TRENDS IN THE DEVELOPMENT OF SOIL CULTIVATION TECHNOLOGIES IN THE MOUNTAINOUS CONDITIONS OF THE REPUBLIC OF ARMENIA IN THE CONTEXT OF ENVIRONMENTAL ISSUES

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Key words: tillage, no-till technology, soil compaction, combined machine, mechanical erosion, wind erosion, minimum soil cultivation, mechanical soil degradation

Introduction

For centuries, plowing has been considered an important technological process in soil cultivation. Currently, plowing is subject to strong criticism for several reasons, among which we can mention the following [Khamukov, 2022, 225-235]:

- Plowing consumes up to 40% of the energy costs for soil cultivation and up to 30% of the labor;
- Powerful and therefore heavy tractors are used for plowing, which cause the soil to become overcompacted under their tracks, leading to the deterioration of conditions for plant growth and development, increased erosion, and so on;
- The damage to the soil structure and the significant wear of the equipment used are associated with plowing;
- During the plowing of slopes, the soil undergoes mechanical erosion. The difficulty of turning the furrow uphill and the low quality of plowing compel the execution of unilateral plowing on slopes, with the furrow being turned downhill. This leads to the displacement of the surface layer of soil downhill and reduces the productivity of the aggregate;
- In a plowed field, hollows and ridges are formed, the elimination of which requires additional technological processes. In other words, when plowing is applied, soil preparation for sowing is not limited to just one or two passes [Tokushev, et al., 2003, 253].

Throughout the entire history of soil cultivation, the process of plowing has been continuously refined, which has significantly reduced costs and lessened the harmful impact of plowing on the environment [Belousov, et al., 2017, 478-479], [Khamukov, 2022, 225 - 235]. However, what has been accomplished is still not sufficient, and work in this direction continues including by us.

Methodology

To prevent the negative consequences of plowing, the search for alternative soil cultivation technologies has begun. Various solutions are being proposed [Bedoeva, et al., 2018, 137-141], [Ilyin, et al., 2021, 61-65].

- Reduction of the mass of heavy technical means,

- Use of multifunctional (combined) machines,
- Transition to a system of permanent technological tracks in fields,
- Use of bridge-like structures over 100 meters in length, from which machines and tools executing various technological processes will be suspended. Thanks to this, the impact of the working parts of agricultural machines on the soil becomes fully controllable.

Many countries see the solution to this problem in the elimination of plowing and propose performing only surface tillage. Currently, the technologies of minimum and zero tillage are more commonly applied, in which the soil is cultivated to a shallow depth corresponding to the sowing depth of the crop; soil inversion with a plow is not performed; the load on equipment and workers is sharply reduced; and tillage costs and energy consumption are decreased. It is considered acceptable from an agronomic point of view, resource-saving, economically beneficial, and ecologically justified. When applying minimum soil cultivation technology, expenses are reduced by about 2-6 times [Tonapetyan, et al., 2021, 30-36].

The main advantage of the aforementioned technologies is that the natural structure of the soil is preserved, and the damage inflicted on the agroecosystem is minimized [Alexandrovsky, 2015, 774-786], [Pykhtin, 2017, 33-36]. To prevent soil overcompaction by heavy machinery, it is proposed to replace synthetic fertilizers, pesticides, and plant growth stimulators with adherence to crop rotation rules and the preservation of plant residues in the field, active use of composts and manure, introduction of mechanical methods for weed control, and the application of biological methods for plant protection [Niklyaev, et al., 2000, 557 pages], [Kogyakova, et al., 2019, 34-39].

Scientists at Stanford University conducted a study on the effects of no-till agriculture and obtained objective evidence of its positive results [Deines, et al., 2019]. These studies confirmed the structural differences between plowed and unplowed soils, substantiating the formation of an overcompacted plow pan layer in the case of plowing (Fig. 1).

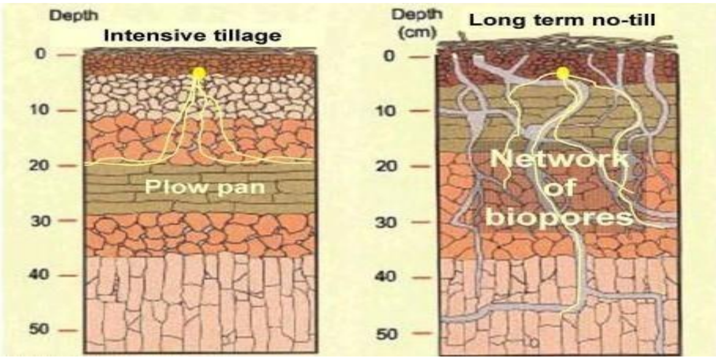

Figure 1. Transverse cross-section of soil under plowing (left image) and no-till (right image) conditions

Below the plowed layer, a compacted layer forms which creates a barrier and prevents the development of plant root systems into deeper layers. In the case of no-till cultivation, such a compacted layer does not form, and the plant's root system freely penetrates into deeper soil layers, creating favorable conditions for the growth, development of the plant.

Literature review

The purpose of agriculture is the reproduction of soil fertility through agrotechnical and reclamation measures, in the form of various impacts on the soil [Khamukov, 2022, 225-235]. Physical, agrochemical, and biological factors that determine soil fertility and, accordingly, the yield and quality of crops are greatly dependent on the method of soil cultivation [Varin, et al., 2023, 30-35]. Scientists have studied the methods and systems of soil cultivation over the past centuries, revealing their positive and negative aspects. The objective and subjective reasons for contradictions arising in the evaluation of the consequences have been identified [Merkulov, et al., 2014, 91-96], [Buklagina, 2005, 167]. To increase soil fertility, it is desirable to rely on natural processes. However, over time, this has given way to the targeted restoration and enhancement of soil fertility, for which various fertilizers have been used, a significant portion of which are, overall, harmful to human health and are not highly encouraged in many of the world's advanced countries. In the near future, one of the decisive directions in anti-erosion research should be the development and justification of a complex of technological measures and technologies that ensure the preservation and restoration of fertility primarily for soils subjected to erosion by applying resource-saving technical means under specific production and economic conditions [Pazova, 2009].

Scientific novelty

In research concerning soil cultivation technologies, one very important issue remains unexplained. The duration of studies on new soil cultivation technologies, including minimum and zero tillage, does not exceed 10-12 years. Therefore, a logical question arises: can we permanently apply no-till cultivation technologies and completely eliminate plowing? Agreeing with the negative consequences associated with plowing, we find:

- Surface tillage no-till technologies cannot be continuously applied over a long period**,** because over time, the fertility of the soil's surface layer decreases, and the soil becomes more "vulnerable" to wind erosion. Only thanks to plowing can the deeper soil layers (25 - 35 cm and more) be involved in the cultivation process. In weed control, plowing is ir-replaceable. Turning the furrow with a plow contributes to the prevention of certain diseases.
- By balancing the positive and negative aspects of plowing, an intermediate solution is proposed: to periodically every 3 to 5 years (depending on soil-climatic conditions) incorporate plowing into the technological processes of soil cultivation.

- To mitigate the negative aspects of plowing, we also suggest performing plowing, even at certain intervals, using a combined machine. This involves integrating it with other pre-sowing technological process or processes, taking into account the specific resistance of the soil [Esoyan, et al., 2023].
- The use of the proposed combined machine is also expedient from an environmental standpoint, particularly as it reduces soil loss and decreases the mechanical degradation of the soil. This has been substantiated as a result of our analysis.

Analysis

Let us provide an ecological assessment of the proposed machine using the analysis of the following expression for determining soil loss due to erosion.

$A=R\times K\times a\times S\times C\times P$ (1)

Where:

A is the soil loss due to erosion,

R is the climatic erosivity factor, which accounts for the degree of rainfall in the studied area,

K is the soil erodibility factor under normal conditions, considering the sensitivity of the studied soil to erosion,

a is the factor accounting for the length of the slope,

S is the factor accounting for the steepness of the terrain,

C is the factor accounting for the degree, to which the soil surface is covered with vegetation,

P is the factor accounting for the soil cultivation technology.

In expression (1), the coefficients a and S that affect erosion are essentially not determined by the proposed machine but depend on the terrain's relief. The value of coefficient C is also not determined by the proposed machine but depends on the qualitative characteristics of the soil, the zoning of the given area, climatic conditions, and so on. The coefficient K depends on the soil's physicomechanical properties and is therefore also not determined by the proposed machine.

R, which accounts for the degree of rainfall in the region, at first glance seems to be determined only by climatic factors. However, from the perspective of erosion, analysis of the consequences of rainfall reveals that it is directly dependent on the method of slope cultivation using the proposed machine, which has a direct impact on water erosion caused by rain. The proposed combined frontal plough for smooth plowing creates deep loosened zones across the slope which prevent rainwater from flowing downhill and almost completely neutralize the harmful effects of rainwater. Therefore, the effect of the R coefficient on soil loss due to erosion is reduced to almost a minimum when using the combined frontal plough for smooth plowing. P also has a direct connection with the proposed combined frontal plough for smooth plowing because it depends on the cultivation technology. While analyzing the operation of the proposed machine, we are convinced that all actions performed with the turning furrow are carried out within the same furrow and do not give rise to mechanical erosion on slopes. We can confidently state that the P coefficient, determined by the cultivation technology, will also have a significant impact on soil loss due to erosion during soil cultivation with the proposed combined frontal plough for smooth plowing. It turns out that of the six factors affecting soil loss due to erosion in expression (1), two R and P have a significant impact on reducing soil loss when the proposed combined frontal plough for smooth plowing is used, which we assessed virtually based on analyses.

We also need to analyze the effectiveness of the proposed machine from the viewpoint of another manifestation of mechanical soil degradation soil compaction. Our proposed combined machine performs three technological processes in one pass: plowing, disc harrowing, and rolling. Let's assume that plowing with the frontal plow is carried out using a T-150K tractor, while harrowing and rolling are done with an MTZ-80 tractor. Based on experimental research results, Professor A. Esoyan has graphically presented the impact of the number of passes of the most commonly used tractors in Armenia on soil density and yield (Figures 2 and 3) [Esoyan, 2006, 188].

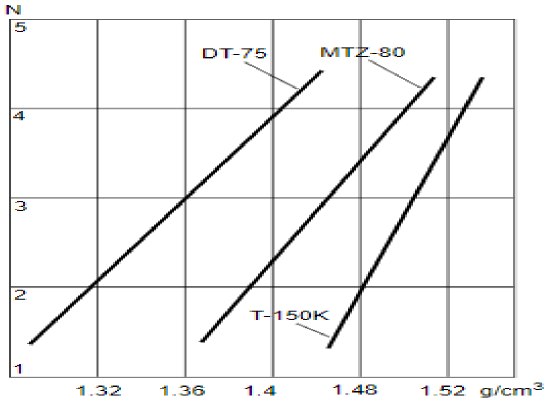

Figure 2. Soil Density (ρ) as a Function of the Number of Tractor Passes (N)

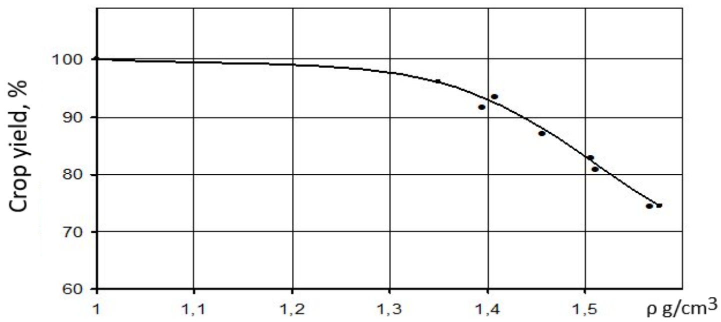

Figure 3. Dependence of Barley Yield (y) on Soil Density (ρ)

Based on the graphical patterns obtained by A. Esoyan regarding soil compaction due to tractor passes and through simple analysis, it becomes clear that by using the proposed machine and combining the mentioned processes, soil density on overlapping tracks will decrease by approximately 0.17 g/cm³, which will result in an increase in yield by about 14%. These figures may vary depending on the physicomechanical properties of the soil, but the overall pattern will not change.

Let's also assess the proposed machine in terms of another form of soil mechanical degradation mechanical erosion on slopes. Unlike traditional plows, which turn the furrow into the adjacent furrow, moving soil downhill by about 60 cm when the furrow is 35x25 cm in size, the proposed combined machine cultivates the soil within the bounds of the furrow area, and almost no soil displacement downhill is observed.

Numerous studies have confirmed, and it is perhaps obvious, that each pass of an agricultural aggregate in the field is accompanied, to some extent, by soil dusting and wind erosion. With the application of the proposed machine, the number of aggregate passes is reduced by two, thus proportionally reducing these negative phenomena.

Conclusions

1. The intensification of agriculture leads to the degradation of soil resources. It is also evident that there is no unified approach to the selection of soil cultivation technology. A technology that has performed excellently in one region may not prove effective in another. Therefore, depending on the soil and climatic conditions, there should be an individual approach for each region.
2. Combining the positive and negative aspects of existing tillage technologies with and without plowing shows that under the mountainous conditions of the Republic of Armenia, it is impossible to unambiguously choose any one of them. All technologies have drawbacks, some of which can be eliminated or mitigated by alternately applying both technologies at certain intervals.
3. One of the ways to solve environmental problems in the field of soil cultivation is considered to be the operation of combined machines. A combined machine has been proposed that unites three technological processes: plowing, cultivation, and rolling. Besides economic efficiency, it solves a number of environmental problems, in particular:

- During each cultivation of slopes, it will prevent mechanical erosion (the movement of soil downhill) by about 60 cm, in the case of furrow dimensions of 35x25 cm.

-The proposed combined machine reduces the number of passes in the field by two. Combining this result with the outcomes of similar studies conducted in Armenia, a simple analysis shows that if these processes are not combined, the soil density on overlapping tracks will decrease by approximately 0.17 g/cm³, resulting in an increase in crop yields by up to 14%. With the same virtual justification, reducing the number of machine passes by two will proportionally reduce wind erosion as well.

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Trends in the development of soil cultivation technologies in the mountainous conditions of the Republic of Armenia in the context of environmental issues

Key words: tillage, no-till technology, soil compaction, combined machine, mechanical erosion, wind erosion, minimum soil cultivation, mechanical soil degradation

The main reasons for the reduction of plowing volumes worldwide have been presented, among which, especially for the conditions of the Republic of Armenia, the high energy costs and negative environmental consequences have been highlighted particularly the large volumes of slope erosion, excessive soil compaction under tractor tracks, and the formation of a compacted plow pan layer, which negatively affects plant growth and development. Alternative soil cultivation technologies have been discussed specifically minimum and zero tillage. Several other technologies that do not have widespread application have also been considered. A comparative analysis of new and old soil cultivation technologies has been conducted. It has been clarified that the duration of scientific research related to minimum and zero tillage does not exceed 10-12 years; therefore, a logical question has arisen: is it possible to permanently apply no-till cultivation technologies? The idea of minimizing the damage inflicted on the agro-ecosystem has been set as the basis for choosing soil cultivation technologies.

By combining the positive and negative aspects of different plowing and no-till cultivation technologies, an intermediate solution has been proposed: to perform plowing periodically once every 3-5 years (depending on soil-climatic conditions) and to mitigate the negative consequences of plowing, it is planned to perform it only with combined machines equipped with a plow.

An environmental assessment of the proposed combined machine has been provided. For this purpose, indicators such as soil loss, mechanical and wind erosion, as well as mechanical soil degradation have been selected. For the latter, soil compaction under tractor tracks has been considered.

Using the patterns developed in previous scientific research on mechanical soil degradation, it has been clarified that when using the proposed combined machine, the soil density under tractor tracks will decrease by about 0.17 g/cm³, as a result of which the yield will increase by up to 14%, and during slope cultivation (mechanical erosion) by about 60 cm. Wind erosion will also be significantly reduced.