Study of energy consumption of the process of surface tillage by the combined stubble unit KSA-3,8M "Svarog" with improved rolling working bodies

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Abstract. The article provides an analysis of the main directions for improving the soil-cultivating working bodies of rollers in combined units. The traction resistance of the sections of loosening paws, sections of treadle harrows, modernized rollers, as well as the total traction resistance of the combined unit is theoretically substantiated. To confirm the theoretical prerequisites for substantiating the energy indicators of the unit, its field tests were carried out on an area of 120 hectares on southern micellar-carbonate chernozem. As a result, the tested rolling sections in the unit have the greatest difference in traction resistance (12,1%) at a speed of 8 km/h and a soil cultivation depth of 0.05 m. On average, the traction resistance of the modernized experimental combined unit KSA-3,8M "Svarog" is 16,17% less than that of the serial KPE-3,8V. This variation in the differences in traction resistance is explained by the fact that with an increase in the depth of soil cultivation by the main working bodies - flat-cutting paws, a large mass of soil fractions is carried to the soil surface. The sizes of the fractions increase with increasing depth of cultivation and lead to an increase in the height and mass of the ridges. As a result, after distribution by the leveling working bodies, the partially leveled mass and destroyed clods fall under the bars and segment knives of the roller. During the operation of the roller, the absolute speed vector of the knife is perpendicular to the cutting edge, which leads to a chopping effect on the destroyed soil lump without additional energy costs for its movement. As a result, a fine-grained soil layer is formed for sowing.

1 Introduction

The issues of studying the processes of destruction and movement of soil during the impact of rollers on it, taking into account the modern development of mechanics of deformable solids and the magnitude of forces acting in the contact zone, are not given primary attention in the works of domestic and foreign researchers.

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It should be noted that the process of developing rolling working bodies should be considered from the point of view of the possibility of regulating the process of changing the properties and, accordingly, the possible control of the movement of soil particles by working bodies. It should be interconnected with the initial properties of the soil, its ecosystem and the operating conditions of the soil-cultivating roller in it. The biosystem model "external environment - soil - rolling working body" should be considered, with the presence of feedback [1, 2].

An analysis of existing work in the field of mechanization of soil compaction showed that insufficient research has been carried out to substantiate the parameters and operating modes of soil-cultivating rollers, as applied to the high-quality formation of a seed layer with an optimal fractional composition, depending on the cultivated agricultural crop; there are no studies on compacting working bodies, including as part of combined soil-cultivating units [3].

At the same time, the main disadvantages of the design elements of soil-cultivating rollers in combined units are:

– high metal consumption;

– pressing in soil lumps and blocks without destroying them or obtaining very small fractions;

– insufficient number of adjustments, which leads to a decrease in functional capabilities and does not allow creating the required pressure of the working bodies for different types of soil;

– lack of versatility and adaptability leads to the impossibility of using roller sections as part of combined soil-cultivating units [4].

Based on the above-mentioned shortcomings of the elements of the working bodies, a diagram has been created that includes the main directions for improving the soil-cultivating working bodies of rollers as part of combined units [5,6,7], which is presented in Figure 1.

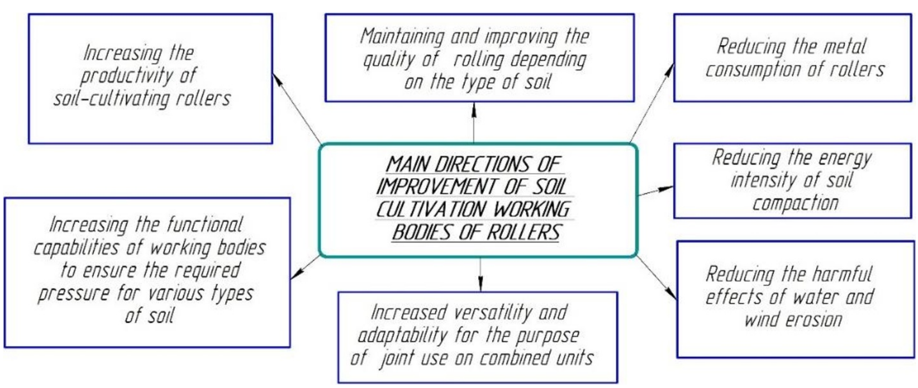

Fig. 1. Main directions of improvement of soil-cultivating working bodies of rollers.

The main technical result of the subsequent development of agricultural engineering is the creation of combined soil-cultivating technical means, including rolling working bodies, with the help of which high-quality pre-sowing soil cultivation will be possible, with minimal labor costs and savings in fuel consumption [8,9,10]. At the same time, an important result of the research and development work carried out should be the development, testing and implementation of these combined soil-cultivating units.

The aim of the research is to theoretically substantiate the energy intensity of the process of surface soil cultivation by the new working bodies of the KSA-3.8M "Svarog", as well as to experimentally verify the comparative indicators of the energy efficiency of the modernized rolling working bodies of the studied unit.

2 Materials and methods

The theoretical substantiation of the energy intensity of the process of combined soil cultivation by the KSA-3,8M "Svarog" unit was carried out in the department of mechanization of production and development of new types of equipment of the Federal State Budgetary Institution of Science "Research Institute of Agriculture of the Crimea" in 2024. When substantiating the total traction resistance of individual sections of the working bodies of the combined unit, the basic provisions of agricultural mechanics were used/

3 Results

The total traction resistance P_{unit} of the combined unit KSA-3.8M "Svarog" includes the traction resistances of individual sections of the working bodies included in its composition, as well as the traction resistance to rolling of the entire unit:

$$P_{unit} = 2 \cdot P_{ps} + P_{hs} + P_{rs} + P_r, \tag{1}$$

where P_{ps} is the traction resistance of the loosening paw section;
P_{hs} is the traction resistance of the tine harrow section;
P_{rs} is the traction resistance of the packer roller section;
P_r is the traction resistance to rolling of the unit.
The traction resistance of the loosening paw section is determined by an expression of the form:

$$P_{ps} = n_{rp} \cdot k_{sp.p.} \cdot h_{rp} \cdot b_{rp} = k_{sp.p.} \cdot h_{rp} \cdot b_{unit}, \tag{2}$$

where $k_{sp.p.}$ is the specific traction resistance of the soil at the set processing depth;
h_{rp} is the depth of the ripper paws;
b_{rp} is the width of one ripper paw;
n_{rp} is the number of ripper paws in a section;
b_{unit} is the width of the combined unit.
The traction resistance of a section of treadle harrows P_{hs} will arise due to the energy expenditure on the destruction and movement of soil lumps and will be determined by the expression:

$$P_{hs} = n_{lh} \cdot k_{sp.hs.} \cdot h_{lh} \cdot b_{lh} = k_{sp.hs.} \cdot h_{lh} \cdot b_{unit}, \tag{3}$$

where $k_{sp.hs.}$ specific traction resistance of the soil at a set depth of cultivation with tine harrows;
h_{lh} is the depth of the loosening harrows;
b_{lh} is the width of one loosening harrow;
n_{lh} is the number of loosening harrows in the section.
During the steady-state operation, the rolling roller, operating without slipping due to the periodic engagement of the toothed sectors with the soil, performs high-quality destruction of soil lumps. At the same time, under the influence of the toothed surface of the working parts of the roller, the process of soil destruction occurs in a low-energy mode due to the

creation of alternating loads in the contact zone with the soil. The traction resistance of the rollers can be determined using the Grandvoine-Goryachkin formula [11]:

$$P_{rc} = 0{,}86\sqrt[3]{\frac{G^4}{qbd^2}}, \tag{4}$$

where G is the weight of the roller;
q is the coefficient of volumetric soil compaction;
d is the diameter of the roller;
b is the width of the roller, $b = b_{unit}$.
In our case, due to the presence of toothed sectors, the total rolling resistance of the modernized rollers is determined by the formula:

$$P_{rs} = P_{rc} + P_{ts} = 0{,}86\sqrt[3]{\frac{G^4}{q \cdot b_{unit} \cdot d^2}} + k_{ts} \cdot k_{sh} \cdot k_{sp.ts.} \cdot h_{ts}, \tag{5}$$

where P_{ts} is the additional traction resistance created by the cutting elements on the roller surface;
k_{ts} is the coefficient taking into account the number of toothed sectors simultaneously engaged with the soil, $k_{ts} = \frac{n_{ts1r}}{b_{unit}}$;
n_{ts1r} is the number of toothed sectors in one row;
k_{sh} is the coefficient taking into account the shape of the working surface of the toothed sectors;
$k_{sp.ts.}$ is the specific traction resistance of one toothed sector;
$h_{ts}$is the depth of immersion of the toothed sectors in the soil.
Traction resistance to rolling of the combined unit:

$$P_r = f_{unit} \cdot M_{unit} = f_{unit}(m_f + 2 \cdot m_{lp} + m_{hs} + m_{rs}), \tag{6}$$

where f_{unit} is the coefficient of resistance to rolling of the unit;
M_{unit} is the mass of the combined unit;
m_f is the mass of the frame;
m_{lp} is the mass of the section of loosening paws;
$m_{hs}$is the mass of the section of tine harrows;
m_{rs} is the mass of the roller section.
Thus, taking into account dependencies (2)-(6), expression (1) will have the following form:

$$P_{unit} = (2 \cdot k_{sp.p.} \cdot h_{rp} + k_{sp.hs.} \cdot h_{lh}) \cdot b_{unit} + 0{,}86\sqrt[3]{\frac{G^4}{q \cdot b_{unit} \cdot d^2}} + \frac{n_{ts1r}}{b_{unit}} \cdot k_{sh} \cdot k_{sp.ts.} \cdot h_{ts} + f_{unit}(m_f + 2 \cdot m_{lp} + m_{hs} + m_{rs}). \tag{7}$$

The obtained formula (7) characterizes the technological process of combined soil cultivation by the KSA-3,8M soil-cultivating unit under various cultivation modes and can be applied in the development of similar designs applicable to soils of different mechanical composition. The obtained formula was experimentally verified during surface treatment of fallow land and non-moldboard cultivation of stubble after harvesting spring crops on an area of 120 hectares on southern mycelial-carbonate chernozem in the field crops department of the Federal State Budgetary Institution of Science "Research Institute of Agriculture of the Crimea".

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During the tests, two compaction sections of the rollers and the units as a whole were compared separately, both for the KSA-3.8M "Svarog", as shown in Figure 2, and for the KPE-3,8V. First of all, the main energy indicator was determined - traction resistance P.

Fig. 2. General view of the experimental modernized combined stubble unit KSA-3.8M "Svarog" before testing.

The results of the obtained values of traction resistance P of the compared units are presented in Table 1.

Table 1. Results of the study of traction resistance of the modernized experimental combined stubble unit KSA-3,8M "Svarog" and serial KPE-3,8V.

Speed indicator, V, km/h	KSA-3,8M "Svarog"		KPE-3,8V		Reduction of traction resistance of rolling sections, %
	Traction resistance of the unit P, N	Traction resistance of the rolling sections P, N	Traction resistance of the unit P, N	Traction resistance of the rolling sections P, N	
Depth of experimental passage of the unit h_{rp}, – 0,05 m					
8	10537,3	1247,6	12641,3	1398,34	12,1
10	10812,5	1473,8	12968,7	1647,71	11,8
12	11744,7	1560,5	14091,3	1732,2	11,0
Depth of experimental passage of the unit h_{rp}, – 0,1 m					
8	12390,14	1345,6	14712,24	1491,8	10,84
10	13459,17	1591,2	15984,5	1758,6	10,52
12	14323,11	1638,7	16977,5	1806,2	10,22
Depth of experimental passage of the unit h_{rp}, – 0,15 m					
8	18010,5	1449,7	20991,4	1591,8	9,81
10	18625,7	1714,8	21688,6	1877,2	9,47
12	20474,5	1767,4	23816,4	1928,2	9,09

The results of processing the data from Table 1 using the Microsoft Excel program are presented in the graph of the dependence of the traction resistance P on the speed of movement V of the rolling sections of the combined units studied in field conditions, shown in Figure 3.

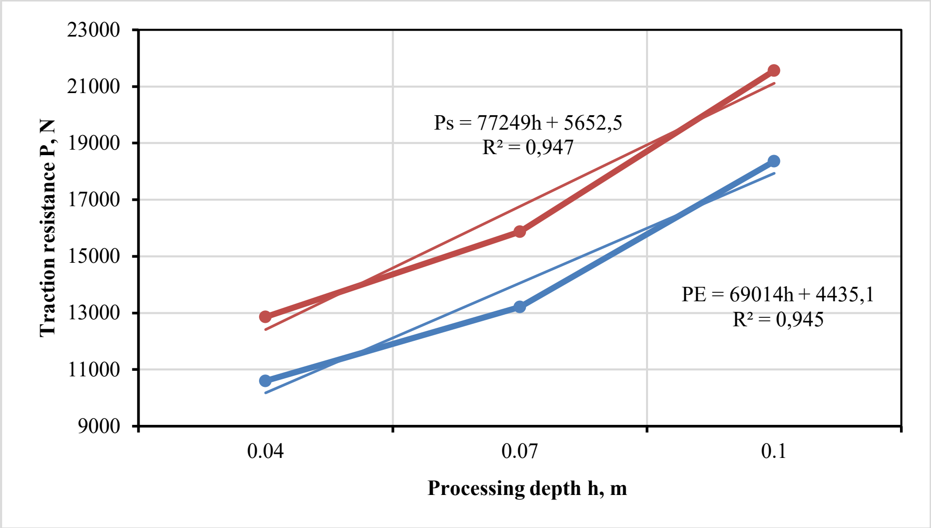

Fig. 3. Graph of the dependence of traction resistance P on the speed of movement V at the depth of the experimental passage of the unit h_{rp} = 0,05 m: P_E – experimental combined unit KSA-3,8M “Svarog”; P_S – serial combined unit KPE-3,8V.

In the process of operation of the rolling sections of the studied units on the processed soil background, taking into account the data of the tabular values of the graphic dependencies, as well as the regression equations, it was determined that the improved rolling section of the modernized combined unit KSA-3,8M "Svarog" provides an increase in traction resistance depending on the depth of processing of the flat-cutting paws of the unit - h_{rp} in the range of 0,05-0,15 m, and its speed V in the range of 8-12 km/h, from 1247,6 to 1767,4 N. With the same variable factors of field tests, the rolling section of the combined unit KPE-3,8V in comparison with the KSA-3,8M "Svarog" shows an increase in traction resistance in the range from 1398,34 to 1928,2 N. This variation in the differences in traction resistance is explained, firstly, by the fact that with an increase in the depth of soil cultivation by the main working bodies - Flat-cutting paws cause a large mass of soil fractions to be removed to the soil surface.

The sizes of fractions increase with the depth of processing and lead to the increase in the height and massif of ridges. As a result, after distribution by the leveling working bodies, the partially leveled massif and destroyed clods fall under the bars and segment knives of the roller. Secondly, during the operation of the roller, the absolute speed vector of the knife is perpendicular to the cutting edge, which leads to a chopping effect on the destroyed soil lump without additional energy costs for its movement. As a result, a fine-grained soil layer is formed for sowing. The greatest difference in traction resistance (12,1%) of the tested rolling sections in the units is at a speed of 8 km/h and a soil processing depth of 0,05 m. On average, the traction resistance of the modernized experimental combined unit KSA-3,8M "Svarog" is 16,17% less than that of the serial KPE-3,8V.

4 Conclusion

The traction resistance of the sections of loosening paws, sections of tine harrows, modernized rollers, as well as the total traction resistance of the combined unit have been theoretically substantiated. Field tests of the unit have been conducted to confirm the theoretical prerequisites for substantiating the energy performance indicators of the unit. As a result, the tested rolling sections in the units have the greatest difference in traction resistance (12,1 %) at a speed of 8 km/h and a soil cultivation depth of 0,05 m. On average, the traction resistance of the modernized experimental combined unit KSA-3,8M "Svarog" is 16,17 % less than that of the serial KPE-3,8V.

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