

Research Article

Theoretical Substantiation of the Parameters of a Roller-leveller for Soil Crust Softening

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Abstract

This article provides a comprehensive theoretical basis for determining the structural and technological parameters of a roller-type working body, which is specifically designed to loosen the crust that forms on the inter-row soil of cotton crops. The formation of a dense soil crust in cotton fields negatively affects the emergence and growth of seedlings, leading to uneven plant development and potentially reduced crop yields. To mitigate these negative effects and ensure uniform and complete emergence of cotton seedlings, this study focused on identifying key operational parameters of the roller. Among these parameters are the depth of soil penetration by the roller, the large and small diameters of the roller, the number of hexagonal prongs installed on the roller surface, the magnitude of the vertical load applied during operation, and the tension force of the pressure spring that regulates the roller's interaction with the soil. Based on rigorous theoretical research and analysis, the optimal values of the roller's geometric and force parameters were established. These optimal values are determined under the condition that the crust is completely and efficiently loosened while minimizing energy expenditure and mechanical stress on the roller components. The study also takes into account the interaction between the roller and varying soil types, ensuring that the roller's design is versatile and capable of maintaining high-quality performance under diverse field conditions. The findings of this study have practical significance for the improvement of working bodies used in cotton cultivation, particularly for cultivators and other soil-processing machinery. By applying the determined parameters, agricultural engineers and practitioners can enhance the operational efficiency of their equipment, reduce labor and energy costs, and achieve better soil preparation for cotton seedlings. Furthermore, this research contributes to the development of energy- and resource-efficient agricultural technologies, supporting sustainable farming practices. The results serve as a scientific foundation for future design improvements and technological advancements in soil cultivation machinery, ensuring that both productivity and quality are maximized in cotton production.

Keywords

Soil Crust, Roller-harrow, Working Body, Cotton Seedling, Soil Tillage, Cultivator, Hexagonal Bar, Vertical Load

1. Introduction

In cotton-growing regions worldwide, developing technology and equipment for breaking up soil crust has become a modern necessity. This is crucial for ensuring the full and minimally damaged emergence of seedlings in soil and climate

conditions prone to crust formation. Considering that "cotton is grown on 31-34 million hectares worldwide" [1-3], ensuring that these seedlings emerge without loss makes the development of high-quality, efficient, and energy- and

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resource-saving roller-harrow implements and tools for crust breaking one of the most important tasks. In this regard, key objectives include developing a design scheme for implements that cause minimal damage to cotton seedlings during their interaction with the soil crust, substantiating the technological processes involved, and creating implements that ensure resource efficiency and high work quality during soil interaction.

Internationally, scientific research on the harmful effects of soil crust on cotton seedlings, the development of modern devices and working parts to break up this crust, and their scientific validation has been conducted by scholars such as G. Ya. Stamos, I. A. Kachinskiy, K. P. Paganyas, A. I. Kaspirov, N. I. Gorbunov, G. M. Kukta, P. A. Samoylov, G. G. Maslov, A. S. Sergunsov, G. D. Mirzoyev, Yu. I. Matyashin, D. N. Wright, A. S. Putrin, H. Timm, J. W. Perdue, D. A. Sukhov, J. C. Bishop, D. W. Grimes, R. E. Voss, and others. Likewise, within our republic, scientists including Kh. Irgashev, V. A. Sergienko, R. Zh. Tojiyev, U. Akmirzayev, A. G. Mansurov, I. Mamadjanov, B. P. Artikbayev, A. N. Jo'rayev, and others have also carried out scientific research in this field [4-6].

Devices developed from the results of conducted research are currently used for soil cultivation in crop fields. However, these studies have not sufficiently addressed the issues of improving the quality of softening the soil crust that forms on saline lands due to precipitation during the growing season, nor have they adequately substantiated the parameters for a rotating loosening roller that minimizes damage to emerging cotton seedlings [8].

2. Materials and Research Results

Based on an analysis of scientific and technical literature, a roller-type working component was developed to break up the soil crust that forms between cotton rows. Its structural diagram is depicted in Figure 1.

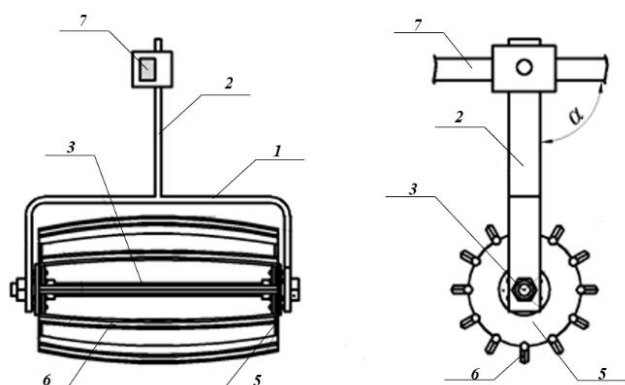


Figure 1. Diagram of the working part for breaking up soil crust.

The roller-type working implement consists of a frame (1), a post (2) mounted on it, and a roller (4) installed by means of

an axle (3). The roller (4) is designed with two bases (5) and steel wires (6) fastened to them. To ensure high-quality loosening of the soil crust and to follow the transverse profiles of the cotton inter-rows, the steel wires have a hexagonal cross-section and are arranged in a convex shape along their length, which defines the working width of the roller. The developed crust-breaking working implement is mounted via the post (2) to the tool-bar (7) of the cotton cultivator's working section (Figure 1) [9, 10].

As the specially designed working implement moves between the cotton rows, its steel wires, through a combination of forward and rotational motion, uniformly break up the soil crust across its entire profile and destroy emerging weeds. This creates favorable conditions for the even germination of cotton seeds and the consistent development of the resulting seedlings.

Theoretical studies were conducted on the developed working tool to ensure the uniform, high quality loosening of the crust between cotton rows without damaging the cotton seedlings.

The following parameters of the roller-type working body, which was developed to break up soil crust, were investigated as a result of theoretical studies:

The roller's penetration depth into the soil, h , in m;

The roller's large diameter, D_1 , and large radius, R_1 , in m;

The roller's small diameter, D_2 , and small radius, R_2 , in m;

The number of hexagonal rods installed on the roller, n , in units;

The vertical load applied to the roller, Q , in N;

The tension force, Q_n , of the pressure spring on the working section of the cotton cultivator where the roller is mounted, in N;

The theoretical determination of these parameters utilized previous research conducted by A. A. Akhmetov, S. Aminov, I. Inoyatov, O'. Boboyev, M. T. Mamarasulova, G. Q. Eshmatova, and others [5-10].

The penetration depth of the roller harrow into the soil is determined by the following condition [11]:

$$h \geq a,$$

where h is the penetration depth of the roller, m; a is the crust thickness, m.

When condition (1) is met, the entire thickness of the crust is softened.

Based on our research, the soil crust in the Bukhara region can reach a thickness of up to 3.5 cm. Taking this into account, the roller's soil penetration depth was set to 4 cm in accordance with expression (1).

The small and large diameters of the roller-harrow are determined by the requirement that it must freely pass over plant stems and other obstacles lying on the crusted surface. Otherwise, these obstacles would accumulate in front of the roller-harrow, leading to a disruption of its technological process [11].

For the roller-chopper to freely pass over plant stems and

other obstacles lying on the surface of the soil crust, the following condition must be met [12].

$$D_2 = \frac{[1 + \cos(\varphi_1 + \varphi_2)]d_p + 2h}{1 - \cos(\varphi_1 + \varphi_2)}, \quad (2)$$

where φ_1, φ_2 are the angles of friction of the plant stems against the hexagonal bars of the roller and the soil crust, respectively;

d_p - the diameter of plant stems lying on the crust surface, m.

D_1 , which is the larger diameter of the roller, is determined by the following expression:

$$D_1 = D_2 + 2h_e \quad (3)$$

or, taking (2) into account,

$$D_1 = \frac{[1 + \cos(\varphi_1 + \varphi_2)]d_p + 2h}{1 - \cos(\varphi_1 + \varphi_2)} + 2h_e, \quad (4)$$

where h_e is the depth of the furrow existing between the cotton rows, in m.

Assuming the values $\varphi_1 = 30^\circ$; $\varphi_2 = 32^\circ$, $d_p = 0.02$ m, $h = 0.05$ m, and $h_e = 0.04$ m, calculations based on expressions (2) and (4) indicate that the small diameter of the roller should be 25 cm, and the large diameter should be 31 cm. Correspondingly, the small radius of the roller must be 12.5 cm and the large radius must be 15.5 cm.

We determine the number of hexagonal bars to be mounted on the reel according to the following condition.

$$n \geq \frac{2\pi R_i(1 + K_c)}{\Delta X}. \quad (5)$$

When this condition is met, complete loosening of the crust by the roller along the direction of movement is ensured [13].

Taking into account expression (4), expression (5) will have the form:

$$n \geq \frac{2\pi R_i(1 + K_c)}{R_i \left\{ \frac{1}{1 - K_c} \left[\pi - 2 \arcsin \left(1 - \frac{h}{R_i} \right) \right] - \left[-2 \cos \arcsin \left(1 - \frac{h}{R_i} \right) \right] \right\} + b_p} \quad (6)$$

By substituting the values $R_i = 0.125 - 0.155$ m, $K_c = 0.2$, $h = 0.05$, and $b_p = 0.014$ m into this formula, we determine that the number of rods to be installed on the gin roller should be 10-12.

The vertical load Q applied to the roller-smoother is

determined by the following expression, based on the condition that it must operate by penetrating to a specified depth [9].

$$Q = q_0(1 + K_v V_u^2)h_0 b_p B, \quad (7)$$

where q_0 is the coefficient of static soil compression, in N/m^3 ;

K_v - coefficient of proportionality, s^2/m^2 ;

h_0 - average penetration depth of the roller's hexagonal rod into the soil crust, m.

Considering that the hexagonal rod of the roller has the shape of a convex parabola, its average penetration depth into the soil crust is determined using the diagram in Figure 2. According to this diagram:

$$h_0 = \frac{S_1 - S_2 - S_3}{B}, \quad (8)$$

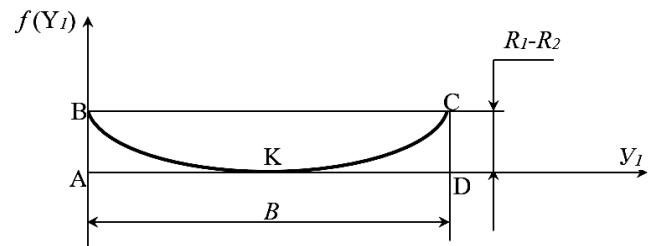


Figure 2. Diagram for determining the average penetration depth of the roller's hexagonal rod into the soil crust.

where S_1 is the area of the quadrilateral ABCD, in m^2 ;

S_2, S_3 are the areas of the figures ABK and KCD, respectively, in m^2 .

Taking into account that $S_2 = S_3$, we can rewrite expression (8) in the following form [14]:

$$h_0 = \frac{S_1 - 2S_2}{B}. \quad (9)$$

according to the diagram in Figure 2.

$$S_1 = (R_1 - R_2)B \quad (10)$$

and

$$S_2 = \frac{1}{2} \int_0^B f(Y_1) dY_1. \quad (11)$$

In accordance with the above, we will assume that $f(Y_1)$ changes according to the following law.

$$f(Y_1) = a_1 + b_1 Y_1 + c_1 Y_1^2, \quad (12)$$

where a_1 , b_1 , and c_1 are the coefficients;

Y_1 - is the horizontal coordinate axis oriented perpendicular to the rows where cotton seeds are planted, m.

We will determine coefficients a_1 , b_1 , c_1 of equation (12) from the following conditions:

When $Y_1 = 0$, we have $f(Y_1) = R_1 - R_2$; when $Y_1 = 0.5B$, we have $f(Y_1) = 0$; and when $Y_1 = B$, we have $f(Y_1) = R_1 - R_2$. Using these conditions, we obtain the following equations to determine a_1 , b_1 , c_1 .

$$R_1 - R_2 = a_1; \quad (13)$$

$$0 = (R_1 - R_2) + b_1 \frac{B}{2} + c_1 \frac{B^2}{4}; \quad (14)$$

$$R_1 - R_2 = (R_1 - R_2) + b_1 B + c_1 B^2. \quad (15)$$

Solving these equations simultaneously, we obtain the following:

$$a_1 = R_1 - R_2; \quad (16)$$

$$b_1 = -\frac{4(R_1 - R_2)}{B}; \quad (17)$$

$$c_1 = \frac{4(R_1 - R_2)}{B^2}. \quad (18)$$

Considering these values of a_1 , b_1 and c_1 , expression (12) takes the following form.

$$f(y_1) = R_1 - R_2 - \frac{4(R_1 - R_2)}{B} y_1 + \frac{4(R_1 - R_2)}{B^2} y_1^2. \quad (19)$$

Substituting this value of $f(y_1)$ into expression (11), we find S_2 .

$$S_2 = \frac{1}{2} \int_0^B \left[R_1 - R_2 - \frac{4(R_1 - R_2)}{B} y_1 + \frac{4(R_1 - R_2)}{B^2} y_1^2 \right] dy_1 \quad (20)$$

or from this

$$\begin{aligned} S_2 &= \frac{1}{2} \left[(R_1 - R_2) y_1 - \frac{4(R_1 - R_2)}{B} \frac{y_1^2}{2} + \frac{4(R_1 - R_2)}{B^2} \frac{y_1^3}{3} \right]_0^B = \\ &= \frac{1}{6} (R_1 - R_2) B. \end{aligned} \quad (21)$$

We substitute the values for S_1 and S_2 from expressions (10) and (21) into (9).

$$h_0 = \frac{(R_1 - R_2)B - 2 \frac{1}{6} (R_1 - R_2)B}{B} = \frac{2}{3} (R_1 - R_2). \quad (22)$$

Taking this into account, expression (7) takes the following form:

$$Q = \frac{2}{3} q_0 (1 + K_v V_v^2) (R_1 - R_2) b_p B. \quad (23)$$

By substituting the values $q_0 = 5 \cdot 106 \text{ N/m}^3$, $K_v = 0.01 \text{ s}^2/\text{m}^2$, $R_1 = 0.5D_1 = 0.155 \text{ m}$, $R_2 = 0.5D_2 = 0.125 \text{ m}$, $b_p = 0.014 \text{ m}$, and $B = 0.50 \text{ m}$ into this expression, we determine that for the ridge roller to operate at the specified depth at a travel speed of 1.7 - 2.2 m/s, the vertical load applied to it must be within the range of 949 - 954 N.

We will determine the tension force of the pressure spring

of the parallelogram mechanism, which is installed on the roller. To do this, we will formulate the equilibrium equation for the forces acting on the roller.

$$P \cos \alpha - N_x = 0; \quad (24)$$

$$mg + Q_n - P \sin \alpha - N_z = 0; \quad (25)$$

$$(mg + Q_n - N_z)l \cos \alpha - N_x \sin \alpha = 0, \quad (26)$$

where α is the angle of deviation from the horizontal of the parallelogram mechanism's longitudinal rods;

l is the length of the parallelogram mechanism's longitudinal rods, in m.

We solve for Q_n in expression (26).

$$Q_n = N_z + N_x \tan \alpha - mg. \quad (27)$$

Taking into account that $N_x = \mu N_z$ (where μ is the

rolling resistance coefficient of the roller) [13], expression (27) takes the following form:

$$Q_n = N_z(1 + \mu tg\alpha) - mg. \quad (28)$$

considering that it is $N_z = Q$

$$Q_n = \frac{2}{3} q_0(1 + K_v V_q^2)(R_1 - R_2)b_p B(1 + \mu tg\alpha) - mg \quad (29)$$

By substituting the aforementioned values for q_0 , K_v , R_1 , V_q , R_2 , b_p , and B into this expression, and assuming $\mu = 0.2$, $\alpha = 10^\circ$, and $m = 62$ kg, we determine that for the roller-equipped parallelogram mechanism to operate at the specified depth at speeds of 1.7-2.2 m/s, the tension force of its pressure spring must be within the range of 353-358 N.

The aforementioned theoretical studies indicate that to ensure the complete loosening of the soil crust throughout its thickness, the roller-type working implement must have a penetration depth of 4 cm. To prevent plant stalks and other similar debris on the crust's surface from accumulating in front of the implement and disrupting the technological process, its small diameter (radius) should be 25 (12.5) cm and its large diameter (radius) should be 31 (15.5) cm. Furthermore, the number of hexagonal rods should be 10-12, the vertical load on the roller at a travel speed of 1.7-2.2 m/s must be between 949 and 954 N, and the tension force of the pressure spring must be between 353 and 358 N [15].

3. Conclusions

As a result of theoretical research, the key design and technological parameters of a roller-type working implement have been scientifically substantiated. This implement ensures the high-quality loosening of the soil crust that forms between cotton rows and operates without damaging the emerging seedlings.

Studies have shown that to ensure the crust is loosened through its full thickness, it is advisable to set the roller's soil penetration depth at 4 cm. It was determined that to freely pass over plant stalks and other obstacles on the crust's surface and to ensure the continuity of the technological process, the roller's small diameter must be 25 cm (radius 12.5 cm) and its large diameter 31 cm (radius 15.5 cm).

To ensure the complete loosening of the crust along the direction of travel, the number of hexagonal rods to be installed on the roller was determined to be 10-12. Calculations have shown that for the roller to operate stably at the specified depth at a speed of 1.7-2.2 m/s, the vertical load applied to it must be in the range of 949-954 N, and the tension force of the parallelogram mechanism's pressure spring must be in the range of 353-358 N.

Abbreviations

α Angle of Deviation from the Horizontal of the Parallelogram Mechanism's Longitudinal Rods

Author Contributions

Nodirbek Egamov: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The author declares no conflicts of interest.

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Biography



Nodirbek Egamov is an independent researcher at Bukhara State Technical University. He conducts scientific research in the field of agricultural machinery. To date, more than 10 scientific articles have been published in this area.

Research Field

Nodirbek Egamov: Development and justification of the parameters of a working organ with a color softener for a cotton cultivator