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Ensuring the stability of the suspended chisel-cultivator processing depth

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Abstract. The depth of tillage and its uniformity are the main performance indicators of chisel cultivators, as well as all tillage machines. Only when these indicators are at the level of demand, favorable conditions are created for the uniform development and ripening of crops throughout the field and their high yield. The article theoretically explores the problem of ensuring a smooth movement of the suspension chisel cultivator along with the working depth. The results show that the given depth of tillage and its uniformity at the required level is mainly due to the correct selection of the vertical distance from the base plain of the chisel-cultivator to the lower hanging points. The vertical distance from the base plain to the lower hanging points must be at least 48.1 cm in order for the condition N>0 to be fulfilled and the chisel-cultivator to sink to the specified depth and run steadily at this depth. Suspended chisel-cultivators with 3-4 class wheeled tractors, which are widely used in agricultural production of the republic, the vertical distance from the base plains to the lower hanging points. Determined to be at least 48.1 cm.

1 Introduction

The depth of tillage and its uniformity are the main performance indicators of chisel cultivators, as well as all tillage machines [1-6]. Only when these indicators are at the level of demand, favorable conditions are created for the uniform development and ripening of crops throughout the field and their high yield [7-12]. This, in turn, leads to the development of other branches of agriculture, including livestock, poultry and fish farming [13-18]. Otherwise, that is, if the given depth of cultivation and its stability is not ensured, as a result of uneven development of plants, crop yields will decrease, they will not ripe evenly. Also, in the autumn-winter period, when the depth of tillage is uneven, there is a decrease in soil moisture, spreading weed in the fields, a decrease in unit productivity, and an increase in fuel consumption [1, 3].

To ensure that the given tillage depth and its level are even at the required level, the chisel-cultivator should sink to the specified depth and move steadily at that depth, i.e. without

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changing the tillage depth. However, this issue has not been adequately studied in previous studies [2–6]. Based on the above, we researched the example of a suspended chisel-cultivator (hereinafter referred to as the chisel-cultivator) to ensure that the chisel-cultivators sink to a certain depth and ensure stable movement at this depth. This article describes the results of this research

For the chisel cultivator to sink to the specified depth and ensure its uniformity, the condition $N>0$ (where N is the total reaction force acting on the base wheels of the chisel cultivator by the soil) must be fulfilled [1, 2, 7, 10], because only then its base wheels are constantly pressed against the field surface, and as a result, the working bodies sink to the specified depth and work without changing the working depth. Otherwise, that is, when $N<0$, the base wheels do not touch the field surface, and as a result, the working bodies sink to a depth less than the specified. Also, in this case, changes in the physical and mechanical properties of the soil, the speed of the aggregate, and other external factors lead to changes in the depth of immersion of the working bodies in the soil, resulting in a uniform depth of tillage [12] is not provided

2 Materials and methods

Using the scheme shown in Figure 1, we determine the total reaction force acting on the base wheels of the chisel-cultivator. To do this, we construct the equation of equilibrium of all the forces acting on the chisel-cultivator concerning its instantaneous center of rotation π in the longitudinal-vertical plane and solve it concerning N, we get the following.

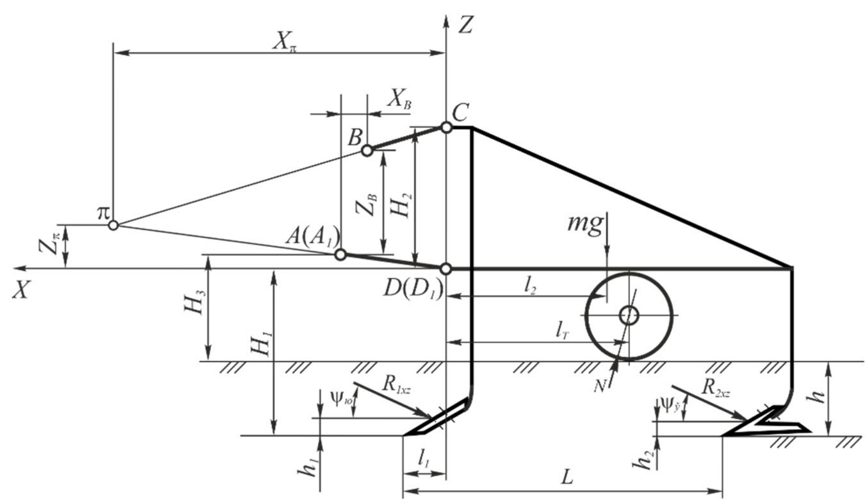

Fig. 1. Scheme for determining the total reaction force acting on the base wheels of the chisel-cultivator.

$$N = \sqrt{1+\mu^2}\left\{\left[mg + R_{1xz}\sin\psi_{ю} + R_{2xz}\sin\psi_{ў}\right]X_{\pi} + mgl_2 - \right.$$

$$-\left[R_{1xz}\cos\psi_{ю}+R_{2xz}\cos\psi_{ў}\right]Z_{\pi}+R_{1xz}\left\{\left[h_1(ctg\alpha_{ю}+ctg\psi_{ю})-l_1\right]\sin\psi_{ю}-\right.$$

$$\left.-H_1\cos\psi_{ю}\right\}+R_{2xz}\left\{\left[L+h_2(ctg\alpha_{ў}+ctg\psi_{ў})-l_1\right]\sin\psi_{ў}-H_1\cos\psi_{ў}\right\}:$$

$$:\left[X_{\pi}+l_T+\mu(Z_{\pi}+H_1-h-0{,}5d_T)\right], \tag{1}$$

where μ – rolling resistance coefficients of chisel-cultivator support wheels; m – the mass of the chisel-cultivator, kg; g – free falling acceleration, m/s^2; X_π, Z_π – the horizontal and vertical distances from the lower hanging points $D(D_1)$ of the chisel-cultivator, respectively, to the center of its instantaneous rotation in the longitudinal-vertical plane, m; l_2 – the horizontal distance from the lower hanging points of the chisel cultivator to its center of gravity, m; R_{1xz}, R_{2xz} – equal effects of resistance forces acting on the working bodies of the first and second rows of the chisel-cultivator, respectively, N; l_1 – longitudinal distance from the lower hanging points of the chisel cultivator to its front row working bodies, that is, the blade of the softening claws, m; h_1, h_2 – vertical distances from the blades of the working bodies of the chisel-cultivator in the first and second rows to the points where the equal forces of the resistance forces acting on them by the soil, m; $\psi_{ю}$, $\psi_{ў}$ – the angles of direction (deviation) of the forces R_{1xz}, R_{2xz} relative to the horizon, acting on the softening and axial claws of the chisel-cultivator,, degrees, H_1 – vertical distance from the base plane of the chisel-cultivator to the lower hanging points, m; L – longitudinal distance between the working bodies of the chisel-cultivator, m; h – the tillage depth, m; d_T – the diameter of the base wheels of the chisel-cultivator, m; l_T – longitudinal distance from the lower suspension points of the chisel cultivator to the center of rotation of the base wheels, m.

We express X_π and Z_π in expression (1) by the dimensions and parameters of the tractor hanging mechanism and the chisel-cultivator hoisting device. To do this, we construct the equations of straight lines passing through the points D (0; 0) and $A(A_1)$ ($\sqrt{l_б^2-(H_3+h-H_1)^2}$; H_3+h-H_1) and C(0; N2) and B($\sqrt{l_б^2-(H_3+h-H_1)^2}-X_B$; $H_3+h-H_1+Z_B$) in the $XD(D_1)Z$ coordinate system. They will have the following appearance accordingly

$$Z=\frac{(H_3+h-H_1)X}{\sqrt{l_б^2-(H_3+h-H_1)^2}} \tag{2}$$

and

$$Z=\frac{(H_3+h+Z_B-H_1-H_2)X}{\sqrt{l_б^2-(H_3+h-H_1)^2}-X_B}+H_2, \tag{3}$$

where H_2 – vertical distance between the lower and upper hanging points of the chisel-cultivator, m; H_3 – vertical distance from the base plane of the tractor to the stationary hinges A (A1) of the lower traction of the suspension mechanism, m; $l_б$ – the length of the bottom traction of the tractor suspension mechanism, м; X_B, Z_B – the longitudinal and perpendicular distances between the $A(A1)$ and B fixed pulleys of the lower and central pulleys the tractor suspension mechanism, м;

Solving the equations (2) and (3) together, we have the following

$$X_\pi=\frac{H_2\sqrt{l_б^2-(H_3+h-H_1)^2}\left[\sqrt{l_б^2-(H_3+h-H_1)^2}-X_B\right]}{(H_2-Z_B)\sqrt{l_б^2-(H_3+h-H_1)^2}-(H_3+h-H_1)X_B} \tag{4}$$

and

$$Z_\pi = \frac{H_2\left(H_3 + h - H_1\right)\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B}. \qquad (5)$$

Considering expressions (4) and (5), expression (1) has the following appearance

$$N = \sqrt{1+\mu^2}\left\{\left[mg + R_{1xz}\sin\psi_{ю} + R_{2xz}\sin\psi_{ў}\right]\times\right.$$
$$\times\frac{H_2\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2}\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} + mgl_2 -$$
$$-\left[R_{1xz}\cos\psi_{ю} + R_{2xz}\cos\psi_{ў}\right]\times\frac{H_2\left(H_3 + h - H_1\right)\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} +$$
$$+ R_{1xz}\left\{\left[h_1(ctg\alpha_{ю} + ctg\psi_{ю}) - l_1\right]\sin\psi_{ю} - H_1\cos\psi_{ю}\right\} +$$
$$\left. + R_{2xz}\left\{\left[L + h_2(ctg\alpha_{ў} + ctg\psi_{ў}) - l_1\right]\sin\psi_{ў} - H_1\cos\psi_{ў}\right\}\right\}:$$
$$:\left[\frac{H_2\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2}\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} + l_T + \right.$$
$$\left. + \mu\left(\frac{H_2\left(H_3 + h - H_1\right)\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} + H_1 - h - 0{,}5d_T\right)\right]. \qquad (6)$$

It can be seen from this expression that the total reaction force acting on the base wheels of the chisel-cultivator by the soil is depended on their location (l_T) and diameter (d_T), the weight of the chisel-cultivator (mg) and its set point (l_2), the chisel-cultivator and its operation, parameters of bodies (l_1, L, $b_{ю}$, $b_{ў}$), forces acting on working bodies (R_{1xz}, R_{2xz}) and their directions ($\psi_{ю}$, $\psi_{ў}$) and set points (h_1, h_2), working depth (h), an increase of chisel-cultivator the size and parameters (H_1, H_2, H_3, X_B, Z_B) of the device of the chisel-cultivator and the tractor suspension mechanism. However, the size and parameters of the tractor hanging mechanism and the vertical distance between the lower and upper hanging points of the chisel-cultivator hanging device are standardized [10] and known due to the tractor, the size and parameters of the chisel-cultivator and its working bodies and the mass (weight) given that the process is reliable and high-quality, low energy-material conditions, the chisel-cultivator sinks to a certain depth and stays stable at this depth, mainly due to the change in the distance N1 from its base plane to the lower hanging points.

To determine the value that satisfies the condition N>0 of H_1, it is necessary to construct a graphical relationship N=f(H_1) according to expression (6). To do this, we express the forces acting on the chisel-cultivator through the parameters of it and its working bodies, the depth of cultivation and the physical and mechanical properties of the soil [1, 2, 11, 12].

$$m = qB; \tag{7}$$

$$R_{1xz} = \frac{R_{1T}}{\cos\psi_{ю}} = \frac{n_1\left(K_{ю} + E_{ю}V^2\right)b_{ю}h}{\cos\psi_{ю}}; \tag{8}$$

and

$$R_{2xz} = \frac{R_{2T}}{\cos\psi_{ў}} = \frac{n_2\eta\left(K_{ў} + E_{ў}V^2\right)b_{ў}h}{\cos\psi_{ў}}, \tag{9}$$

where q – the mass of the improved chisel-cultivator corresponding to the coverage width of each meter, kg; B – coverage width of chisel-cultivator, m; η-the coefficient taking into account the effect of the performance of the arrow-shaped grid in open cutting conditions on its resistance to gravity; n_1, n_2 – the number of working bodies located in the first and second rows of the chisel-cultivator, respectively, pieces; $K_{ю}$, $K_{ў}$ – the relative resistance of the soil to the softening and axial claws, respectively, Pa; $E_{ю}$, $E_{ў}$ – a coefficient that takes into account the effect of velocity on the tensile resistance of the softening and axial claws; $b_{ю}$ – the width of the softening claw, m; $b_{ў}$ – half of the coverage width of the occlusal claw, m.

Taking into account $n_1 = \frac{B}{2a_k} + 1$ and $n_2 = \frac{B}{2a_k}$, (8)-(9) expressions will have the following appearance:

$$R_{1xz} = \left(\frac{B}{2a_k} + 1\right)\left(K_{ю} + E_{ю}V^2\right)b_{ю}h / \cos\psi_{ю}; \tag{10}$$

$$R_{2xz} = \frac{B}{a_k}\eta\left(K_{ў} + E_{ў}V^2\right)b_{ў}h / \cos\psi_{ў}; \tag{11}$$

We put the values of M, R_{1xz}, and R_{2xz} in terms of expressions (7) and (10)-(11) and get the following result

$$N = \sqrt{1 + \mu^2} \times$$

$$\times\left\{\left[qBg + \left(\frac{B}{2a_k} + 1\right)\left(K_{ю} + E_{ю}V^2\right)b_{ю}h\,tg\psi_{ю} + \frac{B}{a_k}\eta\left(K_{ў} + E_{ў}V^2\right)b_{ў}h\,tg\psi_{ў}\right]\times\right.$$

$$\frac{H_2\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2}\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} + qBgl_2 -$$

$$-\left[\left(\frac{B}{2a_k} + 1\right)\left(K_{ю} + E_{ю}V^2\right)b_{ю}h\,tg\psi_{ю} + \frac{B}{a_k}\eta\left(K_{ў} + E_{ў}V^2\right)b_{ў}h\,tg\psi_{ў}\right]\times$$

$$\times\frac{H_2\left(H_3 + h - H_1\right)\left[\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - X_B\right]}{\left(H_2 - Z_B\right)\sqrt{l_б^2 - \left(H_3 + h - H_1\right)^2} - \left(H_3 + h - H_1\right)X_B} +$$

$$+\left(\frac{B}{2a_k}+1\right)\left(K_{ю}+E_{ю}V^2\right)b_{ю}h\left\{\left[h_1(ctg\alpha_{ю}+ctg\psi_{ю})-l_1\right]tg\psi_{ю}-H_1\right\}+$$

$$+\frac{B}{a_k}\eta\left(K_{ў}+E_{ў}V^2\right)b_{ў}h\left\{\left[L+h_2(ctg\alpha_{ў}+ctg\psi_{ў})-l_1\right]tg\psi_{ў}-H_1\right\}:$$

$$:\left[\frac{H_2\sqrt{l_б^2-\left(H_3+h-H_1\right)^2}\left[\sqrt{l_б^2-\left(H_3+h-H_1\right)^2}-X_B\right]}{\left(H_2-Z_B\right)\sqrt{l_б^2-\left(H_3+h-H_1\right)^2}-\left(H_3+h-H_1\right)X_B}+l_T+\right.$$

$$\left.+\mu\left(\frac{H_2\left(H_3+h-H_1\right)\left[\sqrt{l_б^2-\left(H_3+h-H_1\right)^2}-X_B\right]}{\left(H_2-Z_B\right)\sqrt{l_б^2-\left(H_3+h-H_1\right)^2}-\left(H_3+h-H_1\right)X_B}+H_1-h-0{,}5d_T\right)\right]. \quad (12)$$

3 Results and discussions

Data presented in the literature [1, 2, 11, 12] and based on our studies μ=0,2, q=236 kg/m, B=4,0 m, g=9,81 m/s^2, a_k=0,2 m, $K_{ю}$=112,5·103 Pa, h=0,2 m, h_1=0,08 m, h_2=0,04 m, $b_{ю}$=0,05 m, $K_{ў}$=22,5·10^3 Pa, $b_{ў}$=0,20 m, l_T=0,56 m, d_T=0,5 m, η=0,5, $a_{ю}$=30º, $a_{ў}$=30º, $\gamma_{ў}$=30°, φ_1=30°, $\psi_{ю}$=0º, $\psi_{ў}$=0º as well as H_2=0,7 m, H_3=0,6 m, X_B=0,3 m, Z_B=0,56 m for tractors designed to perform general work in 3-4 Class, a change graph was constructed N_y depending on H_1 (Figure 2).

It can be seen from this graph that the vertical distance from the base plain to the lower hanging points must be at least 48.1 cm in order for the condition N>0 to be fulfilled and the chisel-cultivator to sink to the specified depth and run steadily at this depth.

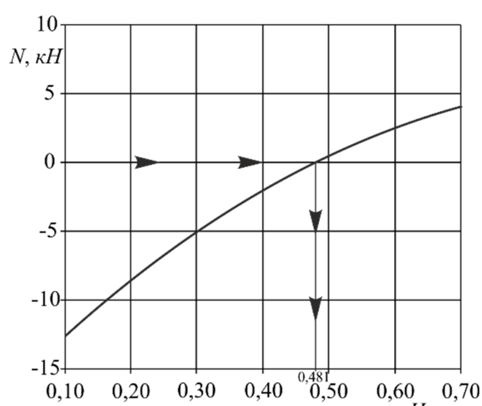

Fig. 2. Graph of Change N in relation to H1.

4 Conclusions

The vertical distance from the base plain of the chisel cultivator to the lower hanging points is at least 48.1 cm in order for the chisel cultivator to sink to the specified depth and run steadily at that depth.

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