E3S Web of Conferences **264**, 04036 (2021) https://doi.org/10.1051/e3sconf/202126404036
CONMECHYDRO - 2021

Traction resistance of the combined machine plough

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Abstract. Subsoils are widely used on tillage and combination machines. The tiller of the combined machine for preparing the soil for sowing melons and gourds carries out strip loosening of the subsoil layers. The study aims to theoretically determine the traction resistance of a soil deepener of a combined machine for preparing the soil for sowing melons and gourds. The study uses the basic provisions of mathematics, theoretical mechanics, and agricultural mechanics. In studies, it is assumed that the destruction of the soil under the influence of the drill bit occurs by separation. The total traction resistance of the subsoiler was determined as the sum of the resistance of the rack and the bit. An analytical expression has been obtained to determine the traction resistance of a tilting machine with an inclined stand, depending on its design, technological parameters, and the physical and mechanical properties of the soil. As a result of theoretical studies, it was found that the traction resistance of the soil deepener is mainly influenced by its design parameters, the depth of soil cultivation, the physical and mechanical properties of the soil, and the speed of the machine.

1 Introduction

Soil deepeners designed for subsurface loosening of the soil are widely used on plows [1-11], combined tillage machines [12-34]. As a result of the subsurface loosening of the soil, the most favorable conditions are created to grow and develop plant roots. Irrigation water and the root system of plants easily penetrate into the loosened soil layers [1-2, 8, 22-24].

In combined machines, subsurface loosening is carried out simultaneously with the processing and preparation of the soil for sowing. The authors have developed a combined machine for soil preparation for sowing melons and gourds in one pass [6, 9, 16-17, 20]. For sub-plowing strip loosening of the soil, tillers with an inclined stand are installed on the machine bodies. The study aims to theoretically determine the traction resistance of a soil deepener of a combined machine for preparing the soil for sowing melons and gourds.

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2. Methods

On the combined machine proposed by the authors for preparing the soil for sowing melons and gourds, a soil deepener with an inclined stand 1 is installed, the chisel 2 of which is made in the form of a trihedral oblique wedge (Fig.1). The tiller stand is installed obliquely in the transverse-vertical plane at an angle β_1 and a longitudinal-vertical plane at an angle β_2.

The total traction resistance of the tiller installed on the body of the combined machine consists of the resistance of its rack 1 and chisel 2, that is

$$R_{px} = R_{sx} + R_{dx}, \tag{1}$$

where R_{sx} and R_{dx} is the thrust resistance of the rack and bit, respectively.
The traction resistance of the drill bit in the form of a triangular wedge can be expressed as follows

$$R_{dx} = R_{1x} + R_{2x} + R_{3x} + R_{4x}, \tag{2}$$

where R_{1x} is the resistance to penetration of the bit blade into the soil; R_{2x} is the resistance of the soil to deformation (shear); R_{3x} is the resistance to the movement and rise of the soil layer along the working surface of the bit; R_{4x} is resistance (dynamic pressure of the formation), due to the force of inertia of the soil layer.

The AB bit blade, located at an angle γ to the direction of movement, perceives normal pressure N_l from the soil side (Fig.2). Since the angle (90°-γ) is greater than the angle of friction of the soil against the chisel blade, the soil slides along the blade, which causes force.

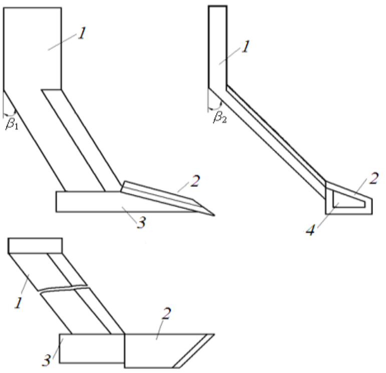

Fig. 1. A tiller with an inclined rack: 1 is rack; 2 are chisels; 3 is shoe

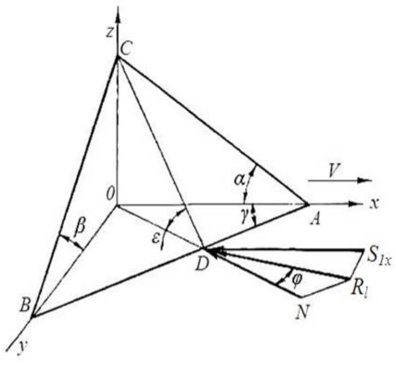

Fig. 2. Forces acting on the blade of an oblique triangular wedge

For this case, the soil resistance on the chisel blade is determined by the following expression

$$R_{1x} = \frac{b_d}{\sin\gamma}\delta\sigma_o\sqrt{1+f^2}\cos(\gamma+\varphi), \tag{3}$$

where σ_o is temporal resistance of the soil to crushing on the chisel blade, Pa; δ is chisel blade thickness, m; b_0 is chisel width, m; f and φ are the coefficient and angle of soil friction, respectively.

The displacement of the soil by the inclined plane of the wedge, located in the orthogonal section of the *COD* at an angle ε to the horizon, occurs at a certain angle ψ_1 (Fig. 3) [34-36]. In conditions of blocked cutting, the shear area is determined by the following expression

$$F_1 = \frac{a_p[b_d \sin\psi + a_p tg(\frac{\pi}{2} - \frac{\varphi_2}{2})\sin\gamma]}{\sin\gamma \sin^2\psi}. \qquad (4)$$

The shear force is

$$S_1 = \tau F_1 = \tau \frac{a_d[b_u \sin\psi + a_p tg(\frac{\pi}{2} - \frac{\varphi_2}{2})\sin\gamma]}{\sin\gamma \sin^2\psi}, \qquad (5)$$

where τ is the net shear coefficient, Pa. S_1 is force projection on the horizontal plane

$$S_{1_g} = S_1 \cos\psi_1.$$

S_1 is force projection on the *X*-axis

$$S_{1x} = S_1 \cos\psi_1 \sin\gamma. \qquad (6)$$

In addition, the shear force S_1 causes a friction force fN on the bit surface.
In addition, the shear force causes a friction force on the bit surface. Force fN is directed at an angle α_1 to the horizontal and is deflected from the longitudinal-vertical plane at an angle γ_1.
Here

$$\alpha_1 = \arcsin tg\alpha \cos\varepsilon, \qquad (7)$$

$$\gamma_1 = arctg \frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}. \qquad (8)$$

The component of the traction shear resistance R_{2x} is equal to the sum of the projections of the forces S_1 and fN [34-36]

$$R_{2x} = S_1[\cos\psi_1 \sin\theta + f\sin(\varepsilon + \psi_1)\cos\alpha'\cos\theta'].$$

Substituting the value of S_1 in (8) by expression (5), we have

$$R_{2x} = \frac{\tau a_p}{\sin\gamma \sin^2\psi}[b_d \sin\psi + a_p tg(\frac{\pi}{2} - \frac{\varphi_2}{2})\sin\gamma][\cos\psi_1 \sin\gamma + \\ + f\sin(\varepsilon + \psi_1)\cos\alpha_1 \cos\theta_1]. \qquad (9)$$

Substituting the values of α_1 and γ_1 in (9) by expressions (7) and (8), we obtain

$$R_{2x} = \frac{\tau a_p}{\sin\gamma \sin^2\psi}(b_d \sin\psi + a_p tg(\frac{\pi}{2} - \frac{\varphi_2}{2})\sin\gamma)[\cos\psi_1 \sin\gamma + \tag{10}$$

$$+ f \sin(\varepsilon + \psi_1)\cos(\arcsin tg\alpha \cos\varepsilon)\cos(arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon})].$$

The resistance to movement and rise of the soil layer along the working surface of the bit is also determined by the method of A.T.Vagin [34].

A.T.Vagin believes that when moving in the soil along the *X* axis, the lower point of the layer *O*, when the wedge passes the path *OA*, will move to point *E* along the straight line *AEE*'. In this case, we neglect the magnitude of the formation compression. The rest of the points of the lower plane of the seam also move along straight lines parallel to *AE*' at an angle α_1 to the horizon, deviating from the longitudinal-vertical plane *xOz* by some angle γ_1. The traction resistance to the movement and rise of the soil layer along the working surface of the bit is determined by the following expression proposed by A.T.Vagin [34]

$$R_{3x} = G_1(\sin\alpha_1 + f\cos\gamma)\cos\alpha_1\cos\gamma_1, \tag{11}$$

where G_1 is the weight of the soil on the inclined plane of the bit, kN.
Soil weight

$$G_1 = \gamma a_p b_d(\frac{b_d}{2tg\gamma} + \frac{l_z}{\cos\alpha}), \tag{12}$$

where l_z is length of the quadrangular part of the bit (Fig. 4), m.
We can put the value of G_1 in the expression (13) according to (12)

$$R_{3x} = \gamma a_p b_d(\frac{b_d}{2tg\gamma} + \frac{l_d}{\cos\alpha})(tg\alpha\cos\varepsilon + f\cos\gamma)x \tag{13}$$

$$x\sqrt{1-(tg\alpha\cos\varepsilon)^2}\cos[\arg tg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}].$$

Traction resistance (dynamic pressure of the formation), due to the force of inertia of the soil layer when moving and lifting it along the working surface of the bit, is determined by the following formula [34]

$$R_{4x} = \frac{\gamma}{g}F_2\upsilon^2\sin\theta\cos\psi_1(1-i_{\max})[\sin\theta\cos\psi_1 + f\sin(\delta+\psi_1)\cos\alpha_1\cos\theta_1], \tag{14}$$

where F_2 is the actual cross-sectional area of the *OMNB,* formation destroyed by the oblique wedge, that is, the bit; γ is the volumetric weight of the soil; i_{max} is coefficient of maximum soil shrinkage.

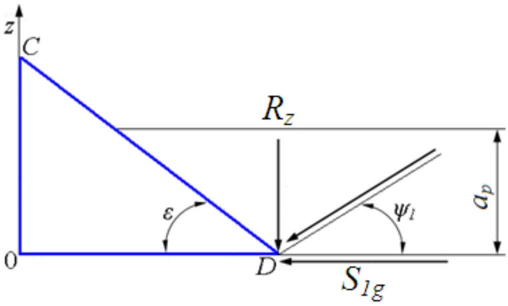

Fig. 3. Scheme of the soil layer displacement by an oblique wedge in a section orthogonal to the bit blade

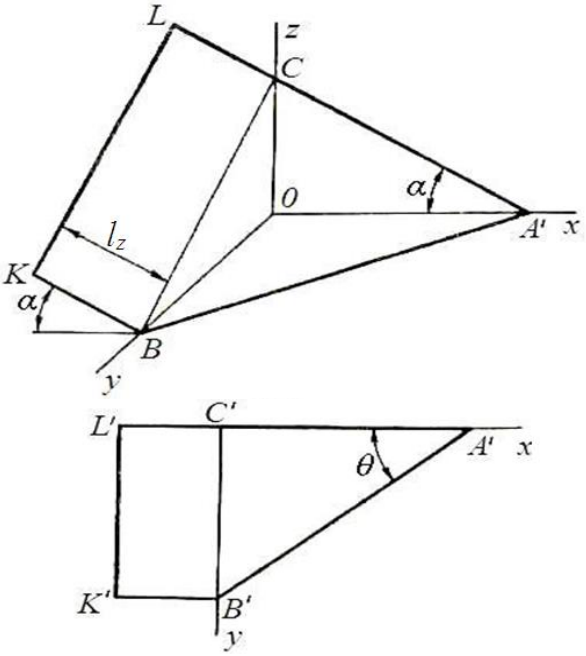

Fig. 4. Diagram of a bit in the form of an oblique wedge

From Fig. 5 we have

$$F_2 = \frac{1}{2} a_p \left(\frac{a_p \cos\gamma}{tg\psi_1} + 2b_d\right). \tag{15}$$

Substituting the value of F_2 in (13), we have

$$R_{4x} = \frac{\gamma}{g}\frac{1}{2} a_p \left(\frac{a_p \cos\gamma}{tg\psi_1} + 2b_d\right)\upsilon^2 \sin\theta \cos\psi_1 (1 - i_{\max})[\sin\theta \cos\psi_1 + \\ + f \sin(\delta + \psi_1)\cos\alpha_1 \cos\theta_1]. \tag{16}$$

Substituting the values of α_1 and γ_1 in (6) by expressions (7) and (8), we obtain

$$R_{4x} = \frac{\gamma}{g}\frac{1}{2}a_p\left(\frac{a_p\cos\gamma}{tg\psi_1}+2b_d\right)V^2\sin\gamma\cos\psi_1(1-i_{\max})[\sin\gamma\cos\psi_1 + \tag{17}$$

$$+ f\sin(\varepsilon+\psi_1)\cos(\arcsin tg\alpha\cos\varepsilon)\cos arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}].$$

Substituting the values R_{1x}, R_{2x}, $R_{3x,}$ and R_{4x} according to expressions (1), (9), (11) and (17) in (18), we determine the traction resistance of the trench bit

$$R_{ux} = \frac{b_d}{\sin\gamma}\delta\sigma_o\sqrt{1+f^2}\cos(\gamma+\varphi)+\frac{\tau a_p}{\sin\gamma\sin^2\psi}$$

$$[b_d\sin\psi + a_p tg(\frac{\pi}{2}-\frac{\varphi_2}{2})\sin\gamma][\cos\psi_1\sin\gamma + f\sin(\varepsilon+\psi_1)\cos(\arcsin tg\alpha\cos\varepsilon)x$$

$$x\cos(arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon})]+\gamma a_p b_d(\frac{b_d}{2tg\gamma}+\frac{l_u}{\cos\alpha})(tg\alpha\cos\varepsilon+f\cos\gamma)x \tag{18}$$

$$x\sqrt{1-(tg\alpha\cos\varepsilon)^2}\cos[argtg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}]+\frac{\gamma}{g}\frac{1}{2}a_p(\frac{a_p\cos\gamma}{tg\psi_1}+$$

$$+2b_d)V^2\sin\gamma\cos\psi_1(1-i_{\max})[\sin\gamma\cos\psi_1 +$$

$$+ f\sin(\varepsilon+\psi_1)\cos(\arcsin tg\alpha\cos\varepsilon)\cos arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}].$$

The resistance of the inclined part of the rack consists of the resistance of the blade and the chamfer of the working surface, the friction force arising on the side face of the rack

$$Rt_x = R_{lx} + R_{fx} + R_f, \tag{19}$$

The angle of inclination of the rack in the longitudinal-vertical plane $\beta_l=18^0$, while $\beta_l\leq\varphi$. In this case, cutting occurs with a longitudinal movement. For this case, the direction of the resultant force coincides with the direction of movement.
Where in

$$R_{ln} = \sigma_o l_n\delta,\ R_{lx} = \sigma l_n\delta,$$
$$R_{lx} = \sigma_0\delta\frac{l_t}{\cos\beta_1}, \tag{20}$$

here l_t is rack blade length.

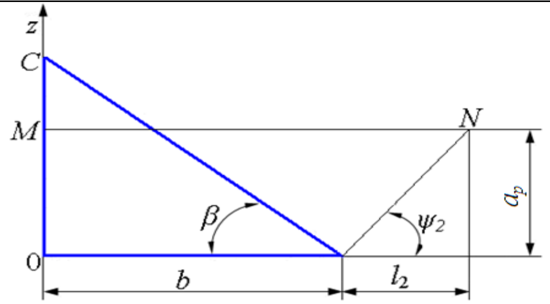

Fig. 5. Scheme of soil displacement by an oblique wedge in a longitudinal-vertical plane

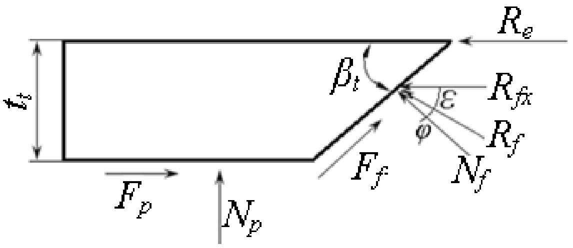

Fig. 6. Diagram of the forces acting from the soil on the rack

Rack blade length.

$$l_t = \frac{a_p - h_d}{\cos\beta_b}, \tag{21}$$

where h_d is the bit height, m,
The equal effect of the elementary normal forces of soil resistance on the chamfer can be determined by the following formula

$$N_{tn} = p_t l_t b_f = q\, l_t t_t^{\,2}/sin\beta_t \tag{22}$$

where p_t is the specific pressure of the soil in the chamfer, $p_t = qt_t$; b_t is bevel width, $b_f = t_t/sin\beta_t$; β_t is the sharpening angle of the handle.

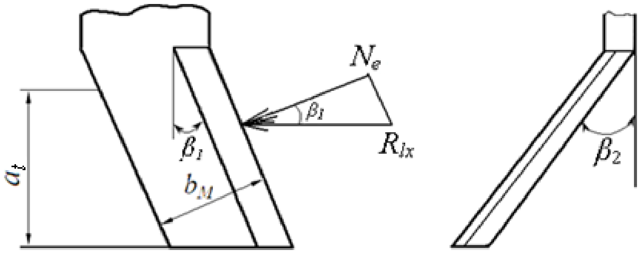

Fig. 7. Stance parameters and forces acting on it

The horizontal component of the resultant elementary normal forces of soil resistance to the chamfer of the rack can be determined by the following formula

$$N_{fx} = pl_t b_f = ql_t t_t^2. \tag{23}$$

The resultant frictional forces arising on the side faces of the rack can be determined by the following expression

$$F_x = N_p f = \frac{pfb_t}{\sin\beta_1}[2(a_p - h_d) - \frac{t_t}{\sin\beta_2}], \tag{24}$$

where p is specific soil pressure on the working surface of the inclined part of the rack.

Substituting the values of R_{lx}, N_{fx}, and F_x according to (19), (22), and (24) in (17), we obtain the following expression for determining the thrust resistance of the rack

$$R_{tx} = \sigma_0 \delta \frac{l_t}{\cos\beta_1} + q l_t t_t^2 + \frac{pfb_t}{\sin\beta_1}[2(a_p - h_d) - \frac{t_t}{\sin\beta_1}]. \tag{25}$$

Substituting the values of R_{dx} and R_{sx} according to (19) and (25) into (17), we determine the total traction resistance of the subsoiler

$$\begin{gathered} R_{cx} = \frac{b_d}{\sin\gamma}\delta\sigma_o\sqrt{1+f^2}\cos(\gamma+\varphi) + \frac{\tau a_p}{\sin\gamma\sin^2\psi}x \\ x[b_d\sin\psi + a_p tg(\frac{\pi}{2} - \frac{\varphi_2}{2})\sin\gamma][\cos\psi_1\sin\gamma + f\sin(\varepsilon+\psi_1)\cos(\arcsin tg\alpha\cos\varepsilon)x \\ \cos(arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon})] + \gamma a_p b_d(\frac{b_d}{2tg\gamma} + \frac{l_d}{\cos\alpha})(tg\alpha\cos\varepsilon + f\cos\gamma)x \\ x\sqrt{1-(tg\alpha\cos\varepsilon)^2}\cos[\arg tg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}] + \frac{\gamma}{g}\frac{1}{2}a_p(\frac{a_p\cos\gamma}{tg\psi_1} + \\ + 2b_d)V^2\sin\gamma\cos\psi_1(1-i_{\max})[\sin\gamma\cos\psi_1 + \\ + f\sin(\varepsilon+\psi_1)\cos(\arcsin tg\alpha\cos\varepsilon)\cos arctg\frac{(1-\cos\varepsilon)tg\gamma}{1+tg^2\gamma\cos\varepsilon}] + \\ + \sigma_0\delta\frac{l_t}{\cos\beta_б} + q l_t t_t^2 + \frac{pfb_t}{\sin\beta_1}[2(a_p - h_d) - \frac{t_t}{\sin\beta_2}]. \end{gathered} \tag{26}$$

The analysis of the obtained expression shows that the traction resistance of the tiller of the combined machine depends on its parameters (t_t, h_d, α, γ, β_1, β_2, δ), depth of tillage (a_p), physical and mechanical properties of soil (a_p), physical and mechanical properties of soil (σ_o, τ, φ_1, φ_2, ρ, W, q, f) and vehicle speed. Calculations by expression (26) at σ_o=1,44·10^6Pa, τ=2·10^4Pa, f=0,5774, φ_1=30^0, φ_2=40^0, ρ=1520 kg/m^3, W=14%, δ=0,002 m; b_d=0,05 m, t_t=0,015m, h_d=0,008 m, l_d=0,14 m, q=1,5·10^7N/m^3, p=1,64·10^2Pa, α=18^0, γ=45^0, β_1=18^0, β_2=25^0, b_t=0,08 m, t_t=0,015 and a_p=0,15 m show that at vehicle speeds 2-2.5 m/s the traction resistance of the tiller of the combined machine is 1710-1820 N.

3 Results and Discussion

This paper presents the results of a series of calculations of the current field in the river bed during floods and low-water conditions.

Two-dimensional Saint-Venant's equations were solved numerically using an explicit finite-difference scheme described in [**Ошибка! Источник ссылки не найден.**]. To study the flow regime in the river channel, the following conditions were set: an initial water level in the area, a water flow rate at the entrance to the area, a water flow rate of water withdrawn from the river to the canal and the curve of the relationship between the flow rate and the water level at the exit from the area. After that, calculations were carried out until the time when the flow regime is stabilized, and the sum of the flow rate withdrawn from the river to the canal and the flow rate at the exit from the area will become equal to the flow rate of water at the entrance to the area.

The results of the initial calculations of the current field were carried out based on the available topographic data (Figure 1).

4 Conclusions

1. Analytical relationships have been obtained to determine the soil resistance forces that arise when a soil deepener with an inclined stand is exposed to it.
2. It has been established that the traction resistance of the soil deepener depends on the parameters of the stand and chisel, the depth of the working body, the physical and mechanical properties of the soil, and the speed of the machine.

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