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 $\beta_1$ and a longitudinal-vertical plane at an angle $\beta_2$.

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

$$R_{px} = R_{sx} + R_{dx},$$  \hspace{1cm} (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

$$R_{dx} = R_{1x} + R_{2x} + R_{3x} + R_{4x},$$  \hspace{1cm} (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 $\gamma$ to the direction of movement, perceives normal pressure $N_l$ from the soil side (Fig.2). Since the angle $(90^\circ - \gamma)$ is greater than the angle of friction of the soil against the chisel blade, the soil slides along the blade, which causes force.

$$R_{sx} = \frac{b_d}{\sin \gamma} \delta \sigma_n \sqrt{1 + f^2} \cos(\gamma + \phi),$$  \hspace{1cm} (3)

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

$$d x s p R R R = \sqrt{\frac{1}{2}}$$  \hspace{1cm} (1)

where $R_s x$ and $R_{dx}$ is the thrust resistance of the rack and bit, respectively.

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where $R_1 x$ is the resistance to penetration of the bit blade into the soil; $R_2 x$ is the resistance of the soil to deformation (shear); $R_3 x$ is the resistance to the movement and rise of the soil layer along the working surface of the bit; $R_4 x$ is resistance (dynamic pressure of the formation), due to the force of inertia of the soil layer.

The bit blade, located at an angle $\gamma$ to the direction of movement, perceives normal pressure $N_l$ from the soil side (Fig. 2).

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

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

$$F_1 = a_\sigma [a_2 \sin \gamma + a_2 \frac{\pi}{2} - \frac{\phi_2}{2}] \sin \gamma \sin^2 \psi \sin \gamma.$$  \hspace{1cm} (3)

The shear force is

$$S_1 = dF_1 = \frac{a_\sigma [a_2 \sin \gamma + a_2 \frac{\pi}{2} - \frac{\phi_2}{2}] \sin \gamma \sin^2 \psi \sin \gamma}{\sin \gamma \sin^2 \psi}.$$  \hspace{1cm} (4)

where $\tau$ is the net shear coefficient, Pa. $S_1$ is force projection on the horizontal plane

$$S_{1x} = S_1 \cos \psi_1.$$  \hspace{1cm} (5)

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 $\alpha_1$ to the horizontal and is deflected from the longitudinal-vertical plane at an angle $\gamma_1$. Here

$$\alpha_1 = \arcsin \frac{\tan \gamma}{\cos \epsilon},$$  \hspace{1cm} (7)

$$\gamma_1 = \arctan \frac{(1-\cos \epsilon) \tan \gamma}{1+\tan^2 \gamma \cos \epsilon}.$$  \hspace{1cm} (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]

$$R_{2x} = S_1 [\cos \psi_1 \sin \theta + f \sin (\epsilon + \psi_1) \cos \alpha_1 \cos \theta].$$

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

$$R_{2x} = \frac{a_\sigma [a_2 \sin \gamma + a_2 \frac{\pi}{2} - \frac{\phi_2}{2}] \sin \gamma \sin \psi_1 \cos \psi_1 \sin \gamma + f \sin (\epsilon + \psi_1) \cos \alpha_1 \cos \theta_1].$$  \hspace{1cm} (9)

Substituting the values of $\alpha_1$ and $\gamma_1$ in (9) by expressions (7) and (8), we obtain
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 \( \alpha_1 \) to the horizon, deviating from the longitudinal-vertical plane \( xOz \) by some angle \( \gamma_1 \).

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]

\[
R_{3x} = G_1 (\sin \alpha_i + f \cos \gamma) \cos \alpha_i \cos \gamma_1, \tag{11}
\]

where \( G_1 \) is the weight of the soil on the inclined plane of the bit, kN.

Soil weight

\[
G_1 = \gamma a_p b_i (\frac{b_i}{2 \tan \gamma} + \frac{l_z}{\cos \alpha}), \tag{12}
\]

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)

\[
R_{3x} = \gamma a_p b_i (\frac{b_i}{2 \tan \gamma} + \frac{l_z}{\cos \alpha}) (\tan \alpha \cos \epsilon + f \cos \gamma) x \\
\times \sqrt{1 - (\tan \alpha \cos \epsilon)^2} \cos [\arctan (\frac{1 - \cos \epsilon \tan \gamma}{1 + \tan^2 \gamma \cos \epsilon})]. \tag{13}
\]

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]

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

where \( F_2 \) is the actual cross-sectional area of the \( OMBN \) formation destroyed by the oblique wedge, that is, the bit; \( \gamma \) is the volumetric weight of the soil; \( i_{\max} \) is coefficient of maximum soil shrinkage.
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 Х axis, the lower point of the layer О, when the wedge passes the path ОА, will move to point Е along the straight line АЕЕ'. 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 АЕ at an angle α1 to the horizon, deviating from the longitudinal-vertical plane xOz by some angle γ1.

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],

\[ R_z = f \gamma \frac{G_1}{\sin \theta \cos \psi_1} \]

where \( G_1 \) is the weight of the soil on the inclined plane of the bit, kN.

Soil weight

\[ \gamma \frac{l_z}{\tan \theta b} = \gamma \frac{l_z}{\tan \psi_1 \theta} \]

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)

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

\[ R_s = \frac{1}{2} \alpha_p \left( \frac{a_p \cos \psi_1}{\tan \psi_1} + 2b_d \right) \]

Substituting the values of \( \alpha_1 \) and \( \gamma_1 \) in (6) by expressions (7) and (8), we obtain

**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

\[ F_2 = \frac{1}{2} a_p \left( \frac{a_p \cos \gamma}{\tan \psi_1} + 2b_d \right) \]

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

\[ R_s = \frac{\gamma}{2} a_p \left( \frac{a_p \cos \gamma}{\tan \psi_1} + 2b_d \right) \]

Substituting the values of \( \alpha_1 \) and \( \gamma_1 \) in (6) by expressions (7) and (8), we obtain
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

\[
R_{tx} = \frac{b_d}{\sin \gamma} \delta \sigma_0 \sqrt{1 + f^2 \cos(\gamma + \varphi)} + \frac{a_p}{\sin \gamma \sin^2 \varphi}
\]

\[
[\frac{b_d}{\sin \gamma} \sin \psi + a_p \tan(\frac{\pi}{2} - \frac{\phi_2}{2}) \sin \psi][\cos \psi_1 \sin \gamma + f \sin(\varepsilon + \psi_1) \cos(\arcsin \alpha \cos \varepsilon)]x
\]

\[
x \cos(\arcsin \gamma \cos \varepsilon)(1 - \cos \varepsilon \tan \gamma \sin \psi_1) + \frac{a_p}{\tan \gamma}(\frac{b_d}{2 \tan \gamma} + \frac{L}{\cos \alpha})(\tan \gamma \cos \phi + f \sin \gamma)x
\]

\[
x \sqrt{1 - (\tan \gamma \cos \varepsilon)^2 \cos[\arcsin \gamma \cos \varepsilon]} + \frac{\gamma}{2} \frac{1}{a_p}(\frac{a_p \cos \gamma}{\tan \gamma \sin \psi_1}) + 2b_d V^2 \sin \gamma \cos \psi_1(1 - i_{max}) \sin \gamma \cos \psi_1 + f \sin(\varepsilon + \psi_1) \cos(\arcsin \alpha \cos \varepsilon \cos \arctan \gamma \cos \varepsilon)
\]

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

\[
R_{tx} = R_{tx} + R_{tx} + R_{\phi}
\]

The angle of inclination of the rack in the longitudinal-vertical plane \( \beta_i = 18^\circ \), while \( \beta_i \leq \varphi \). 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

\[
R_{ln} = \sigma_{oln} \delta, \quad R_{lt} = \sigma_{ol} \delta, \quad R_{ln} = \sigma_{ol} \delta \frac{l}{\cos \beta_i},
\]

here \( l_i \) is rack blade length.

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**Fig. 5.** Scheme of soil displacement by an oblique wedge in a longitudinal-vertical plane
Substituting the values \( R_{lx}, N_{fx}, \) and \( F_x \) according to (19), (22), and (24) in (17), we obtain
the following expression for determining the thrust resistance of the rack

\[ R_{tx} = \sigma_0 \delta \frac{l_t}{\cos \beta_1} + q t_i^2 + \frac{p f b}{\sin \beta_1} \left[ 2(a_p - h_d) - \frac{t_i}{\sin \beta_1} \right]. \]  

(25)

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

\[ R_e = \frac{b_d}{\sin \gamma} \delta \sigma_0 \sqrt{1 + \frac{f^2}{2}} \cos(\gamma + \varphi) + \frac{a_p}{\sin \gamma \sin^2 \gamma} x \]

\[ x[b_d \sin \psi + a_p \tan(\frac{\pi - \varphi}{2}) \sin \gamma] \cos \psi_i \sin \gamma + f \sin(\epsilon + \psi_i) \cos(\arcsin \varphi \cos \epsilon) x \]

\[ \cos(\arctan(\frac{1 - \cos \epsilon \varphi \gamma}{1 + \gamma \cos \epsilon})) + \frac{a_p}{\sin \gamma \sin^2 \gamma} x \]

\[ + \frac{b_d}{\sin \gamma} \frac{l_t}{\cos \epsilon} + q t_i^2 + \frac{p f b}{\sin \beta_1} \left[ 2(a_p - h_d) - \frac{t_i}{\sin \beta_1} \right]. \]  

(26)

The analysis of the obtained expression shows that the traction resistance of the tiller of the combined machine depends on its parameters (\( t_i, h_d, \alpha, \gamma, \beta_1, \beta_2, \delta \)), depth of tillage (\( a_p \)), physical and mechanical properties of soil (\( a_p \)), physical and mechanical properties of soil (\( \sigma_0, \tau, \varphi_1, \varphi_2, \rho, W, q, f \)) and vehicle speed. Calculations by expression (26) at \( \sigma_0=1,44 \cdot 10^6 \text{Pa}, \tau=2 \cdot 10^6 \text{Pa}, f=0,5774, \varphi_1=30^0, \varphi_2=40^0, \rho=1520 \text{ kg/m}^3, W=14%, \delta=0,002 \text{ m}; \]

\( b_d=0,05 \text{ m}, t_i=0,015 \text{ m}, h_d=0,008 \text{ m}, W=14%, \rho=1,510 \text{ N/m}^2, p=1,64 \cdot 10^6 \text{Pa}, \alpha=18^0, \gamma=45^0, \)

\( \delta=0,002 \text{ m}, \beta_1=18^0, \beta_2=25^0, b_i=0,08 \text{ m}, t_i=0,015 \text{ m} \) and \( a_p=0,15 \text{ m} \) 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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