200.0 m contributes to reducing soil washout and improving its water-physical properties. Among soil conservation tillage, the most effective was chisel tillage combined with mole drainage to a depth of 50.0–55.0 cm. Flat-cut tillage combined with moisture accumulation techniques also contributed to creating a reliable anti-erosion background and reducing soil washout by more than 29 times compared to plowing.

Soil tillage for winter wheat on sloping soils must necessarily include mole drainage to a depth of 50.0–55.0 cm. The use of traditional plowing increases liquid runoff and solid soil washout. The lowest level of liquid runoff was recorded with chisel tillage combined with mole drainage (0.9 $m^3$ $ha^{-1}$), which is explained by the preservation of plant residues and the improved structure of the arable layer.

Placing agricultural crops every 200.0 m with embankment-terraces and shelterbelts significantly reduces soil washout and minimizes the impact of water erosion. The length of the runoff line is a critical factor: increasing the length beyond 100 m leads to a sharp increase in soil losses, especially on convex slopes. The content of agronomically valuable aggregates (10.0–0.25 mm) in the 0–40.0 cm layer was practically the same regardless of the tillage method. Conventional plowing increases the content of aggregates >1.0 mm in the topsoil and enhances erosion resistance to water jet (130.0 N) by bringing stable aggregates to the surface, while with flat-cut and chisel tillage – 93.0 and 73.0 N, respectively. The obtained data can be used to develop adaptive strategies for soil fertility conservation in the forest-steppe zone of Ukraine.

## REFERENCES


1. Ahmed S., Rudra R., Gharabaghi B., Mackenzie K., Dickinson W. (2012). Within-storm rainfall distribution effect on soil erosion rate. *ISRN Soil Science, 2012*, 1–7. https://doi.org/10.5402/2012/310927
2. Akshalov K.A. (2010). Methodological recommendations for the study and control of water erosion of soils in modern farming systems. *Astana, 25*. (in Russian).
3. Artemjev A.A., Guryanov A.M. (2019). Changes in agrochemical parameters of leached chernozem under the influence of differentiated use of minerals. Agricultural Science Euro-North-East, 20(2), 144–152. https://doi.org/10.30766/2072-9081.2019.20.2.144-152
4. Bastrakov G.V. (1977). Erosive strength of rocks. *Geomorphology. 3*, 52–55. (in Russian).
5. Bastrakov G.V. (1994). *Erosion stability of relief and anti-erosion protection of lands*. Bryansk: Publishing house of BSPI. 260.
6. Bavrovska N., Koshel A., Tykhenko O. (2024). Balanced use of agricultural land affected by war in Ukraine as a prerequisite for sustainable development. *Zemleustrìj, Kadastr ì Monìtorìng Zemel, 1*. (in Ukrainian). https://doi.org/10.31548/zemleustriy2024.01.04
7. Belkin I. (2024). The agricultural sector of Ukraine in war conditions: problems and prospects of development. *Naukoviperspektivi, 4*(46). (in Ukrainian). https://doi.org/10.52058/2708-7530-2024-4(46)-484-498
8. Belolipskii V.A., Bulygin S.Yu. (2009). An ecological and hydrological analysis of soil- and water-protective agrolandscapes in Ukraine. *Eurasian Soil Science, 42*(6), 682–692. (in Ukrainian). https://doi.org/10.1134/s1064229309060143
9. Bulygin S.Yu., Vitvitsky S.V. (2024). *Soil protection: textbook*. Chornobayvka: Chornobayvske KPP, 464. (in Ukrainian).
10. Bulygin S.Yu., Nearing M.A. (1999). *Formation of ecologically balanced landscapes: the problem of erosion*. Kharkiv, Eney LTD, 272. (in Ukrainian).
11. DSTU 4362:2004. (2004). *National Standard of Ukraine*. Soil quality. Soil fertility indicators https://zakon.isu.net.ua/sites/default/files/normdocs/dstu_4362_2004.pdf
12. Fajeriana N., Ali A., Rini R.P. (2024). Soil tillage and planting along the contour on sloping land to minimize the potential for erosion and surface

runoff. *Sarhad Journal of Agriculture, 40*(1). https://doi.org/10.17582/journal.sja/2024/40.1.82.93

13. Gholami V., Booij M.J., Nikzad Tehrani E., Hadian M.A. (2018). Spatial soil erosion estimation using an artificial neural network (ANN) and field plot data. *Catena, 163*, 210–218. https://doi.org/10.1016/j.catena.2017.12.027
14. Goewin F.W., Soeryamassoeka S.B., Yulianto E. (2024). Influence of land use change on the magnitude of the runoff coefficient in the upper kapuas river basin. *Jurnal Teknik Sipil, 24*(1). https://doi.org/10.26418/jts.v24i1.75238
15. Guo W. (2018). Application of geographic information system and automated guidance system in optimizing contour and terrace farming. *Agriculture, 8*(9), 142. https://doi.org/10.3390/agriculture8090142
16. Harvey H.J., Wildman R.D., Mooney S.J., Avery S.V. (2020). Soil aggregates by design: Manufactured aggregates with defined microbial composition for interrogating microbial activities in soil microhabitats. *Soil Biology and Biochemistry, 148*, 107870. https://doi.org/10.1016/j.soilbio.2020.107870
17. Jin H., Shi D., Lou Y.B., Zhang J., Ye Q., Jiang N. (2021). Evaluation of the quality of cultivated-layer soil based on different degrees of erosion in sloping farmland with purple soil in China. *Catena, 198*, 105048. https://doi.org/10.1016/j.catena.2020.105048
18. Koshel A., Kolhanova I., Kempa O., Stacherzak A. (2023). On the issue of developing working land management projects to improve the condition of agricultural lands and protect lands from erosion in Ukraine. *Land management, cadastre and land monitoring, 0*(3), 23–31. (in Ukrainian). http://dx.doi.org/10.31548/zemleustriy2023.03.03
19. Kucher L., Poltoretskyi S., Vasylenko O, Krasnoshtan I, Zamorsky O. (2022). Peculiarities of the primary process of the soil formation on the mine rock dumps under the influence of biotic factors. *Journal of Ecological Engineering, 23*(11), 101–108. https://doi.org/10.12911/22998993/153399
20. Labaz B., Waroszewski J., Dudek M., Bogacz A., Kabala C. (2022). Persistence of arable chernozems and chernic rendzic phaeozems in the eroded undulating loess plateau in Central Europe. *Catena, 216*, 106417. https://doi.org/10.1016/j.catena.2022.106417
21. Lal R. (2018). Applying soil quality concepts for combating soil erosion. *Soil Quality and Soil Erosion*, 309–317. https://doi.org/10.1201/9780203739266-17
22. Litvinova O., Dehodiuk S., Litvinov D., Havryliuk O., Kyrychenko A., Borys N., Dmytrenko O. (2023). Efficiency of technology elements for growing winter wheat on typical chernozem. *Agronomy research, 21*(3), 1199–1212. https://doi.org/10.15159/AR.23.079
23. Methodological recommendations for accounting for surface runoff and soil washout in the study of water erosion. L.: Gidrometeoizdat, (1975). 88. (in Russian).
24. Moskalenko A., Heryn A. (2023). Geoinformation modeling of wind erosion. *Land management, cadastre and land monitoring, 0*(4), 102–109. (in Ukrainian) http://dx.doi.org/10.31548/zemleustriy2022.04.11
25. Nsabimana A., Niyitanga F., Weatherspoon D.D., Naseem A. (2021). Land policy and food prices: Evidence from a land consolidation program in Rwanda. *Journal of Agricultural & Food Industrial Organization, 19*(1), 63–73. https://doi.org/10.1515/jafio-2021-0010
26. Pavlichenko A., Dmytrenko O., Litvinova O., Kovalova S., Litvinov D,, Havryliuk O. (2023). Changes in gray forest soil organic matter pools under anthropogenic load in agrocenoses. *Agronomy research, 21*(3), 1266–1277. https://doi.org/10.15159/AR.23.095
27. Peng T., Wang S. (2012). Effects of land use, land cover and rainfall regimes on the surface runoff and soil loss on karst slopes in southwest China. *Catena, 90*, 53–62. https://doi.org/10.1016/j.catena.2011.11.001
28. Pham B.T., Le L.M., Le T.-T., Bui K.-T.T., Le V.M., Ly H.-B., Prakash I. (2020). Development of advanced artificial intelligence models for daily rainfall prediction. *Atmospheric Research, 237*, 104845. https://doi.org/10.1016/j.atmosres.2020.104845
29. Searchinger T., Peng L., Zionts J., Waite R. (2023). *The global land squeeze: Managing the growing competition for land*. World Resources Institute. https://doi.org/10.46830/wrirpt.20.00042
30. Shahzad H. (2020). Rhizobacterial inoculation to quantify structural stability and carbon distribution in aggregates of sandy clay loam soil. *Eurasian Soil Science, 53*(5), 675–685. https://doi.org/10.1134/s1064229320050142
31. Shein, E.V. (2005). *Course of soil physics*. M.: Publishing house of Moscow State University. 432. (in Russian).
32. Shwebs H.I. (1974). Formation of water erosion of sediment runoff and their evaluation (on the example of Ukraine and Moldova). L.: *Hydrometeoizdat, 180.* (in Russian).
33. Six J., Paustian K., Elliott E.T., Combrink C. (2000). Soil structure and organic matter I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Science Society of America Journal, 64*(2), 681–689. Portico. https://doi.org/10.2136/sssaj2000.642681x

34. Standard. Soil quality. Measurement of the stability of soil aggregates subjected to the action of water. (n.d.). (in Ukrainian). https://doi.org/10.3403/30199147u
35. Sukhanovsky Yu.P., Vytovtov V.A., Solovieva Yu.A., Prushchik A.V., Sanzharova S.I., Titov A.G. (2016). Methodology for determining losses of biogenic substances from soil using a portable sprinkler. *Achievements of science and technology of the agro-industrial comple, 30*(6), 68–75. (in Russian).
36. Thai S., Davídek T., Pavlů L. (2022). Causes clarification of the soil aggregates stability on mulched soil. *Soil and Water Research, 17*(2), 91–99. https://doi.org/10.17221/151/2021-swr
37. Torri D., Ciampalini R., Gil P.A. (1998). The role of soil aggregates in soil erosion processes. *Modelling Soil Erosion by Water*, 247–257. https://doi.org/10.1007/978-3-642-58913-3_19
38. Truman C.C., Strickland T.C., Potter T.L., Franklin D.H., Bosch D.D., Bednarz C.W. (2007). Variable rainfall intensity and tillage effects on runoff, sediment, and carbon losses from a loamy sand under simulated rainfall. *Journal of Environmental Quality. 36*(5), 1495–1502. https://doi.org/10.2134/jeq2006.0018
39. Voytovyk M., Butenko A., Prymak I, Tkachenko M., Mishchenko Y., Tsyuk O., Panchenko O., Kondratiuk I., Havryliuk O., Sleptsov Y, Polyvanyi A. (2024). Mobile Phosphorus Presence of Typical Chernozems on Fertiliser System. *Rural Sustainability Research.* (51), 346 (August 2024). https://doi.org/10.2478/plua-2024-0006
40. Wischmeier W.H., Smith D.D. (1965*). Prediction rainfall erosion losses from cropland east of the Rocky Mountains: A Guide for Selection of Practices for Soil and Water Conservation*. Agricultural Handbook, 282, 47.
41. Yakovenko V.M. (2019). Technique for preparation thin sections of structural soil aggregates of certain size fractions. *Fundamental and Applied Soil Science, 19*(2), 55–58. https://doi.org/10.15421/041911
42. Yongshan W, Samir A. El-Swaify. (2001). Analyzing rainfall intensity effects on interrill splash and wash processes. Soil Erosion. https://doi.org/10.13031/20130.4844
43. Zbarskyi V., Ostapchu A., Zbarska A. (2020). Economic security of Ukraine in the conditions of transformation processes. Scientific papers of Dmytro Motornyi Tavria state agrotechnological university. *Economic Sciences, 42*, 41–48. https://doi.org/10.31388/2519-884X-2020-42-41-48
44. Zhu T., Xu X. (2021). Simulation modeling of hydrological and erosion processes. *Watershed Erosion Processes*, 147–155. https://doi.org/10.1007/978-3-030-81151-8_9
45. Zos-Kior M.V., Sokolova N.S. (2012). *Quality management and competitiveness of agricultural products in the context of economic globalization*. Monograph. Lugansk: LNAU. Elton-2. 248. (in Ukrainian).