The dependence of the quality of soil treatment on the parameters and operating modes of the working bodies of the cutter

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Abstract. The purpose of the field research was to verify the theoretical assumptions, calculations and comparative tests in the economic conditions of the mill. The object of research was a milling cutter with a horizontal axis of rotation of working bodies. The dependence of the quality of soil treatment on the parameters of the cutter: the speed of the unit, the circumferential speed of the knife, the depth of soil treatment is determined. Regression analysis methods are used to search for a regression equation that adequately describes the quality of soil cultivation from the studied parameters. It was found that the values of the homogeneity of the fractional composition of the soil during processing by the working bodies of the cutter meet the agrotechnical requirements at the values of the kinematic parameter $\lambda = 4$ and the processing depth $a = 0.14$ m. The best indicators of the fractional composition of the soil were obtained when the drum diameter $D = 0.4$ m and the number of cutter knives in one plane $Z = 3$–$4$ PCs. The purity of tubers in the combine hopper ranges from 10 to 30%, which is 1.5 times lower compared to the control area.

1 Introduction

In crop production, the most energy-intensive operations include tillage, which accounts for up to 40% of the total energy consumption. Research [1–8] found that for a given number of knives on the rotor circle to determine the quality of soil treatment in accordance with agricultural requirements, you need to take into account the parameters: the speed of the unit, feed to the knife, the depth of processing, and others. The research results were obtained when processing light and medium-sized soils with mechanical composition. In the southern Urals, large areas fall on medium-loamy soils. In this regard, research on these types of soil is relevant, aimed at justifying the rational parameters and operating modes of the milling tool, which provides high-quality grinding and sealing of plant residues, crumbling of the soil, mixing the soil with mineral fertilizers.

The aim of the work is to eliminate soil compaction, which further ensures the quality of the process of harvesting potato tubers.

2 Materials and methods

The purpose of this work is to avoid compaction of the soil, which further ensures the quality of the potato tubers harvesting process. For processing heavy soils with a mechanical composition, straight knives with a horizontal axis of rotation are preferred (fig.1). When the cutter is working, the cutting edges of its working bodies make a complex movement: rotational with an angular velocity $\omega$,...
relative to the axis of the drum and translational with the speed of movement of the machine frame \( V \), m/s. the cutter can only work if

\[
\lambda = \frac{V_0}{V_t} = \frac{R\omega}{V} > 1,
\]

where \( \lambda \) is the kinematic indicator that determines the supply to the working body; \( V_0 \) – linear velocity, m/s; \( V_t \) – translational velocity of the gun; m/s; \( R \) is the radius of the rotor, m.

If the kinematic index is \( \lambda < 1 \), then the working body of the cutter will interact with it not with the blade, but with the back (end) side when submerged in the soil.

Analysis of studies [6-13] devoted to the study of the influence of design parameters of working bodies on agricultural and energy indicators of the MTA, as well as modes and conditions of their operation, confirms that the determining factors are the ratio between the linear speed of the knife \( V_0 \) and the translational speed of the tools \( V_t \), the processing depth \( a \), the radius of the Rotor \( R \), the number of knives \( Z \) located in one plane of the rotary mill.

Kinematic indicator \( \lambda \) determines the number of acts of influence of the working body on the processed material. Since the translational speed of the unit during tillage must be constant, changing the kinematic parameter is possible by changing the rotation frequency of the cutter rotor. The minimum linear speed that ensures high-quality mixing depends on the coefficient of friction of the soil on the surface of the knife and the angle of its inclination to the plane of rotation.

When the working bodies of the cutter are working, ridges are formed on the bottom (fig. 2). During pre-planting preparation of the soil, the depth of processing \( a \) changes slightly and the formation of the soil sole \( h \) is excluded during subsequent processing, and therefore this indicator is not considered by us under the assumption that the height of the ridges \( h \) is set by agricultural requirements.

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**Figure 1.** Working body of the milling type

**Figure 2.** Calculation scheme for determining the relative value of the feed \( S/D \) from the kinematic parameter \( \lambda \) and the number of knives \( Z \)
Feed of the working body-an indicator that is taken into account when choosing the mode of operation of the milling drum, determined by agrotechnical requirements.

Feed of the working body, a parameter that is taken into account when choosing the mode of operation of the cutter, is determined by agrotechnical requirements. The energy characteristics of rotary machines depend on this. The feed rate, in turn, depends on many design parameters and operating modes. To determine the feed to the knife, it is necessary to consider the process of cutting the soil between neighboring working bodies that rotate in the same vertical plane. The trajectory of the knife 1 moves horizontally relative to the neighboring knife 2 by the amount of feed $S=\nu \cdot t$, where $t$ is the time during which the knife turns at an angle equal to the angle between the neighboring knives.

With the number of knives $Z$ in the same plane of the milling drum disk, the angle between neighboring knives is $\frac{2\pi}{Z}$. Then the time is $t=\frac{2\pi}{Z\omega}$, and the feed is

$$S = \frac{2\pi}{Z\omega} \quad \text{either} \quad S = \frac{\pi R}{Z\lambda}.$$  \hspace{1cm} (2)

Most often, the ratio of the feed value to the diameter of the milling drum is used, which are determined by the kinematic parameter and the number of teeth. If formula (2) is represented as

$$\frac{S}{2R} = \frac{S}{D} = \frac{\pi}{Z\lambda},$$ \hspace{1cm} (3)

then it is suitable for analyzing and justifying the milling drum of various diameters. In the process of tillage, the working body of the milling drum cuts a certain amount of soil $\delta$, called chips, limited by the points ABCD (fig. 2) necessary to determine the cutting force with knives. The chip thickness decreases from the largest value to zero.

The thickness of the chip to be cut is determined by the distance between adjacent knife paths measured in the radial direction from the center of the drum and depends on the angle of rotation between the working bodies and the time of rotation between these working bodies. The angle of rotation between the working bodies of the milling drum is determined by the dependence

$$\varphi = \frac{2\pi}{Z}. \hspace{1cm} (4)$$

The time of one rotation of the working bodies of the milling drum, expressed in terms of the angle of rotation, is determined by the dependence

$$t = \frac{\varphi}{\omega + \frac{V}{R}}. \hspace{1cm} (5)$$

The value of the chip thickness obtained from equations (2) is expressed as a dependency

$$\delta = x(t);$$

after substitution we get the dependence for determining the chip thickness taking into account the angle of rotation of the working bodies

$$\delta = x\left(\frac{2\pi}{Z\omega} + \frac{V}{R}\right). \hspace{1cm} (6)$$

3 Results

From the expression (3), you can determine the approximate value of the drum diameter $D$ (fig. 3, 4). When $\lambda=2...4$, the feed change is within $S=0.05...0.20$ m. the values of the drum diameter change
within \( D = 400-500 \) mm. When comparing the theoretical values \([14,15]\) obtained by us and the values obtained by Sineokov G.N. and Kanev N.F., it was found that the values of chip thickness closely coincide with each other (table 1).

![Figure 3](image)

**Figure 3.** Dependence of the chip thickness \( \delta \) on the angle of rotation \( \phi_z \) of the working body of the cutter at different feed values \( S \) and the diameter of the cutter \( D=0.4\text{m}. \)

![Figure 4](image)

**Figure 4.** Dependence of the feed \( S \) to the working body on the kinematic parameter \( \lambda \) for different values of the diameter of the mill drum \( D \).

**Table 1.** Change in chip thickness \( (S = 23 \text{ cm}, \ D = 42.5 \text{ cm} \) and \( \lambda = 2.9 \) \) from the angle of rotation of the working body.

| The angle of rotation of the working body’s, \( \alpha^o \) | Theoretical data \( \delta = x \frac{2\pi}{\omega + \frac{V}{R}} S \cos \alpha \) | Chip thickness calculated by the formulae, cm | Kanev N.F. \( \delta = S \cos \alpha + (1 - \cos \Delta \alpha) \) | Sineokov G.N. \( \delta_{\text{max}} = S \cos \alpha_i = \frac{S}{R} \sqrt{2R - a^2} \) |
|---|---|---|---|---|
| 30 | 18,0 | 21,50 | 19,92 |
| 45 | 16,0 | 19,49 | 16,26 |
| 60 | 10,0 | 16,46 | 11,50 |
| 75 | 5,0 | 12,22 | 5,95 |
| 90 | 0,0 | 6,76 | 0,0 |

Theoretical studies have found that when the angle of rotation of the cutter from zero to \( 87.5^0 \) with feeds of 0.05-0.20 m, the chip thickness at these feeds varies within 5-20 cm. When working with the kinematic parameter \( \lambda = 3-4 \), the diameter of the cutter drum is \( R = 400-500 \) mm.
The number of cutter knives in one plane at these parameters is \( Z = 3-5 \) pieces. The main task of planning experiments was to find the mathematical dependence of the process optimization parameters on the influence of each of the studied factors (Table 2) or their combined effect on the process.

### Table 2. Levels and intervals of variation of factors.

| Factors                        | Designation | Level of variation | Interval |
|--------------------------------|-------------|--------------------|----------|
| Number of knives               | \( Z \)     | Article I.         | \( X_1 \) | 18 24 32 6 |
| Ratio of circumferential speed to translational speed | \( \lambda \) | Article II. | \( X_2 \) | 2 4 6 2 |
| Depth of processing            | \( a \)     | Article III.       | \( X_3 \) | 10 14 18 4 |
| Drum diameter                  | \( D \)     | Article IV.        | \( X_4 \) | 400 500 600 100 |

The model of the object of research of the second order has the form (Fig. 5)

\[
F = -56.265 + 14.659Z - 3.008\lambda - 398.41a - 30.277D - 0.286Z^2 + 0.626\lambda^2 + 1504.441a^2 + 35.642D^2 - 0.723Z\lambda aD. \tag{7}
\]

![Figure 5. Dependence of the fractional composition of the soil \( F \) from changes in the diameter of the cutter \( D \) and the number of knives \( Z \).](image)

### 4 Conclusions

It was found that the values of uniformity of fractional composition of the soil in the processing of the working bodies of the cutters, meet the agronomic requirements for the values of the kinematic parameter \( \lambda = 4 \) and the depth \( a = 0.14 \) m. The Best performance of the fractional composition of the soil obtained when the value of the drum diameter \( D = 0.4 \) m and number of blades of the cutter in the same plane \( Z = 3-4 \) pieces of Ranges of values for the drum diameter and number of blades coincide with the theoretical values. The extreme condition corresponds to the maximum at 20-22% soil humidity.

Field tests of potato harvesters were carried out on sites that were treated with tillage machines with active and passive working bodies in various combinations on medium-loamy soils. It was found that with an increase in the forward speed of the harvesting machine from 0.6 to 1.54 m/s, the amount of sifted soil entering the separating bodies increases almost twice. The purity of tubers in the combine hopper ranges from 10 to 30%, which is 1.5 times lower compared to the control area.

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