Impact of the No-Till technology on erosive degradation of soils in hollows

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Abstract. The present research is aimed at studying the impact of the modern no-till agricultural technology on the development of erosion processes on cultivated arable land in the subzone of the southern chernozems of the Volgograd region. Evaluation of the impact of this agricultural technology was based on the analysis and comparison of soil cover in hollows located in the fields cultivated using either the classic technology or the no-till technology. The research methodology is based on combination of remote, field and laboratory methods for studying the soil cover. Analysis and generalization of data obtained in the course of laboratory studies of selected soil samples made it possible to identify a high degree of erosion processes in the hollows located in the fields, which had been cultivated using the no-till technology for three years. Comparison of the values of the content of organic carbon in the zones of removal, transit and accumulation of fine earth indicates the development of water degradation processes in the middle part of the hollows. Thus, for soil samples taken from a depth of 0-10 cm, the value of organic carbon content in the variant of soil tilled using the new technology is 2.6%, while in the variant tilled using the classic technology, this value is equal to 3.1%. The revealed differences in the soil cover of the hollows can be explained by interaction of the patterns of development of erosion-accumulation processes and the features of the no-till technology in specific natural and climatic conditions.

1. Introduction
To date, a certain amount of data on the impact of the no-till technology on agricultural landscapes has been accumulated both in our country [1-5] and abroad [6-14]. The accumulated experience is contradictory, therefore, researchers put in the foreground the issues related to systematization of accumulated knowledge based on studying the zonal-provincial aspects of the impact of the new technology, as well as on common methodological approaches to evaluating the impact of agricultural technologies on agricultural landscapes [2;4;11].

In most scientific works, researchers approach the issue of studying the impact of the no-till technology on the development of erosion processes either from the viewpoint of the effect of mulch from plant residues or from the standpoint of changes in the humus content in the surface soil layer [2-
4]. In these studies, the authors conclude that the no-till technology contributes to the prevention of water erosion. There are a number of limitations on dissemination of the findings of these studies. This is directly indicated by the authors of a review article prepared on the basis of the analysis of materials from 678 studies conducted in 63 countries [11]. These limitations are primarily related to the complexity of spatial organization of territories. Most studies are carried out in laboratory conditions or on objects (experimental fields), which are located in upland conditions and occupy extremely limited areas of several hectares.

The purpose of the present research is to establish agro-ecological aspects of the no-till technology impact and to find out peculiarities in the development of water degradation processes in soils of the steppe zone of the Volgograd region.

2. Materials and methods

The research object is represented with the soil cover of the agrolandscapes of the Elansky district of the Volgograd region. An experimental crop rotation was set up on an area of 250 hectares on the farm of OOO Bolshoy Morets (LLC) to study various aspects of application of the no-till technology. As of the time of the study, the period of cultivation of agricultural crops using the new technology lasted 3 years.

According to the World reference base for soil resources (WRB), the area under study refers to the Calcic Chernozem zonal soil type. The climate is moderately arid. The hydrothermal coefficient is 0.8-0.7. The long-term annual average precipitation is 393 mm. In terms of geomorphology, the territory of the research object belongs to the eastern end of the Khoper-Buzuluk plain. The density of the ravine-beam network makes 1-1.5 km/km². The experimental site is located on the territory of two beam catchment areas, on the left bank of the Vyazovka River. The northwestern slope is 0.5-1.0° steep and 3 km long.

The research methodology is based on the use of remote, field and laboratory methods for studying the soil cover and consists of three stages.

The stage of preliminary research was aimed at selecting key areas for field research. QuickBird satellite images and topographic maps (M 1:25000) were used in the process of gathering cartographic and remote information on the territory of the research object.

The stage of field research included full-scale field studies of all the hollows of the experimental site, photographic recording of vegetation cover and soil surface, soil sampling in soil pits and wells.

The third stage was aimed at laboratory studies of soil samples, their analysis and generalization, as well as making conclusions. Laboratory analysis of materials selected during the field studies was carried out according to generally accepted methods. Determination of the content of organic carbon in the soil was performed according to the method of I.V. Tyurin.

An important component of the research methodology consists in the use of statistical methods. The soil sampling includes 348 samples. Sampling was carried out from 32 soil wells and 2 soil pits. The soil wells were laid at the sampling sites located in four zones of each hollow. The soil samples were taken at a depth of 1 m, layer by layer, every 10 cm. The wells were laid four times. In the pits, sampling was carried out in two ways - layer by layer every 10 cm and along soil horizons. The generalized data (arithmetic mean values of the studied indicators) were used in the materials of the article.

Solving the problem of diagnosing and classifying soils by the degree of water erosion reveals a variety of methodological approaches. In general, classifications are built on two diagnostic features – 1) degree of decrease in the thickness of humus horizons and 2) change in the content of organic carbon in the surface layers of soil in % as compared to the soil not subjected to water erosion. The work of G.P. Surmach [15] outlines the positive and negative aspects of each of the methodological approaches. The present paper also substantiates the great practical significance and accuracy of the method based on the evaluation of the thickness of soil horizons for the purposes of soil erosion mapping.
The thickness of soil horizons was determined on the basis of the data of field standardization. Analysis of soil samples taken from the pits located on the watershed and in the lower part of the slope (figure 1b, control sites 9 and 10) made it possible to determine the ranges of values of the considered parameters corresponding to the genetic horizons of the studied soils. Thus, the range of values of the index of organic carbon content for the humus horizon (A) is 2.7-2.3%; for the transitional humus horizon (AB), the index is equal to 2.2-1.1%; for the transitional horizon (B), the index is equal to 1-0.6%; for the upper layers of the parent rock (C), the index is less than 0.5%.

3. Results
The results of the work carried out at the preliminary stage of the research include determining the location of the key area of the experimental site and identifying the structure of the hollow’s catchment territories in the key area (figure 1a). The site has 17 hollow’s catchment areas and 2 plots of inter-catchment territories (convex slopes of one-sided dip – between the 12th and the 13th catchments and between the 17th and the 1st catchments).

Establishing the boundaries of catchments made it possible to obtain the main morphometric indicators of the studied catchments. The length of the talweg of the hollows in the key area ranges from 130 m to 1600 m, the arithmetic mean is 430 m. The minimum area of catchments is 0.03 km², the maximum area is 0.33 km², the arithmetic mean is 0.2 km². The excess of heights in the studied catchments varies from 5 to 15 meters, and the arithmetic mean is 10 m. The elongated shape of the catchments prevails.

The main result of the preliminary studies consists in the selection of a typical catchment territory of the hollow in the key area for the ground stage of the ongoing research (the site is cultivated using the no-till technology), as well as the selection of an analogue site based on the morphometric characteristics of the hollow’s catchment territory (the site is tilled using the classic technology). These catchments are represented with catchments 4 and 18 (figure 1a). The main morphometric indicators of the studied hollows are equal: the length of the talweg of the hollows is 800 m, the catchment territory is 0.18 km², and the elevation is 10 m. The morphometric indicators of the hollows, in which the ground studies were carried out, tend to the arithmetic mean of the hollows located in the studied area.

Soil sampling sites at points 1, 2, 3, 4 are located in the no-till fields, and, at points 5, 6, 7, 8, they are located on the fields cultivated using the classic technology (figure 1b).

Figure 1. The structure of catchments and key areas of the experimental site: a – structure of catchments in the hollows of the studied area; b – layout of key areas at the experimental site.
Field research of the hollow link of the hydrographic network of the key area showed the presence of microrill erosion in the fields where the no-till technology was used. It should be noted that a peculiarity of the vegetation cover in the hollows was revealed in the course of the field research. In the no-till fields, there is a significant decrease in quantity and quality of weeds because of the use of herbicides.

Figure 2 presents summarized data obtained in the course of the laboratory studies of the content of organic carbon in the samples taken in the hollows located in the fields cultivated using either the no-till technology or the classic technology.

Figure 2. Dynamics of organic carbon content in the profile of arable soils in hollows located either in the no-till field or the classic field: a – watershed; b – top of the hollows; c – middle part of the hollows; d – mouths of hollows.
Comparison of the results of laboratory analyses of soil samples generally confirms the patterns of soil changes caused by erosion processes: removal (top of the hollow), transit (middle part of the hollow), and accumulation of fine earth (lower part of the hollow).

Despite the short period of application of the no-till technology, there is an obvious difference in the state of the soil cover of hollows, indicating a greater development of erosion-accumulation processes on arable land cultivated using the no-till technology.

The most intense process of water degradation of the soil was observed in the middle part of the hollow. Samples taken in the upper soil layers are characterized by a lower content of organic carbon as compared to samples taken from the same depths in the classic field. From a depth of 20 cm (organic carbon content of 2.5%), a sharp decrease in the content of organic carbon in the soil was observed. The humus horizon (A) is eroded, which makes it possible to classify the studied soil as subjected to water erosion and moderately eroded [16]. The humus horizon of the soil in the middle part of the hollows of the key area cultivated according to the classic technology, on the contrary, is not eroded and has greater thickness parameters than in the watershed. At the same time, it is distinguished by a slightly higher content of organic carbon in the surface layer of the soil (3.1% versus 2.7%).

The lower part of the studied hollows is characterized by the processes of accumulation of soil particles washed out by water. This process is also more distinct in the hollows located in the no-till field. The average thickness of the sediment layer at the sampling point in the no-till field is about 40 cm, while in the field cultivated according to the classic technology this value is equal to 20 cm. The content of organic carbon in the sample taken from a layer of 0-10 cm in a hollow located in the no-till field reaches a maximum value among all the samples – 3.3%.

4. Discussion
The discrepancies that arise between the results of the study and the conclusions made by other authors can be explained by the structure of modern erosion processes and the difference in methodological approaches to their study. For example, in the work of O.P. Ermolaev [17], soil erosion appears to be the result of a combination of processes: drip-rain destruction and microrill washout.

The conclusions about contribution of the no-till technology to prevention of soil erosion are based either on the study of changes in the properties of the surface layer of soils (water permeability, changes in organic carbon content, resistance of aggregates to water degradation, granulometric composition of soils, content of carbonates, phosphorus, nitrogen, carbon, humic and finely dispersed substances, etc.) or on the study of the effect of mulch from plant residues [1-2;5-6;9;14]. These studies can be referred to the investigation of the rain-drop component of soil destruction.

The key points in the study of microrill washout include the issue of establishing the degree of water degradation of soil [15-16] and taking into account the nature of linear erosion processes (concentric erosion, self-developing erosion). However, the above works do not contain research on these issues with regard to the fields cultivated using the no-till technology.

Since the no-till technology can help prevent drip-rain soil destruction, but at the same time it can enhance microrill washout, it is important that the methods for studying the impact of this technology on soil erosion take into account both components of the complex of erosion processes. In other words, the existing methodological approaches to the study of the impact of modern agricultural technologies on the development of soil erosion do not contradict, but complement each other.

5. Conclusion
An important peculiarity of the development of water erosion processes is a pronounced staging, which manifests itself in the morphological features of erosion processes. The initial stage of the erosion process, the stage of the “hanging” ravine, is characterized by the formation of gullies, their active growth and merging, the formation of a concentric channel, its merging with the existing hydrographic network.
In the classic fields, most of the waterholes formed as a result of snow melting, as well as the result of heavy rainfall during the growing season, are destroyed by leveling and shifting the upper soil layers during periodic tillage, which takes place often as compared to the no-till technology. In the no-till fields, the formed waterholes are not destroyed by tillage, but serve as channels (attractors) for the passage of melt and rain water. In addition, waterholes, as a rule, contribute to accumulation of snow in the most erosion-prone areas.

Thus, the erosion process in the fields cultivated using the classic technology every year begins from the initial stage – the stage of transition of planar erosion into its linear forms. In the fields cultivated using the no-till technology, the erosion process is characterized by consistent, progressive, concentrically directed development associated with the formation of a channel.

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