

IMPACT OF INNOVATIVE SOIL CULTIVATION DISCS ON AGRONOMICALLY VALUABLE SOIL

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Abstract

The final stage of the mechanical action of soil tillage machinery is the attainment of a target aggregate composition, defined by the size distribution of the resulting soil fractions. This study investigates the performance of innovative disk type working bodies and their effectiveness in achieving a specific degree of soil fragmentation. Agronomically valuable structure is characterized by aggregates ranging from 1 to 25 mm, which ensure optimal aeration, water regime, and root development. The experimental setup includes three operating speeds of the machine-tractor unit and two different soil terrains. The tests were conducted using a tillage mill equipped with non-standard disk working bodies with a horizontal axis of rotation, designed for enhanced kinematic and energy efficiency. For each experimental configuration, the degree of fragmentation was determined by collecting five evenly spaced soil samples along the length of the test plot. The results indicate that, under specific combinations of soil type, moisture content, and operating speed, the innovative disk working bodies achieve optimal aggregate composition, confirming their applicability for high efficiency soil tillage processes.

Key words: soil tillage machines, agronomically valuable soil, percentage of soil fragmentation.

INTRODUCTION

Tillage machines play a fundamental role in agricultural production systems, as they form the physical environment necessary for the optimal development of cultivated plants (Mitkov, 2023). Their main function is to modify the soil structure in such a way as to ensure a favorable water-air regime, uniform germination and stable initial development of crops. In addition, tillage is a key factor in maintaining soil fertility, which in turn determines the long-term productivity of agroecosystems. Soil is a complex, dynamic and multi-component natural system formed as a result of long-term pedogenetic processes occurring on geological time scales. It occupies the surface horizon of the lithosphere, usually 20-50 cm thick, in specific cases reaching 1-1.5 m. Its physical, chemical and biological properties are highly sensitive to external influences and are constantly changing depending on the structure, aggregate state and the ratio between solid, liquid and gas phases. Fertility - an integrative indicator of soil quality - is determined by its ability to provide plants with accessible nutrients, water and oxygen, as well as its biological activity.

The technological properties of the soil, including its workability, density, plasticity and resistance to deformation, depend to a significant extent on the water regime and aeration (Hristova et al., 2022). Within traditional intensive agricultural systems, the number of tillage operations can reach 10-12 per year, which leads to significant energy costs and a load on production resources. In addition to economic disadvantages, frequent mechanical impacts cause degradation processes – soil profile compaction, destruction of the aggregate structure, reduction of porosity and increased risk of water and wind erosion, especially in the absence of vegetation cover (Mandradzhiev, 1982). These negative trends require the development of strategies for soil cultivation optimization, aimed at minimizing mechanical interventions and increasing the sustainability of agroecosystems. Combining shallow cultivation with periodic deep interventions, the introduction of high-performance machinery and the application of reduced or zero-tillage technologies are key directions in modern agro-engineering practice (Bakhtin, 1969). These approaches are the basis of the concept of regenerative agriculture, which aims to restore soil ecosystem functions, limit degradation processes and

increase the long-term sustainability of agricultural production.

Regenerative agriculture is an integrated system of principles and management practices aimed at restoring, maintaining and long-term improving agro-ecosystems. Its philosophy is based on the understanding that sustainable agriculture cannot be achieved without purposefully strengthening the ecological functions of the soil, protecting natural resources and creating conditions for improving human health and the economic viability of farms. In this context, regenerative practices emphasize the restoration of soil health as a key factor for increasing the productivity and sustainability of agricultural systems.

A key element in this approach is the cessation of degradation processes and the limitation of erosion, which are leading threats to soil fertility. Restoring the soil to its natural functional state requires minimizing mechanical interventions, maintaining a biologically active environment and stimulating natural biogeochemical cycles. Therefore, regenerative agriculture conceptually and technologically builds on the principles of Conservation Agriculture - a system developed for more than six decades within the framework of industrial agriculture.

Conservation agriculture is based on three fundamental pillars: minimal mechanical impact on the soil (including zero tillage), maintaining a constant soil cover and a high level of plant diversity. These principles aim to improve biodiversity and activate natural biological processes in both the soil profile and above-ground plant biomass. As a result, the efficiency of water and nutrient use increases, leading to more sustainable and stable production.

Modern research shows that the implementation of innovative active tillage tools can accelerate the transition to regenerative practices, allowing reduced tillage, precise incorporation of preparations and minimal disturbance of the soil structure (Dallev, 2014). These technological solutions are especially important in the context of climate change and increased pressure on soil resources.

For the conduct of scientific research, as well as for the effective. Improving soil structure through reduced-intensity and regenerative tillage practices has become a central objective

in modern sustainable agriculture (Manhart and Delibaltova, 2022). Active-drive working bodies, which combine rotational and translational soil movement, offer potential advantages in achieving optimal aggregate formation while minimizing soil disturbance (Dallev, 2012). The present study investigates a novel configuration of disk-type working bodies mounted on a horizontal shaft, designed to enhance soil fragmentation and promote the formation of stable aggregates within the agronomically preferred size range.

MATERIALS AND METHODS

The research builds upon the need for efficient surface tillage tools capable of operating effectively in heavy clay soils, which are often characterized by high cohesion and resistance to mechanical breakdown. By integrating innovative working body geometry with controlled kinematic parameters, the study aims to evaluate the capacity of the prototypes to produce a soil structure suitable for regenerative agricultural systems (Dimov, 1979). The experimental work includes the design and fabrication of the working bodies, their assembly and testing under field conditions, and a detailed assessment of soil aggregate distribution following cultivation. The purpose of the present study is to examine newly developed active-drive working bodies intended for shallow soil cultivation. The investigated concept integrates the motion characteristics of a tillage machine with a horizontal rotational axis and the lateral displacement of soil achieved through a disk-type working element (Dallev, 2015). This combination is expected to produce a soil structure that meets agronomic requirements. To fulfil the research objective, the following activities were carried out:

- Development and fabrication of prototype working bodies.
- Installation of the working bodies on a horizontal shaft at a predefined operational angle.
- Characterization and analysis of the soil conditions at the test site.
- Execution of field trials under controlled parameters.
- Processing, evaluation, and interpretation of the collected data.

Table1. Interpretation of the collected data

N	Wa %	V m/s	1-25 mm (%)
1	11.5	0.69	47.6
2	12.8	0.69	49.8
3	14.8	0.69	50.7
4	15.8	0.69	55.2
5	17.8	0.69	54.4
6	18.9	0.69	56.3
7	22.1	0.69	59.7
8	23.5	0.69	58.9
9	25.7	0.69	64.1
1	12.8	1.2	59.7
2	14.8	1.2	62.4
3	15.8	1.2	62.6
4	17.8	1.2	67.9
5	18.9	1.2	66.3
6	22.1	1.2	71.4
7	23.5	1.2	71.2
8	25.7	1.2	70.6
9	11.5	2.08	74
1	12.8	2.08	23.5
2	14.8	2.08	25.1
3	15.8	2.08	28.6
4	17.8	2.08	26.7
5	18.9	2.08	30.4
6	22.1	2.08	30.3
7	23.5	2.08	35
8	25.7	2.08	36.1
9	11.5	2.08	41.6

Research data summarized in Table 1

The innovative working body is made of 65G steel. The experimental work was carried out in the city of Plovdiv at the base of the Agricultural University-Plovdiv on land previously subjected to plowing (Figure 1). The soil in the area is classified as a heavy clay type (TGP), containing approximately 50% physical clay. The machine used in the trials was aggregated with a TK-80 tractor and equipped with an active tillage implement with a working width of 0.76 m. The PTO operated at 540 min^{-1} , while the forward speeds tested were 0.69, 1.2, and 2.08 m/s. The working depth was maintained at 12 cm, and soil moisture during the experiments varied between 11% and 26%. Laboratory analyses performed using the Kaczynski pipette method confirmed the soil's classification as heavy clay with 50% physical clay content. For each experimental run, soil fragmentation into aggregates was assessed. Five samples were collected at equal intervals along the experimental plot. Sampling was performed by inserting a bottomless metal box with dimensions $400 \times 230 \times 230 \text{ mm}$ into the soil, placing a base plate underneath, and

removing the box together with the enclosed soil.



Figure 1. Presents the location of the experiments performed

The samples were air-dried indoors and subsequently separated into fractions using sieves with openings of 1 mm and 25 mm. The acceptable deviation in aggregate distribution was limited to $\pm 5\%$. According to agronomic standards, optimal soil structure after cultivation is achieved when:

- 70% of the aggregates fall within the 1-25 mm size range;
- aggregates smaller than 1 mm do not exceed 30%;
- and the soil surface remains even and free of excessive compaction.

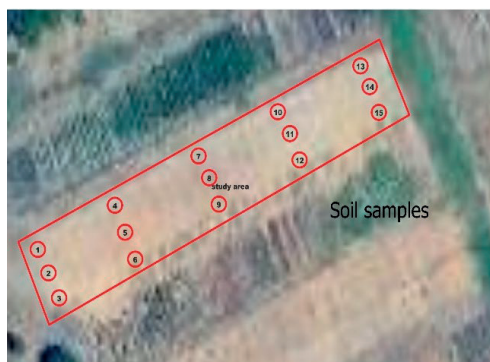


Figure 2. General view of the innovative working bodies

The study area is located in Agricultural university-Plovdiv, Bulgaria. The study territory is overspread nearest 140 m^2 . The location maps are generated by GIS platform named QGIS (Figure 2). For more good and presentative effects is used open sources data from Google Satellite. On the map, it is presented the

experimental field and points of soil samples. The field is with size 7 m x 20 m. The area allows to be prepared 15 soil samples. The results of them are presented on the study below.

Used GIS product is QGIS program. Selected data is from open source information-Google Satellite.

The present study presents the concept, design characteristics and agro-ecological effects of a newly developed multifunctional machine designed to implement regenerative agricultural practices through a single mechanized pass. The machine combines localized loosening, precise crushing and obtaining agronomically valuable soil in a single pass (Figure 3). The results show a significant improvement in soil structure, increased water holding capacity, increased biological activity and reduced energy costs. The technology demonstrates the potential for sustainable management of soil resources in the face of climate change and increased production requirements.



Figure 3. General view of the innovative working bodies

The aim of this paper is to analyze the influence of soil humidity (W_a) and processing speed (V) on the 1-25 mm fraction, using a multiple linear regression model and a sensitivity analysis of the process when using a new soil tillage machine. The study is based on experimental data showing the changes in the percentage of the 1-25 mm fraction as a function of soil moisture (W_a) and machine speed (V). The data were collected from tests conducted with a new model of tillage machine and cover different values of these variables.

RESULTS AND DISCUSSIONS

Although all these requirements are of great importance, the leading factor remains the size of the soil aggregates, which determines both the physical properties of the soil and the effectiveness of subsequent treatments. The profile of the already treated area is directly dependent on the type and geometry of the working bodies that have passed through it. Different machines leave a characteristic structural imprint, determined by their design features.

The materials used in the production of agricultural machinery are decisive for the durability and quality of treatment. The literature indicates recommended materials for wear-resistant coatings of parts, assemblies and elements of soil-tillage machines, as well as their areas of application (Penyashki et al., 2003). The presented graph illustrates a three-dimensional surface dependence between the moisture content of the material (W_a , %), the process speed (Velocity, m/s) and the relative share of the 1-25 mm fraction (%) (Figure 4). The surface is built as an interpolation network (wireframe), allowing visualization of the combined influence of the two independent parameters on the output characteristic of the process.

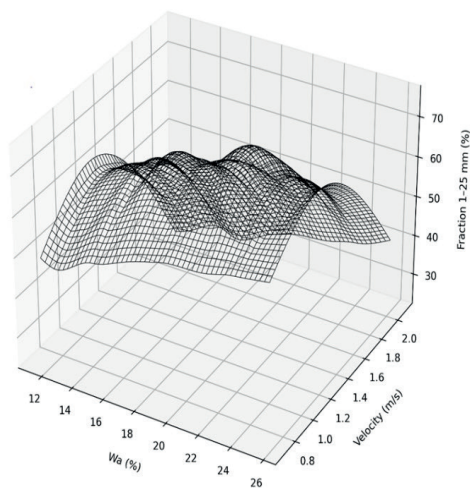


Figure 4. Three-dimensional surface dependence between the moisture content of the material (W_a , %), the process speed (Velocity, m/s) and the relative share of the 1-25 mm fraction (%)

The graph below shows the comparison between the actual values of the 1-25 mm fraction and the predicted values calculated by multiple regression (Figure 5). The graph shows that by analyzing the sensitivity of the results to changes in W_a and V , we have established the following conclusions:

- W_a has a positive influence on the 1-25 mm fraction. This means that increasing humidity leads to an increase in this fraction size, which is desirable in agronomic practices.
- V has a negative influence. High processing speeds lead to the disintegration of larger particles and a decrease in the stability of the 1-25 mm fraction.

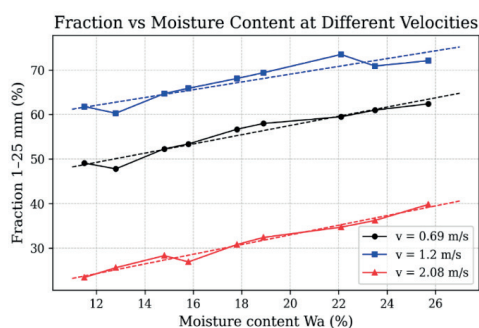


Figure 5. Comparison between the actual values of the 1-25 mm fraction and the predicted values calculated by multiple regression

The surface analysis shows a clearly pronounced nonlinear dependence of the 1-25 mm fraction content on the studied factors. In the range of speeds 0.8-1.2 m/s, the highest values of the fraction (up to approximately 70-75%) are observed, which indicates favorable conditions for the process at lower kinetic intensity. With an increase in the speed above 1.6-1.8 m/s, a steady trend towards a decrease in the relative share of the target fraction (up to about 40-50%), which can be associated with increased dispersion, secondary crushing or poor separation efficiency, is observed.

The influence of moisture content (W_a) also exhibits a nonlinear character. In the interval of approximately 18-22%, a local maximum of the response function is formed, which suggests the presence of an optimal humidity at which the mechanical and rheological properties of the material contribute to the formation or preservation of a fraction of 1-25 mm. At lower

or higher values of W_a , a certain decrease in the output indicator is observed.

The combined effect of the two factors indicates the presence of an optimization area characterized by moderate to increased moisture content and lower process speed. The shape of the surface suggests the existence of an interaction effect between the variables, which should be confirmed by regression analysis or experimental design methodology (e.g. Response Surface Methodology).

The results obtained show that the speed is a dominant factor in terms of the influence on the relative share of the fraction, while the moisture content plays a regulating role, determining the optimal operating range. The practical significance of the analysis is expressed in the possibility of determining rational technological parameters leading to maximizing the yield of the target fraction 1-25 mm with minimal energy and process losses.

The data from the conducted study show a clear relationship between the air flow velocity and the separation efficiency of the 1-25 mm fraction. At low and medium speeds (0.69 and 1.2 m/s), increasing humidity leads to a gradual increase in the fraction of the separated fraction. The highest and most stable efficiency is observed at 1.2 m/s. At the highest speed (2.08 m/s), the results become more heterogeneous, which suggests the occurrence of turbulent effects or a change in the behavior of particles at high kinetic energy. This indicates that the optimal speed for the process is about 1.2 m/s, at which the best balance between air flow and material humidity is achieved.

CONCLUSIONS

The newly developed multifunctional machine represents a significant step towards sustainable and resource-efficient agriculture. It allows the implementation of regenerative practices through a single mechanized pass, combining agronomic, environmental and economic advantages. The technology has the potential for widespread implementation in modern agricultural systems, especially in regions with degraded soils and climate risks. The results show that the new model of tillage machine has significant potential for improving the 1-25 mm fraction at optimized moisture values and tillage

speed. To achieve the best results, it is advisable to use an optimal speed of about 1.2 m/s and to control the soil moisture to improve the structure.

ACKNOWLEDGEMENTS

This work was funded and supported by project 17-12 "Support for publication activities" from the Agricultural University Plovdiv (Bulgaria).

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