Simulation of the Impact of the Plough Body Parameters, Soil Properties and Working Modes on the Ploughing Resistance

Arvids Vilde and Adolfs Rucins
Latvia University of Agriculture
Latvia

1. Introduction

Ploughing is one of the most power-consuming and expensive processes in agricultural production. It is known from our previous investigation (Vilde, 1999) that the draft resistance of ploughs and energy requirement for ploughing depend on the plough body parameters and on such soil properties as its hardness, density, friction and adhesion. These properties and the tillage quality depend mainly on mechanical composition and humidity of the soil.

However, there were no sufficient analytical correlations that would enable to determine the impact of the plough body parameters on the draft resistance of the share-mouldboard surface and the plough body, as a whole, as well as on the ploughing quality and expenses depending on the body parameters, on the humidity and composition of soil.

In literature there is difference of opinions on the impact of plough body working width on its specific draft resistance. F. P. Ciganov in this dissertation had written that decreasing of the body width decreases specific draft resistance of ploughing (Ciganov, 1969). W. R. Gill and G. E. Vanden Berg have opposite views. Their data show that "specific draft generally tended to decrease as size of cut increased" (Gill & Vanden Berg, 1967, p. 262). In the Kverneland plough prospect has written that by increasing the furrow width from 35 cm to 45 cm (14" to 18") the consumption of diesel fuel is reduced by as much as 18% and working capacity will be increased by up to 30% (Rucins & Vilde, 2005b).

The purpose of the investigations was to study the factors that determine the quality and energy requirement of ploughing, the impact of body parameters, working modes and speed, as well as soil properties on it and to find technical solutions to improve the ploughing efficiency.

2. Materials and Methods

On the basis of the survey a hypothesis has been advanced that the draft resistance of soil tillage machines, as well as ploughs depends on two types of effective forces: the forces related to physical and mechanical properties of soil (its mechanical strength) which manifest themselves as the penetration resistance of operating parts, soil deformation resistance and adhesion; and the forces caused by the mass of the soil moving along the lifting surface (gravity and inertia forces). Therefore both the relationships of the material resistance and theoretical mechanics have been applied for an analytical estimation of the draft resistance of operating parts, as well as their component elements.

The objects of the research are the forces acting on the plough body and its draft resistance depending on the body design parameters, as well as the physical and mechanical properties of soil and the mode of operation. On the basis of the previous investigations (Vilde, 1999) a computer algorithm has been worked out (Rucins & Vilde, 2005a) for the simulation of the forces exerted by soil upon the operating (lifting and supporting) surfaces of the plough body, and the draft resistance caused by these forces (Fig. 1).

Mathematical methods and computer algorithms worked out for the simulation of soil tillage processes allow calculating the forces acting upon the machine operating parts and their optimal design (including the plough body) for qualitative soil tillage with minimum energy consumption.

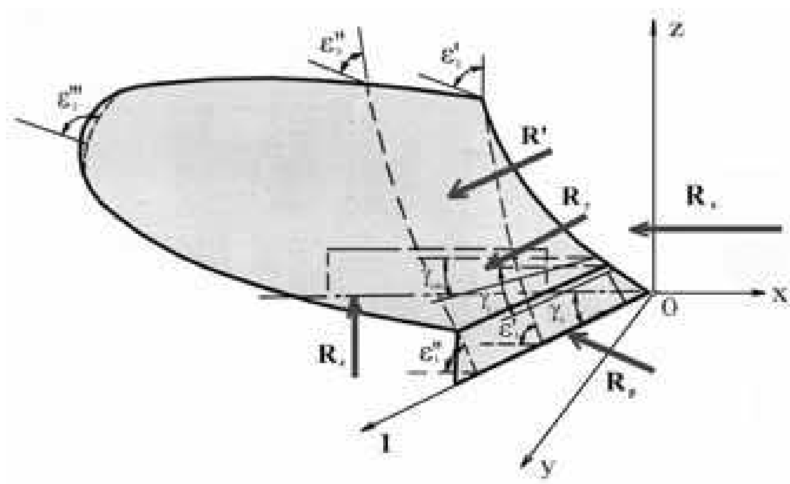


Fig. 1. Scheme of the plough body, its parameters and acting forces.

According to our previous investigations (Vilde 1999) the draft resistance R_x of the plough body is determined by the share of the cutting resistance R_{Px}, the resistance caused by the gravity (weight) R_{Gx} of the soil slice lifted, by the inertia forces R_{Jx}, by soil adhesion R_{Ax} and by weight R_{Qx} of the plough body itself (including a part of the weight of the plough).

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

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

$$R_z = \sum R_{iz} \quad ; \qquad R_y = \sum R_{iy} \qquad (2; 3)$$

The total draft resistance R_x of the operating part is composed of the resistance of the working surface R'_x and the resistance of the supporting (lower and lateral) surfaces R''_x:

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

where: f_0 is the coefficient of the soil friction along the working and supporting surfaces of the plough body; p_{Axy} and p_{Axz} – the specific adhesion force applied, respectively, to the lower and the lateral supporting surfaces of the body; S_{xy} and S_{xz} - the surface area, respectively, of the lower and the lateral supporting surfaces of the body.
The friction resistance F_x is a constituent part of these reactions and their components (Rucins et al. 2003), and, by analogy, we can write that

$$F'_x = \Sigma F'_{ix} = F'_{Px} + F'_{Gx} + F'_{Jx} + F'_{Ax} + F'_{Qx} = R'_x - R'_{xo} \qquad (5)$$

$$F''_x = f_0 (R_z + R_y + p_{Axy} S_{xy} + p_{Axz} S_{xz}) = R''_x \qquad (6)$$

$$F_x = F'_x + F''_x \qquad (7)$$

The friction resistance of the share-mouldboard surface is defined as the difference between the total resistance (general value of the partial resistance) and resistance R_{xo} in operation without friction ($f_0= 0$).

$$F_{ix} = R_{ix} - R_{ixo}\ ; \qquad F_x = R_x - R_{xo} \qquad (8; 9)$$

Ratio λ_F of the friction resistance in the partial and total resistance (reaction) is determined from their correlations:

$$\lambda_{Fix} = F_{ix} R_{ix}^{-1}\ ; \qquad \lambda_{Fx} = F_x R_x^{-1} \qquad (10; 11)$$

Ratio λ_R of the supporting reactions in the partial and total draft resistance is determined from correlation:

$$\lambda_{Rx} = R_i R_{ix}^{-1} \qquad (12)$$

2.1. Cutting resistance R'_{Px} is proportional to soil hardness ρ_0 and the share edge surface area ω:

$$R'_{Px} = k_p \rho_0 \omega = k_p \rho_0 ib \qquad (13)$$

where k_p is the coefficient involving the impact of the shape of the frontal surface of the ploughshare edge; i and b - the thickness and width of the edge.
It is evident from formula (5) that the friction of soil along the edge does not influence the cutting resistance of the edge.
At a sharp ploughshare (the rear bevel is absent):

$$R_{Pz} = 0 \qquad (14)$$

At a blunt (threadbare) ploughshare having rear bevel the vertical reaction R_{Pz} on the hard soils can reach the summary value of vertical reactions, this summary value arising from

other forces acting on the share-mouldboard surface (soil gravity and inertia) and the weight of the body Q.
At an inclined ploughshare a lateral reaction R_{Py} arises, its value being affected by the friction reaction.

$$R_{Py} = k_p \rho_0 \, ib \, ctg(\gamma_0 + \varphi_0) \tag{15}$$

where γ_0 is the inclination angle of the edge towards the direction of movement (the wall of the furrow); φ_0 - the angle of friction.
When friction is absent, $f_0 = 0$, $\varphi_0 = 0$ and

$$R_{Pyo} = k_p \rho_0 \, ib \, ctg \, \gamma \tag{16}$$

Friction of soil along the ploughshare edge reduces the lateral pressure of the ploughshare (the pressure of the plough body against the wall of the furrow).
The resistance of the supporting surface

$$R''_{Px} = k_p \rho_0 \, ib \, f_0 \, ctg(\gamma_0 + \varphi_0) = F''_{Px} \tag{17}$$

The total cutting resistance

$$R_{Px} = k_P \rho_0 \, ib \left[1 + f_0 \, ctg(\gamma_0 + \varphi_0)\right] \tag{18}$$

The lateral cutting resistance of the knife is determined by formulae, similar to those for the cutting resistance from below. Consequently, similar to the above formulae will also be the formulae defining the impact of friction on the total resistance of the knife.

2.2 Forces caused by the weight of the lifting soil strip:

$$\begin{aligned} R'_{Gx} \approx\ & q\delta g k_y r \sin^{-1}\gamma \{ [(\sin\gamma \cos\varepsilon_1 + \cos^2\gamma \sin^{-1}\gamma) e^{f_0 \sin\gamma(\varepsilon_2 - \varepsilon_1)} - \\ & -(\sin\gamma \cos\varepsilon_2 + \cos^2\gamma \sin^{-1}\gamma)] \cos\varepsilon_1 + (\cos\varepsilon_1 e^{f_0 \sin\gamma(\varepsilon_2 - \varepsilon_1)} - \cos\varepsilon_2) * \\ & * (\cos\varepsilon_1 - f_0 \sin\varepsilon_1 \sin\gamma)^{-1} \sin\varepsilon_1 \left[\sin\varepsilon_1 \sin\gamma + f_0(\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma)\right] \} \end{aligned} \tag{19}$$

$$R_{G_z} \approx q\delta g \, r \sin^{-1}\gamma \, (\varepsilon_2 - \varepsilon_1) \tag{20}$$

$$R_{G_y} \approx q\delta g \, r \sin^{-1}\gamma (\varepsilon_2 - \varepsilon_1)(\varepsilon_1 + 0.52) \, ctg \, \gamma \tag{21}$$

$$R''_{Gx} = f_0 (R_{Gz} + R_{Gy}) = F''_{Gx} \tag{22}$$

2.3. Forces caused by the soil inertia:

$$R'_{Jx} = q\,\delta v^2 k_y^{-1} \sin\gamma \{ (\sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma) e^{f_0 \sin\gamma(\varepsilon_2-\varepsilon_1)} - \\ -(\sin\gamma\cos\varepsilon_2 + \cos^2\gamma\sin^{-1}\gamma) + (\cos\varepsilon_1 - f_0\sin\varepsilon_1\sin\gamma)^{-1} e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)} * \\ * \sin\varepsilon_1 \left[\sin\varepsilon_1\sin\gamma + f_0(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right] \} \tag{23}$$

$$R_{Jz} = q\,\delta\, v^2 k_y^{-1} \sin\gamma\sin\varepsilon_2\, e^{f_0 \sin\gamma\,(\varepsilon_2-\varepsilon_1)} \tag{24}$$

$$R_{Jy} \approx q\,\delta\, v^2 k_y^{-1} \sin\gamma\cos\gamma\,(1-\cos\varepsilon_2) \tag{25}$$

$$R''_{Jz} = f_0(R_{Jz} + R_{Jy}) = F''_{Jx} \tag{26}$$

2.4. Forces caused by soil adhesion:

$$R'_{Ax} = p_A\, b r \sin^{-1}\gamma\,(e^{f_0\sin\gamma\,(\varepsilon_2-\varepsilon_1)} - 1)\{ \sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma + \\ +(\cos\varepsilon_1 - f_0\sin\varepsilon_1\sin\gamma)^{-1}\sin\varepsilon_1\left[\sin\varepsilon_1\sin\gamma + f_0(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right]\} \tag{27}$$

$$R_{Az} = 0 \tag{28}$$

$$R_{Ay} = 0 \tag{29}$$

$$R''_{Ax} = f_0\,(p_{Axy} S_{xy} + p_{Axz} S_{xz}) = F''_{Ax} \tag{30}$$

where: q - the cross section area 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 soil friction coefficient against the surface of the operating element; v - the speed of the movement of the plough body; p_A - the specific force of soil adhesion to the operating surface; b - the surface width of the soil strip; ε_1 and ε_2 are correspondingly the initial and the final angles of the lifting (share - mouldboard) surface; γ - the inclination angle of the horizontal generatrix towards the direction of movement (the wall of the furrow); g - acceleration caused by gravity (g = 9.81).

2.5. The draft resistance caused by the ploughs weight Q:

$$R''_{Qx} = Qf_0 \tag{31}$$

The soil friction coefficient and the specific force of soil adhesion are not constant values. Their values decrease with the increase in speed (Vilde, 2001, 2003). This is considered in calculations.
The resistance of the supporting surfaces of the plough body depends on the values of the reacting forces. Yet their value is dependent, in many respects, on the manner of unification and perfection of the hydraulically mounted implements of the tractor. The vertical reaction

of the plough with modern tractors having power regulation is transferred to the body of the tractor, and it affects the plough resistance to a considerably lesser degree (Rucins & Vilde; Rucins et al., 2006).
The obtained correlations (1)–(31) allow determination of the forces acting on the plough body and its draft resistance depending on the body parameters, as well as evaluation of their impact on the ploughing efficiency: energy and the fuel consumption and the quality of work. These parameters are: the initial and the final angles of the lifting (share - mouldboard) surface ε_1 and ε_2 ; the inclination angle of the horizontal generatrix towards the direction of movement (the wall of the furrow) γ_i (see Fig. 1) and regularity (law-governed nature) of its variation; the thickness of the share edge i; the radius r of the lifting (share - mouldboard) surface and the area of the lifting and supporting surfaces $2\pi r(\varepsilon_2 - \varepsilon_1)b$, S_{xy} and S_{xz}.
Soil hardness ρ_0 is characterising the resistance to the penetration of the flat round steel tip having a cross-section area of 1 cm² depends on its mechanical composition and humidity. As a result of the research it is found out that soil hardness of natural structure, depending on its granulometric composition and humidity, and containing the organic matter from 1.4 to 1.9% of its total mass, as determined by Yu.Yu. Revyakin's hardness gage is subject to the following relationship (Vilde, 2003):

$$\rho_0 = \delta_0(b'' + d''m)e^{-l''W^n} \tag{32}$$

where ρ_0 - soil hardness characterising the resistance to the penetration of the flat round steel tip having a cross-section area of 1 cm², N 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 humidity, %; b'', d'' and l'' - coefficients; n - exponent; e =2.718… For the investigation of soil the coefficients and the exponent entered into formula (32) have the following values: b'' = 1100; d'' = 200; l'' = 4.10^{-3} and n = 2.

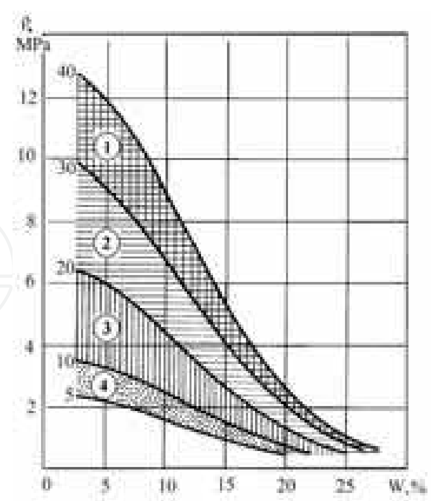


Fig. 2. Dependence of the hardness of soils having different mechanical composition on their humidity: 1 – medium loam; 2 – light loam; 3 – loamy sand; 4 – adhesive sand. The numbers at the soil hardness curves stand for the percentage of the physical clay in the soil. Soil hardness is determined by Yu.Yu. Revyakin's hardness gage having a flat tip with a cross-section area 1 cm².

Hardness variations of soils having different mechanical composition that depends on their humidity calculated according to formula (1) is graphically presented in Figure 2.
The graph allows to trace the change of soil hardness of a certain mechanical composition depending on its humidity, and to fix the hardness range of the represented soil types – adhesive sand, loamy soil, light and medium loam.
Soil density δ is dependent on the strata density (the mass of a volume unit of the dried soil) δ_0 and soil humidity W:

$$\delta = \delta_0 (1 + W) \tag{33}$$

Observations indicate that the density of mineral soils may vary in a very wide range: from 700 kg m^{-3} for dry, loose (freshly ploughed) soil to 2200 kg m^{-3} for wet, compact soil, but generally it 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 (Vilde, 2001, 2003).
As a rule, all the sources provide sliding resistance coefficients of soil. In order to clarify the nature of the sliding resistance for soil on the working surfaces of the tillage machines, Deryagin's binomial sliding (slipping) resistance formula (Deryagin, 1963) is used as more adequate (Vilde, 2001, 2003):

$$f = f_0 (1 + p_A p^{-1}) \tag{34}$$

where f - the resistance coefficient of soil sliding along a surface; f_0 - the friction coefficient of soil along a surface; p - the specific pressure of the layer (soil) upon the surface; p_A - the specific soil adhesion force to the surface.
In order to determine the coefficient of friction and the specific adhesion depending on sliding speed, the soil sliding resistance is assessed at a speed to 5 m s^{-1} and at several different values of the specific pressure between the sliding surfaces. On the basis of these data, by the method of least squares, is determined the coefficients of friction and specific adhesion force, after that dependencies were deduced between them and the mechanical composition, and humidity of soil (Vilde et al., 2007):

$$f_0 = (a + e^{-[b_1 (b_2 - m)]^2}) e^{-b_3 W^2} + (c + dm) e^{-[(k + lm)(t + zm - W)]^2} \tag{35}$$

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 slides; e = 2.718; W – absolute humidity 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:

$$p_A = (a' + b' p) + (c' + d' m) e^{-\left[(k' + l' m)(t' + z' m - W)\right]^2} \tag{36}$$

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 slides.
As an example, the values of these indices for the polished steel surfaces are:
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.

The numerical values of the indices in Formulae (35) and (36) for mineral soils and some steel surfaces are determined for a residual soil (ground), the sliding velocity and temperature being close to 0.
Variations of the friction coefficient and the specific force of soil adhesion to steel depending on the humidity and mechanical composition of soil are presented in Figures 3 and 4.

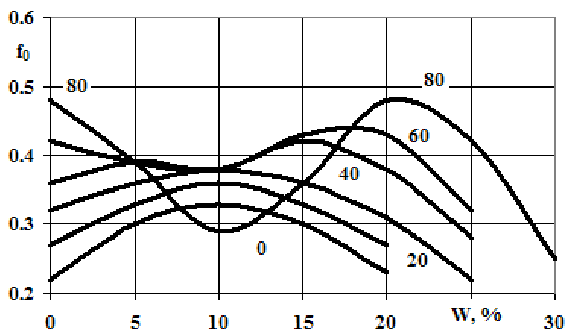


Fig. 3. Variations of the friction coefficient of soils having different mechanical composition along steel depending on the humidity of the soil. The numbers on the curves stand for percentage content of physical clay (particles of the size less than 0.01 mm) in soil.

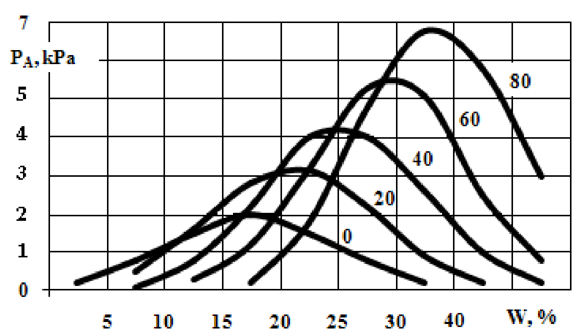


Fig. 4. Variations of the specific adhesion force of soils having different mechanical composition along steel depending on the humidity of soil at the pressure of 100 kPa. The numbers on the curves stand for percentage content of physical clay (particles of the size less than 0.01 mm) in soil.

Further, as it was mentioned above, the soil sliding resistance along steel depends on the sliding speed, the structure of soil, the humus content and the surface temperature. The effect of these parameters may be considered by respective coefficients. In view of this we can write:

$$f_0' = f_0 k_v k_{st} k_h k_t \tag{37}$$

$$p_A' = p_A k_v' k_{st}' k_h' k_t' \tag{38}$$

where f'_0 and p'_A - the coefficients of sliding resistance and specific adhesion force of soil to steel at a certain speed of sliding, structure, humus content in soil, and temperature; f_0 and p_A - the coefficients of sliding resistance and specific adhesion force to steel of residual soil not containing humus at a temperature, close to 0 °C; k_v and k_v' - the coefficients of velocity; k_{st} and k'_{st} - the coefficients of the soil structurality; k_h and k'_h - the coefficients of the humus content; k_t and k'_t - the temperature coefficients.

There are decoded some of these coefficients. For example, the coefficients of velocity k_v and k'_v are (Vilde, 2003):

$$k_v = k_{vmrg}\left[1 + a(1 + bv^n)^{-1}\right] \quad (39)$$

$$k'_v = k'_{vmrg}\left[1 + a'(1 + b'v^{n'})^{-1}\right] \quad (40)$$

where k_{vmrg} and k'_{vmrg} - the marginal value of the velocity coefficient; v - the speed of sliding, m s^{-1}; a, a' and b, b' - indices; n and n' - exponents of indices.

It is highly probable that the marginal value of the velocity coefficient depends on the mechanical composition and humidity of soil yet the data to prove this are presently absent.

The parameters entering Formulae (39) and (40) that are calculated on the basis of experimental data by M.I. Bredun have the following values for wet soil with distinctly pronounced adhesion: k_{vmrg}= 0.66; $k_v'_{mrg}$ = 0.2; a = 0.52; a'= 4; b = 0.50; b'= 1; n = 2; n'= 2. (Bredun, 1964).

Variations of the coefficients indicating the influence of the speed of sliding for the given type of soil are shown in Figure 5.

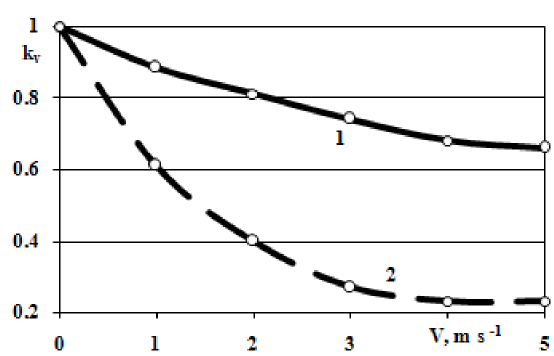


Fig. 5. Variations of the coefficients indicating the influence of the speed of sliding upon the coefficient of friction and specific adhesion for wet soil. 1 – variations of coefficient k_v; 2 – variations of coefficient k'_v.

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 that on the basis of the data provided by H.G. Riek (Riek & Vorkal, 1965) described by the following relation:

$$p_A = p_{A_0}(1 - 10^{-4}t^{-2}) \quad (41)$$

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 sliding 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 optimum humidity of soil at which the draft resistance will be minimal is determined by equating the first derivative its function to zero:

$$dR_x(dW)^{-1} = 0 \tag{42}$$

Because of the complexity of this equation in its full view, partial decisions can be used, and the optimum humidity of soil can be determined from the variables of the partial resistance depending on the humidity of soil, its mechanical structure, and the speed of work of the plough.

3. Results

The materials of the calculations carried out using the correlations indicated above present the values and regularity of the changes in the forces acting on the share-mouldboard and the supporting surfaces, the draft resistance of the share-mouldboard and the supporting surfaces, as well as the total resistance of the plough body and its components under working conditions depending on the body parameters, soil properties and the working speed. Possibilities to reduce the tillage energy requirement have been clarified.

3.1 Simulation of the Impact of the Plough Body Parameters on the Ploughing Resistance

The presented work discusses, as an example, the theoretical research results of the forces acting on the plough body and the specific draft resistance at various angles γ of the horizontal generatrices and at various values of initial lifting angle ε_1 of the plough body (at the angle between the horizontal generatrix of the operating surface and the vertical longitudinal plane γ=40˚) depending on the speed of operation, as well as at various its working width when ploughing loamy soils that predominate in Latvia. The calculations were carried out with the computer according to the foregoing formulaes.
As an example, the following values of the basic factors were taken into consideration, which affect the resistance of the share-mouldboard surface and the plough body.

Parameters of the plough body:

Thickness of the share blade and knife	i = 0.004 m
Working width of the share	b_s= 0.35 m
The initial angle of the lifting strip of soil	ε_1 = 20°-40°
The final angle of the lifting strip of soil	ε_2 = 100°
The angle between the horizontal generatrix of the operating surface and the vertical longitudinal plane	γ = 15°…90°
The radius of the curvature of the lifting surface	r = 0.5 m
The area of the lower supporting surface	S_{xy} = 0.0157 m^2

The area of the lateral supporting surface $S_{xz} = 0.068$ m^2
The weight on the plough body Q = 200 kg
Physical and mechanical properties of soil:
The hardness of soil $\rho = 4.1$ MPa
The density of soil $\delta = 1600$ kg m^{-3}
The coefficient of soil friction against the surface of the operating element $f_0 = 0.4$
The adhesion force $p_{A0} = 2.5$ kPa
The mode and status of work:
The body working width 0.30...0.50 m
The ploughing depth a = 0.20 m
The cross section area of the lifted soil strip q = 0.06...1.00 m^2
The soil compaction coefficient in front of the operating part $k_y = 1.1$
The working speed v = 1…5 m s^{-1}
The inclination angle γ of the horizontal generatrix of the real share-mouldboard surfaces of plough bodies lies between 26°…50°. Steeper surfaces (γ > 50°) refer to the slanting blades of bulldozers.
The calculation results of the draft resistance of the lifting surface, of supporting surfaces and of plough body in total depending on the inclination angle γ of the horizontal generatrix and speed v (ε_1 = 30°) are presented in Fig. 6 – 8, those values depending on initial lifting angle – in Fig. 9 – 11.

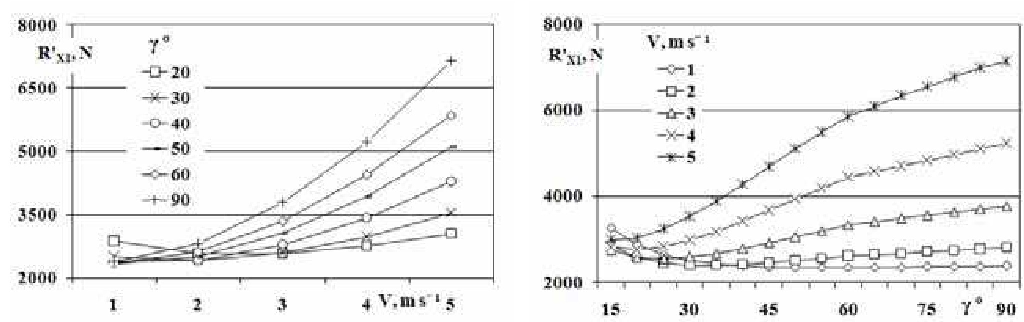


Fig. 6. Total draft resistance of the share-mouldboard surface caused by soil gravity, inertia forces, adhesion and share cutting resistance depending on speed v and the inclination angle γ of the horizontal generatrix.

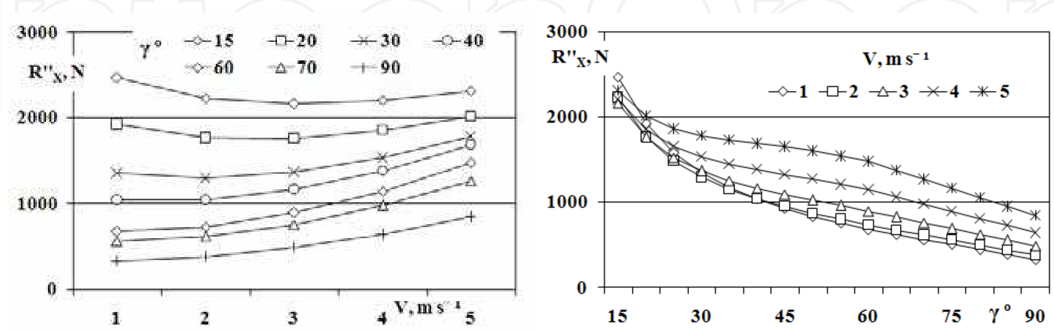


Fig. 7. Total draft resistance of the supporting surfaces depending on speed v and the inclination angle γ of the horizontal generatrix.

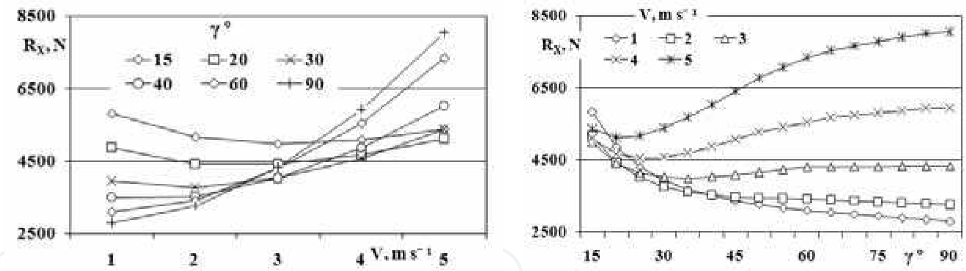


Fig. 8. Total draft resistance of the plough body depending on speed v and the inclination angle γ of the horizontal generatrix.

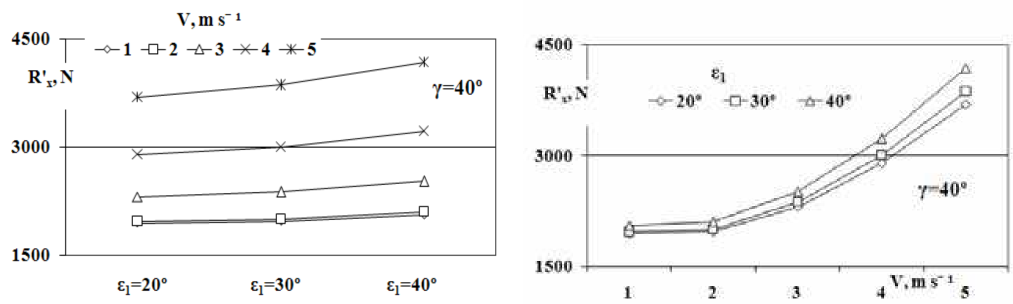


Fig. 9. Total draft resistance of the lifting surface caused by soil gravity, inertia forces and adhesion depending on the initial lifting angle ε_1 and speed v.

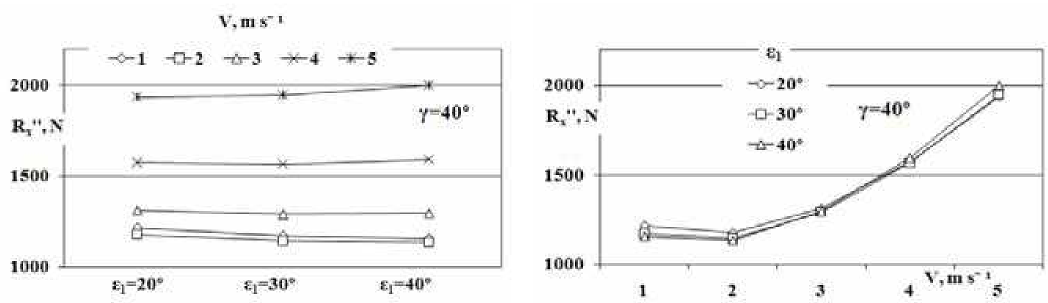


Fig. 10. Summary draft resistance of the plough body supporting surfaces depending on the initial lifting angle ε_1 of the soil strip and speed v.

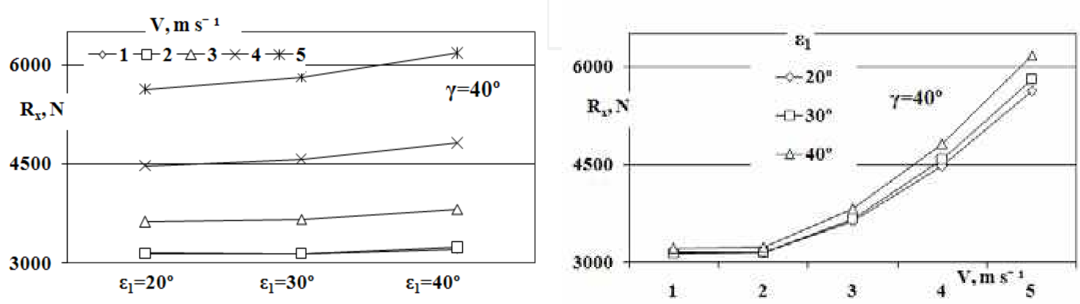


Fig. 11. Total draft resistance of the plough body depending on the initial lifting angle ε_1 of the soil strip and speed v.

Further the presented work discusses too, as an example, the research results of the forces acting on the plough body and the specific draft resistance of the plough body at various its working width when ploughing loamy soils that predominate in Latvia.
The calculation results of the specific draft resistance of the plough body and its components are presented in Fig. 12 –15 and Table 1.

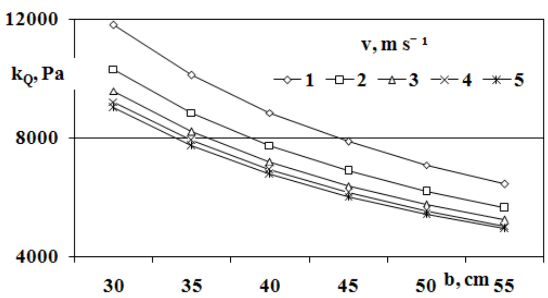


Fig. 12. The specific draft resistance k_Q of the plough body caused by its weight Q depending on the body working width b at various speeds v.

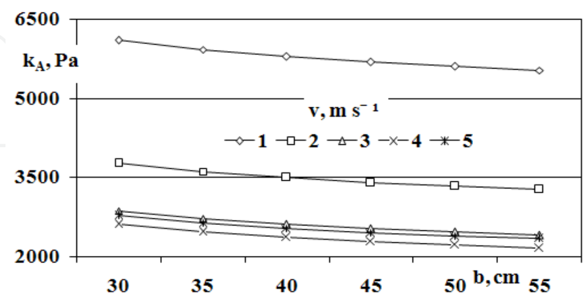


Fig. 13. The specific draft resistance k_A of the plough body caused by soil adhesion depending on the body working width b at various speed v.

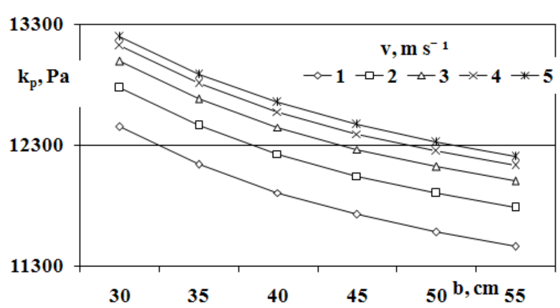


Fig. 14. The specific draft resistance of the plough body k_P caused by cutting resistance R_{Px} depending on the body working width b at various speed v.

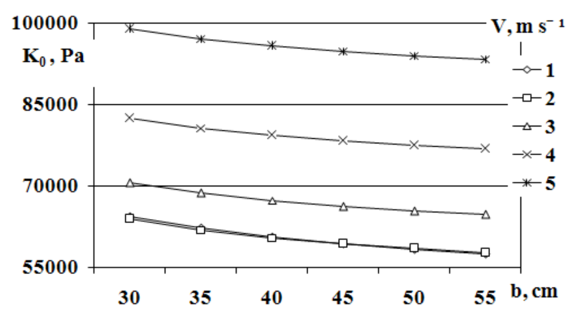


Fig. 15. Total specific draft resistance of the plough body K_0 depending on the body working width b by various speed v.

v, m s^{-1}	1	2	3	4	5
k_G, Pa	31616	28575	27100	26390	26013
k_J, Pa	2311	8386	17933	31080	47897
k_G+k_J, Pa	33928	36962	45034	57471	73911

Table 1. Specific draft resistance caused by soil weight k_G and inertia forces k_J.

Experimental studies are carried out on the "Kverneland Vary Width" plough, having bodies working width from 30 cm to 50 cm. Results are shown in graph (Figure 16).
The graph (Fig. 16.) shows how the specific draft resistance and energy consumption in ploughing depends on the working width of each body. Increasing it the energy capacity and specific fuel consumption in ploughing decreases by 10-16%. The greater is the

ploughing depth, the greater is the effect due to the increased working width of the body. This phenomenon is caused by more high soil hardness and density of deeper soil layers.

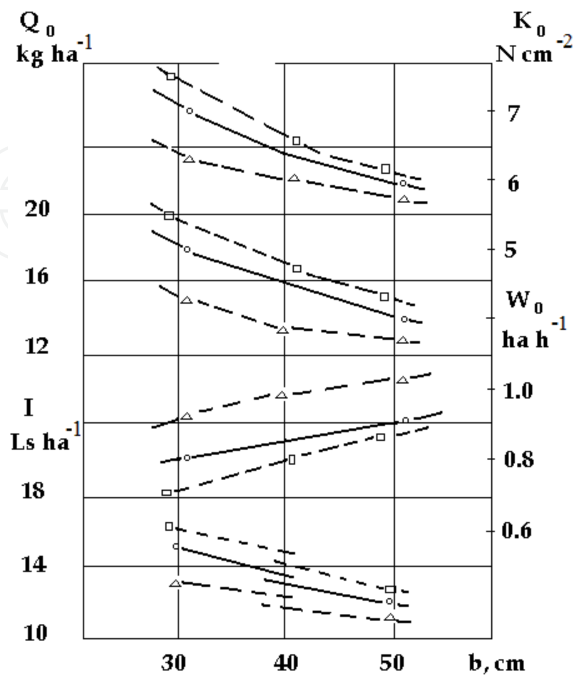


Fig. 16. Variations of energetic and economic characteristics of the Kverneland AB-85 plough with semihelicoidal bodies No 8 depending on the body width in ploughing grassland on a loamy soil at the speed 8.7-9 km h^{-1}: b - the body width, cm; K_0 - the specific draft resistance, N cm^{-2}; Q_0 - the specific fuel consumption, kg ha^{-1}; W_0 - the direct labour productivity, ha h^{-1}; I - ploughing costs Ls ha^{-1} (1 Ls = 1.42 EUR).- -□ - - the ploughing depth of 24 cm; ---o--- the ploughing depth of 22 cm; -- Δ-- the ploughing depth of 19 cm.

In loamy soil increase in the working width of the bodies at the ploughing depth of 18…19 cm decreases the specific fuel consumption by 2…3 kg ha^{-1} but at the depth of 24 cm by 4…5 kg ha^{-1}. Correspondingly, there is a rise in labour efficiency, and the ploughing costs fall by 2…4 Ls ha^{-1}. (2.84…5.68 EUR ha^{-1}). Therefore, when ploughs are used that have a possibility to vary the working width, it is recommended to work at the maximum width and, if necessary (insufficient power of the tractor), to reduced the number of bodies.

Thus, for example, in the aggregate with the MTZ-82 tractor it is more purposeful to work with the Kverneland AB-85 two-body plough with the working width of each body 50 cm (the total width 1 m) than with three bodies having the width of 33 cm each and the same working width.

The obtained materials show that by increasing the initial lifting angle ε_1 (inclination angle of share toward furrow bottom) the draft resistance increases. For economical ploughing the initial lifting angle of the soil slice (the angle between share and furrow bottom) must have a minimal value - 24°…30°. The smallest inclination angle is not desirable because by wear out of the share there is a possibility at the blunt (threadbare) ploughshare to obtain a rear bevel which can hinder the plough body from going into soil. This phenomenon is observed with the Kverneland plough bodies No. 8 having a 20° inclination angle of their outer part.

More complicated is the impact of the inclination angle γ of the horizontal generatrix. Depending on the working speed the change of its value can impact the value of the draft resistance positively or negatively, that is, to decrease or increase the draft resistance. When the inclination (angle γ) of the generatrix is increased, the resistances, because of the soil weight and adhesion, fall but the resistance due to the inertia forces increases, particularly when operating at higher speeds. The decrease of the first ones can be explained by the fact that its length decreases at a steeper share-mouldboard surface, and, because of this, there is a decrease in the mass of soil sliding along it. Decreasing the area of its surface leads to a lower resistance due to soil adhesion. As a result, the total draft resistance of the share-mouldboard surface shows a marked minimum, which, at a greater operating speed, moves towards lower inclination values of the horizontal generatrix. Thus, if the speed increases, the optimum inclination value of the horizontal generatrix for the minimum draft resistance decreases. In loamy soils, at the initial lifting angle ε_1 =30°, when the operating speed is 1…3 m s^{-1}, its optimum value for the share-mouldboard surface on its initial part is correspondingly 40°…25°, for the plough body, as a whole, they can be 65°…33° (if working in a floating mode). When the vertical reaction of the plough (or part of it) with modern tractors having power regulation is transferred to the body of the tractor, the optimal inclination value of the horizontal generatrix obtains medium indices – approximately 50°…30°. At contemporary ploughing speeds 2…2.5 m s^{-1} (7…9 km h^{-1}) the optimal inclination of the horizontal generatrix on the initial part of the share-mouldboard surface is 38°…34°. To ensure sufficient turning of the slice, the angle of the top generatrix must not be less than 48° (Rucins & Vilde, 2006).

If radius r of the mouldboard increases, the draft resistance of the body increases, which is connected with increased partial resistance caused by the weight and adhesion of the soil. For general- purpose ploughs its value varies within the range of 0.5 m.

The working width of the body influences its draft resistance too. If the working width of the body is increased from 30 cm to 50 cm (at constant frontal width of the share), the specific consumption of energy, fuel and the ploughing costs decrease (in loamy soil by 10…16%) but labour efficiency correspondingly increases (Rucins & Vilde, 2005b).

The cutting resistance is proportional to the thickness of the share edge. To obtain a low value of the cutting resistance, its value must be minimal – 2…3 mm. In the ploughing process the share wears out and the thickness of its edge increases to 5 mm, and more. This causes increased draft resistance, especially in hard (dry loamy) soils. Therefore self-sharpening shares are better which do not lose their sharpness in ploughing process.

The conducted investigations show that those ploughs generally meet the requirements mentioned above which have bodies with gently sloping semi-helicoidal or helicoidal share-mouldboard surfaces, such as, the Kverneland plough body No. 8.

There may be cases (at quite a flat share-mouldboard surface) when the draft resistance in wet loamy soils does not increase but even decreases whereas its speed increases (within the range of 1…2 m s^{-1}). Such a phenomenon may occur when the decrease in resistance, due to the lower friction coefficient and specific soil adhesion, proceeds more intensely than the growth in the resistance caused by the soil inertia forces within the given range of speeds.

In such a way, the deduced analytical correlations and the developed computer algorithm enable simulation of the soil coercion forces upon the share-mouldboard surface of the plough body, taking into consideration its draft resistance, as well as determination of the optimum parameters at minimum resistance.

3.2 Simulation Impact of Soil Friction on the Ploughing Resistance

As an example, the calculation results of the impact of the soil friction coefficient f_0 upon the draft resistance of the plough body share-mouldboard (lifting) surface, as well as reacting forces on the supporting surfaces, the draft resistance and the total draft resistance of the entire plough body at the inclination angle ε_1 = 30° of the share (initial soil slice lifting angle), at the inclination angle γ = 30°…50° of the horizontal generatrix and at various speeds v are presented in the following graphs.

The draft resistance of the lifting (share-mouldboard) surface is presented in Fig. 17, the draft resistances of the supporting surfaces - in Figs. 18 and 19, and the total draft resistance of the plough body – in Fig. 19.

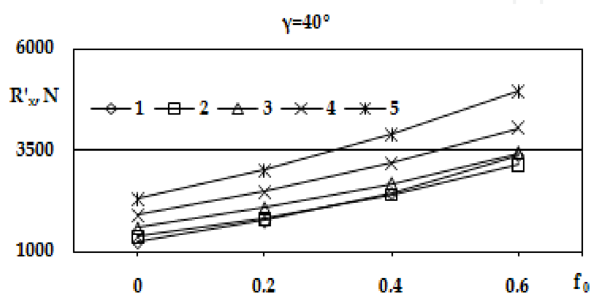
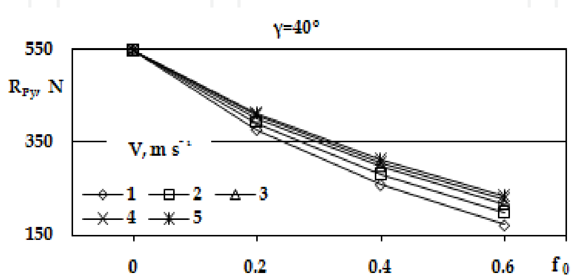


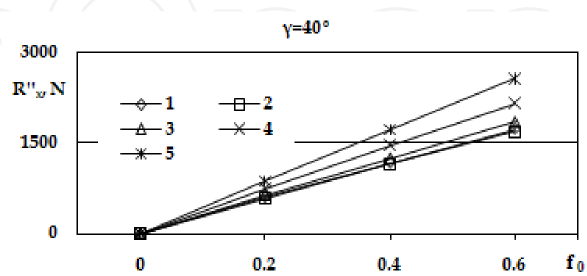
Fig. 17. Impact of the soil friction coefficient f_0 upon the total draft resistance of the plough body share-mouldboard surface caused by the soil gravity, the inertia forces, adhesion and soil cutting resistance at the inclination angle of the horizontal generatrix: γ = 40°.

From the graphs (Fig. 17) it follows that at the soil friction coefficient f_0 = 0.3...0.4 and at the speed v=2…3 m s^{-1}, presently predominating-in ploughing, the draft resistance caused by friction takes 36…42% of the total draft resistance of the share-mouldboard surface.

The graph (Fig. 18 a) shows that at the values of the friction coefficient f_0 = 0.3...0.4 the lateral reaction caused by the soil cutting decreases on 36…55 %.

It follows from the graphs below (Fig. 18 b) that the increase in speed increases the draft resistance of the supporting surfaces caused by soil friction. The value of the inclination angle of the horizontal genetratrix γ at the interval γ = 35°…45° has only a little influence on the draft resistance of the supporting surfaces.





a b

Fig. 18. a - Impact of the soil friction coefficient f_0 upon the lateral reaction caused by the soil cutting with the plough share at the inclination angle of the cutting edge γ_0 = 40°. b - impact of the soil friction coefficient f_0 upon the draft resistance of the supporting surfaces of the plough body at the inclination of the horizontal generatrix γ = 40°.

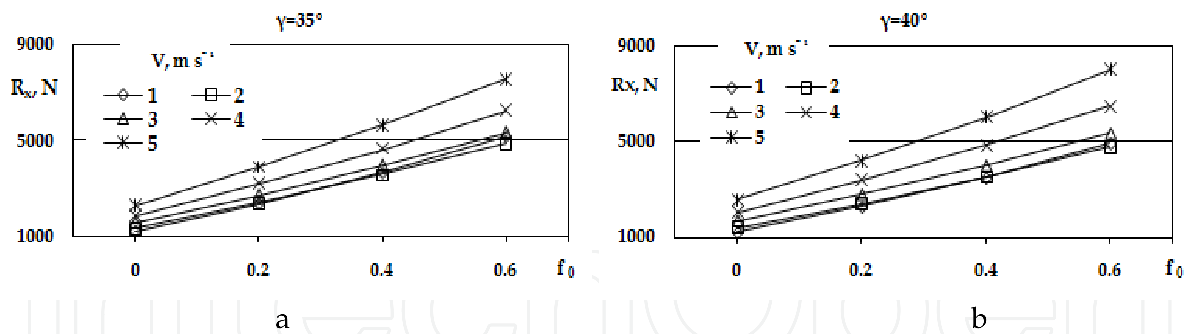


Fig. 19. Impact of the soil friction coefficient f_0 upon the total draft resistance of the plough body at the inclination angle of the horizontal generatrix: a - γ =35°; b - γ = 40°.

It follows from the graphs above (Fig. 19) that at the values of the friction coefficient f_0 = 0.3...0.4 the draft resistance caused by the soil friction takes 46…62 % of the total draft resistance of the plough body. It follows that the total draft resistance is approximately proportional to the friction coefficient. Increasing the speed decreases the share (ratio λ_F) of the friction resistance in the total draft resistance of the plough body. This phenomenon can be explained by the decreasing value of the friction coefficient when the speed is increasing (Vilde et al., 2007).
From the graphs (Fig. 19) it is evident too that at the values of the friction coefficient f_0 = 0.3...0.4 increasing the inclination angle of the horizontal genetratrix γ in the interval γ = 35°…40° increases the draft resistance of the plough body. This phenomenon is in agreement with the previous conclusions that the optimal values for the inclination angle of the horizontal genetratrix γ on the initial part of the share-mouldboard surface are 34…38° (Rucins & Vilde, 2007).
It follows from formulas (19)-(27) too, that increasing the initial lifting angle ε_1 increases the draft resistance of the share-mouldboard surface, including the resistance of the soil friction (Rucins at al., 2007), but increasing the working width of the body decreases the specific draft resistance of ploughing (Rucins & Vilde, 2005b). It was established from them that the optimal values of the initial lifting angle are ε_1 = 28°...32° and the optimal working width of the plough body – b = 45...50 cm.
From the presented example it is evident that the draft resistance of the supporting surfaces is considerable. It can reach 25…30 % of the total plough body draft resistance, or 36…44 % of its share-mouldboard draft resistance.
Therefore it is very important for the reduction of the energy consumption of ploughing to reduce the draft resistance of the supporting surfaces. It may be obtained by using a contemporary hang-up device with the tractors, for example, power regulation allowing the transfer of the vertical reactions of the plough to the body of the tractor (Vilde et al., 2004). It may decrease the draft resistance of the ploughs to 6…10%.

3.3 Simulation Impact of Soil Humidity on the Ploughing Resistance

The methods and equations given above allow studying the regularities of the ploughing draft resistance depending on the humidity of soil, its mechanical composition, the plough body parameters, and its working speed. As an example, comparative studies for simulation the impact of the soil humidity on the ploughing resistance have been made with ploughs having semi-helicoidal bodies with the main parameters given before. Further there is

showed results of simulation impact of the soil humidity on the ploughing resistance for the body with working width 0.45 m.
The indices of some soil properties used in the calculations are given in Table 2.

Type of soil	Content of physical clay m, %	Humidity W, %	Density δ, κg m^{-3}	Coefficient of friction f_0	Specific force of adhesion p_A , Pa	Hardness ρ_0 , MPa
Loamy sand	10	5	1260	0.34	600	3.4
		10	1320	0.36	1600	2.5
		15	1380	0.33	2500	1.6
		20	1440	0.27	2300	0.8
Clay	40	5	1575	0.40	200	12.0
		10	1650	0.38	800	8.9
		15	1725	0.41	2200	5.2
		20	1800	0.37	4000	2.8
		25	1875	0.27	4000	1.2
Clay dark chestnut (temno-kashtanovaya) (Mogilnij, 1957)	63	5	1520	0.64	0	11.0
		10	1595	0.45	200	9.0
		15	1670	0.30	1100	6.5
		20	1740	0.30	3150	4.3
		25	1810	0.42	5400	2.0
		30	1875	0.62	5100	1.0

Table 2. The indices of some soil properties used in calculations

The draft resistance of the plough body and its elements depending on the soil humidity at various working speeds and soil types is shown by the following graphs (Fig. 20).
The graphs above show that variations in the soil humidity have lesser impact on the plough body resistance on the light sandy-loam soils, but a considerable impact – on the clay soils. The clay soils show minima of the resistance at humidity - 18…25%. Such a change of the ploughing resistance depending on the soil humidity is obtained also in the investigations by other researchers, for example, P. U. Bahtin, I. P. Mogilnij a.o. (Bahtin, 1960, pp. 250-259; Mogilnij, 1957, pp. 473-479).
The correlations obtained allow assessment of the ploughing resistance depending on the soil humidity, mechanical composition and the working speed of the plough, determination of the optimal soil humidity range when the tillage capacity is the lowest. Humidity most of all impacts the soil hardness and cutting resistance which considerably dominates in the summary resistance of the plough body. An increase in the soil humidity leads to a decrease in the ploughing resistance that is more remarkable on the clay soils.

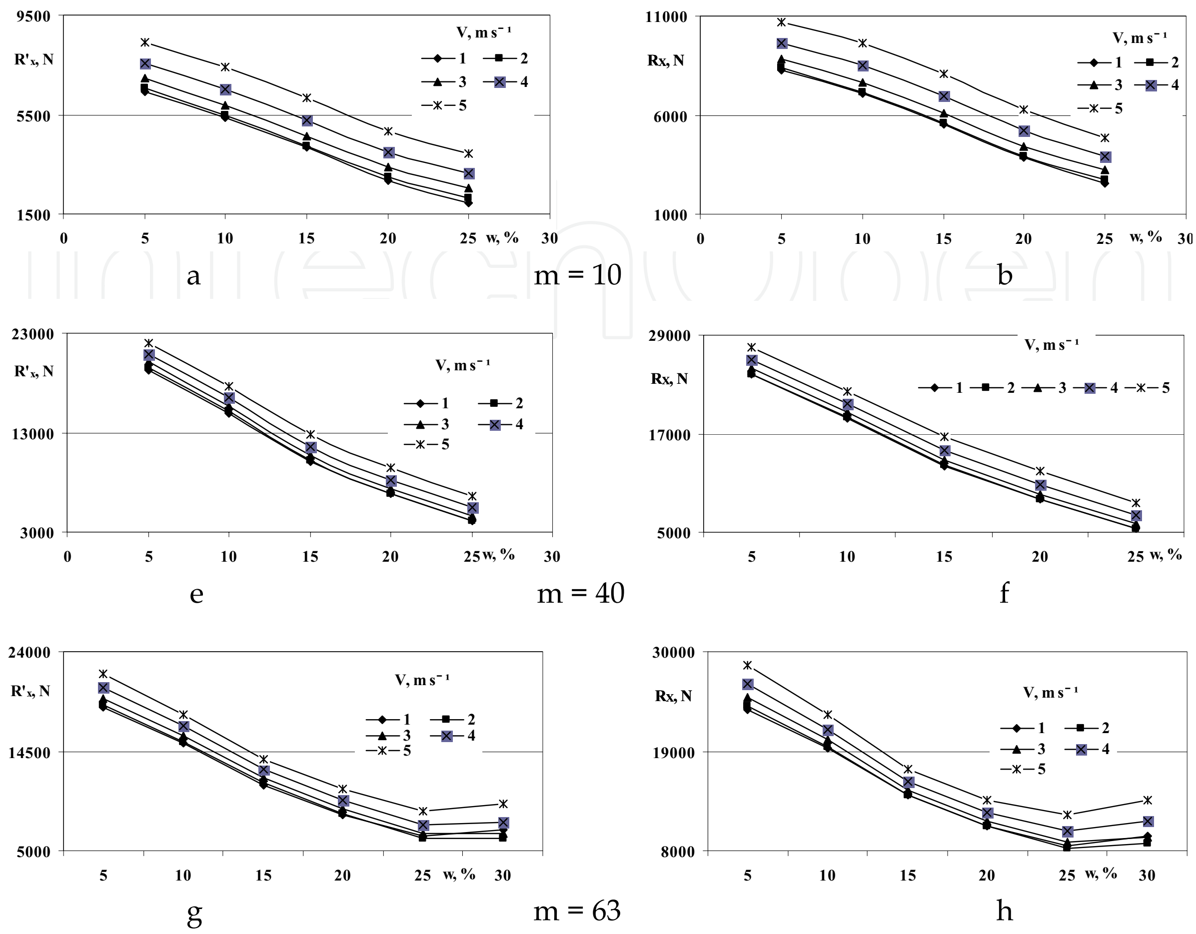


Fig. 20. The draft resistance of the plough body depending on the soil humidity of some soil types and speeds at γ = 40°: a, c, e, – the resistance of the share-mouldboard surface; b, d, f, – the total draft resistance.

4. Discussion

The research material presented by other authors (Vagin, 1965, 1967; Zelenin, 1968; Sineokov & Panov, 1977; Gill & Vanden Berg, 1967) includes analytical correlations for the determination of separate components of draft resistance (caused by the forces of gravity, inertia, soil deformation) fit for simple two-sided and three-sided wedges. However, there are no analytical dependencies for the determination of the draft resistance of curved and complicated wedges (share-mouldboard surfaces). Publications in the theory of share-mouldboard surfaces and determination of the resistance to soil sliding along them (Gyachev, 1961; Goryachkin, 1968; Donner & Nichols, 1934; Gill & Vanden Berg, 1967) are chiefly of general theoretical character and are little significance for practical calculations and clarification of optimum parameters of operating parts. Even the most outstanding scientists in the field of soil tillage machines recognise that "at the present stage of the plough theory the forces of soil resistance arising due to the impact of soil upon the plough bodies cannot be determined through calculations" (Sineokov & Panov,1977, p. 137).

The draft resistance of the operating parts with curved operating surfaces is determined exclusively in an experimental way. In order to clarify the design and adjustment parameters of the operating parts, their physical modelling (simulation) and comparative studies are carried out under various conditions, which is connected with great losses of labour, finances and time; however, not always the best solutions among those compared are optimum ones. Introduction of powerful tractors and subsequent increasing the working speeds need further improvement of the design of soil tillage machines and optimisation of their parameters in accordance with the new conditions and requirements of work. Yet this is hampered by the absence of a reliable theoretical basis, which leads to a delay in the development of the designs of operating parts of soil tillage machines and their disagreement with contemporary requirements.

In the sources provided by other authors there are no materials about the application of the simulation methods in order to study the impact of the plough body parameters, as well as the soil friction properties on the draft resistance of the plough bodies. In order to obtain a better design of the plough body, a series of different bodies were built and tested (Larsen, 1968; Burchenko et al., 1976; Burchenko, 2001; Nikiforov & Ivanov, 1973). Yet it is bound with a great loss of resources, labour and time, so the best solution of the compared variants may not always be the optimum ones.

The materials of our investigations carried out by using the correlations indicated above present the values and regularity of the changes in the forces, the soil friction, acting on the share-mouldboard and the supporting surfaces, the draft resistance of the share-mouldboard and the supporting surfaces, as well as the total resistance of the plough body and its components under the working conditions depending on the body parameters, the soil friction coefficient and the working speed. In such a way it is possible to discover the draft resistance structure of the body, to assess the ratio of each element in the total resistance, to search and find possibilities how to reduce the tillage energy requirement.

On this background special attention should be centred on methods of theoretical estimation of the technological impact upon soil and the draft resistance of the operating parts of the machine as a function of their design parameters under particular conditions of work even if these methods are merely approximate. They enable more profoundly substantiated calculation of machine designs and finding optimum parameters of the operating parts that would ensure qualitative soil tillage with minimum losses of energy resulting in higher yields of the cultivated crops, reduced losses of labour and financial means, i.e., higher efficiency of agricultural production.

To succeed in solving the fixed tasks a new complex approach was needed in order to conduct investigations which consists in the review of a design and parameters of operating parts and machines in close connection with the technological process performed by them, natural and production conditions, modes of work and energetic resources. On the basis of observations we carried out theoretical research applying the relationships of theoretical mechanics (the d'Alembert principle, the Eulerian theorem) to reveal the correlations and mathematical dependencies among phenomena, material destruction, analytical geometry and mathematical analysis. After that the agreement between the calculated and experimental data was proved under laboratory and field conditions. Such an approach allowed working out general propositions concerning the course of the technological process of soil tillage. The methods of mechanics and mathematics applied for its description allowed to state the impact of forces of soil upon the operating parts and their elements, to substantiate rational solution of their design, optimise their parameters, as well as the principal parameters of soil tillage machines and aggregates.

Representation of the total draft resistance of the working part as the sum of partial resistances (resistance to the penetration of the edge into soil, resistance to its deformation, gravity and inertia forces, forces of friction) can also be found in the works by other researchers (Vagin, 1965, 1967; Sineokov & Panov, 1977). However, in contrast to them, there is a different approach in our paper to the division of the total resistance into components (a separate treatment is given to the resistance caused by soil adhesion, attention is paid to the force acting from the adjacent zone of the operating surface, the forces of friction are discussed together with the forces that cause the previous ones, there is considered the impact of other components upon the resistance to soil adhesion). This ensured a possibility to analyse more profoundly and thoroughly the change of each component of the working parts parameters and operating conditions, to determine their influence on the variations in the total resistance and clarify the ways and prospects of their minimisation.

Such a methodical approach allowed deduce generalised analytical correlations that characterise the impact of forces of soil upon the operating parts of soil tillage machines and their elements, to reveal the essence of processes going on in soil tillage, to state the principal factors which influence the resistance of the operating parts. The obtained analytical dependencies of the draft resistance of the wedge and the operating parts are confirmed by experimental data. They do not contradict the well-known relationships and data provided by other researchers, yet in a number of cases they treat in a different way the phenomena that occur during soil tillage and their impact on draft resistance.

So, for instance, in comparison with the Goryachkin rational formula of draft force, the expressions of draft resistance deduced by the author of this paper are more complete since they allow to determine the draft resistance of the machine (plough body) depending on their design and adjustment parameters, physical and mechanical properties of soil, the speed of movement and working conditions. V.P. Goryachkin held the view that the value of the second term in his formula which is proportional to the area of the cross section of the lifted slice of soil is dependent on the resistance to soil deformation but the impact of soil gravity upon the draft resistance of the plough is insignificant and can be ignored (Goryachkin, 1968).

In contrast to this, we found out that the value of the second term depends mainly on the weight of the lifted slice of soil which is actually proportional to the area of its cross section but the resistance caused by soil deformation, especially in soft soils, is insignificant and can be neglected.

Our studies and the obtained expressions of the specific draft resistance confirm V.V.Katsygin's suggestion proposed by analogy with hydrodynamics about the technological pressure of the strip of soil (Katsygin, 1964) although for its definition he presents dependencies of quite different character. According to our studies, the value of the first component of the technological pressure – static pressure – depends on the weight of the slice (column) of soil which is supported by the operating surface of the working part (plough body), and the pressure from the side of soil during the penetration of it in soil. The value of the second component – the dynamic pressure – is defined by the changing amount of motion (kinetic energy) of the slice of soil along the operating surface.

Consequently, the technological pressure of the slice of soil both by the essence of the phenomenon and the form and contents of expressions for their definition is similar to analogous expressions known in hydrodynamics.
The most rational one is such a design of operating parts that ensures qualitative realisation of the technological process with minimum losses of energy, i.e., having minimum specific resistance. It may be related to a unit of the area of the cross section of the of soil slice - K_0, or to a unit of the working width of the machine – K_1 (Vilde, 1999).
In an expanded form the specific resistance written in accordance with the Goryachkin formula of the draft force (Goryachkin, 1968):

$$R_x = f_0 Q + kaB + \varepsilon aB\nu^2 \tag{43}$$

may be presented by the expression

$$K_0 = R_{Qx} q^{-1} + (R_{Px} + R_{Gx} + R_{Dx} + R_{Ax}) q^{-1} + R_{Jx} q^{-1} \tag{44}$$

$$K_0 = k_Q + k + \varepsilon \nu^2 \tag{45}$$

where k and ε are resistance coefficients determined in the Goryachkin formula (43) only in an experimental way but in formulaes (44) and (45) offered by us – through theoretical calculations; k_Q - the component of specific resistance caused by the proper weight of the machine; B - the working width of the machine; a - the depth of soil cultivation.
The sum of the last two terms in formula (45) defines the technological pressure p_0 of the strip mentioned by V.V. Katsygin (Katsygin 1977):

$$p_0 = k + \varepsilon \nu^2 \tag{46}$$

In the last expression k is static pressure and εv^2 the dynamic pressure of the soil slice.
Formulas (1) to (45) offered by us allow to determine through calculation the total resistance of a soil tilling machine or an operating part, as well as its components. They allow also calculating the specific resistance and coefficients of its components k_Q , k and ε:
In a general way

$$k = (R_{Px} + R_{Gx} + R_{Dx} + R_{Ax}) q^{-1} \tag{47}$$

$$k_Q = R_{Qx} q^{-1} \tag{48}$$

$$\varepsilon = R_{Jx} q^{-1} \nu^{-2} \tag{49}$$

The representation of draft resistance in the form of three components obstructs their experimental determination. Therefore we have proposed a two-term formula of draft resistance according to which the total draft resistance of the machine is defined as a static resistance that does not directly depend on the working speed, and a dynamic resistance the value of which is related to the working speed. In this case the specific draft resistance is presented by the expression.

$$K_0 = k' + \varepsilon \nu^2 \tag{50}$$

where k′ - the coefficient of static resistance; ε – the coefficient of dynamic resistance.

$$k' = k_Q + k \tag{51}$$

In a similar way the specific resistance related to a unit of the working width is expressed:

$$K_1 = R_x B^{-1} \tag{52}$$

$$K_1 = k_1' + \varepsilon_1 v^2 \tag{53}$$

where k'_1 - the static resistance of the machine related to a unit of the working width; ε_1 - the coefficient of the dynamic resistance of the machine related to a unit of the working width.
The propositions worked out, the presented methods and research materials allow a new, scientific approach to the development of more rational designs of soil tillage machines, to the improvement of the existing designs and methods of their application.
On the basis of this theoretical research methodology is worked out how at experimental tests to determinate energetic characteristics of the soil tillage machines including ploughs obtaining their coefficients of static and dynamic resistance for compare their (Vilde, 1998).
The existing data allow to draw only some of the relationships linking the frictional properties of soil (the sliding friction coefficient and the specific adhesion force) with individual parameters of its physical condition (mechanical composition and humidity) and the conditions of the sliding process (the speed of sliding and the surface temperature). In order to specify the numerical values of the coefficients and exponents entering the relationships deduced and to arrive at more generalised regularities, it is necessary to carry out a series of complex studies of the frictional properties of various soils under different conditions. A principal diagram has been worked out for such studies in the Baltic region.
Such an all-round investigation of the frictional properties of soil is a highly labour-consuming process. Thus, in order to search out the sliding resistance of mineral soils along steel under various conditions, it is necessary to take more than one million of measurements (Vilde, 1973). Therefore the selective method should be widely used to minimise labour input, and mechanised equipment applied to determine the sliding resistance of soil on the material studied.

5. Conclusions

1. The deduced analytical correlations and the developed computer algorithm enable simulation of the soil coercion forces upon the operating surfaces of the plough body, determination of its specific draft resistance depending on the body design, the working parameters and soil properties and motivation of the optimal values of parameters.
2. Presentation of the draft resistance of the plough body as the sum of its components – the cutting resistance of the soil slice, the resistance caused by its weight, the soil inertia forces and adhesion - allows analysis of the forces acting upon the share-mouldboard surface, finding out the character of their changes depending on speed and the parameters of the surface, and assessment of their ratio in the total resistance.
3. The main parameters affecting the ploughing efficiency are: the initial and the final angles of the lifting (share-mouldboard) surface; the inclination angle of the horizontal generatrix

towards the direction of the movement and the regularity of its variation; the thickness of the share edge; the radius of the lifting surface and the area of the lifting and supporting surfaces.
4. Increase in the inclination of the horizontal generatrix leads to a decrease in the draft resistance caused by the weight and adhesion of soil but it increases the resistance caused by inertia forces, particularly, when the speed increases. The inclination of the generatrix (the edge of the share) does not affect the cutting resistance of the soil slice.
5. In loamy soils, when the speed grows from 1 to 3 m s^{-1}, the optimum value of the inclination angle between the horizontal generatrix of the share-mouldboard surface and the wall of the furrow decreases from 65°…40° to 33°…25° . At the ploughing speed 2…2.5 m s^{-1} it is 38°…34°.
6. To ensure sufficient turning of the slice, the angle of the top generatrix must not be less than 48°.
7. Increasing the working width of the body from 30 cm to 50 cm (at a constant frontal width of the share), the specific consumption of energy, fuel and the ploughing costs decrease (in loamy soil by 10…16%) but the labour efficiency correspondingly increases.
8. The impact of the soil-metal friction upon the draft resistance of the plough body is significant. It may reach 50…60% of total draft resistance including the resistances of the supporting surfaces (25…30%). Therefore measures will be taken to diminution it, for example, using antifriction materials (Teflon or others).
9. The draft resistance of the supporting surfaces is considerable. It can reach 25…30% of the total plough body draft resistance, or 42…54% of its share-mouldboard draft resistance.
10. The correlations obtained allow assessment of the ploughing resistance depending on the soil humidity, mechanical composition and the working speed of the plough, determination of the optimal soil humidity range when the tillage capacity is the lowest. Humidity most of all impacts the soil hardness and cutting resistance which considerably dominates in the summary resistance of the plough body. An increase in the soil humidity leads to a decrease in the ploughing resistance that is more remarkable on the clay soils. The optimum humidity of sticky clay soils when ploughing at a speed 2…2.5m s^{-1} is 18…25%.
11. The optimal values of the main parameters of the bottoms for contemporary ploughs, working at the speeds of 2...2.5 m s^{-1} are: the inclination angle of share towards the furrow bottom – 28°…32°; the inclination angle of the horizontal generatrix towards the furrow wall on the initial part of the share-mouldboard surface – 34°…38°, on the top - not less than 48°; the working width of the bottom – 45…50 cm.
12. The use of bodies having optimal parameters allows obtaining a good ploughing quality, reduction of the draft resistance by 12…20% and a corresponding rise in the efficiency, saving fuel and financial means for ploughing.

6. References

Donner, R.D & Nichols, M.L. (1934). Dynamics of Soil Flow Mouldboard Surfaces Related to Scouring. *Agricultural Engineering,* vol. 15, No.1, pp. 9-12.

Gill, W.R. & Vanden Berg, G.E. (1967). *Soil Dynamics in Tillage and Traction.* Agriculture Handbook No. 316. Washington. 511 p.

Larsen, L.W. Lovely, W.G. & Bockup C.W. (1968). Predicting draught forces using model mouldboard ploughs in agricultural soils. In: *Trans. American Society of Agricultural Engineers,* 11, pp. 665-668.

Riek, H.G. & Vorkal, W. (1965). Experimentelle Untersuchungen iiber die Adhäsion zwischen Boden und festen Werkstoffen. *Landtechnische Forschung,* Jg. 15, H. 5, S. 157-162.

Rucins, A. & Vilde, A. (2004). Mathematical modelling of the operation of plough bodies to determine their draft resistance and optimum parameters. In: TEKA *Commission of Motorization and Power Industry in Agriculture*, Volume IV. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp. 177–184.

Rucins, A.; Vilde A. & Tanas, W. (2006). Forces acting on a plough body. In: TEKA *Commission of Motorization and Power Industry in Agriculture*, Volume VI. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp. 135-145.

Rucins, A. & Vilde, A. (2006). Impact of the Plough Body Parameters on the Soil Tillage Efficiency. *Proceedings 5th International Scientific Conference. Engineering for Rural Development.* Latvia University of Agriculture, Faculty of Engineering, Jelgava, Latvia, pp. 42 – 47.

Rucins, A. & Vilde, A. (2005a). Modelling forces acting on the plough body. In: *Simulation in Wider Europe.* 19th European Conference on modelling and Simulation ECMS 2005 June 1-4, Riga, Latvia, pp. 414-419.

Rucins, A. & Vilde, A. (2005b). Impact of the working width of the plough body on the tillage efficiency. In: *Research for rural development 2005. International scientific conference proceedings.* Jelgava, 19-22 May, 2005. Jelgava, Latvia, pp. 36-42.

Rucins, A.; Vilde, A. & Nowak, J. (2007). Impact of the share inclination angle on the ploughing resistance. In: TEKA *Commission of Motorization and Power Industry in Agriculture*, Volume VII. Polish Academy of Sciences Branch in Lublin, Lublin, Poland, pp. 199–209.

Rucins, A.; Vilde, A. (2003). Impact of soil-metal friction on the draft resistance of ploughs. *Research for rural development 2003. International scientific conference proceedings* Jelgava, Latvia 21-24 May, 2003. Jelgava, Latvia University of agriculture, pp. 61-63.

Vilde, A.; Rucins, A. & Sevostjanovs, G. (2007) Impact of Speed on the Soil Sliding Resistance. In: *International Conference 'Technical and Technological Progress in Agriculture'*, No 12, 20–21 September 2007. Raudondvaris, Lithuania, pp. 34–38.

Vilde, A. (2004). Mechanical and mathematical foundations for modelling the dynamics of soil tillage machine operating parts. In: TEKA *Commission of Motorization and Power Industry in Agriculture*, Volume IV. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp.228–236.

Vilde, A. (2003). The impact of soil moisture and composition on its properties and energy consumption of tillage. In: TEKA *Commission of Motorization and Power Industry in Agriculture,* Volume III. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp. 249–255.

Vilde, A. (1999). Dynamics of the soil tillage machine operating parts and their elements. In: *Proceedings of the Latvia University of Agriculture*, Vol.1 (295). Jelgava, Latvia, pp. 36-44.

Vilde, A. (1998). Energetical estimation of soil tillage machines by testing. Theoretical motivation and methods. *Proceedings of the Latvia University of Agriculture. B – Technical sciences,* Nr. 13 (290), Jelgava, Latvia, pp. 39- 54.

Бредун, М. И. (1969). К вопросу исследования фрикционно-адгезионных свойств почвы. *Труды ВИМ,* т. 36, Москва, с. 103-121.

Бурченко, П.Н.; Иванов, А.Н.; Кашаев, Б.А.; Кирюхин, В.Г. & Мильцев, А.И. (1976). Результаты исследования рабочих органов скоростных плугов. В кн.: *Повышение рабочих скоростей машинно-тракторных агрегатов.* Москва: Колос, с. 215-218.

Бурченко, П.Н. (2001). К теории развертывающейся лемешно-отвальной поверхности корпуса плуга. В кн.: *Машинные технологии и техника для производства зерновых, масличных и зернобобовых культу. Сборник научных докладов*, том 3, часть 1. Москва: ВИМ, с. 38-51.

Вагин, А. Т. (1965). К вопросу взаимодействия клина с почвой. Обоснование основных параметров агрегатов для послойного внесения удобрений в почву В кн.: *Вопросы сельскохозяйственной механики.* Минск: Урожай, т.15, с. 4-152.

Вагин, А. Т. (1967). К вопросу обоснования параметров рабочих органов для основной обработки почв. - В кн.: *Вопросы сельскохозяйственной механики*. Минск: Урожай, т.16, с. 57-98.

Вилде, А.А. (1976). К вопросу резания грунта клином. В кн.: *Механизация и электрификация сельского хозяйства.* Рига: Звайгзне, вып. 2 (9), с. 115-129.

Вилде, А.А. (1973). О рациональности конструкции рабочих органов почвообрабатывающих орудий для работы на повышенных скоростях. В кн.: *Повышение рабочих скоростей машинно-тракторных агрегатов.* Москва: Колос, с. 367-374.

Вилде, А.А. (1983). К определению сопротивления отделению пласта от почвенного массива. В кн.: *Механизация и электрификация сельского хозяйства.* Рига: Авотс, вып. 8 (15), с. 184-203.

Вилде, А.А. (1973). Исследование закономерностей сопротивления скольжению почвы по стали. В кн.: *Труды ЛатвНИИМЭХ,* т. IV. Рига: Звайгзне, с. 183-195.

Дерягин, Б. В. (1963). *Что такое трение*. М., 1963, 230 стр.

Гячев, Л.В. (1961). *Теория лемешно-отвальной поверхности*. Зерноград. 317 с.

Горячкин, В.П. (1968). *Собрание сочинений.* 2-е изд. Москва: Колос, т.2. – 456 с.

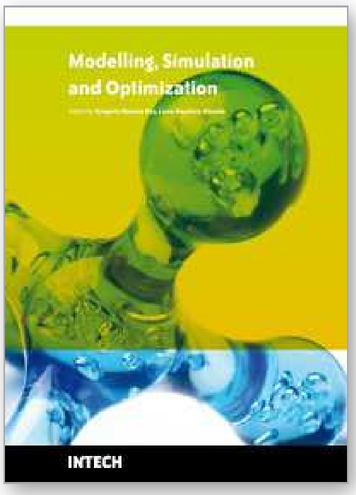
Кацыгин, В.В. (1954). Основы теории выбора оптимальных параметров мобильных сельскохозяйственных машин и орудий. В кн.: *Вопросы сельскохозяйственной механики.* Минск: Урожай, т.13, с. 5-147.

Могильный, И. П. (1957). Влияние влажности на удельное сопротивление и трение металлов корпуса плуга о почву. *Научные труды Украинской СХА,* т. IX, Киев, с. 473-479.

Никифоров, П.Э. & Иванов, А.Н. (1973). Исследование рабочих органов плугов для работы со скоростями 10-15 км/ч. В кн.: *Повышение рабочих скоростей тракторов и сельскохозяйственных машин.* Москва: ЦИНТИАМ, с. 197-203.

Синеоков, Г.Н. & Панов, Н.И. (1977). *Теория и расчет почвообрабатывающих машин.* Москва: Машиностроение. 328 с.

Зеленин, А.Н. (1968). *Основы разрушения грунтов механическими способами.* Москва: Машиностроение. 376 с.



Modelling Simulation and Optimization
Edited by Gregorio Romero Rey and Luisa Martinez Muneta

ISBN 978-953-307-048-3
Hard cover, 708 pages
Publisher InTech
Published online 01, February, 2010
Published in print edition February, 2010

Computer-Aided Design and system analysis aim to find mathematical models that allow emulating the behaviour of components and facilities. The high competitiveness in industry, the little time available for product development and the high cost in terms of time and money of producing the initial prototypes means that the computer-aided design and analysis of products are taking on major importance. On the other hand, in most areas of engineering the components of a system are interconnected and belong to different domains of physics (mechanics, electrics, hydraulics, thermal...). When developing a complete multidisciplinary system, it needs to integrate a design procedure to ensure that it will be successfully achieved. Engineering systems require an analysis of their dynamic behaviour (evolution over time or path of their different variables). The purpose of modelling and simulating dynamic systems is to generate a set of algebraic and differential equations or a mathematical model. In order to perform rapid product optimisation iterations, the models must be formulated and evaluated in the most efficient way. Automated environments contribute to this. One of the pioneers of simulation technology in medicine defines simulation as a technique, not a technology, that replaces real experiences with guided experiences reproducing important aspects of the real world in a fully interactive fashion [iii]. In the following chapters the reader will be introduced to the world of simulation in topics of current interest such as medicine, military purposes and their use in industry for diverse applications that range from the use of networks to combining thermal, chemical or electrical aspects, among others. We hope that after reading the different sections of this book we will have succeeded in bringing across what the scientific community is doing in the field of simulation and that it will be to your interest and liking. Lastly, we would like to thank all the authors for their excellent contributions in the different areas of simulation.

Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821