AGRICULTURAL UNIVERSITY - PLOVDIV

FACULTY OF VINEGARSHIP - HORTICULTURE

DEPARTMENT OF "AGRICULTURAL MECHANIZATION"

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COMPARATIVE STUDY OF ACTIVE DISC WORKING BODIES FOR SURFACE CULTIVATION OF SOIL

AUTHOR OF ABSTRACT

of the dissertation for the award of the educational and scientific degree "DOCTOR" in

Mechanization and electrification of crop production

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The defense of the dissertation will take place on .... from ....hours in hall No....................... of the Agrarian University - Plovdiv, at a meeting of a Specialized Scientific Jury appointed by the Rector of the Agrarian University with Order No. RD-16-101/23.01.13, composed of:

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USED SYMBOLS AND ABBREVIATIONS

k - Structural coefficient, (%)

B - Working width, m

D - Drum diameter, mm

a - Maximum milling depth, cm

n - Drum rotation frequency, min-1

G - Machine mass, kg

N - Required drive power, kW

V m - Machine forward speed, m/s

XZ - Milling pitch, cm

n - Voltage magnitude

λ - Kinematic index

ω - Angular velocity min-1

t - Duration, s

r - Circle radius, m

T - Time for one milling cutter revolution, min

R - Agronomically valuable soil, %

Wa - Absolute soil moisture, %

l - Length, m

Bp - Machine working width, m

V - Soil volume, m3

Abstract

This paper presents a comparative study of two innovative active disc tillage implements with different design profiles, intended for surface tillage of the soil. Their development was motivated by the need to overcome established limitations of traditional active tillage implements, related to excessive crushing, risk of pulverization and insufficient adaptability to different soil conditions.

The aim of the study is to assess the impact of the new disc tillage implements on the quality of the tilled soil layer by analyzing the crushing, uniformity of the maintained depth, the bottom profile after tillage and the efficiency of the incorporation of the ameliorant. Mechano-mathematical models have been built to describe the kinematics of the discs, which allow for a simulation study of the working process under different kinematic regimes.

The experimental setup includes tests of both types of discs at varying values of the forward speed and absolute soil moisture on two different soil backgrounds. A comparative analysis of the performance indicators under real operating conditions has also been conducted.

The results obtained confirm that the newly developed disc working bodies provide a more uniform impact on the soil, better mixing of the treated layer and reduced tendency to sprinkling. High stability of the maintained depth and better homogeneity of the furrow bottom were established compared to basic designs.

GENERAL CHARACTERISTICS OF THE DISSERTATION

Relevance of the problem: Soil is a complex dispersed system, the main properties of which - humidity, porosity, structure and density - determine its fertility and stability. Mechanical processing significantly affects these properties, and improper impact can lead to destruction of the soil structure, increased sprinkling and increased erosion sensitivity. In the conditions of modern agriculture, climate change and the need for sustainable management of soil resources, gentle and effective processing of the surface layer acquires particular importance.

Machines with active drive of the working bodies are an important part of the soil preparation processes, as they provide intensive crushing and mixing. However, they have significant limitations: excessive crushing of aggregates, formation of ultrafine fractions, risk of pulverization, high energy consumption and limited adaptability to different soil and climatic conditions. The kinematic features of traditional milling working bodies lead to an uneven bottom, unwanted compaction and limit the possible working speed. These shortcomings directly affect the quality of processing and the long-term condition of the soil environment.

Scientific and engineering developments in the field of soil tillage machines clearly show that the profile, shape and kinematics of the working body are of decisive importance for the quality of processing, the degree of crushing and energy efficiency. This creates a need to develop new design solutions that provide a more uniform impact on the soil, reduce the risk of pulverization and improve the homogeneity of the processed layer.

In this context, the development and study of active disk working bodies with a new profile is a current and significant scientific task. Combining horizontal displacement of the soil with the kinematics of a milling working body opens up opportunities for improved energy distribution, more gentle processing and higher adaptability to different soil conditions. This approach is important both for improving the quality of agrotechnical operations and for preserving soil resources in the long term.

The aim of the dissertation is to comparatively study two innovative working bodies, with different profiles and active drive, for surface tillage of the soil, combining the kinematics of a soil tillage machine with a horizontal axis of rotation and the horizontal displacement of the soil by a disk working body.

Achieving the set goal requires solving the following main tasks:

1. Justification of the working bodies for surface tillage of the soil.

2. Mechano-mathematical model of the movement of the working bodies.

3. Experimental study of soil fragmentation on two soil backgrounds.

4. Experimental study of mixing of ameliorant into the soil with the two working bodies.

5. Experimental study of the resistance of the working bodies to maintain a uniform depth.

6. Experimental study of the uniformity of the bottom of the furrow after processing.

STATE OF THE ISSUE ANALYSIS AND RESEARCH TASKS

The state of the issue analysis covers the study of the physical, mechanical and technological properties of the soil as a medium for mechanical processing, as well as the features of traditional and innovative soil tillage working bodies. The influence of active working bodies on the aggregate composition, structure, porosity and density of the soil, as well as the factors leading to pulverization and disruption of the natural structure of the tilled layer, are considered. The limitations associated with the kinematics of existing soil tillage tillers are traced - including the formation of an uneven bottom, compaction by the rear surfaces of the hoes, limited possibilities for working at different speeds and the difficulty of maintaining the same depth. The analysis conducted outlines the need to develop a new type of active working bodies that would combine horizontal displacement of the soil with the kinematics of a milling machine. This approach creates prerequisites for improving the uniformity of processing, limiting dusting, increasing the quality of crushing and better mixing of the soil with ameliorants. On this basis, the tasks of the present dissertation work have been formulated, aimed at a comparative study of two innovative active disk working bodies.

Research methods: The dissertation work uses the systematic approach, the analytical and comparative method, the methods for planning and analysis of multifactor experiments, mathematical modeling, methods of mathematical statistics and approaches for optimization of multifactor processes. The study combines theoretical and experimental approaches, including simulation models, laboratory and field tests on two different soil backgrounds and statistical analysis of the results.

Research approval: The main scientific results of the dissertation work were approved by presenting them to the department council of the Department of Agricultural Mechanization at the Agricultural University - Plovdiv, as well as at scientific sessions held at the Agricultural University - Plovdiv.

Publications on the dissertation work - Three scientific works have been published on the topic of the dissertation work, including two articles in specialized scientific publications and one report presented at a scientific conference. The publications reflect the main results of the research on soil fragmentation, aggregate composition, the interaction of working bodies with different soil backgrounds and the efficiency of incorporating ameliorant.

Variety, volume and structure of the dissertation work:

The dissertation work contains an introduction, seven chapters, general conclusions, contributions, a list of used literature and applications. The text is presented on 129 pages and includes 25 tables and 66 figures that present the theoretical models, the experimental setup and the results obtained. The list of cited literature includes 101 sources in Cyrillic, reflecting a wide range of scientific publications and works in the field of agricultural mechanization. The structure of the work is logically consistent and follows the entire research process - from the analysis of the problem to the summary of scientific and applied results.

CONTENT OF THE DISSERTATION

Chapter I. ANALYSIS OF THE STATE OF THE ISSUE

The chapter examines the state of the problem related to the surface cultivation of the soil and the influence of active working bodies on its physical and structural properties. Traditional soil tillage machines and their main limitations are analyzed - excessive crushing, pulverization, uneven bottom and limited adaptability to different soil conditions. The main approaches and designs used in practice are presented, as well as the factors determining the quality of processing. Based on the critical analysis, the need for the development of new active disk working bodies, combining horizontal displacement of the soil with milling kinematics, is justified.

From the analysis of the existing situation, the following conclusions can be drawn about machines with active drive of the working bodies:

1. Excessive soil crushing

Active soil tillage working bodies have a strong impact effect on the soil, which leads to ultra-fine crushing of the aggregates. This phenomenon is described in detail by Ivanov (2018), who emphasizes that excessive fragmentation violates natural porosity and creates prerequisites for water and wind erosion.

2. High energy consumption

Continuous rotation and large working width require significant power from the tractor. According to Petrov et al. (2020), the energy costs of active machines are 25–30% higher than classic plows. This leads to an increase in fuel consumption and operating costs, which calls into question the economic efficiency of their application in modern conditions.

3. Lack of adaptability to different soil conditions

The standard geometry and kinematics of active disk tillage working bodies do not allow optimal work on different types of soils - dry, heavy, wet or with high density.

1. From the kinematics of the tillage machine it is seen that the reciprocating movement of the unit requires the working body to be mounted so that the rear surface of the hoe does not rest on uncultivated soil.

2. Increasing this angle leads to a greater vertical reaction and, as a consequence, an uneven bottom.

3. Limiting the mounting angle also limits the reciprocating speed of the unit.

4. The rear surface of the hoes compacts the bottom of the cultivated layer.

5. From the equations of motion of points on the milling drum and the newly created working body, the profile of the bottom of the cultivated soil layer cannot be established.

Based on the conclusions made, it is advisable to continue improving the machine combining the horizontal displacement of the soil by a disk working body with the kinematics of a tillage machine with a horizontal axis of rotation.

Chapter II. METHODOLOGY OF EXPERIMENTAL RESEARCH

The quality of work of soil cultivation machines and tools is assessed by the following indicators: deviation from the set cultivation depth, degree of soil crushing, degree of incorporation of the ameliorant into the soil and uniformity of the bottom of the furrow in experimental fields on a plowed soil background and stubble. These indicators are determined during laboratory-field testing, for which a suitable section with certain dimensions, terrain slope, type and condition of the soil is selected. On the selected area, immediately before the experiments, a detailed characteristic is drawn up, determining: the type of soil, previous cultivation, relief and microrelief, soil moisture, composition and amount of plant residues in the field, etc. For carrying out the study, and not only for growing any crop, the type of soil or the so-called soil analysis is of utmost importance.

Compliance with the set cultivation depth is determined immediately after the MTA work stroke. The distance from the field surface to the solid bottom of the furrow is measured, at 5 places at equal distances of 5 m. The conducted studies are carried out in three repetitions for each of the soil backgrounds - plowed and stubble, with disks 1 and disks 2.

The factors that have an influence are speed and humidity. The speed is taken at 3 levels - 0.69 m/s, 1.20 m/s, 2.08 m/s measured in advance and maintained by the gear and engine speed. Each tractor model has a table that shows what speed each gear gives at given speeds. The humidity was measured with a soil moisture meter as the values are in the range for the two soil backgrounds:

Ploughed soil background from 18.5% - 24.3%

Stubble soil background 22.1- 25.7%

The percentage of soil fragmentation into aggregates: It is determined for each experiment, by taking 5 soil samples at equal distances along the working stroke in the following way: a box without a bottom measuring 400 x 230 x 230 mm is driven in. The bottom is inserted under it and the box with the soil is removed. The samples taken are left indoors, where they are dried to an air-dry state and separated by sieves into 3 fractions - with sizes up to 1 mm; with sizes from 1 to 25 mm and with sizes over 25 mm. Agronomically valuable soil is determined by the fraction with sizes from 1 to 25 mm.

And in this part of the experiment, the study was carried out in three repetitions, at different speeds, at different soil backgrounds, with disks 1. The data are statistically processed using specialized software.

The study of the uniformity of the introduction of a soil amendment into the soil is determined in the following way. On an area of 1m2, a soil amendment with a certain weight is spread randomly. After the machine passes, the soil layer is removed at a depth of 8 cm in 2 cm increments and the samples are dried. Then, using the weight method, the amount of soil amendment at different depths is calculated in percentage. The experiment was carried out in three repetitions at four different depths again on the two soil backgrounds, with the studied disks 1 and 2. The data are statistically processed using specialized software.

The profile of the bottom of the furrow. Machines with active working bodies with a horizontal axis of rotation for surface soil cultivation work by cutting the soil with subsequent crushing. This leads to irregularities in the profile of the bottom. On the designated area for conducting the experiments after the passage of the soil tillage machine, after careful cleaning of the soil until reaching the bottom of the furrow. They are measured in a cross-section of the furrow at a distance of 10 cm, and along the length of the terrain at an interval of 50m. When preparing the soil, agrotechnical requirements for the height of the ridges must be up to 20% of the set depth of cultivation or h=0.2.a[cm]. The experiment was carried out in three repetitions, at three different speeds, on two soil backgrounds, respectively with the two types of discs, the data are statistically processed using specialized software.

Data processing methods Mathematical data for Mathematical modeling of the trajectory of movement of points from a disc, from chapter three. The models were obtained with the GEO-GEBRA program. A regression analysis was conducted to track the relationships between speed, humidity and the set depth of cultivation. A statistical processing program, STATISTIKA 7, was used at a significance level of α=5% and regression equations and graphs describing the process were derived.

III. RESULTS OF EXPERIMENTAL RESEARCH

3.1. Theoretical research

The object of the study is Innovative working bodies. A principle diagram of the arrangement of the working bodies relative to the shaft is given. Both models are made with a different profile of steel 65G.

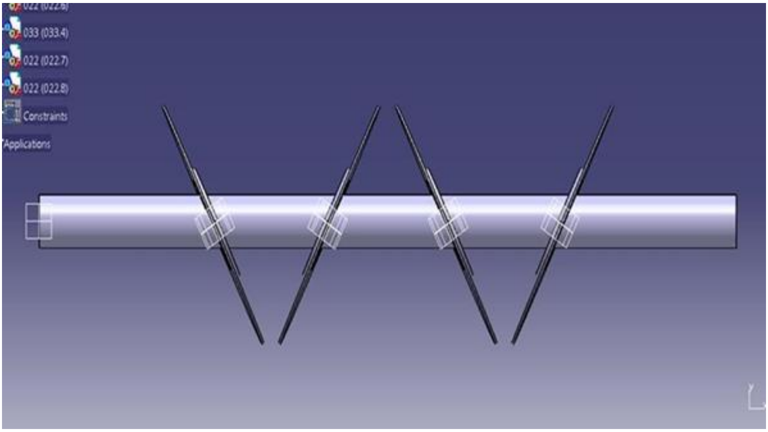


Fig. 1. Working parts - Disk 1

Disc 1 characteristics:

• round shape R=200 mm

• on its periphery there are holes with d=70 mm

• thickness of the working elements h=4mm

Fig. 2. Working parts - Disk 2

Disk 2 characteristics:

toothed disk with wavy periphery, R= 200 mm

the height of each tooth is h=80mm

width is 50 mm

thickness of working elements h=4mm

3.2. Mathematical modeling of a point on the disk.

$V_m=1,2$ m/s и $V_{per}=4,5$ m/s (1)

The following equations of a point on the disk were obtained

$$\left| \begin{array}{l} x = r(0{,}267.\omega t - \sin \omega t \\ \quad z = \ -r cos\omega t \end{array} \right. \qquad (2)$$

where ω is the angular velocity and $0 \leq t \leq 2\pi$

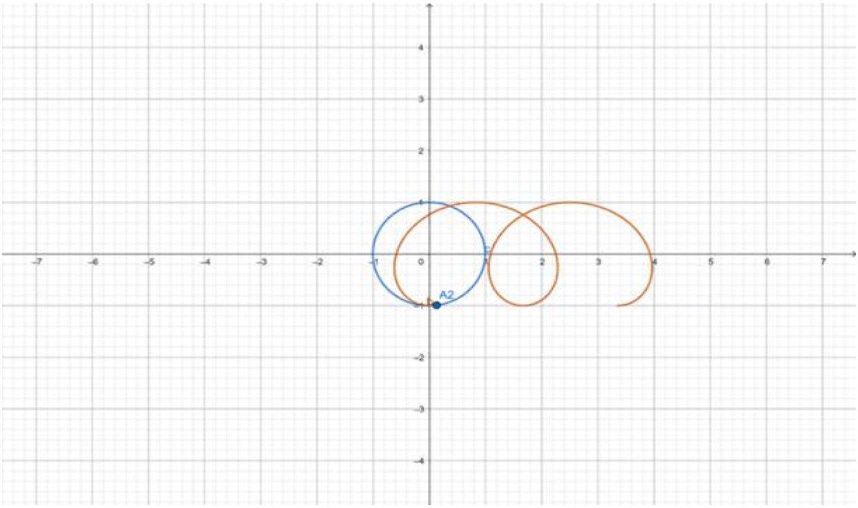
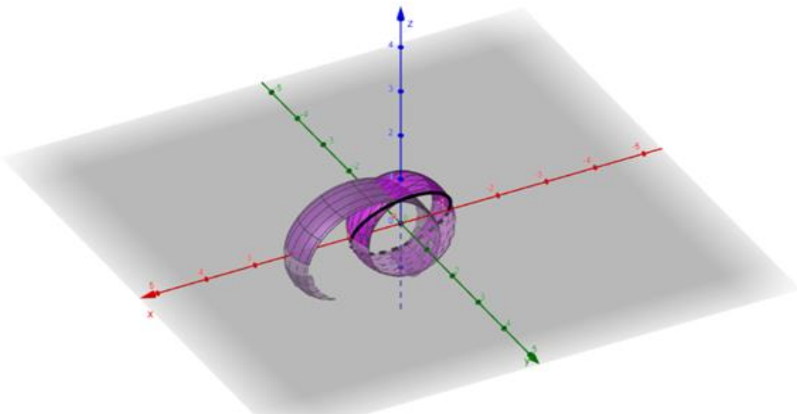


Fig. 3. Trajectories of points of the disk working bodies

The parametric equations of the surface obtained from the equations of cycloids during rotation and uniform motion of an arbitrary point on the circle.

$$S: \left| \begin{array}{l} x = r\sqrt{cos^2 t + 0.79\, sin^2 t}\ (0.267\varphi - sin\varphi) \\ \qquad y = r cos 63° sint \\ \quad z = -r\sqrt{cos^2 t + 0.79\, sin^2 t}\ \ cos\varphi \end{array} \right. \qquad (3)$$

$$0 \leq t \leq 2\pi, \ \ 0 \leq \varphi \leq 2\pi$$



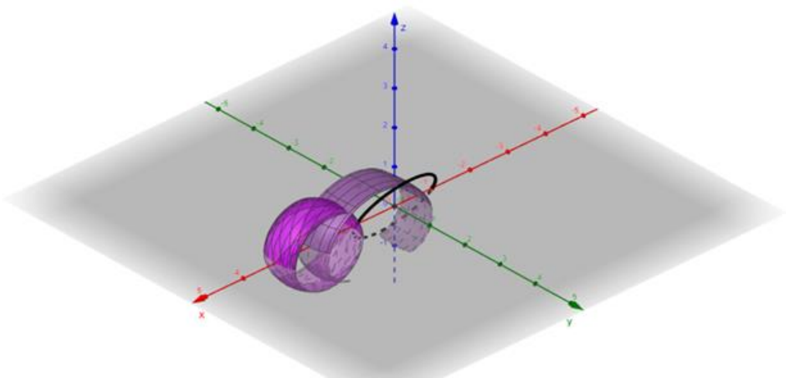


Fig. 4. Spatial model and trajectory of movement of an active disk working body

Figure 4 presents a three-dimensional model of an innovative soil tillage implement, the geometry of which is optimized to improve the quality of tillage.

At a disk inclination of α=27° relative to the perpendicular, the volume of soil of the rotary body:

For a disk with a radius r=200 mm=0.2 m

$$V=0.09345.\pi 3. 〚0.2〛 3=[m3] \quad (4)$$

r3 = (0.2)3 ≈ 0.008 m3 π 3 ≈ 30.9905

V ≈ 0.09345·30.9905·0.008 ≈ 0.0232 m3

We determine the amount of processed soil, take 50% of the volume of the rotary body and get:

$V1$"≈" $\mathbf{0{,}0116\ m3}$

3.3. Experimental studies

The experiments were carried out in the experimental plot of the Department of Plant Breeding at the Agrarian University-Plovdiv opposite the Department of Agricultural Mechanization, on two soil backgrounds: plowed and stubble.

The soil is a representative of TGP (heavy clay soil) with a content of 50% physical clay. The TK-80 tractor is aggregated with an active machine, whose working width is Bp - 0.76 m, PTO speed 540 min-1, and a set working depth a = 12 cm. As noted in the previous section, the following parameters were observed from the work of the studied objects:

Maintaining the set working depth

3.3.1. Study of maintaining the working depth with disks 1 and 2 on a plowed soil background

Data from von Oran's experimental studies

Table 1

No	W, %	V, m/s	$a_{Диск\ 1}$, cm	$a_{Диск\ 2}$, cm
1	18,5	0,69	10	9
2	18,5	1,20	8	12
3	18,5	2,08	7	9
4	18,5	0,69	9	8
5	18,5	1,20	7	8
6	18,5	2,08	6	8
7	18,5	0,69	10	9
8	18,5	1,20	9	7
9	18,5	2,08	7	6
10	20,8	0,69	9,5	10
11	20,8	1,20	9	8
12	20,8	2,08	8,5	7
13	20,8	0,69	10	10,5
14	20,8	1,20	9	9
15	20,8	2,08	8	8
16	20,8	0,69	10,5	11,5
17	20,8	1,20	10	11
18	20,8	2,08	9	9
19	24,3	0,69	12,5	12
20	24,3	1,20	11,5	10
21	24,3	2,08	11	8
22	24,3	0,69	12	12,5
23	24,3	1,20	12	11
24	24,3	2,08	11,5	10
25	24,3	0,69	12,5	12
26	24,3	1,20	12	11
27	24,3	2,08	11	10

The following models were obtained from the regression analysis: The models are adequate and can be used for prediction and solving optimization research problems.

- for disk 1

a= 7.47-5.529 V+0.008W2+0.19WV

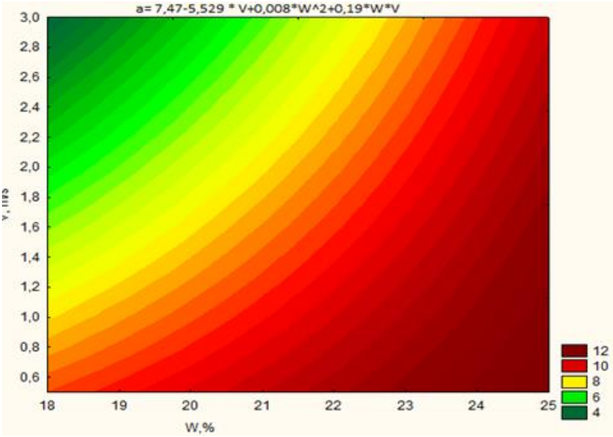


Fig. 5. Graphical dependence of the indicator a on the absolute soil moisture (W) and the forward speed (V) disk 1

- for disc 2

a= 6.39 +0.01W² - 0.074WV ($a = 6.39 + 0.01W^2 - 0.074WV$)

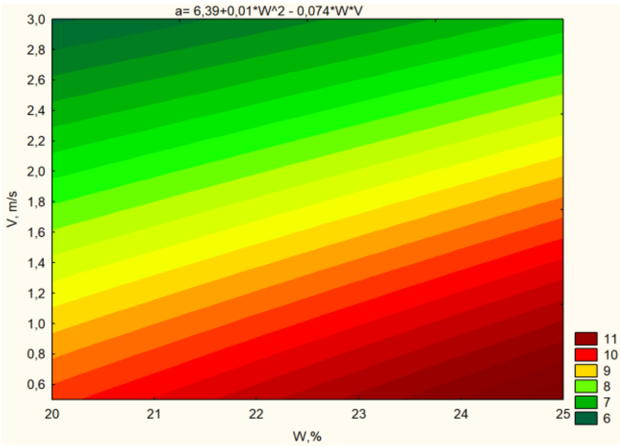


Fig. 6. Graphical dependence of the indicator a on the absolute soil moisture (W) and the forward speed (V) Disk 2

3.3.2. Study of the maintenance of the working depth with disks 1 and 2 on a soil stubble background

Data from the experimental studies on a stubble background

Table 2

No	W, %	V, m/s	aДиск 1, cm	aДиск 2, cm
1	18,5	0,69	5	9
2	18,5	1,20	6	8
3	18,5	2,08	5	7
4	18,5	0,69	8	10
5	18,5	1,20	6	8
6	18,5	2,08	7	8
7	18,5	0,69	6	10
8	18,5	1,20	6	8
9	18,5	2,08	5	7
10	20,8	0,69	9	12
11	20,8	1,20	9	9
12	20,8	2,08	7	6
13	20,8	0,69	10	12
14	20,8	1,20	8,5	8
15	20,8	2,08	8	5
16	20,8	0,69	9,5	12,5
17	20,8	1,20	9	10
18	20,8	2,08	8	8
19	24,3	0,69	10,5	11,5
20	24,3	1,20	10	10
21	24,3	2,08	8	6
22	24,3	0,69	11,5	12
23	24,3	1,20	11	11
24	24,3	2,08	10	7
25	24,3	0,69	12	12
26	24,3	1,20	11,5	8
27	24,3	2,08	10	6

W– absolute humidity [%], V– forward speed of the machine [m/s], a – depth of cultivation, cm.

Research with discs 1 and 2 on a soil background stubble for depth of cultivation, cm

- for disc 1

$$\boldsymbol{a = 0{,}02\,W^{2} - 0{,}05\,WV}$$

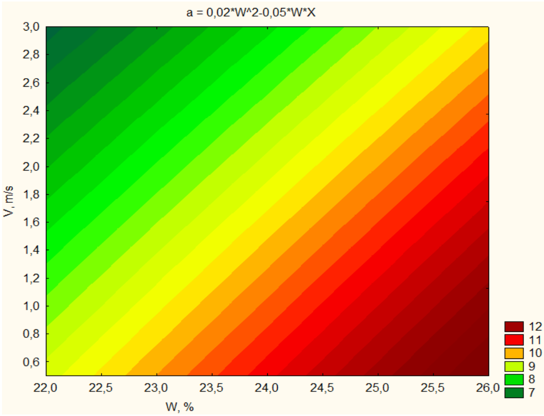


Fig. 7. Graphical dependence of the indicator a on the absolute soil moisture (W) and the forward speed (V) Disks 1

- for disk 2

$$a= 0{,}522W+0{,}008W^2+1{,}74\ V^2-0{,}39WV$$

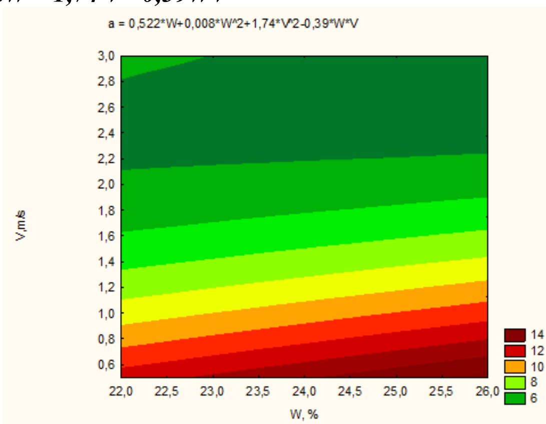


Fig. 8. Graphical dependence of the indicator a on the absolute soil moisture (W) and the forward speed (V) with Disks 2

Disk 1:

- More stable in plowed soil at medium and high humidity

- More sensitive to speed - significant lack of depth above 2 m/s

- In stubble: pronounced dependence on humidity and speed does not maintain a stable depth at W < 23%

Disk 2:

- Best behavior on a "plowed" soil background, even at low humidity (18.5%)

- In stubble: achieves a high depth at W > 23%, but the depth is not maintained - high speed

- More flexible under different soil conditions, but requires careful speed control

3.4. Crushing of aggregates on two soil backgrounds at different speeds and humidity.

Data from experimental studies for disk 1

Table 3

N	**Wa %**	**V m/s**	**< 1 mm (ploughing) (%)**	**1-25 mm (ploughing) (%)**	**> 25 mm ploughing () (%)**	**< 1 mm (stubble) (%)**	**1-25 mm (stubble) (%)**	**> 25 mm (stubble) (%)**
1	11,5	0,69	38,9	48,3	12,8	19,33	50,8	29,87
2	12,8	0,69	37,3	48,9	13,8	19,22	59,95	20,83
3	14,8	0,69	33,9	51,5	14,6	16,6	63,8	19,6
4	15,8	0,69	31,1	54,5	14,4	9,9	70	20,1
5	17,8	0,69	28,9	55,9	15,2	10	72,8	17,2
6	18,9	0,69	26,8	57,1	16,1	6,5	74,4	19,1
7	22,1	0,69	23,1	58,8	18,1	3,66	76,24	20,1
8	23,5	0,69	18,6	60,1	21,3	2,06	73,19	24,75
9	25,7	0,69	15,1	63,3	21,6	1,1	74,3	24,6
1	11,5	1,2	19,6	60,9	19,5	17,2	66,1	16,7
2	12,8	1,2	18,1	61,2	20,7	16,37	69,9	13,73
3	14,8	1,2	16,1	63,9	20	14,6	70,8	14,6
4	15,8	1,2	12,5	66,8	20,7	14,9	71	14,1
5	17,8	1,2	11,8	67,2	21	12	72,8	15,2
6	18,9	1,2	7,9	70,5	21,6	8,5	74,4	17,1
7	22,1	1,2	4,9	72,3	22,8	5,66	76,24	18,1
8	23,5	1,2	4,3	69,8	25,9	4,06	70,19	25,75

9	25,7	1,2	1,8	73,2	25	3,1	69,3	27,6
1	11,5	2,08	13,8	22,2	64	14,9	24,3	60,8
2	12,8	2,08	12,1	26,4	61,5	11,3	28,9	59,8
3	14,8	2,08	12,8	27,2	60	10,9	31,7	57,4
4	15,8	2,08	11,2	27,8	61	9,1	35,5	55,4
5	17,8	2,08	10,1	29,7	60,2	8,8	36,3	54,9
6	18,9	2,08	9,6	31,2	59,2	6,8	39,1	54,1
7	22,1	2,08	7,4	33,6	59	5,1	38,8	56,1
8	23,5	2,08	6,4	37,4	56,2	4,6	42,1	53,3
9	25,7	2,08	5,2	40,57	54,2	2,1	45,3	52,6

R – soil fragmentation into aggregates [%], W– absolute humidity [%], V– forward speed of the machine [m/s]

For the agronomically valuable fraction, the process of crushing different fractions separately at different speeds and humidity, on two different soil backgrounds, was considered.

DISCS 1 ON SOIL BACKGROUND PLOW

- aggregates with a size of < 1mm:

$$R_{<1mm} = 110{,}52-2{,}21W-25{,}25V+1{,}77V^2+0{,}21WV,\ [\%]$$

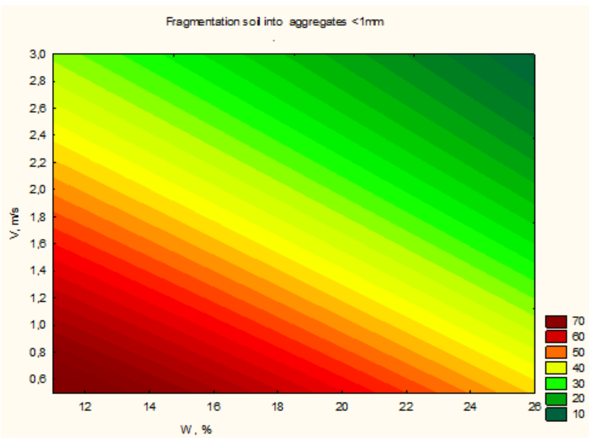


Fig. 9. Graphical dependence of the <1 mm fraction on humidity and speed

• aggregates with a size of 1 to 25mm:

$$R_{1\text{-}25\ mm} = -18,57+1,02W+31,26V-3,62V^2, [\%]$$

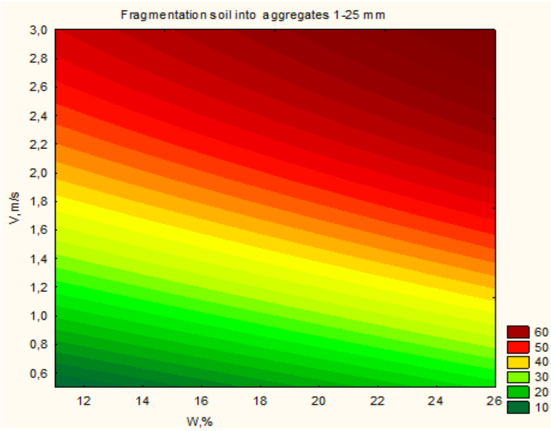


Fig. 10. Graphical dependence of the 1–25 mm fraction on humidity and speed - aggregates with a size >25mm:

• aggregates with size >25mm:

$$R_{>25mm} = 1,51W-3,92V+1.76V20,27WV, [\%]$$

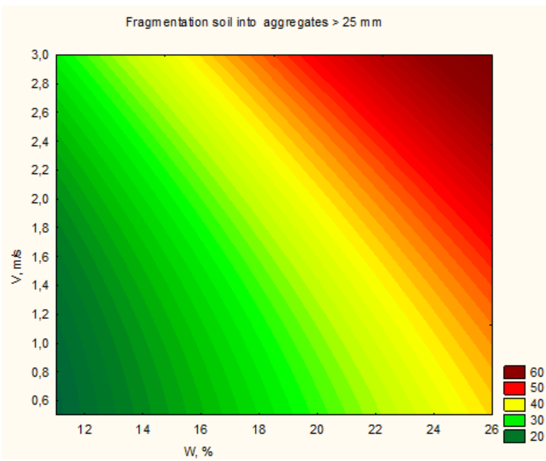


Fig. 11. Graphical dependence of the fraction >25 mm on humidity and speed

DISCS 1 ON SOIL BACKGROUND STUBBORNE

• aggregates with size < 1mm

$$R_{<1mm} = 36{,}39 - 1{,}68W - 3{,}30V^2 + 0{,}44WV\ ,\ [\%]$$

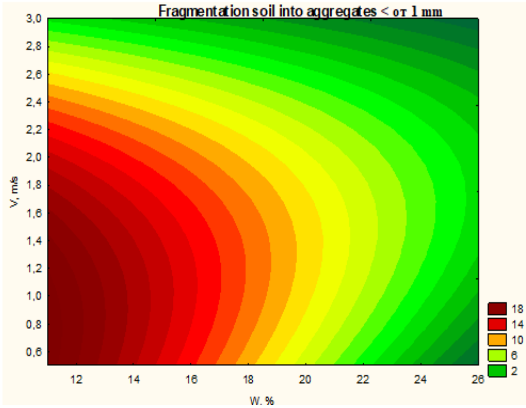


Fig. 12. Graphical dependence of the <1 mm fraction on humidity and speed

• aggregates with a size of 1 to 25mm

$$R_{1\text{-}25\ mm} = 10{,}07 + 2{,}67W + 35{,}2V - 17{,}79V^2\ ,\ [\%]$$

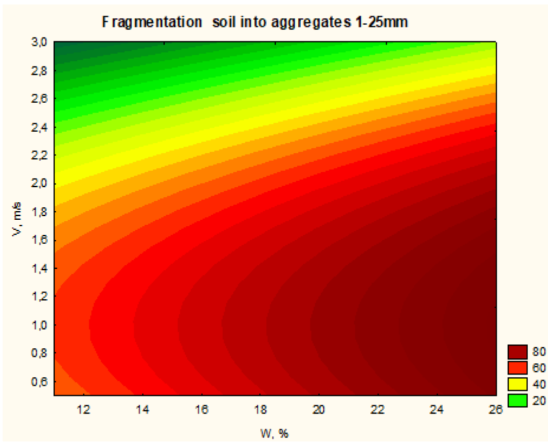


Fig. 13. Graphical dependence of the fraction 1–25 mm on W and V

• aggregates with a size of >25mm:

$$R_{>25mm} = 47{,}14 - 63{,}18V + 26{,}63V^2 + 0{,}29WV \text{ , [\%]}$$

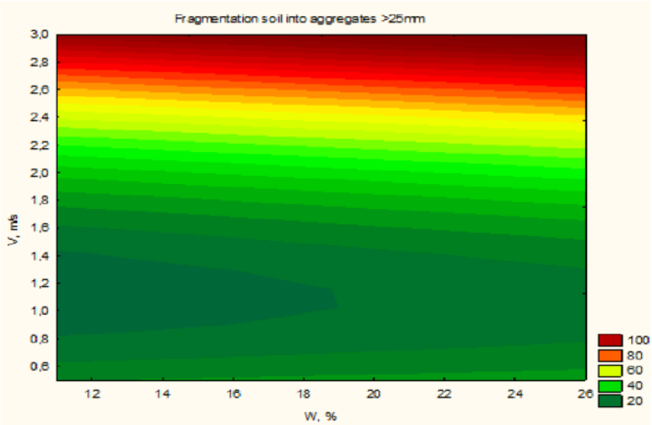


Fig.14. Graphical dependence of the fraction >25 mm on W and V

Discs 2

Table 4

DISCS 2 ON SOIL PLOW

N	Wa %	V m/s	< 1 mm (оран) (%)	1-25 mm (оран) (%)	> 25 mm (оран) (%)	< 1 mm (стърнище) (%)	1-25 mm (стърнище) (%)	> 25 mm (стърнище) (%)
1	11,5	0,69	20,1	51,6	30,5	20,1	51,6	30,5
2	12,8	0,69	20	60,7	21,1	20	60,7	21,1
3	14,8	0,69	17,3	64,6	20,1	17,3	64,6	20,1
4	15,8	0,69	10,5	70,9	20,4	10,5	70,9	20,4
5	17,8	0,69	10,7	73,6	17,7	10,7	73,6	17,7

6	18,9	0,69	6,9	75,3	19,4	6,9	75,3	19,4
7	22,1	0,69	3,9	77,1	20,3	3,9	77,1	20,3
8	23,5	0,69	2,4	74,1	25	2,4	74,1	25
9	25,7	0,69	1,4	75,1	24,9	1,4	75,1	24,9
1	11,5	1,2	17,2	66,1	16,7	17,2	66,1	16,7
2	12,8	1,2	16,37	69,9	13,73	16,37	69,9	13,73
3	14,8	1,2	14,6	70,8	14,6	14,6	70,8	14,6
4	15,8	1,2	14,9	71	14,1	14,9	71	14,1
5	17,8	1,2	12	72,8	15,2	12	72,8	15,2
6	18,9	1,2	8,5	74,4	17,1	8,5	74,4	17,1
7	22,1	1,2	5,66	76,24	18,1	5,66	76,24	18,1
8	23,5	1,2	4,06	70,19	25,75	4,06	70,19	25,75
9	25,7	1,2	3,1	69,3	27,6	3,1	69,3	27,6
1	11,5	2,08	15,6	25,4	61,2	15,6	25,4	61,2
2	12,8	2,08	12	30,1	60,1	12	30,1	60,1
3	14,8	2,08	11,6	32,8	57,9	11,6	32,8	57,9
4	15,8	2,08	9,8	36,7	55,9	9,8	36,7	55,9
5	17,8	2,08	9,4	37,5	55,4	9,4	37,5	55,4
6	18,9	2,08	7,4	40,2	54,5	7,4	40,2	54,5
7	22,1	2,08	5,7	39,9	56,6	5,7	39,9	56,6
8	23,5	2,08	5	43,4	53,9	5	43,4	53,9
9	25,7	2,08	2,8	46,6	52,9	2,8	46,6	52,9

• aggregates with size < 1mm

$$R_{<1mm} = 3,57\,W - 8,009V - 0,14W^2 + 8,07V^2$$

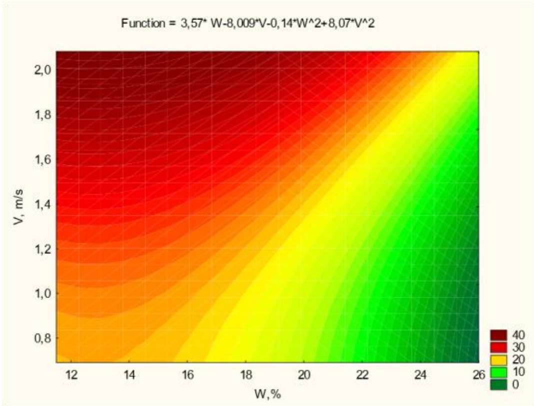


Fig. 15. Aggregate crushing at Disk 2 depending on W and V

• aggregates with a size of 1 to 25mm:

$$R_{1\text{-}25mm} = 42,137 + 21,49V - 22,05V^2 + 1,14WV$$

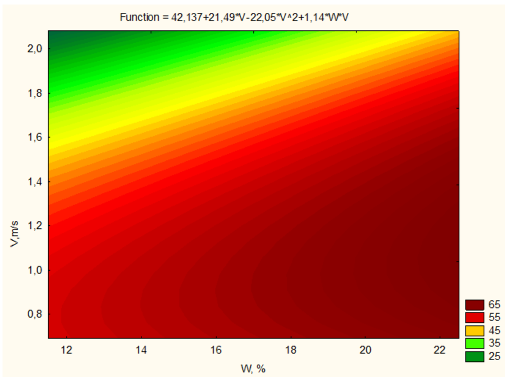


Fig. 16. Influence of humidity and speed on the degree of crushing at Disc 2

• aggregates with size >25mm:

$$R_{>25mm}=12,96-12,28V+0,03W^{2}+21,29V^{2}0,857WV$$

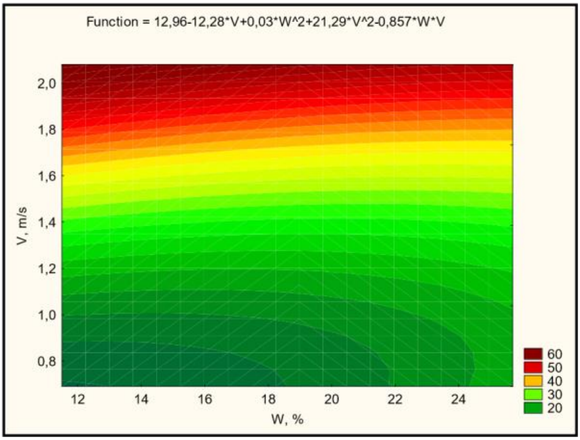


Fig. 17. Influence of humidity and speed on the degree of crushing at Disc 2

The most favorable speed for obtaining agronomically valuable soil (1–25 mm) is 1.2 m/s. At this speed and high humidity (over 18–20%), an optimal ratio is reached - over 70% of the soil is in the valuable fraction.

SOIL BACKGROUND STUBBORN WITH DISCS 2

• aggregates with size < 1mm

$$R_{<1mm} = 36,62-1,66\,W-3,07V^{2}+0,41WV$$

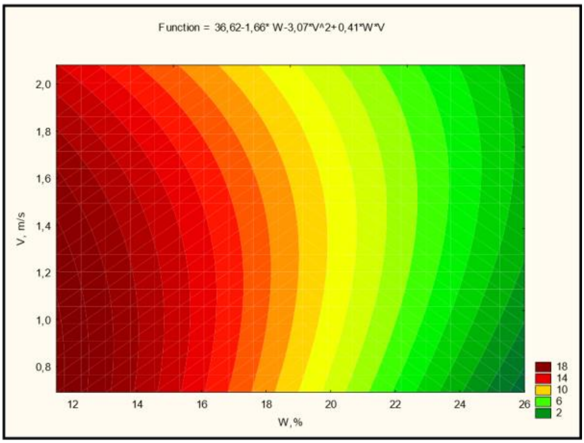


Fig. 18. Influence of humidity and speed on the proportion of aggregates <1 mm in Disk 2

• aggregates with a size of 1 to 25mm:

$$R_{1\text{-}25mm} = 4{,}10W+56{,}19V-0{,}08W^2-28{,}78V^2$$

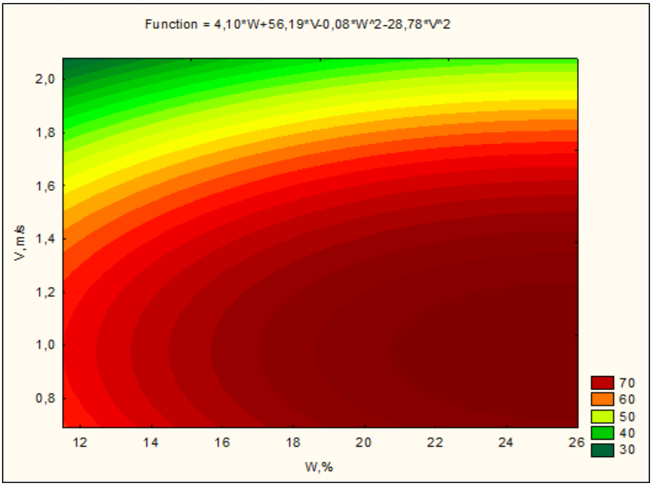


Fig. 19. Dependence of the degree of crushing of aggregates from 1-25mm at Disk 2 on humidity and speed

• aggregates with size >25mm:

$$R_{>25\ mm} = 92{,}63-4{,}05W-78{,}099V+0{,}11W^2+37{,}10V^2$$

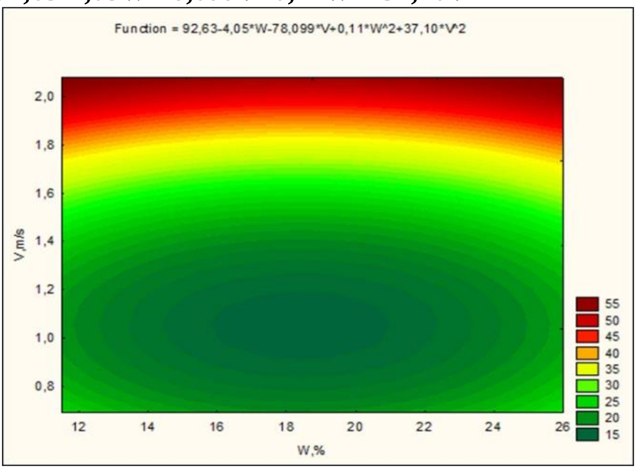


Fig. 20. Dependence of the degree of crushing of aggregates > 25mm at Disk 2 on humidity and speed

Comparative conclusion disc1 vs. disc2

The largest share of the agronomically valuable fraction (1–25 mm) is obtained with Discs 1 on a stubble soil background, at low speed (0.69 m/s) and humidity of about 22% – then the valuable structure reaches 77.1%.

Discs 2 have a slight advantage in stubble and high humidity, while Discs 1 are slightly more effective at low speed and plowing. At high speed (2.08 m/s) both types of discs are ineffective – they leave too many large aggregates (>25 mm). The comparative analysis shows that both types of discs are close in efficiency, with the differences being minimal and occurring mainly under specific conditions (stubble, high humidity).

3 Study of the uniformity of the introduction of ameliorant into the soil

The presented experimental data reflect the maximum ameliorant content achieved at different speeds of movement (see chapter Material and method) and two soil backgrounds – plowed and stubble, for two structurally different discs (Disc 1 and Disc 2).

Table 5

Disks	Soil Background	Speed (m/s)	Highest Mezhorant Content (%)	Depth (cm)	Minimum Content (%)	Depth (cm)
1	Plowed	0.69	27.27	4	22.73	6
1	Plowed	1.2	53.41	2	0	8
1	Stubble	0.69	39.77	8	12.5	6
1	Stubble	1.2	76.14	2	0	8
2	Plowed	1.2	56.82	2	10.23	4
2	Plowed	0.69	44.32	4	2.27	6
2	Stubble	1.2	75.00	2	1.14	8
2	Stubble	0.69	48.86	4	3.41	8

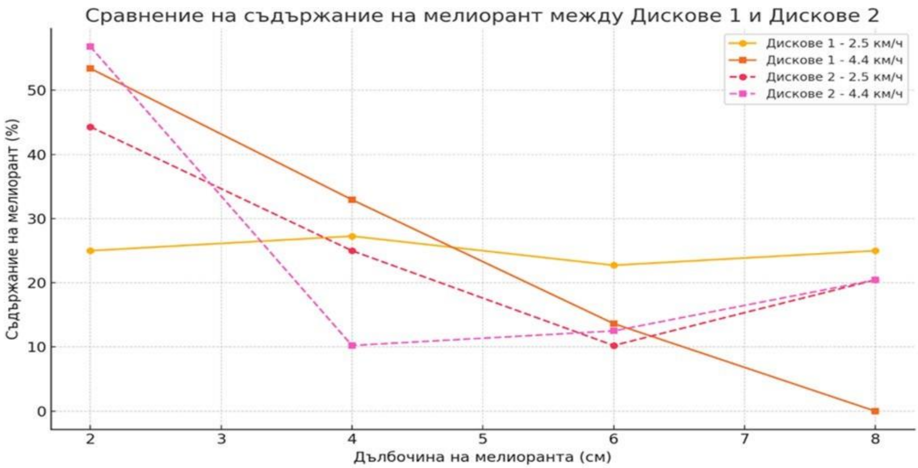


Fig. 21. Influence of depth and speed on the distribution of the ameliorant in the two working bodies

Graph analysis

• Discs 1

- Effective at low speeds, especially on plowed soil – good penetration up to 8 cm.
- In stubble, the behavior is unstable – there are high values, but the distribution is uneven.
- At high speed, the ameliorant is concentrated mainly in the upper layer.
- Discs 2
- Highest ameliorant concentrations at 2–4 cm, regardless of the soil background.
- In stubble and high speed, the ameliorant practically does not reach the lower layers (1–3% at 6–8 cm).

4 Study of the evenness of the bottom profile after processing

The aim of this analysis is to determine under which conditions — a combination of the type of working body (Disc 1 or Disc 2), soil background (ploughing or stubble) and driving speed — less unevenness is achieved along the bottom of the processed soil layer. The vertical deviations from the bottom profile (in cm) after processing — are considered as a measure of the unevenness of the processed layer.

Table 6

Condition	**At 2.5 km/h**	**At 4.4 km/h**	**At 7.5 km/h**
Soil background: plowed (Field No.1) with disks 1	2 cm	2 cm	5.5 cm
Soil background: stubble (Field No.2) with disks 1	1 cm	4.5 cm	5.5 cm
Soil background: plowed (Field No.1) with disks 2	1 cm	4.5 cm	5.5 cm
Soil background: stubble (Field No.2) with disks 2	4 cm	3.5 cm	5.5 cm

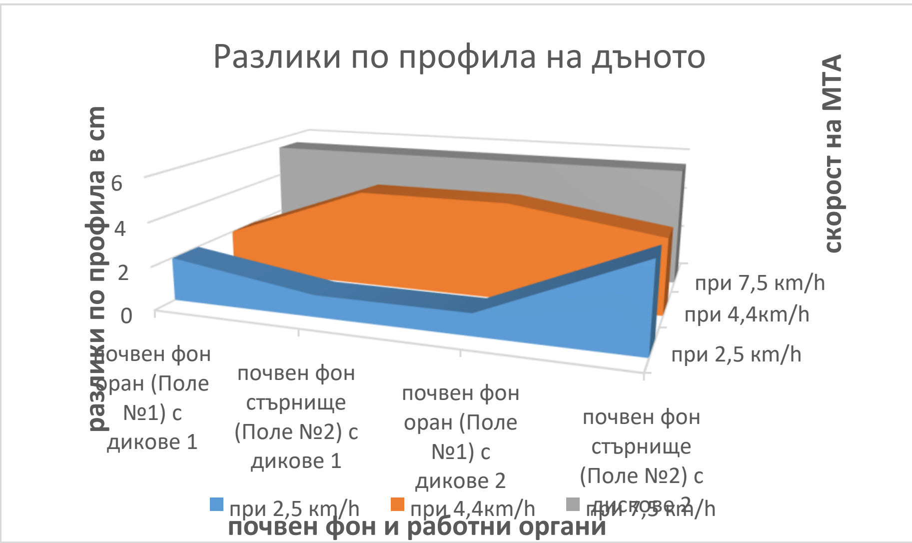


Fig.22. Deviations in the bottom profile when working with Disc 1 and Disc 2 on plowed and stubble land at different speeds

A minimum unevenness of 1 cm was recorded for:

Disc 1 on stubble;

Disc 2 on ploughed soil.

Disc 1 shows better ploughing behaviour at 2.5 and 4.4 km/h (2 cm difference), which makes it more suitable for maintaining a constant depth in this soil background.

Disc 2 demonstrates less unevenness in ploughing at 2.5 km/h (1 cm), but significantly greater unevenness in stubble (4 cm), which indicates a high sensitivity to the structure of the soil background.

At high speed (7.5 km/h), both discs on both backgrounds show the same and maximum deviations (5.5 cm), which confirms that this speed is not agrotechnically suitable for any of the configurations.

- **Title:** Differences in Bottom Profile

- **Axes:**

- Left: profile differences (cm)
- Right: speed of MTA
- Bottom: soil background and working tools

- **Categories:**

- plowed soil background (Field No.1) with discs 1
- stubble soil background (Field No.2) with discs 1
- plowed soil background (Field No.1) with discs 2
- stubble soil background (Field No.2) with discs 2

- **Legend:**

- at 2.5 km/h •
- at 4.4 km/h
- at 7.5 km/h

IV CONCLUSIONS:

Two new actively driven working bodies for surface soil cultivation have been developed, which combine the kinematics of a soil tiller with a horizontal axis of rotation and horizontal displacement of the soil by a disk working body.

2. A new machine design and a structural solution providing a combined effect on the soil layer have been sintered.

3. A mechano-mathematical model has been created, describing the movement of an actively driven disk working body mounted on a horizontal shaft at an angle to its axis. The model allows for analytical determination of the parameters affecting the interaction between the disk and the soil.

4. Through numerical experiments on the model, optimal values of the mounting angle (27°) and the disk diameter (400 mm) have been established, which provide theoretically maximum irregularities at the bottom of the furrow of 20.8 mm. This proves the applicability of the model for engineering design.

5. It has been experimentally proven that disc 1 better maintains the set depth regardless of the forward speed and humidity, due to its larger contact surface with the soil. Disc 2 shows lower resistance due to its cut shape.

6. Experiments show that with a “stubble” soil background, better soil fragmentation is achieved compared to a “ploughed” background. The agronomically valuable fraction (1–25 mm) is more clearly expressed in stubble.

7. The type of soil background has a significant impact on the efficiency of processing. With a “ploughed” background, greater processing depths are achieved under the same conditions, while a “stubble” background limits penetration due to plant residues and greater density.

8. The design features of the discs determine their efficiency. Disc 2 shows better results when working on stubble, while Disc 1 demonstrates more stable operation when maintaining a set depth. This requires the choice of working body to be tailored to the specific soil background.

9. It has been experimentally established that a “ploughed” soil background provides better homogenization of the ameliorant, while a “stubble” background allows for deeper penetration.

- For surface enrichment (up to 4 cm), discs 2 are preferred.
- For deeper penetration (up to 8 cm), discs 1 at low speed give the most balanced results.

10. It has been experimentally established that a minimum unevenness of 1 cm is achieved with:

- Disc 1 on stubble;
- Disc 2 on ploughed soil. at a kinematic index λ=3.75

V CONTRIBUTIONS

The results of the theoretical and experimental research conducted in accordance with the aim and objectives of the dissertation work are summarized in the following main contributions:

Scientific - applied

1. Two innovative active working bodies have been developed, which combine the kinematics of a soil tillage machine with a horizontal axis of rotation and horizontal displacement of the soil by means of a disk working body.

2. A new approach to the design of machines for surface soil cultivation has been proposed, providing simultaneous crushing and displacement of the soil layer.

3. A mechano-mathematical model of motion has been created, describing the movement of an actively driven disk working body mounted on a horizontal shaft at an angle to its axis. The model allows for analytical study of the interaction between the disk and the soil, taking into account the geometric and kinematic parameters of the system.

4. A methodology has been created for conducting numerical experiments at the design stage, through which the optimal values of the installation angle and the diameter of the disk can be determined.

5. A methodology has been developed for simulation modeling of the process of interaction of the working body with the deformable volume of soil.

Applied

1. Two sets of actively driven new working bodies for surface tillage of the soil have been designed. The results obtained prove their functional suitability and efficiency under different agrotechnical conditions.

2. Two prototypes of disk working bodies with different profiles for surface tillage of the soil have been developed and tested.

3. Mathematical dependencies of the kinematic index on the stability for maintaining a given depth of tillage have been established.

4. The operating modes of the created working bodies have been determined, which provide the maximum percentage of agronomically valuable soil structure in the range of 1–25 mm.

5. Speed ranges for mixing the ameliorant have been experimentally established, at which optimal incorporation into the soil is achieved.

6. The degree of influence of the forward speed on the stability and quality of operation of the machine equipped with the two newly created disks has been established.

List of publications related to the dissertation:

1. Genkova, P. (2025, September 24). *Investigation of soil aggregates with a size d < 1 mm with a new type of active disk working elements on a soil background plowing*. *Scientific Atlas, 13*, 8. ISSN 2738-7518. Retrieved from https://scientificatlas.com/uploads/news_docs/04_SCIENTIFIC%20ATLAS_ Petia%20Genkova.pdf
2. Genkova, P. (2025, September 24). *Investigation of soil aggregates with a size d < 1 mm with a new type of active disk working elements on a stubble soil background*. *Scientific Atlas, 13*, 7. ISSN 2738-7518. Retrieved from https://scientificatlas.com/uploads/news_docs/05_SCIENTIFIC%20ATLAS_ Petia%20Genkova.pdf
3. Genkova, P., & Dallev, M. (2025, October 28–31). *Agromelioration activity with a new model of soil cultivating working tool with increased efficiency*. In *Scientific Conference “Traditions Meet Innovations”* (Agricultural University – Plovdiv).

Annotation

This dissertation presents a comparative study of two innovative active disc soiltillage tools with different structural profiles, designed for shallow soil cultivation. Their development is motivated by the need to overcome the established limitations of traditional active tillage tools, related to excessive soil fragmentation, risk of pulverization, and insufficient adaptability to varying soil conditions.

The aim of the research is to evaluate the impact of the newly developed disc tools on the quality of the cultivated soil layer through analysis of soil fragmentation, uniformity of the maintained working depth, bottom profile after tillage, and the effectiveness of soil-ameliorant incorporation. Mechano-mathematical models describing the kinematics of the discs have been developed, enabling simulation studies of the working process under different kinematic regimes.

The experimental setup includes tests of both types of discs at varying forward speeds and absolute soil moisture levels across two distinct soil backgrounds. A comparative analysis of their performance indicators under real operational conditions has also been conducted.

The results confirm that the newly designed disc tools provide a more uniform impact on the soil, improved mixing of the cultivated layer, and reduced susceptibility to pulverization. High stability of the maintained working depth and improved homogeneity of the furrow bottom are demonstrated in comparison with conventional designs.