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Qualitative Performance Indicators of a Ripping-and-Separating Machine for Soil Cultivation

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Abstract. Pre-sowing soil cultivation aims at forming such a soil structure, which will allow increasing the yield. (*Research purpose*) To determine the qualitative indicators of an experimental soil-cultivating ripping-and-separating rotary machine for optimizing the ploughed soil layer, modifying the structure and density of the cultivated soil layer in accordance with the agronomic requirements. (*Materials and methods*) The author has studied physical and mechanical properties of the soil after its spring cultivation in the conditions of bare (black) fallow. Soil structure and aggregate composition depending on the type of cultivation, the density of soil layers at different times, the dynamics of soil moisture changes in the layers for two months after its spring cultivation have been analyzed as well. (*Results and discussion*) The author has studied the operation of a soil tillage ripping-and-separating machine on the soil layer, which is separated after processing into four sublayers: over-seed, seed, under-seed and subsurface ones. Soil fragments (lumps) of a size larger than 20 mm have been completely removed from the over-seed sublayer. The most valuable soil structure in agronomic terms is formed in the seed sublayer, where the size of individual components does not exceed three times the size of seeds, the density of the under-seed sublayer is up to 1.25 grams per cubic centimeter. The subsurface sublayer has a density of not more than 1.3 grams per cubic centimeter and a hardness of more than 3 MPa in the plow sole, which is provided by the main tillage operations. The information for the study has been obtained as a result of the analysis of literary sources. (*Conclusion*) The experimental machine for optimizing the agrophysical properties of the ploughed soil layer allows increasing the structural coefficient by about 2.5 times as compared with traditional cultivators. It has been found that soil cultivation with a ripping-and-separating tillage machine allows to improve the methods of pre-sowing cultivation to improve its agrotechnical characteristics, skip pre-sowing harrowing and cultivation and prepare the soil for sowing in one run.
Keywords: soil structure, layer, structure, composition, machine, surface, tillage, quality.

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Technological operations of soil cultivation by mechanical action are aimed at making favorable conditions for the accumulation and preservation of moisture, seeding, the growth and development of plants [1, 2].

Pre-sowing tillage of soil includes topsoil loosening at the depth of seeding, which provides a fine-grained structure of the seed layer, leveling the field surface, compacting the seedbed at the depth of seeding, embedding of the introduced fertilizers, eradication of germinating weeds and moisture preservation in the cultivated soil layer. Soil cultivation is also aimed at making favorable conditions for the operation of agricultural machines in sowing, cultivating and harvesting [3].

There is an experimental machine for optimizing the agrophysical properties of the ploughed soil layer, to be attached to the KhTZ-17221 tractor, Fig. 1. [4, 5].

It is used for the cultivation of cereals (winter and spring crops) and industrial crops, for performing

Fig. 1. The experimental soil-cultivating friable-separating machine aggregated with tractor XT3-17221

surface and pre-sowing tillage, as well as for stubbling.

The depth of tillage when working in fields to be sown and fallows can be adjusted from 0 to 15 *cm*.

The machine (Fig. 2) consists of a chassis, a frame is attached to it by means of a parallelogram linkage mechanism, which can be moved vertically. Mounted on it are working elements: passive – legs with shares and active – a rotor with rippers. The rotor is located

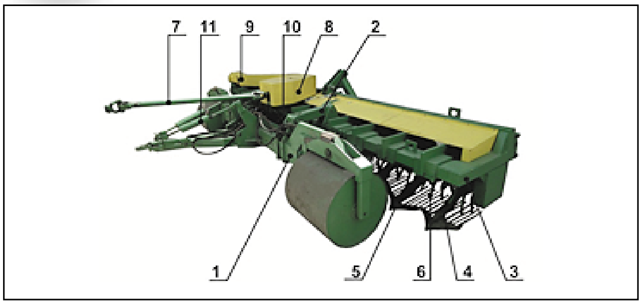

Fig. 2. Experimental soil-cultivating friable-separating machine: 1 – the chassis; 2 – the lever mechanism; 3 – frame; 4 – the rack; 5 – plowshare with separating gratings; 6 – rotor with friablers; 7 – cardan gear; 8 – gear transmission; 9 – chain transmission; 10 – mechanism for adjusting the depth of tillage; 11 – mechanism for adjusting the horizontal position of the frame

above the shares and does not touch them. The shares are provided with separating gratings.

The frame is raised and lowered by means of a hydraulic drive. The rotor is driven by the tractor's power take-off shaft via cardan, chain and gear drives. The machine is equipped with a mechanism for adjusting the depth of tillage and a horizontal positioning mechanism of the frame. The machine chassis and the circle of the hitch device are connected by means of standard mounting elements of the tractor.

The machine works as follows. When moving along the field, the shares cut the soil layer, then, when the cut layer moves along the share surfaces and the rods of the separating grating, it crumbles, and the fine crumpled fraction, which does not exceed three times the size of sown seeds, is spilt through the grating, thus forming a seed sublayer. Further formation of the seed sublayer occurs when the rotor ripper act on the layer crumbling and ripping it, thus moving it along the separating grating. The coarse-grained fraction with fragments of no more than 20 *mm* goes off the grating, forming an over-seed sublayer with parameters corresponding to the optimum water-air mode. In addition, the rotor rippers in the process of interaction with the layer comb out weeds from it, without violating their integrity, and transport them to the surface of the over-seed sublayer, and also clean the share legs from plant debris and weeds [6].

The surface quality after the main and pre-sowing cultivation is determined not only by the depth of cultivation, the surface ridgeness, stubble residues and lumpiness, but also by the structural composition and density of the cultivated layer. The last two parameters are directly related to the physical, physical-and-mechanical and rheological (plastic) properties of soil. Their values in the treated layer must meet the requirements of the sown crops [14]. Therefore, the cultivated layer must also be differentiated for different crops according to the key parameters of soil - its structural composition and bulk density.

Research purpose. Making comparative tests of the experimental soil-cultivating machine and cultivator KPS_4 with tooth harrows in operating conditions, studying the performance quality indicators of the machine.

Materials and methods. Basing on the germination and development conditions of plants, the structure of the optimal cultivated layer before sowing should meet the following requirements (Fig. 3):

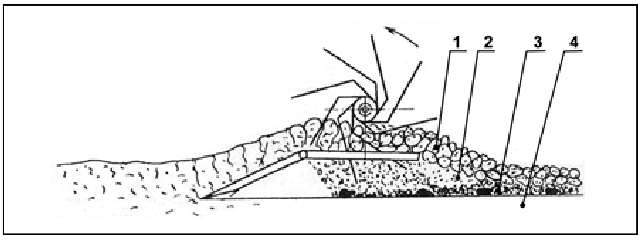

Fig. 3. Structure of the processing layer: 1 –over-seed layer; 2 – the seed layer; 3 – under-seed layer; 4 – subsurface layer

- the cultivated layer must consist of four sublayers: over-seed, seed, under-seed and subsurface ones;
- lumpy fragments of soil larger than 20 *mm* should be completely removed from the over-seed sublayer. The presence of such fragments whittle down all the advantages offered by the structure of the cultivated layer;
- in the seed sublayer, the most agrotechnically valuable structure should be concentrated, with the size of individual fragments not exceeding 3 times the size of seeds;
- the bulk density of the under-seed sublayer should not exceed 1.25 g/cm^3;
- a sub-plow sublayer should not have a density of more than 1.3 g/cm^3 and a hardness in the plow sole of more than 3 *MPa*, which is ensured by the main tillage operations [17].

The fulfillment of these requirements will ensure a good contact of the seeds with soil, their rapid swelling, germination and unhindered penetration of the roots deep into the soil, economical consumption of moisture accumulated during the autumn-winter period (due to the layered structure), and effective assimilation of nutrient elements from fertilizers by plants [16].

The granulometric composition of soil is determined by the quantitative ratio of four main fractions: sand (a particle size of 2.00-0.05 *mm*); dusty (a particle size of less than 0.002 *mm*); coarse-grained sandy loam with a particle size of 2 to 25 *mm*, and lumps with particles larger than 25 *mm* [7].

For a certain crop, the field is cultivated until the necessary looseness of soil is obtained, but in view of the reduction in energy costs. With insignificant amount of weeds, good soil condition, it is always necessary to use traditional cultivation systems, which include stubbling, plowing, and pre-sowing tillage. These methods can be replaced by soil cultivation with simultaneous sowing [8, 9]. This combined treatment is faster with the lowest energy costs and time saving.

It is known that the content of at least 40-45% of waterproof elements with a size of more than 0.25 *mm* in the plow layer ensures that the density, hardness, total porosity and aeration porosity are within optimal limits. The ploughed layer of chernozems contains 55-60% of such elements [9].

The over-saturation of the soil composition with large aggregates and lumps leads to an increase in the degree of aeration, while the predominance of dust fraction in the fine earth contributes to wind erosion. Both of these lead to the desiccation of soil and the loss of humus.

The influence of the ratio of structural soil particles and permissible standards of their content on the yield of agricultural crops is reflected in the works of V.R. Williams, P.A. Nekrasov, P.A. Piguevsky and others [10-13]. In his studies, V.V. Medvedev established the most favorable grain size composition of soil, which provides plants with nutrients and moisture. In this case, soil aggregates (granules) of 5-20 *mm* in size should be about 20-25%, agrotechnically valuable soil aggregates of 0.25-5.0 *mm* – 60-65%, and smaller than 0.25 *mm* – less than 15% [14].

With this ratio of structural soil aggregates, plants effectively use moisture and nutrients. It was also found that the maximum yield of crops was obtained with almost equal seed and soil grain size of the seed layer, and the upper layer of soil up to 4 *cm* thick should have larger soil aggregates of 5-20 *mm* in size [14].

The density of the surface layer of soil affects the development of plants during the growing season, which increases by 0.08 g/cm^3 in dry years, and decreases by 0.05 g/cm3 in wet years. Therefore, to maintain the optimal soil density in the upper layer of the ploughed horizon, it is advisable to perform compaction or loosening [14].

Studies of many scientists have shown that the soil density, hardness and porosity are optimal, when the content of agrotechnically valuable structural aggregates in the ploughed layer of soil is up to 40-45%.

To preserve moisture and lower the temperature of the soil surface, its surface is mulched with plant residues [15, 16]. Soil mulching can be done during the harvesting of crops by spreading chopped straw over the field surface.

Basing on the results of the conducted studies, it can be concluded that the most favorable conditions for plants are made by differentiating the cultivated soil layer according to its structural composition. In this case, aggregates of 5 to 20 *mm* in size should prevail in the surface layer of soil, and those from 0.25 to 10 *mm* – in the seeding zone.

Modern means of mechanization for soil tillage in mouldboard, non-mouldboard (subsurface) and minimum (reduced) tillage systems provide the necessary conditions for crop cultivation. However, to bring physical-and-mechanical properties of soil closer to optimal, and also to control weeds, it is necessary to carry out a relatively large number of mechanical operations, often using herbicides to clean the fields.

To obtain a fine-grained soil structure in the seed location, it is not necessary to crush it intensively and thereby increase the energy intensity of the process. The desired structure can be obtained by combining the operation of crumbling soil and its fractional distribution along the depth of cultivation.

Results and discussion. In the field, the qualitative indices of the machine performance for optimizing the ploughed layer of soil were assessed by the soil structure, density, and moisture. An experimental plot of 1 hectare was ploughed in autumn into a depth of 25-27 cm and divided into two parts. One part of the plot (control) in the spring was tilled with the KPS-4 cultivator with tooth harrows into a depth of 10 cm, the second part was tilled with an experimental machine into the same depth. The physical and mechanical properties of soil during the experiments were determined in accordance with OST 70.2.15-73.

The moisture content of soil was determined by thermal drying in fivefold retaking. Soil samples weighing 0.03-0.04 *kg* were placed in aluminum cups, weighed and dried in a moisture-testing oven at a temperature of 105°C for eight hours. After drying, the soil samples were weighed again. The moisture content of soil was determined according to the formula:

$$W_a = \frac{m_в - m_c}{m_c} 100\% \qquad (1)$$

where $m_в$, $m_с$ – respectively, the mass of wet and dry soil, *kg*.

The hardness of soil was determined with the help of the VISHOM hardness tester in a fivefold retaking.

The soil density was determined in a threefold retaking by the cutting ring method according to N.A. Kochinsky.

To determine the structural-aggregate composition of soil, a method was used to sift it on sieves with round holes. A sample weighing not less than 2.5 *kg* (in triplicate retaking) was brought to an air-dry state and sieved through a sieve without wiping. The soil remaining on the sieves was weighed and the relative weight of each fraction was calculated according to the formula:

$$\Phi = \frac{m}{M} 100\%, \qquad (2)$$

where *m* – the fraction mass, *kg*;

M – mass of the sample received for analysis, *kg*.

The coefficient of soil structure was calculated according to the formula:

Table 1

Structural composition of black soil typical (April), number of units in, %

Aggregate dimensions, mm	Depth, 10^{-2} m					
	Control			Experiment		
	0-5	5-10	15-25	0-5	5-10	15-25
Dry sifting						
>10	45.01	43.40	46.0	11.4	26.9	47.2
10-7	8.31	10.27	10.4	5.2	9.5	10.6
7-5	7.45	6.77	7.9	4.4	7.0	8.1
5-3	9.93	9.36	9.6	7.0	8.0	10.5
3-2	9.15	8.52	8.1	11.7	11.3	8.4
2-1	12.90	15.28	11.9	34.6	2.0	9.0
1-0.5	1.50	1.36	1.4	3.4	2.7	1.4
0.5-0.25	3.34	2.94	2.7	11.6	10.9	2.6
<0.25	2.38	2.10	2.2	1.3	1.7	1.6
10-0.25	57.61	54.50	51.8	87.3	73.1	51.2
$K_{стр}$	1.27	1.20	1.08	3.41	2.72	1.05
Wet sifting						
7-5	0.58	0.56	0.13	0.30	0.66	0.08
5-3	1.08	1.53	0.23	0.05	1.11	0.14
3-2	1.10	1.01	0.56	0.08	1.10	0.40
2-1	3.27	2.94	2.62	0.77	3.58	2.66
1-0.5	16.08	13.12	12.28	7.13	7.75	14.90
0.5-0.25	40.85	39.48	44.60	44.73	14.25	43.95
>1	6.03	6.02	3.54	1.15	6.44	3.28
>0.25	62.96	58.62	60.41	53.06	58.43	62.12
$K_{стр}$	0.65	0.60	0.62	0.60	0.60	0.63

$$K_{cmp} = \frac{K_{10-0,25}}{K_{>10} + K_{<0,25}}, \quad (3)$$

where $K_{10-0.25}$ – percentage of agrotechnically valuable soil fractions in the sample;

$K_{>10}$, $K_{<0,25}$ – percentage of the content of soil fractions in the sample, respectively, less than 0.25 *mm* and more than 10 *mm*.

The physical and mechanical properties of soil are determined in two stages after the spring cultivation in conditions of a bare (black) fallow field: in April and in July (Tab. 1 and 2).

Table 2

Structural composition of black soil typical (July, dry sifting), number of units in, %

Aggregate dimensions, mm	Depth, 10^{-2} m					
	Control			Experiment		
	0-5	5-10	15-25	0-5	5-10	15-25
>10	5.6	28.0	34.8	7.1	24.8	30.3
10-7	4.2	8.3	10.6	3.3	7.2	9.5
7-5	4.1	8.2	8.7	4.1	7.6	10.3
5-3	6.8	11.5	11.7	6.4	9.2	14.3
3-2	11.1	12.3	10.9	10.1	10.8	13.2
2-1	36.4	20.5	15.5	37.6	22.5	14.6
1-0.5	3.8	1.9	1.5	3.1	2.3	1.6
0.5-0.25	12.3	5.3	3.4	11.7	7.3	3.9
<0.25	15.7	4.0	2.9	16.6	8.4	3.3
10-0.25	71.9	68.0	62.3	76.3	66.8	66.4
$K_{стр}$	2.55	2.14	1.73	3.26	2.02	2.42

It can be seen from Table 1 that after soil cultivation by the experimental machine, the amount of soil aggregates larger than 10 *mm* as compared with the control ones in layer 0-5 is 4 times lower and in layer 5-10 is almost 2 times lower. The number of agrotechnically valuable soil aggregates (10-0.25 *mm*) in the experimental version is greater by approximately 30% than in the control one. The structural coefficient of the cultivated soil layer (0-10 *cm*) by the experimental machine is approximately 2.5 times higher as compare with the control one.

Wet sifting of the soil showed that there is practically no difference in the coefficients of water resistance of soil clumps in both variants. In the structural-aggregate composition of soil, in two months after its cultivation, the differences between the experimental and control areas are smoothed out.

The difference in soil density over the layers at different times did not exceed 3-4% (Tab. 3).

Table 3

Density of soil composition, g/cm³

Depth, 10^{-2} m	April		July	
	Control	Experiment	Control	Experiment
0-5	1.06	1.05	1.10	1.11
5-10	1.14	1.15	1.19	1.16
15-25	1.19	1.18	1.12	1.19
30-40	1.18	1.12	1.13	1.13

Fig. 4 shows the quality of cultivating a section of the field by the experimental machine

Fig. 4. A section of the field processed by an experimental machine

Data on the dynamics of changes in soil moisture content over the layers are presented in Table 4. Almost in all soil layers with depth in the soil cultivation variant by the experimental machine as compared with the control variant, the moisture content of soil during two months after its spring cultivation was 1-2% higher;

Table 4

Soil moisture content in layers, %

Depth, 10^{-2} m	April		July	
	Control	Experiment	Control	Experiment
0-5	16.33	18.19	15.59	17.95
5-10	21.33	23.46	20.25	21.37
15-25	25.03	24.29	21.37	23.70
30-40	23.34	25.18	22.34	24.86

moreover, the difference in soil moisture persisted even in July.

To establish how the experimental machine affects the weed infestation of the fields, a bare (black) fallow field was tilled in mid-May. The results of using the experimental machine are shown in Fig. 5.

Fig. 5. The result of black fallow processing by an experimental machine

Weed plants, including root shoots, are thrown out to the surface of the field with an intact root system (Fig. 6), provided that self-seeding is not allowed the costs of introducing herbicides are thus eliminated.

Fig.6. Weed on the surface of the field with an intact root system

Conclusion. Field studies have shown that the ripping-and-separating machine provides a 1.7-fold increase in the coefficient of the soil structure, better accumulation and preservation of moisture, by 3-4% higher as compared to the control variant. Pre-sowing tillage with the use of the machine allows to skip pre-sowing harrowing and cultivation, as well as prepare the soil for sowing in one run. The considered machine for optimizing the agrophysical properties of the ploughed soil layer, as compared with traditional cultivators, allows to increase the structural ratio by about 2.5 times, to maintain the soil moisture content in summer by 1-2% higher than in the control variant, and significantly reduce the weed infestation of the cultivated soil layer.

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