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Soil structure after treatment with different operation modes of spading machine

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Abstract. *The article presents the results of a field survey of the work of a spading machine. The influence of the following factors on the structure of the Chernozem type soil has been investigated: operating speed, deflector cover deflection angle and rotation speed of the power take-off shaft of the tractor on soil crushing. The relative share of aggregates smaller than 1mm, from 1 to 10mm, from 10 to 25mm, from 25 to 50mm, from 50 to 100mm and over 100mm has been determined. Regression relations have been created to determine the proportion of soil fractions of certain sizes depending on the controllable factors. The operating speed and the position of the machine cover have the greatest influence on the granulometric composition of the soil in cultivation with a spading machine. The resulting regression relations can be used to determine the operating parameters of the machine to achieve the desired granulometric composition of the soil depending on the purpose of the cultivation.*

Keywords: spading machine, granulometric composition of soil, operating speed, PTO speed, step of the working tools

Introduction

Ordinary ploughs are traditionally used for basic soil cultivation. Their plough bodies cut the soil layer, then lift it, move it away and turn it. They have the following main disadvantages: formation of the so-called "plow pan", poor mixing of plant residues, distortion of the field microrelief as the soil is moved away in laterally in the direction of movement. The latter is a serious problem in basic soil cultivation in greenhouses or undersized plots. Unlike ploughs, when using spading machines there is no compaction of the sub-plough layer (Brzózko and Murawski, 2007). These machines work on the principle of reversing the soil with a straight shovel. The working tools of the machines (spades) cut off the soil almost vertically, break it off and move it backwards (Giordano et al., 2015). With this principle of soil reversal, uniform distribution of plant residues is achieved throughout the entire cultivation depth (Juzwik et al., 1997). The basic soil cultivation with the spading machine contributes to a positive agronomic effect on the penetration and location of the plant roots in the soil (Gasparetto, 1966). Spading machines are suitable for soil cultivation in small-sized plots, greenhouses, vegetable gardens, etc., where the application of ploughs is problematic (Kiselev, 1995). In addition to the basic cultivation, soil structure suitable for sowing without other soil cultivation operations can be achieved (Giordano et al., 2015). This is achieved by changing the step of the working tools by varying the speed of the machine (Donati and Fedrizzi, 2018). From an agronomic point of view the most precious fraction in pre-sowing soil cultivation are aggregates with diameter between 0.5–10mm (Mandradzhiev, 1982). The objective of this paper is to study and analyse the effect of the spading machine operation mode on the degree of crushing the soil layer.

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Material and methods

The study has been conducted at the farm of agricultural producer „Agro New Bulgaria "Ltd., situated on the territory of the village of Gornik, Cherven bryag municipality in June 2017. The soil type of the experimental field was Chernozem with moisture about 10%. Spading machine Gramegna V 84/30B–220 has been used (Figure 1), attached to tractor Landini Vision 100. The technical parameters of the machine are given in Table 1.

Figure 1. Spading machine Gramegna V84/30B-220

Table 1. Technical parameters of spading machine Gramegna V84/30B-220

Technical parameters	Values
Working width, m	2.15
Overall width, m	2.2
Weight, kg	837
Required power, kW	44 – 51
Cultivating depth, m	up to 0.3
Number of blades spades	10
Gear ratio of the reducer, i	3.21
PTO speed, min^{-1}	540

Multi-factor experiment type B_3 has been carried out with the following values of the controlled factors**:**

- x_1 – operating speed: v = 0.063 m/s; v = 0.147 m/s and v = 0.231 m/s. This is achieved through changing the tractor gears;
- x_2 – deflection angle of the deflector cover as to the vertical plain: α = 0°; α = 20° and α = 40°. The position of the cover is determined by the relevant chain-unit, attached to the machine frame;
- x_3 – frequency of rotation of the tractor PTO: n = 460 min^{-1}; n = 500 min^{-1} and n = 540 min^{-1}.

The baseline output parameters are the relative share Y_n of the soil aggregates of a certain size. The soil aggregates dimensions are determined according to the Kachinsky classification (Kachinsky, 1965). During each experiment from the experiment plan a soil sample is taken to working depth, which is divided by sieves into fractions of different aggregate sizes. Sieves with openings 1, 10, 25, 50 and 100 mm are used, these are weighed to the nearest 1g and the values are averaged. The relative share of fractions in the sample is determined by the dependence (Tenu et al., 2012):

$$Y_n = \frac{G_{cf}}{G_e}.100,\%, \quad (1)$$

Where:

G_{cf} is the weight of a certain fraction, g;

G_e - the weight of the entire sample, g.

Depending on the size of the aggregates, the output parameters are:

$Y_{(<1)}$ – relative share of aggregates sized under 1 mm, %;

$Y_{(1-10)}$ – relative share of aggregates sized from 1 to 10 mm, %;

$Y_{(10-25)}$ – relative share of aggregates sized from10 to 25 mm, %;

$Y_{(25-50)}$ – relative share of aggregates sized from 25 to 50 mm, %;

$Y_{(50-100)}$ – relative share of aggregates sized from 50 to 100 mm, %;

$Y_{(>100)}$ – relative share of aggregates sized over 100 mm, %.

Data processing has been done by standard methods (Mitkov, 2011) with the software package STATISTICA.

Regression dependences have been defined for each baseline output parameter of the following type:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (2)$$

To illustrate the effect of the main factors diagrams of the lines at one and the same level are used.

Results and discussion

Experimental matrix

The experimental matrix and the results obtained from the conducted studies are presented in Table 2.

The following regression dependencies have been obtained in studying the soil structure after cultivation with a spading machine and processing the results obtained:

Fraction sized less than 1 mm

$$Y_{(<1)} = -3,02293 + 0,01935x_3 - 0,02525x_1x_3 + 7,82182x_1^2 - 0,00054x_2^2 \quad (3)$$

Significant at α=0.1 are the free coefficient and the coefficients before x_1^2, x_2^2 and x_3. The model describes 97% (R^2=0.9752) of the change of parameter $Y_{(<1)}$. The probability p<0.00001<0.1 shows that it is adequate. Fischer's criterion is $F_{(4.9)}$ = 88.417.

The diagram on Figure 2 shows that the minimum share of the fraction sized less than 1mm is obtained at high operating speed and small rotation frequency of the PTO. When reducing the speed of movement (x_1) the share of the fraction increases. The change in the rotation frequency of the PTO (x_3) within the accepted limits does not exert significant influence on the share of that fraction. It grows negligibly by increasing the rotation speed.

In greater rotation speed of the machine crankshaft, the speed of the spade will be greater as well as the speed of the soil aggregate throw away by the workpiece spade. The kinetic energy of the aggregate hitting the cover will grow, which facilitates the better crushing and increasing the share of aggregates with these sizes. These aggregates are considered erosion hazardous.

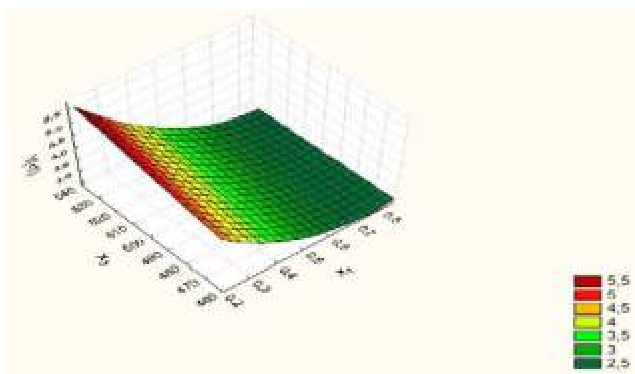

Figure 2. Surface of response of the function $Y_{(<1)}$=f(x_1; x_3) at x_2 = 40°

Fraction sized from 1 to 10 mm

$$Y_{(1-10)} = 63.95207 - 0.14x_1x_3 \quad (4)$$

Significant at α = 0.1 are the free coefficient and the coefficient before the joint influence of x_1x_3. Effect of the x_2 factor is not reported at α = 0.1. The model describes 80% (R^2 = 0.8006) of the change of parameter $Y_{(1-10)}$, the probability p<0.00002<0.1 shows that it is adequate. Fischer's criterion is $F_{(1,12)}$ = 48.184.

Aggregates with sizes up to 10mm are the most desired in pre-sowing soil tillage. When using the machine for pre-sowing soil tillage it is preferable the share of that fraction to be maximum. Figure 3 shows that by decreasing the rotation frequency of the PTO (x_3) and the operating speed (x_1) the share of aggregates with this size increases. Basic influence on obtaining that fraction is exerted by the machine operating speed (x_1). By decreasing the operating speed mainly by switching gears the step of the spades is reduced, the removed layer is small in size and mass, which facilitates easier crushing after hitting the machine cover. The reduction in the rotation frequency results in slight increase of the share of aggregates with that size. The rotation frequency of the PTO influences mainly the speed of throwing away the soil layer by the spade. In greater rotation speed the absolute speed of releasing the soil layer by the spade will increase, and hence the kinetic energy at the moment of hitting the cover. That facilitates crushing the layer into aggregates of smaller size.

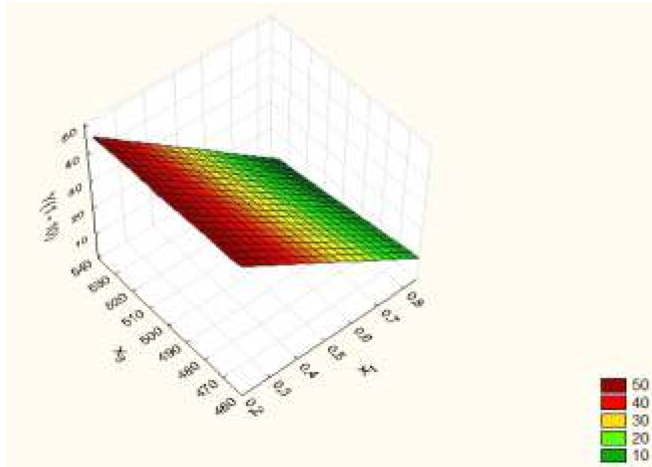

Figure 3. Surface of response of the function $Y_{(1-10)}=f(x_1;\ x_3)$

Fraction sized from 10 to 25 mm

$$Y_{(10-25)} = 794,4312 + 0,5684x_2 - 3,1143x_3 - 39,8582x_1^2 - 0,0151x_2^2 + 0,0031x_3^2 \quad (5)$$

It is evident that significant at α = 0.1 are the free coefficient and the coefficients before x_1^2, x_2^2 and x_3^2. The model describes 94% (R^2=0.94152) of the change of parameter $Y_{(10-25)}$. The probability is $p<0.0001<0.1$, which shows that it is adequate. Fischer's criterion is $F_{(5,8)} = 25.76$.

Aggregates of that size, as well as the previous ones (sized from 1 to 10mm) should have greater share when using the machine for pre-sowing tillage. In low and high values of the rotation speed of the PTO (x_3) the share of that fraction is the greatest (Figure 4), which is due to the increase in the absolute speed of releasing the layer by the spade and the smallest in the middle of the studied interval. As in the previous case, by decreasing the operating speed of the machine, the share of aggregates with this size increases.

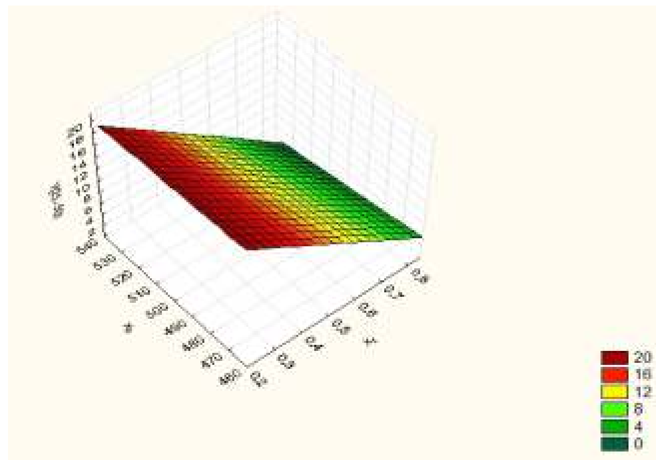

Figure 4. Surface of response of the function $Y_{(10-25)}=f(x_1;\ x_3)$ at x_2=20°

Table 2. Plan of the experiment and the results obtained

Experiment No.	Factors encoded			Share of the fraction in percentages					
	x_1	x_2	x_3	Under 1 mm $Y_{(<1)}$	From 1 to 10 mm $Y_{(1-10)}$	From 10 to 25 mm $Y_{(10-25)}$	From 25 to 50 mm $Y_{(25-50)}$	From 50 to 100 mm $Y_{(50-100)}$	Over 100 mm $Y_{(>100)}$
1	+1	+1	-1	0.7	3.93	1.81	0	0	93.55
2	+1	-1	-1	1.46	3.6	0	0	0	94.4
3	+1	0	0	1.34	3.28	0	0	95.38	0
4	+1	-1	+1	1.82	2.4	5.52	0	0	90.03
5	+1	+1	+1	0.68	3.94	0	0	0	95.37
6	0	0	-1	1.74	28.31	24.1	24.66	21.18	0
7	0	-1	0	2.18	39.28	19.28	12.23	27.22	0
8	0	+1	0	0.99	10.25	8.89	2.81	77.04	0
9	0	0	+1	2.13	46.3	26.19	25.,37	0	0
10	-1	+1	-1	3.16	51.95	27.92	16.97	0	0
11	-1	-1	-1	3.49	49.86	20.43	26.22	0	0
12	-1	0	0	4.3	44.86	28.3	13.54	8.5	0
13	-1	-1	+1	4.52	50.68	28.45	16.35	0	0
14	-1	+1	+1	3.8	38.35	28.34	17.62	11.88	0

Fraction sized from 25 to 50 mm

$$Y_{(25-50)} = 26{,}66315 - 0{,}05875x_1x_3 \quad (6)$$

It is evident from the function that significant at $\alpha = 0.1$ are the free coefficient and the coefficient before the joint effect of the factors x_1x_3. The effect of the factor x_2 at $\alpha = 0.1$ is not taken into account. The model describes 57% ($R^2 = 0.5727$) of the change of parameter $Y_{(25-50)}$. The probability $p<0.00173<0.1$ shows that it is adequate. Fischer's criterion is $F_{(1,12)} = 16.084$.

Basic influence on obtaining aggregates of that size has the operating speed x_1 and by decreasing it the share of the fraction increases (Figure 5). That is due to throwing away aggregates of greater size and their poorer crushing. Rotation frequency has small effect on obtaining aggregates of such size.

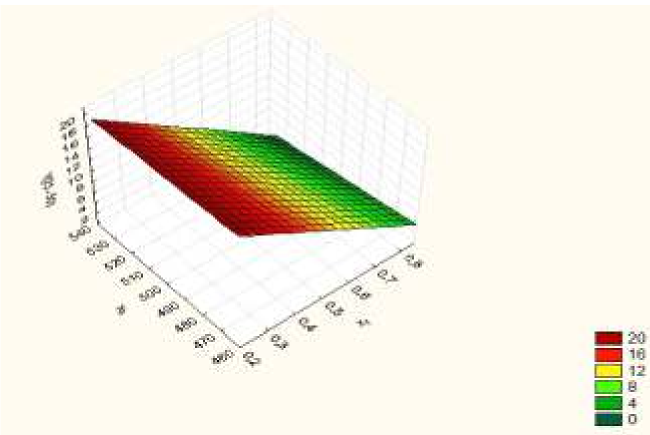

Figure 5. Surface of response of the function $Y_{(25-50)}= f(x_1; x_3)$

Fraction sized from 50 to 100 mm

$$Y_{(50-100)} = -7561.64 + 24.82x_1 + 30.43x_3 - 0.03x_3^2 \quad (7)$$

The function shows that significant at $\alpha = 0.1$ are the free coefficient and the coefficients before x_1 and x_3. The effect of factor x_2 at $\alpha = 0.1$ is not reported. The model describes 59% ($R^2 = 0.59907$) of the change of parameter $Y_{(50-100)}$. The probability $p<0.02286<0.1$ shows that it is adequate. Fischer's criterion is $F_{(3,10)} = 4.9808$.

Similar size of aggregates is suitable for basic soil cultivation. The minimum share of that fraction (Figure 6) is obtained in low rotation frequency of the PTO (x_3) – 460 min^{-1}. At frequency above 460 min^{-1} kinetic energy increases, which facilitates obtaining fraction of smaller size (less than 50mm). By increasing the operating speed (x_1) the share of that fraction increases mainly due to increase of the step of the spades.

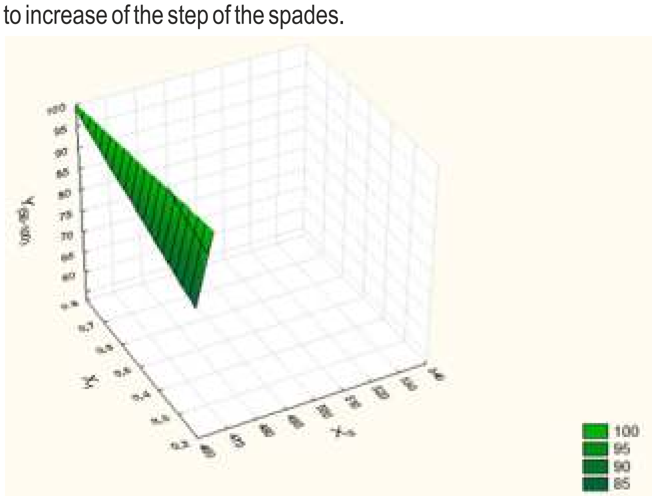

Figure 6. Surface of response of the function $Y_{(50-100)}=f(x_1; x_3)$

Fraction sized above 100 mm

$$Y_{(>100)} = -36{,}8548 + 0{,}2402x_1x_3 \quad (8)$$

It is evident that significant at $\alpha = 0.1$ are the free coefficient and the coefficient before the joint effect of x_1x_3. The effect of the factor x_2 at $\alpha = 0.1$ is not reported. The model describes 54 % ($R^2=0.5427$) of the change of the parameter $Y_{(>100)}$. The probability $p<0.00264<0.1$ shows that it is adequate. Fischer's criterion is $F_{(1,12)} = 14.257$.

Aggregates of that size as well as the previous ones are suitable for basic soil cultivation. The minimum share of the fraction (Figure 7) is achieved at low operating speed (x_1). The rotation frequency of the PTO slightly alters the share of that fraction with these sizes.

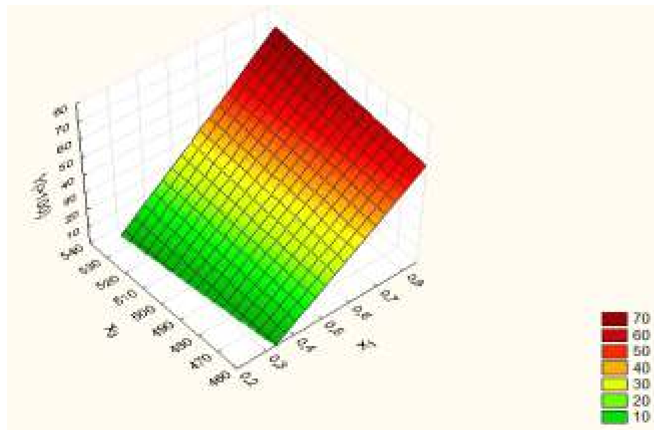

Figure 7. Surface of response of the function $Y_{(>100)}=f(x_1; x_3)$

Research has shown the achievement of a broad range of changes in the share of aggregates sized over 100mm. By changing the machine modes, soil with a different granulometric composition can be obtained. A major impact on soil crushing is the step of the spades (by changing the gears and hence the operating speed) and the position of the machine cover. In small step obtained at low operating speed, as well as at a small angle of deflection of the cover from the vertical plane, soil is crushed to a condition suitable for sowing, planting or transplanting. At a larger step obtained by increasing the operating speed and at greater angle of deflection of the cover, soil is crushed to a condition corresponding to basic tillage.

Conclusion

The regression dependences for determining the share of soil fractions of certain size have been drawn in relation to operating speed, frequency of rotation of the PTO of the tractor and the position of the deflector cover. The granulometric composition of the soil when cultivated with a spading machine is influenced by the machine operating speed and the position of the cover. The resulting regression dependences can be used to determine the operating parameters of the machine to achieve the desired granulometric composition of the soil depending on the cultivation purposes.

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