IMPACT OF SOIL MOISTURE AND COMPOSITION ON ITS PROPERTIES AND ENERGY CONSUMPTION OF TILLAGE

Augsnes mitruma un sastāva ietekme uz tās īpašībām un apstrādes energoietilpību

A. Vilde
Latvia University of Agriculture, Institute of Agricultural Engineering,
Ulbroka Research Centre 1 Instituta Street, Ulbroka LV-2130, Latvia.
Phone: +371-7910879, +371-7910987; Fax: +371-2910873; E-mail: uzc@delfi.lv

Abstract
Two of the many factors that influence soil properties and energy consumption are soil moisture and soil composition. The correlations derived from our theoretical and experimental research allow to evaluate physical and mechanical properties of soil such as density, hardness, friction, adhesion, and to assess the draft resistance of soil tillage machines (ploughs, cultivators) depending on the value of the moisture of soil and its composition, as well as on the design parameters and operating speed of the machines, and to determine the optimum range of soil moisture when the energy capacity of tillage is the lowest.

Keywords: *soil properties, draft resistance of machines, theoretical correlations, soil density, soil hardness, soil-metal friction, soil adhesion, energy capacity of tillage.*

Introduction

Energy consumption for soil tillage is determined by the specific draft resistance of the tillage machines. It is known from our previous investigation [1] that the draft resistance of the tillage machines depends on such soil properties as its hardness, density, friction and adhesion. These properties and the tillage quality depend mainly on the soil mechanical composition and moisture [2]. However, there are no correlations that would enable to determine the draft resistance of the tillage machines (ploughs, cultivators), depending on the soil moisture and compositions.

The purpose of the investigation is to evaluate the soil properties and to estimate the forces acting upon the surfaces of the soil tillage machines as well as their draft resistance depending of the soil moisture, mechanical composition and working speed.

Objects and methods

The objects of the research are the draft resistance of the tillage machines, and the tillage quality depending on their design parameters, as well as the soil moisture and composition. On the basis of the previous investigations [1] a computer algorithm has been worked out for the simulation of the forces exerted by soil upon the operating (lifting and supporting) surfaces of the tillage machines, and the draft resistance caused by these forces. The tillage quality is estimated by testing.

Results and discussion

According to our earlier studies [1], the draft resistance R_x of the tillage machines is determined by the share cutting resistance R_{Px}, the resistance caused by weight R_{Gx} of the strip lifted, by the inertia forces R_{Jx}, by soil adhesion R_{Ax} and by weight R_{Qx} of the machine itself:

$$R_x = \sum R_{ix} = R_{Px} + R_{Gx} + R_{Jx} + R_{Ax} + R_{Qx} \quad . \tag{1}$$

The vertical reaction R_z and the lateral reaction R_y of the operating part are defined by corresponding partial reactions:

$$R_z = \Sigma\, R_{iz}\,; \qquad R_y = \Sigma\, R_{iy}\ . \qquad (2;\ 3)$$

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The total draft resistance R_x of the operating part is composed of the resistance of the lifting (share-mouldboard) surface $R^{/}_{x}$ and the resistance of the supporting (lower and lateral) surfaces $R^{//}_{x}$:

$$R_x = R'_x + R''_x = \sum R'_{ix} + f_0 \ (\sum R_{iz} + \sum R_{iy} + p_{Axy} S_{xy} + p_{Axz} S_{xz}), \qquad (4)$$

where f_0 is the coefficient of soil friction along the working and supporting surfaces of the operating part;

p_{Axy} and p_{Axz} - specific adhesion forces, respectively, acting upon the lower and the lateral supporting surfaces of the operating part;

S_{xy} and S_{xz} - the surface areas, respectively, of the lower and the lateral supporting surfaces of the operating part.

Cutting resistance $R^{/}_{Px}$ is proportional to soil hardness ρ_0 and the share edge surface area ω:

$$R^{/}_{Px} = k_p \rho_0 \, \omega = k_p \rho_0 \, ib \ , \qquad (5)$$

where k_p is a coefficient involving the impact caused by the shape of the share edge frontal surface;

i and b - the edge thickness and width.

$$\rho_0 = \delta_0 \, (b^{//} + d^{//} m) \, e^{-l^{//} W^{n}} , \qquad (6)$$

where ρ_0 - soil hardness characterising the resistance to the penetration of the flat round steel tip having a cross-section area of 1 cm^2, H/m^2;

δ_0 - soil (dried) density, kg/m^3;

m - the contents of physical clay (particles of the size <0.01 mm, %);

W - absolute soil moisture, %;

$b^{//}$, $d^{//}$ and $l^{//}$ - coefficients;

n - exponent;

e =2.718…

For the investigation of soil the coefficients and the exponent entered into formula (6) have the following values: $b^{//}$ = 1100; $d^{//}$ = 200; $l^{//}$ = 4.10^{-3} and n = 2.

Hardness variations of soils having different mechanical composition that depends on their moisture is graphically presented in Figure 1.

For plough bodies mould-boards:

Resistance caused by the weight of the lifted strip:

$$\begin{aligned} R'_{Gx} \approx\ & q\delta g k_y r \sin^{-1}\gamma \, * \\ & * \{ \ [(\sin\gamma \cos\varepsilon_1 + \cos^2\gamma \sin^{-1}\gamma) e^{f_0 \sin\gamma(\varepsilon_1 - \varepsilon_2)} - \\ & -(\sin\gamma \cos\varepsilon_2 + \cos^2\gamma \sin^{-1}\gamma)] \cos\varepsilon_1 + \\ & +(\cos\varepsilon_1 e^{f_0 \sin\gamma(\varepsilon_2 - \varepsilon_1)} - \cos\varepsilon_2)(\cos\varepsilon_1 - f_0 \sin\varepsilon_1 \sin\gamma)^{-1} * \\ & * \sin\varepsilon_1 \left[\sin\varepsilon_1 \sin\gamma + f_0 (\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma) \right] \} \end{aligned} \qquad (7)$$

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Resistance caused by the inertia forces:

$$R'_{Jx} = q\delta v^2 k_y^{-1}\sin\gamma\{\ (\sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma)*$$
$$*e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_2)} - (\sin\gamma\cos\varepsilon_2 + \cos^2\gamma\sin^{-1}\gamma) +$$
$$+(\cos\varepsilon_1 - f_0\sin\varepsilon_1\sin\gamma)^{-1}e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)} \qquad (8)$$
$$\sin\varepsilon_1\left[\sin\varepsilon_1\sin\gamma + f_0(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right]\ \}$$

Resistance caused by soil adhesion:

$$R'_{Ax} = p_A br\sin^{-1}\gamma(e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)} - 1)*$$
$$*\{\ \sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma + (\cos\varepsilon_1 - f_0\sin\varepsilon_1\sin\gamma)^{-1}* \qquad \mathbf{(9)}$$
$$*\sin\varepsilon_1\left[\sin\varepsilon_1\sin\gamma + f_0(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right]\ \}\quad ,$$

where q - the area of the cross section of the strip to be lifted;
δ - the density of soil;
k_y - the soil compaction coefficient in front of the operating part;
f_0 - the coefficient of soil friction against the surface of the operating element;
v - the speed of the movement of the plough body;
p_A - specific force of soil adhesion to the operating surface;
b - the surface width.

Soil density is dependent on the strata density (the mass of a volume unit of the dried soil) δ_0 and soil moisture:

$$\delta = \delta_0\,(1+W)\,. \qquad (10)$$

Observations indicate that the density of mineral soils generally varies from 1200 to 1800 kg/m^3. The resistance of the operating parts of the soil tillage machines varies in proportion to soil density [1].

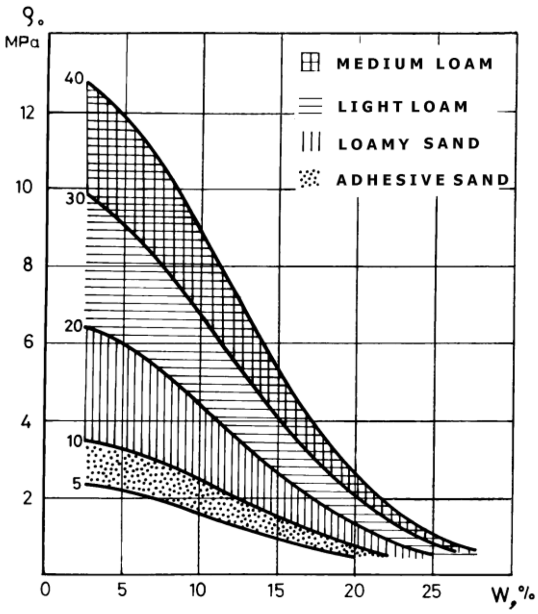

Fig.1. Dependence of the hardness of soils having different mechanical composition on their moisture. The numbers at the soil hardness curves stand for the percentage of the physical clay in the soil. Soil hardness is determined by Yu.Yu.Revyakin's hardness gage having a flat tip with a cross-section area 1 cm^2.

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As a rule, all the sources provide slipping resistance coefficients of soil. On the basis of these data, by the method of least squares, we have determined the coefficients of friction and specific adhesion force, after that dependencies were deduced between them and the mechanical composition, and moisture of soil [2]:

$$f_0 = (a+e^{-[b_1 (b_2 - m)^2}) e^{-b_3 W^2} + (c+dm) e^{-[(k + l m) (t^{/} + z^{/} m - W)]^2} \quad (11)$$

where $a, b_1, b_2, b_3, c, d, k, l, t, z$ - the indices depending on the type of soil, the material and the condition of the surface of the object along which the soil slips;

e = 2.718…;

W – absolute moisture of soil, %;

m – the content of physical clay in soil (the particle size <0.01 *mm*).

Variations in the specific adhesion force p_A of soil correspond to the relation of the type:

$$p_A = (a^{/} + b^{/} p) (c^{/} + d^{/} m) e^{-[(k^{/} + l^{/} m) (t^{/} + z^{/} m - W)]^2} , \quad (12)$$

where p_A - the specific pressure of the layer (soil) upon the surface;
$a^{/}, b^{/}, c^{/}, d^{/}, k^{/}, l^{/}, t^{/}, z^{/}$ - the indices depending on the type of soil, the material and the condition of the surface along which the soil slips.

As an example, the values of these indices for the polished steel surfaces are [2]: a = -0.43; b_1 = 0.007; b_2 = 130; b_3 = 0.1; c = 0.32; d = 0.002; k = 0.05; l = 0.0005; t = 10; z = 0.14; a = 0.2; $b^{/}$ = 1…2.5; $c^{/}$ = 0.1; $d^{/}$ = 0.003; $k^{/}$ = 0.1; $l^{/} = 10^{-4}$; $t^{/}$ = 15; $z^{/}$ = 0,2.

Variations of the friction coefficient and the specific force of soil adhesion to steel depending on the moisture and mechanical composition of soil are presented in Figures 2 and 3.

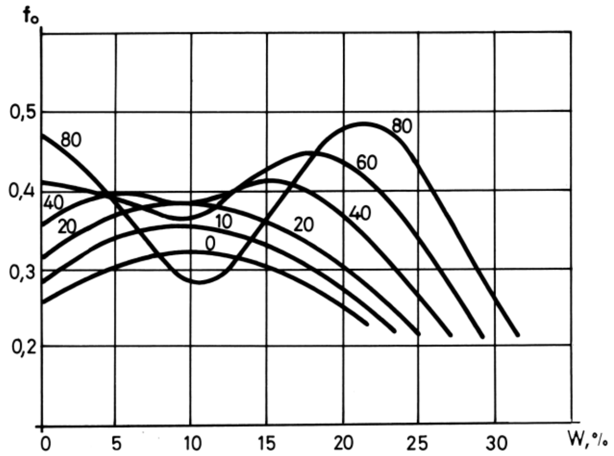

Fig.2. Variations of the friction coefficient of soils having different mechanical composition along steel depending on the moisture of the soil. The numbers on the curves stand for percentage content of physical clay (particles of the size less than 0.01 mm) in soil.

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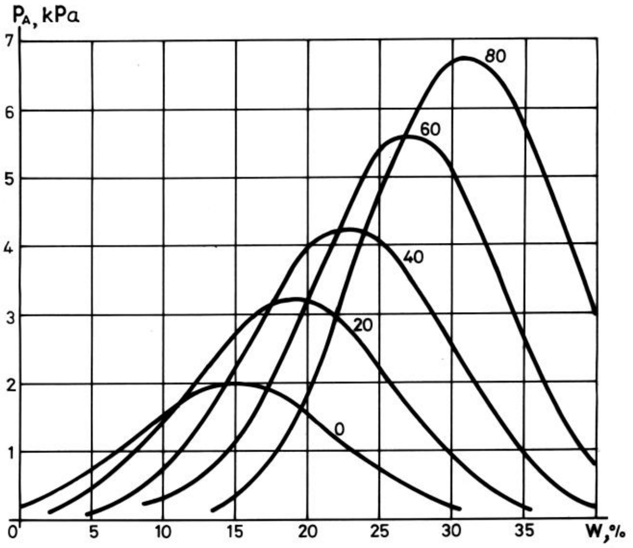

Fig.3. Variations of the specific adhesion force of soils having different mechanical composition along steel depending on the moisture of soil at the pressure of 100 kPa. The numbers on the curves stand for percentage content of physical clay (particles of the size less than 0.01 *mm*) in soil.

The soil slipping resistance along steel depends on the slipping speed, the structure of soil, the humus content and the surface temperature. The effect of these parameters may be considered by respective coefficients. For example, the coefficients of velocity k_v and $k_v^{/}$:

$$k_v = k_{v\,top}\,[1 + a\,(1 + b\,v^{\,n})^{-1}]\,, \tag{13}$$

$$k_v^{/} = k_{v\,top}^{/}\,[1 + a^{/}\,(1 + b^{/}\,v^{\,n^{/}})^{-1}] \tag{14}$$

where $k_{v\,top}$ and $k_{v\,top}^{/}$ - the marginal value of the velocity coefficient; $k_{v\,top} = 0.66$

v - the speed of slipping, *m/s*; $k_{v\,top}^{/} = 0.2$

a, $a^{/}$ and b, $b^{/}$ - indices; $a = 0.52$; $a^{/} = 4$; $b = 0.5$; $b^{/} = 1$;

n and $n^{/}$ - exponents of indices; $n = 2$; $n^{/} = 2$.

Variations of the coefficients indicating the influence of the speed of slipping for the given type of soil are shown in Figure 4.

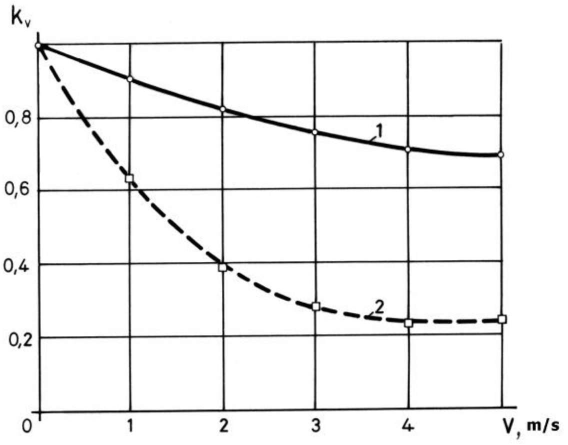

Fig.4. Variations of the coefficients indicating the influence of the speed of slipping upon the coefficient of friction and specific adhesion for wet soil. *1* – variations of coefficient k_v; *2* – variations of coefficient $k_v^{/}$.

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There is insufficient amount of data for deriving mathematical dependencies characterising the influence of temperature upon the friction coefficient of soil along steel. When temperature rises, the specific adhesion force of soil to steel decreases forming a parabolic curve (on the basis of the data provided by H.G.Riek) described by the following relation:

$$p_A = p_{A_0} (1 - 10^{-4} t^2), \quad (15)$$

where p_{A_0} - the specific adhesion force to steel at a temperature, close to 0 °C;

t - the temperature of adhesive surfaces, °C .

There are no data either to deduce dependencies of the influence between the structure and the humus content upon the soil slipping resistance along steel. According to the data by H.G.Riek, if for a wet residual (paste-like) soil the coefficient of structurality $k_{st}^{/}$ is accepted as being 1, for a structured soil it will be 0.75-0.80.

The resistance caused by the weight and inertia forces of the lifted strip of soil is proportional to soil density and its friction coefficient.

The resistance caused by soil adhesion is proportional to the specific adhesion force between soil and the surface of the operating part.

The draft resistance caused by the weight of the machine itself is proportional to the friction coefficient.

The total draft resistance of the machine depends on its component resistances. The maximum resistance occurs in caked clay soils, the minimum – in sandy soils. The moisture increase in clay soils to 14…18 %, leads to their decreased resistance, yet at higher moisture it rises again.

The best tillage quality is also obtained at the optimum moisture.

Conclusions

1. The derived analytical correlations allow assessing the draft resistance of soil tillage machines (ploughs, cultivators) depending on the value of soil moisture and composition, as well as on their design parameters and their working speed.
2. The correlations obtained allow determining the optimal soil moisture range when the tillage energy capacity is the lowest. In clay soils it varies from 14 to 18 %. At this moisture level the tillage quality (degree of loosening) is the best too.

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