

# Process modeling of the first inter-rowcultivation in laboratory conditions

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**Abstract.** The paper considers the formation process of secondary soil ridges by working bodies with flat discs during the first mechanized inter-row cultivation of crops in laboratory conditions. Taking account of the agrotechnical requirements and the physical and mechanical properties of the soil, we adopted the reference profile of the soil ridge formed during mechanized inter-row cultivation of crops, which can conditionally be accepted as ideal, as well as the original optimization criterion  $k_{cs1}$ . After practical implementation of studies in the tillage bin and statistical processing of the obtained data, the corresponding equations were obtained in which the independent process factors were expressed in natural and encoded values. It was found that a change in the speed of a cultivator within 1.2 ... 2.4 m / s, with angles of attack  $\alpha_k$  of flat discs from 5° to 20°, increases the distance at which the soil is thrown off and the thickness of the soil layers covering the sides and the upper base of the primary ridge ( $k_{cs1} \rightarrow \max$ ). At angles of attack  $\alpha_k$  of flat discs within the limits of 25° ... 30° and the speed of the cultivator from 1.2 m / s to 1.6 m / s, an increase in the thickness of the covered soil layers  $h_{np}$ , occurs, and the coefficient  $k_{cs1}$  is maximum ( $k_{cs1} = 0.98$  with a flat disc diameter of 0.3 m).

## 1 Introduction

At present, the method of mechanized row crop weeding is complemented with a chemical one - treatment with selective herbicides or a combined one – the application of mechanical and chemical methods [1, 2, 3, 4, 5, 6, 7].

The analysis of the methods for calculating the estimated indicators of technical means of inter-row cultivation of crops by ridge technology showed that in theories of determining the geometric dimensions and surface shapes of working bodies in inter-row cultivators, there are currently issues that have not been resolved. Moreover, the data obtained from the studies conducted by many scientists cannot be applied to new working bodies with flat discs in inter-row cultivators. Consequently, additional theoretical and experimental confirmation of the optimal structural and operational parameters of the cultivator working bodies mentioned above is required [8, 9, 10].

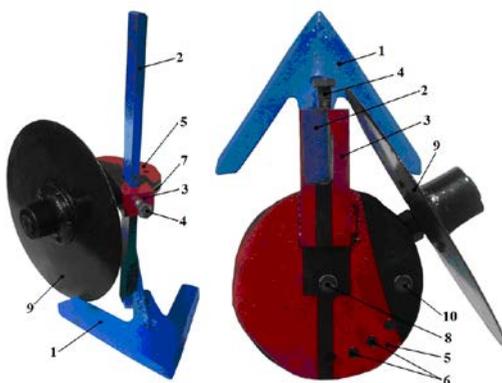
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## 2 The study objects and research methods

A working body of a cultivator with a flat disc mounted on a domestic or imported inter-row cultivator is proposed for mechanical weeding of row crops with the use of ridge technology. The proposed working body of the cultivator will make it possible to cut weeds between the rows of cultivated crops, as well as to cover undamaged weeds on the sides of the ridges and between the stems of the cultivated crop on the upper base of the soil ridge [1, 2, 3].

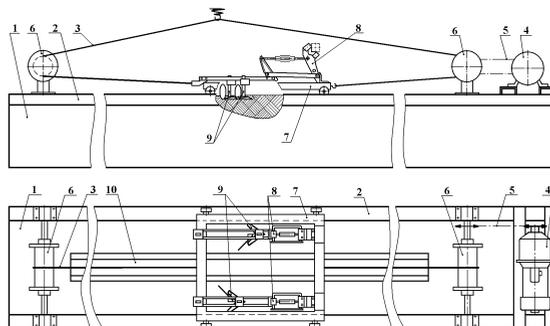
The working body with a flat disc (Fig. 1) has been made in accordance with RF patents Nos. 2475008, 2475009, 2494590, 2477034, 2471327, 2477593, 2464755, 2464756, 2466520, 113110, 113908, 113910, 116001, 116305.



**Fig. 1.** The working body with a flat disc: 1 – A-blade (sweep); 2 - shank; 3 - bracket; 4 - screw; 5 - disc; 6 - holes; 7 - additional disc; 8 - axle; 9 - flat disc; 10 - bolt

In the presented working body of the cultivator, it is possible to change the angle of attack of flat discs and the magnitude of their penetration into the soil. These parameters have a direct impact on the quality of cultivation and the geometric parameters of the initial soil ridge.

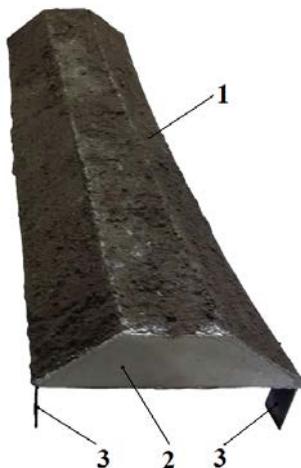
For laboratory studies of the working body, a laboratory complex was used (Fig. 2), consisting of a tillage bin with a trolley and a rail track, a drive unit, and measuring instruments. Two gangs from the cultivator with interchangeable working bodies of various sizes were mounted on the trolley. In addition, between the gangs with the working bodies, soil ridge models were placed in the tillage bin, the sizes of which corresponded to the sizes of soil ridges formed during sowing in the field.



**Fig. 2.** Laboratory complex for the study of the working body in an inter-row cultivator: 1 – tillage bin; 2 - rail track; 3 - cable; 4 - electric motor; 5 - chain transmission; 6 - drums; 7 - trolley; 8 - gangs of the cultivator; 9 - working bodies with right and left flat discs; 10 – soil ridge (model)

Cultivator gangs with working bodies were pulled on the trolley along the rail track by an electric motor with the use of a cable, chain transmission and drums.

To approximate the conditions of the laboratory experiment to real field ones and to ensure the coefficient of friction against the soil, the soil identical to the soil in the bin was glued to the sides and the upper base of the ridge model (Fig. 3). In the lower part of the ridge model, hooks were mounted to prevent the model from being shifted from its place on the soil surface due to the force of the soil movement.



**Fig. 3.** Model of the soil ridge formed during sowing: 1 - steel trapezoidal frame; 2 - ribs; 3 - hooks

In laboratory conditions, working bodies with flat discs were tested in full compliance with the requirements of GOST (state standard), with soil moisture in the tillage bin of 19 ... 23% [9, 10].

The geometric dimensions of the formed secondary ridge of the soil during the first mechanized cultivation (Fig. 4), formed by the working bodies with flat discs, were controlled by the original device, the novelty of which was confirmed by RF patents No. 148575 and No. 150391.



**Fig. 4.** Cross section of the secondary ridge of the soil formed by the working bodies with flat discs after the first mechanized cultivation of crops

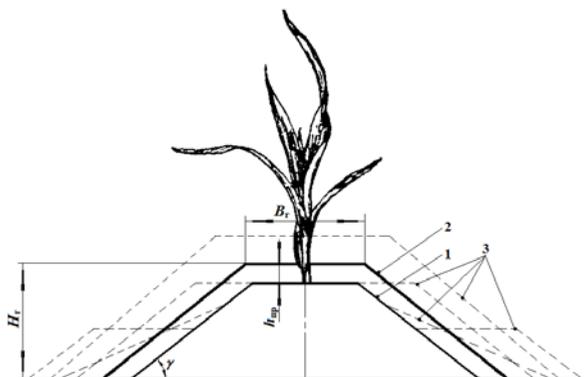
Preliminary exploratory studies have revealed that the formation of the secondary soil ridge, and, accordingly, the thickness of the soil layers covered on the primary soil ridge, depends on the speed of the cultivator and the angle of attack of the flat discs of the

working bodies.

For a joint agrotechnical assessment of the influence of variable independent factors of the process of mechanized crop cultivation, it is advisable to apply such an optimization parameter, the main component of which will be the cross-sectional area of the secondary soil ridge. It was found that the covered soil  $h_{np}$  with a thickness of 2 ... 4 cm during the first mechanized cultivation of row crops will make it possible to cover weed seedlings on the sides and the upper base of the primary soil ridge between cultivated plants.

Thus, it is advisable to apply the reference profile of the secondary soil ridge, formed during mechanized cultivation of crops, with natural falling of soil from the sides of the ridge at an angle  $\gamma$ . Such a profile of the secondary ridge can be considered ideal.

With various combinations of variable factors and the interaction of flat discs with soil, the cross-sectional profile of the formed ridges, as a rule, looks as follows (Fig. 5).



**Fig. 5.** Soil profiles formed during mechanized cultivation of crops: 1 - primary soil ridge formed during sowing; 2 - reference soil ridge; 3 - possible options;  $B_r$  is the width of the upper base of the ridge;  $H_r$  - ridge height

The ridge profiles obtained by the action of working bodies with flat discs with specific structural and operational parameters were compared with the reference profile of the secondary soil ridge. The depth of soil cultivation during the first mechanized cultivation of crops was 5 cm. For various options with the angle of attack of flat discs and the speed of the cultivator, every 0.5 meters the thickness of the soil layers covered on the ridge model was measured.

The optimization criterion for mechanized cultivation of row crops was the original coefficient of compliance with the standard  $k_{c\phi 1}$ , which will allow us to assess the quality of the formed secondary soil ridges by adding the required soil layer to the primary ridge formed during sowing:

$$k_{c\phi 1} = 1 - \left| \frac{S_{MO1}^{\text{ST}} - S_{MO1}^{\phi}}{S_{MO1}^{\text{ST}}} \right|, \quad (1)$$

where  $S_{MO1}^{\text{ST}}$  – the reference cross-sectional area of the soil ridge during the first mechanized cultivation,  $m^2$  (with the mean value of the thickness  $h_{np} = 0,03$  m the area  $S_{MO1}^{\text{ST}} = 0,0262$   $m^2$ );  $S_{MO1}^{\phi}$  – the actual cross-sectional area of the secondary soil ridge formed by working bodies with flat discs during the first mechanized cultivation,  $m^2$ .

The variation levels of independent factors during the formation of the secondary soil ridge are presented in Table 1.

**Table 1.** Variation levels of independent factors during the formation of the secondary soil ridge

Variation levels	Varied factors		
	The speed of the cultivator with the working bodies $v_k$ , m/s	Angle of attack of flat discs of the working bodies $\alpha_k$ , degrees	Diameter of flat discs of the working bodies $d_k$ , m
upper level (+ 1)	2,4	30	0,35
lower level (- 1)	1,2	5	0,20
basic level (0)	1,8	17,5	0,275
interval of variation, $\Delta x_i$	0,4	5	0,05
code notation	$x_6$	$x_7$	$x_8$

### 3 Research results

The equations of response surfaces in natural values of factors when changing the speed of the working bodies and the angle of attack of their flat discs with a diameter of 0.2; 0.25; 0.3 and 0.35 (equations 2, 3, 4 and 5, respectively):

$$k_{c91} = -0,4627 + 0,4341v_k + 0,0516\alpha_k - 0,0556v_k^2 - 0,0058v_k\alpha_k - 0,0005\alpha_k^2, \quad (2)$$

$$k_{c91} = -0,4142 + 0,6025v_k + 0,0459\alpha_k - 0,1024v_k^2 - 0,0058v_k\alpha_k - 0,0005\alpha_k^2, \quad (3)$$

$$k_{c91} = -0,0945 + 0,4225v_k + 0,0614\alpha_k - 0,0673v_k^2 - 0,0072v_k\alpha_k - 0,0011\alpha_k^2, \quad (4)$$

$$k_{c91} = 0,12 + 0,3449v_k + 0,0469\alpha_k - 0,0677v_k^2 - 0,0085v_k\alpha_k - 0,0006\alpha_k^2, \quad (5)$$

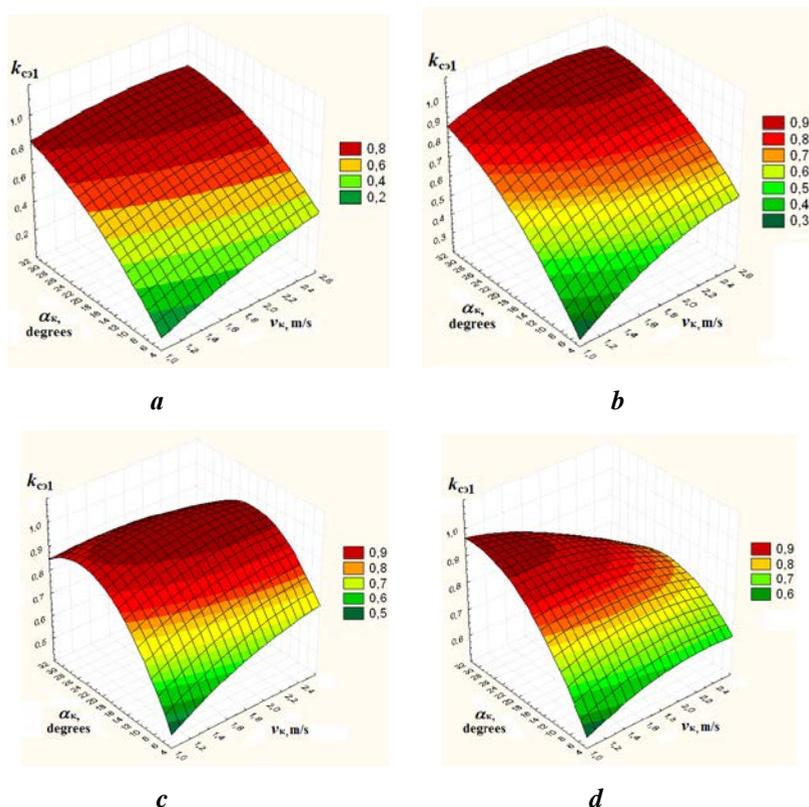
where  $k_{c91}$  – coefficient of compliance with the standard;  $v_k$  – the speed of the inter-row cultivator, m/s;  $\alpha_k$  – angle of attack of a flat disc of the working body in an inter-row cultivator, degrees.

Table 2 gives the evaluation results of equations 2, 3, 4 and 5 by the criteria of Student’s t-test, F-test and Cochran’s C test.

**Table 2.** Results of evaluating regression equations according to the criteria of Student’s t-test, F-test and Cochran’s C-test

Equation number	Criteria					
	$t_p$	$t_T$	$F_p$	$F_T$	$G_p$	$G_T$
2	8,07	2,07	2,62	2,77	0,075	0,155
3	10,478		2,62		0,070	
4	14,958		1,53		0,088	
5	18,831		1,31		0,122	

Graphic displays of the response surfaces for various types of interaction of the speed of the working bodies with flat discs and the angle of attack of flat discs at the first mechanized cultivation of crops are presented in Fig. 6.



**Fig. 6.** Response surfaces from the interaction of the speed of the working bodies and the angles of attack of their flat discs during the first mechanized cultivation of crops: *a* –  $d_k = 0,2$  m; *b* –  $d_k = 0,25$  m; *c* –  $d_k = 0,3$  m; *d* –  $d_k = 0,35$  m

The speed adjustment  $v_k$  of the working bodies with flat discs within 1.2 ... 2.4 m/s, and fixed angles of attack of flat discs with a diameter of 0.2 and 0.25 m (Fig. 6 a, b) makes it possible to increase the distance of the thrown-off soil and the thickness  $h_{np}$  of the soil layers covering the sides and the upper base of the primary soil ridge, i.e.  $k_{c31} \rightarrow max$ . In addition, a change in the angle of attack  $\alpha_k$  of flat discs from 5° to 30° at all speed options of the cultivator also gives a possibility to obtain the maximum value of the coefficient  $k_{c31}$ .

## 4 Discussion

The study of the working bodies with flat discs with a diameter of 0.3 m (Fig. 6 c) allowed us to find that a change in the speed  $v_k$  of the cultivator within 1.2 ... 2.4 m / s, with angles of discs from 5° to 20°, increases the distance of throwing off the soil and the thickness  $h_{np}$  of the soil covering the sides and the upper base of the primary ridge ( $k_{c31} \rightarrow max$ ). At angles of attack  $\alpha_k$  of flat discs within 25° ... 30° and the speed of the cultivator from 1.2 m / s to 1.6 m / s, the thickness of the soil layers covered  $h_{np}$  increases and the coefficient  $k_{c31}$  is maximum ( $k_{c31} = 0,98$ ). A further increase in the speed  $v_k$  the cultivator from 2.0 m / s to 2.4 m / s helps to maximize the thickness of the covered soil layers ( $h_{np} > 0.03$  m) and, naturally, the secondary ridge of an increased soil size, and the coefficient  $k_{c31}$  tends to zero.

The use of flat discs with a diameter of 0.35 m during the first mechanized cultivation of crops made it possible to establish that the speed  $v_k$  of the cultivator has a significant

effect on the maximum value of  $k_{c\alpha 1}$  at  $\alpha_k = 5^\circ \dots 15^\circ$ . At angles  $\alpha_k = 20^\circ \dots 30^\circ$  of attack of flat discs, a change in the speed  $v_k$  of the cultivator from 1.6 m / s to 2.4 m / s contributes to an increase in  $h_{tp}$  of more than 0.03 m and, correspondingly, to the formation of a secondary soil ridge of maximum dimensions, i.e.  $S_{Mol}^{st} < S_{Mol}^{\phi}$ , and  $k_{c\alpha 1} \rightarrow min$ .

## 5 Conclusion

Analyzing equations 6–9, we can conclude that among linear terms the absolute term of the equation has a strong influence on the optimization parameter  $Y$ . Of the non-linear terms of the equation, the angle attack  $x_2^2$  of flat discs of the working bodies has the greatest influence on  $Y$ , and the speed  $x_1^2$  of movement has the smallest influence.

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