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Justification of Parameters of the Rotary Ripper for Cotton Rows

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***Annotation* - In the Republic of Uzbekistan, the bulk of cereals are cultivated by sowing in cotton aisles. In world practice, this technology is not used. *(Purpose of research)* A new special rotary cultivator has been developed at SRIAM for working in the aisles of cotton with insufficient soil moisture, and research has been carried out to substantiate its main parameters. *(Materials and Methods)*. A ripper is a battery of cutting discs of different diameters that match the row spacing. Transverse knives are fixed on the discs. The cutting discs cut through the hard soil in the longitudinal direction, and the cross blades cut through the hard soil in the lateral direction, preventing the formation of large clods of soil. (Results and discussion) The diameter of the cutting disc is justified from the condition of ensuring that it rolls over the soil lumps, cutting them in place and not moving forwards. This depends on the diameter of the soil lumps, the angle of their friction against the working surface of the disc, the internal friction angle of the soil, and the immersion depth of the cultivator in the soil. The number of cutting discs is determined based on the width of the cultivated part of the cotton aisle and the number of transverse knives that ensure continuous rotation and at least one transverse blade of the disc being in contact with the soil during movement at any time interval. The vertical load on the rotary cultivator required for its normal operation depends on the volumetric crushing coefficient of the soil, the thickness of the knives, the speed of the working body and the immersion depth in the soil. Experimental studies were carried out during the wheat-sowing season in cotton aisles for farms in the Tashkent region. The quality of soil crumbling was assessed by the content of soil fractions with dimensions not exceeding 25 mm, and the traction resistance was determined by tensometric measurement. Mathematical planning of a multifactorial experiment was used to study the diameter of the rotary ripper, the transverse distance between the cutting discs, the number of transverse knives on the disc, and the vertical load and speed of the working body. *(Conclusions)* The optimal parameters that ensure the required quality of soil cultivation when sowing winter wheat in cotton aisles with minimal energy consumption are as follows: rotary cultivator diameter - 300 mm, transverse distance between cutting discs - 110 mm, number of transverse knives - 12 pcs, vertical load on the cultivator - 360 N.**

Keywords - Cutting discs, Grain seeder for cotton rows, Optimal parameters, Ripper, Working bodies.

INTRODUCTION

In the Republic of Uzbekistan, approximately 80% of winter cereals are cultivated by sowing in the aisles of growing cotton. In developed grain-sowing countries, this technology is not practised, so the appropriate means of mechanization have not been developed. To sow grain in cotton aisles, SRIAM (Uzbekistan) has developed a combined unit that performs two operations in one pass: it processes the soil in the cotton aisles and sows grain seeds in an ordinary way. All these operations are carried out after the main part of the cotton crop is harvested, when the field is still occupied by its bushes (cotton stems) and a part of the cotton crop remains [1, 2]. A feature of sowing grain between rows of cotton is that in the autumn period, the soil has insufficient moisture; therefore, the process of preparing the soil between rows for sowing grain requires the use of special working tools. In the course of research, a new rotary working body was developed for inter-row soil cultivation under conditions of low humidity (hereinafter referred to as a rotary cultivator) [3].

PURPOSE OF THE STUDY

To conduct theoretical studies to substantiate the main parameters of a rotary cultivator for a combined unit designed for row sowing of grain in cotton aisles.

MATERIALS AND METHODS

A rotary ripper is a battery of cutting discs of different diameters with cross knives. The disc with the largest diameter is placed in the middle of the row spacing, while the others, as the diameter decreases, are placed on the sides of the slopes of the row spacing in accordance with its profile. The novelty of the working body is confirmed by RUz patent No. IAP 05860 [4]. The working body works as follows: when moving along the row spacing, the cutting discs with transverse knives go deeper into the soil and, due to adhesion to the soil, roll over. At the same time, the cutting discs cut the hard soil layer in the longitudinal direction, and the transverse knives cut the hard soil layer in the transverse direction, destroying the solidity of the solid soil layer and preventing the formation of large clods of soil. Since the cutting discs have different diameters, the linear speeds of rotation of adjacent discs are different. This eliminates the possibility of soil clods being stuck between the discs.

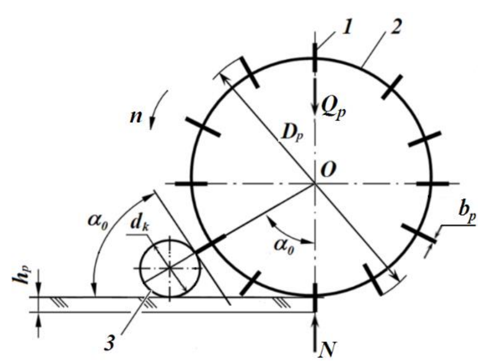
RESULTS AND DISCUSSION

The diameter D_p of the cutting disc with transverse knives should ensure its rolling over the soil lumps (Fig. 1), cutting them in place and not moving forwards in the longitudinal direction [5]. Since the cutting discs have different diameters, it should be noted that this refers to the cutting disc with the smallest diameter, i.e., to the one that is located at the greatest distance from the middle of the row spacing.

This condition is described by the following expression:

$$D_p \geq \frac{d_k\left[1+\cos(\varphi_1+\varphi_2)\right]+2h_p}{1-\cos(\varphi_1+\varphi_2)}, \qquad (1)$$

where d_k is the transverse diameter of the soil lump, m; φ_1 is the angle of friction of the soil lump on the working surface of the cutting parts of the ripper; φ_2 is the angle of internal soil friction; and h_p is the depth of the ripper stroke, m.



1 - cross knife; 2 - cutting disc; 3 - soil lump

FIG. 1. DIAGRAM TO JUSTIFY THE DIAMETER OF A ROTARY RIPPER AND VERTICAL LOAD ON IT

From expression (1), it can be seen that the diameter of the cutting disc with transverse knives depends on the diameter of the soil lumps encountered along the path of its movement, the angle of friction of the soil lump on the working surface of the cutting parts of the ripper, the internal friction angle of the soil, and the immersion depth of the ripper in the soil.

Using data in the literature [6, 7], we adopt the following values for the calculations: d_k = 0.1 m, h_p = 0.05 m, φ_1 = 35° and φ_2 = 40°. Then, according to Formula (1), we determine that the diameter of the smallest cutting disc of the rotary ripper must be at least 0.304 m, i.e., $D_p \geq 304$ *mm*. The diameters of other cutting discs located along the slopes of the row spacing are determined based on the angle of inclination of the slopes from the horizontal.

The distance l between the cutting discs of the rotary ripper in the transverse direction was determined from the following expression:

$$l \leq l_k + b \qquad (2)$$

where l_k – the value of soil fractions allowed according to agrotechnical requirements in the aisles of cotton prepared for sowing grain, m;

b – width of capture of one cutting disc equipped with transverse knives, m.

According to agrotechnical requirements, in cotton prepared for sowing winter cereals, fractions of soil particles up to 25 mm in size should be at least 80%, and fractions 25-50 mm in size should be no more than 5%. The presence of soil fractions larger than 50 mm is not allowed.

The grip width of the cutting disc equipped with transverse knives is determined by the width of the transverse knife, which is taken from design and technological considerations equal to 70 mm.

Therefore, at l_k = 0.05 m and b = 0.07 m from expression (2), we determine that the transverse distance between the cutting discs equipped with transverse knives should be no more than 0.12 m, i.e., $l \leq 120$ mm.

The number z of the cutting discs of the rotary cultivator is determined based on the width of the cultivated part of the cotton aisle. Consider the following expression:

$$z = \frac{B - 2b_3}{l_k + b}, \qquad (3)$$

where B – the width of the row spacing of cotton, m;

b_3 – the width of the unprocessed protective zone, m.

Taking B = 0.90 m and b_3 = 0.05 m and taking into account the above values, from expression (3), we find that the number of cutting discs should be equal to z = 6.

The number n_n of transverse knives of the rotary ripper with the smallest diameter of the cutting disc is determined based on the condition of ensuring its continuous rotation. This condition is fulfilled in the event that during the movement of the unit at any time interval, at least one transverse knife of the cutting disc is in contact with the soil. This condition is described by the expression

$$n_n \geq \frac{2\pi}{\arccos\frac{D_p - 2h_p}{D_p}}. \qquad (4)$$

Substituting the known values, we determine that the number of transverse knives on the disc with the smallest diameter should be at least 7.53 pieces or rounded to $n_n \geq 8$ pieces. For row spacing with a furrow depth of approximately 14 cm, by simple calculations, it can be determined that the number of transverse knives on the middle cutting disc of the ripper should be at least 10.58 pieces or rounded to at least 11 pieces.

To determine the vertical load Q_p on the rotary ripper required for its normal operation, we use the above scheme, according to which we have:

$$Q_p = N = \sigma b b_p z \qquad (5)$$

where σ is the specific resistance of the soil to crushing, N/m^2;

b_p – the thickness of the transverse knife, m.

In expression (5), the value of σ is expressed through the coefficient q_0 of the volumetric crushing of the soil and the depth h_p of immersion of the knives in the soil [8]:

$$\sigma = q_0 h_p \qquad (6)$$

Taking this into account, expression (5) takes the following form:

$$Q_p = q_0 b b_p h_p z \qquad (7)$$

It is known [9] that the coefficient q_0 of the volumetric crushing of the soil depends on the speed of movement of the working body and can be expressed by the following equality:

$$q_0 = q_{01}\left(1 + m_n V^2\right), \qquad (8)$$

where q_{01} is the static coefficient of volumetric crushing of the soil, N/m^3;

m_n - coefficient of proportionality, s^2/m^2.

Substituting the value q_0 from expression (8) into expression (7), we have the following resulting equality:

$$Q_p = q_{01}\left(1 + m_n V^2\right) b b_p h_p z. \qquad (9)$$

Consequently, the vertical load Q_p on the rotary cultivator, required for its normal operation, depends on the coefficient of volumetric crushing of the soil, the thickness of the knives, the speed of the working body and the depth of its immersion in the soil.

Calculations carried out according to expression (9) at a speed of movement of the working body of 1.5-2.0 m/s, while taking N/m^3, m_p=0.08 s^2/m^2, b=0.07 m, b_p =0.005 m, h_p=0.05 m and z=6 pcs [7, 10, 11, 12, 13], showed that the vertical load on the rotary cultivator should be within Q_p = 371.7–415.8 N/m.

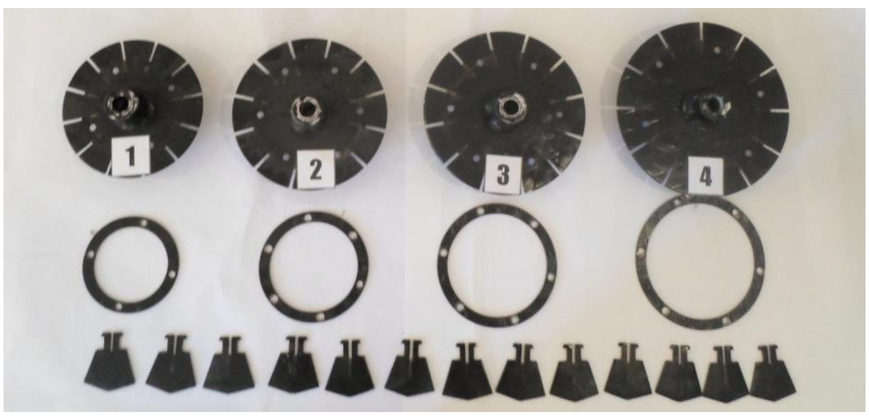
EXPERIMENTAL RESEARCH

To verify the results of theoretical studies and determine the optimal values of the parameters, experimental studies were carried out in which the influence of the main parameters of the rotary cultivator and the speed of its movement on the quality of soil crumbling and the traction resistance of the working body was studied.

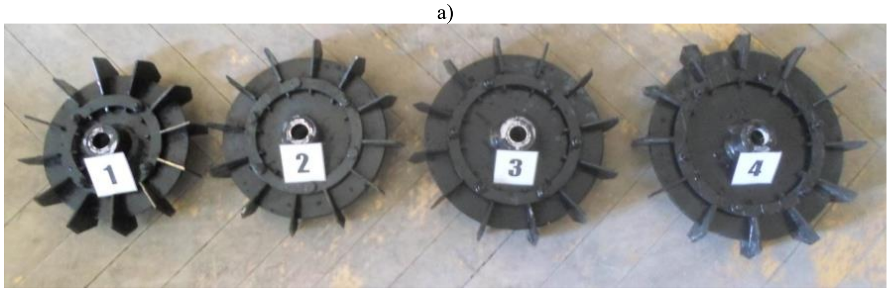
The experiments were carried out in the autumn during the sowing season of wheat in the aisles of cotton in fields in the Tashkent region. The quality of soil crumbling was assessed by the content of soil fractions with sizes of no greater than 25 mm in percent, and the traction resistance was determined by “tensometry”.

Single-factor experiments were carried out to determine the influence of theoretically investigated parameters on the quality of soil crumbling and traction resistance of the working body. According to the results of these experiments, the parameters were established that have the greatest influence on the quality of the ripper operation, as well as the levels of variation of these parameters when optimized by the mathematical planning of the experiment [14, 15]. It should be noted that with the number of transverse knives of the rotary cultivator equal to 8, in single-factor experiments, the quality of soil crumbling turned out to be lower than required. Therefore, when carrying out multifactor experiments, the number of knives ranged from 10 to 14 pieces with an interval of 2 knives.

Experimental models of a rotary ripper of different diameters with 12 knives are shown in Fig. 2.



a)



b)

1 – D_p=260 mm; 2 – D_p=280 mm; 3 – D_p=300 mm; 4 – D_p=320 mm.

FIG. 2. ROTARY RIPPER PROTOTYPES IN DISASSEMBLED (A) AND ASSEMBLED (B) FORMS

Table 1 shows the initial data for conducting optimization experiments. “Hartley” experiments planning “Matrix 5” After processing the experimental results, the following regression equations were obtained, which adequately describe the changes in the soil crumbling quality and traction resistance of the rotary cultivator:

by the quality of soil crumbling (%):

$$Y_1 = 84{,}725 + 5{,}105\,X_1 - 2{,}441\,X_2 + 3{,}972\,X_3 + 3{,}553\,X_4 + 3{,}577\,X_5 - 2{,}230\,X_1^2 + 0{,}621\,X_1X_2 + 0{,}541\,X_1X_3 - 2{,}185\,X_2^2 + 0{,}803\,X_3X_4 + 0{,}851\,X_3X_5 + 1{,}080\,X_4^2 + 1{,}017\,X_4X_5 - 1{,}024\,X_5^2; \quad (10)$$

TABLE 1
LEVELS AND INTERVALS OF VARIATION OF FACTORS

Rotary Ripper Parameters	Unity	Designation of factors	Variation intervals	Variation levels		
				-1	0	+1
1. Diameter (D_p)	mm	X_1	20	280	300	320
2. Distance between cutting discs (l)	mm	X_2	10	110	120	130
3. Number of cross knives (n_n)	piece	X_3	2	10	12	14
4. Vertical load (Q_p)	N	X_4	100	300	400	500
5. Travel speed (V)	m/s	X_5	0,37	1,38	1,75	2,12

by traction resistance (N):

$$Y_2 = 361{,}399 - 8{,}980\,X_1 + 2{,}796\,X_2 + 20{,}959\,X_3 + 33{,}964\,X_4 + 5{,}964\,X_5 + 6{,}890\,X_1^2 - 1{,}698\,X_1X_2 - 1{,}997\,X_1X_3 - 2{,}996\,X_1X_4 + 1{,}858\,X_1X_5 - 2{,}347\,X_2X_3 - 3{,}555\,X_2X_4 + 4{,}375\,X_4^2 + 10{,}165\,X_5^2; \quad (11)$$

Equations (10) and (11) show that all factors had a significant impact on the assessment criteria. Solving the regression equations from the condition of ensuring the quality of soil crumbling (the content of soil fractions with sizes not exceeding 25 mm) at the level "Y_1" ≥ 80% and the minimum traction resistance of the rotary cultivator "Y_2" → min, at speeds of 1.38-2.12 m/s obtained the optimal values of the factors that meet the above conditions (Table 2).

CONCLUSIONS

To ensure the required quality of soil cultivation between rows of cotton before sowing wheat with minimal energy consumption at speeds of 1.38-2.12 m/s, the diameter of the rotary cultivator should be within 303.1–309.1 mm, the lateral distance between the cutting discs should be 110.7–112.9 mm, the number of transverse knives should be 10.8–11.5 pcs, and the vertical load on the rotary cultivator should be in the range of 310.8–362.6 N. At these parameter values, the quality of soil crumbling will be ensured within 80.4–83.4% with a traction resistance of 315.8–360.0 N.

TABLE 2
OPTIMAL VALUES OF THE ROTARY RIPPER PARAMETERS

Travel speed V, (X_5)		Diameter D_p (X_1)		Cross distance between discs, l (X_2)		Number of cross knives n_n, (X_3)		Vertical load Q_p, (X_4)	
Coded	Natural, mm	Coded	Natural, mm	Coded	Natural, mm	Coded	Natural, mm	Coded	Natural, mm
-1	1,38	0,457	309,1	-0,711	112,9	-0,323	11,4	-0,567	343,3
0	1,75	0,383	307,7	-0,788	112,1	-0,609	10,8	-0,374	362,6
1	2,13	0,156	303,1	-0,933	110,7	-0,260	11,5	-0,891	310,8

Based on the above data, we used the following parameters of a rotary cultivator designed for processing cotton row spacings: the diameter of the rotary cultivator at the extreme cutting disc was 300 mm, the transverse distance between the cutting discs was 110 mm, the number of transverse knives was 12 pcs. and the vertical load on the rotary cultivator was 360 N.

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