IMPACT OF THE SHARE INCLINATION ANGLE ON THE PLOUGH BODY RESISTANCE

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Abstract

The main parameters of the plough body that determine the ploughing efficiency are the initial and the final soil strip lifting angles on the share-mouldboard surface, the angles of its horizontal generatrix, the radius of this surface, and the working width of the body. By using analytical correlations derived as a result of theoretical research, a computer algorithm has been worked out for simulating the functions of the plough body and the forces exerted by soil upon the operating parts, as well as its draft resistance. These correlations allow to determinate the forces acting on the plough body and its draft resistance depending on the share inclination angle, as well as to evaluate its impact on the ploughing efficiency: energy, and the fuel consumption, and the quality of work. 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 strip must have a minimal value, its optimum may vary 28…32°. The use of bodies having optimal parameters allows obtaining good ploughing quality, reduce draft resistance by 12…20% and to raise correspondingly the efficiency, to save fuel and financial resources for ploughing.

Key words: plough body parameters, forces acting on the plough body, draft resistance, optimisation of parameters.

Introduction

Ploughing is one of the most power-consuming and expensive processes in agricultural production. It is known from our previous investigations (Vilde, 1999, 2004; Ruciņš et al., 2005) 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. However, there were no sufficient analytical correlations that would enable to determine the impact of the share inclination angle 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.

The purpose of the investigations is to study the factors that determine the quality and energy requirement of ploughing, the impact of body, parameters on it and to find technical solutions for its improvement.

Materials and Methods

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 (Ruciņš et al., 2005) 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).

Results and Discussion

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 (Vilde, 1999, 2004; Ruciņš et al., 2004, 2005). According to this investigation, the draft resistance R_x of the plough body 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 plough body itself (including a part of the weight of the plough). However, the latter is not dependent on the plough parameters:

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

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

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

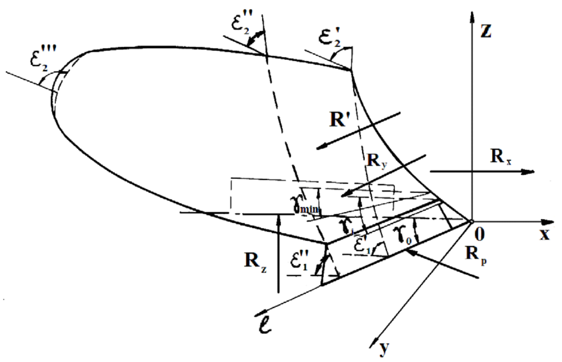

Figure 1. Scheme of the plough body, its parameters and acting forces.

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:

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

where

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

p_{Axy} and p_{Axz} – specific adhesion force, respectively, to the lower and the lateral supporting surfaces of the plough body;

S_{xy} and S_{xz} – the surface area of the lower and lateral supporting surface of the plough body.

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

$$R'_{Px} = k_p \rho_0 ib \,, \quad (5)$$

where

k_p – 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):

$$R_{Pz} = 0 \,. \quad (6)$$

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:

$$R_{Py} = k_p \rho_0 ibctg(\gamma_0 + \varphi_0), \quad (7)$$

where

γ_0 – the inclination angle of the edge towards the direction of movement (the wall of the furrow);

φ_0 – the angle of friction.

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

$$R''_{Px} = k_p \rho_0 ibf_0 ctg(\gamma_0 + \varphi_0) = F''_{Px} \,. \quad (8)$$

The total cutting resistance

$$R_{Px} = k_p \rho_0 ib\left[1 + f_0 ctg(\gamma_0 + \varphi_0)\right] \,. \quad (9)$$

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.

Forces caused by the weight of the lifting soil strip:

$$R'_{Gx} \approx q\delta g k_y r \sin^{-1}\gamma \left\{ \left[(\sin\gamma \cos\varepsilon_1 + \cos^2\gamma \sin^{-1}\gamma) e^{f_0 \sin\gamma (\varepsilon_1 - \varepsilon_2)} - \right.\right.$$
$$- (\sin\gamma \cos\varepsilon_2 + \cos^2\gamma \sin^{-1}\gamma)\right] \cos\varepsilon_1 (\cos\varepsilon_1 e^{f_0 \sin\gamma (\varepsilon_2 - \varepsilon_1)} - \cos\varepsilon_2) *$$
$$* (\cos\varepsilon_1 - f_0 \sin\varepsilon_1 \sin\gamma)^{-1} \sin\varepsilon_1$$
$$\left.\left[\sin\varepsilon_1 \sin\gamma + f_0 (\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma)\right]\right\}, \quad (10)$$

$$R_{Gz} \approx q\delta g r \sin^{-1}\gamma \, (\varepsilon_2 - \varepsilon_1), \quad (11)$$

$$R_{Gy} \approx q\delta g r \sin^{-1}\gamma \, (\varepsilon_2 - \varepsilon_1)(\varepsilon_1 + 0.52) \, ctg\,\gamma, \quad (12)$$

$$R''_{Gx} = f_0 (R_{Gz} + R_{Gy}) = F''_{Gx}. \quad (13)$$

Forces caused by the soil inertia:

$$R'_{Jx} = q\,\delta\, v^2 k_y^{-1} \sin\gamma \left\{ (\sin\gamma \cos\varepsilon_1 + \cos^2\gamma \sin^{-1}\gamma) e^{f_0 \sin\gamma (\varepsilon_1 - \varepsilon_2)} - \right.$$
$$- (\sin\gamma \cos\varepsilon_2 + \cos^2\gamma \sin^{-1}\gamma) +$$
$$+ (\cos\varepsilon_1 - f_0 \sin\varepsilon_1 \sin\gamma)^{-1} e^{f_0 \sin\gamma (\varepsilon_2 - \varepsilon_1)} \sin\varepsilon_1$$
$$\left.\left[\sin\varepsilon_1 \sin\gamma + f_0 (\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma)\right]\right\}, \quad (14)$$

$$R_{Jz} = q\,\delta\, v^2 k_y^{-1} \sin\gamma \, \sin\varepsilon_2 \, e^{f_0 \sin\gamma \, (\varepsilon_2 - \varepsilon_1)}, \quad (15)$$

$$R_{Jy} \approx q\,\delta\, v^2 k_y^{-1} \sin\gamma \, \cos\gamma \, (1 - \cos\varepsilon_2), \quad (17)$$

$$R''_{Jz} = f_0 (R_{Jz} + R_{Jy}) = F''_{Jx}. \quad (18)$$

Forces caused by soil adhesion:

$$R'_{Ax} = p_A b r \sin^{-1}\gamma \, (e^{f_0 \sin\gamma (\varepsilon_2 - \varepsilon_1)} - 1) *$$
$$* \left\{ \sin\gamma \cos\varepsilon_1 + \cos^2\gamma \sin^{-1}\gamma + (\cos\varepsilon_1 - f_0 \sin\varepsilon_1 \sin\gamma)^{-1} * \sin\varepsilon_1 \right.$$
$$\left.\left[\sin\varepsilon_1 \sin\gamma + f_0 (\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma)\right]\right\}, \quad (19)$$

$$R_{Az} = 0, \quad (20)$$

$$R_{Ay} \approx 0, \quad (21)$$

$$R''_{Ax} = f_0 (p_{Axy} + p_{Axz} S_{xz}) = F''_{Ax}. \quad (22)$$

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).

The soil friction coefficient and the specific force of soil adhesion are not constant values. Their values decrease with the increase in speed (Vilde et al., 2004). This is considered in calculations.

The obtained correlations (10) – (19) show how the initial lifting angle ε_1 of the soil strip (the inclination angle of the share) impacts the draft resistance of the share-mouldboard surface, the resistance of the supporting surfaces, and of the plough body in totality. The following graphs (Figs. 2 –12) show those changes of the draft resistances depending on the initial lifting angle ε_1 at the angle between the horizontal generatrix of the operating surface and the vertical longitudinal plane γ=*40°* and at the different speed v.

From the above graphs it follows that increasing of the share inclination angle ε_1 leads to increasing of partial resistances caused by soil strip gravity, inertia forces and adhesion and, as a result – increasing the draft resistance R'_x of the share mouldboard surface (lifting surface) of the plough body from 6% to 13% (Figs. 2 – 5). The increase of the resistance is more remarkable at high speeds.

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 (Vilde et al., 2004).

Increasing of the share inclination angle leads to decreasing of the vertical reaction R_x (reaction of the lower

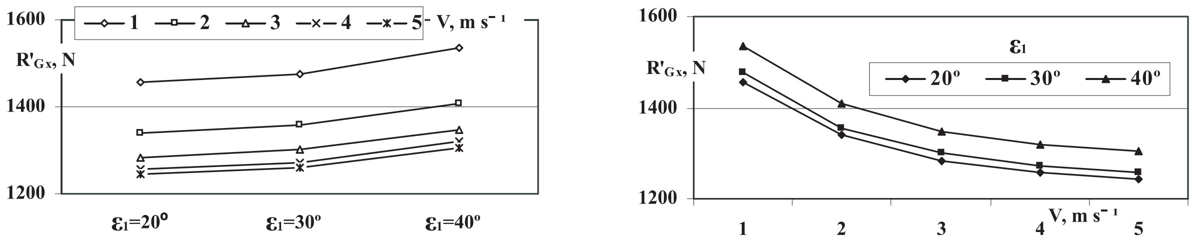

Figure 2. Draft resistance of the lifting surface caused by the gravity of the soil strip depending on the initial lifting angle ε_1 and speed ν.

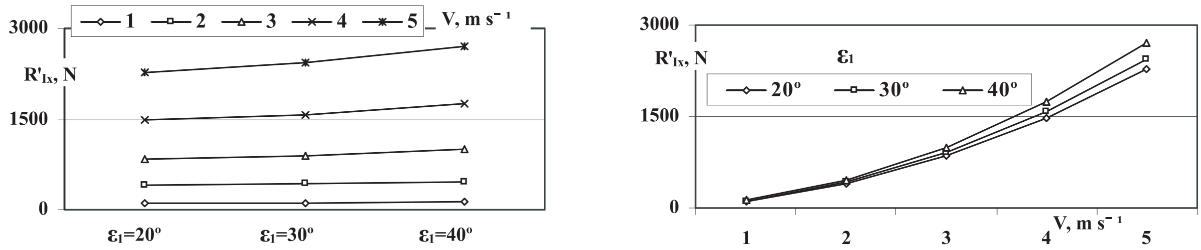

Figure 3. Draft resistance of the lifting surface caused by the soil inertia forces of the soil strip depending on the initial lifting angle ε_1 and speed ν.

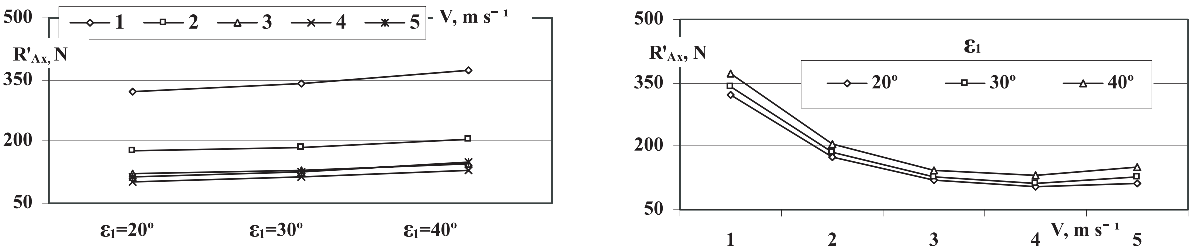

Figure 4. Draft resistance of the lifting surface caused by soil adhesion depending on the initial lifting angle ε_1 and speed ν.

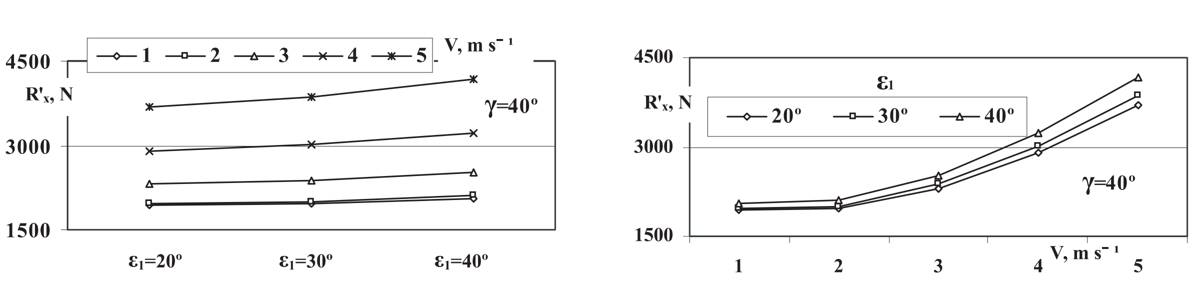

Figure 5. Total draft resistance of the lifting surface caused by soil gravity, inertia forces and adhesion depending on the initial lifting angle ε_1 and speed ν.

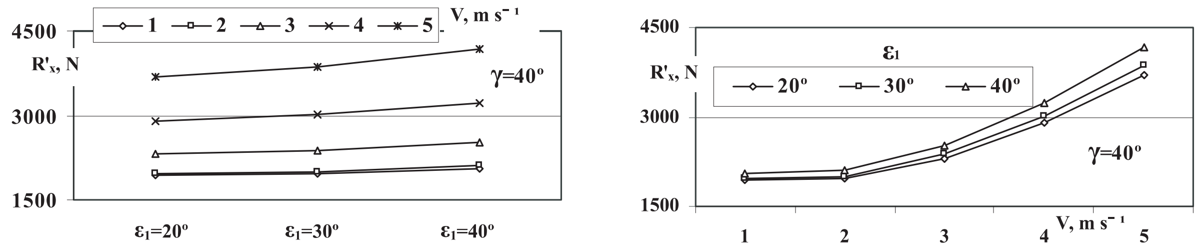

Figure 5. Total draft resistance of the lifting surface caused by soil gravity, inertia forces and adhesion depending on the initial lifting angle ε_1 and speed ν.

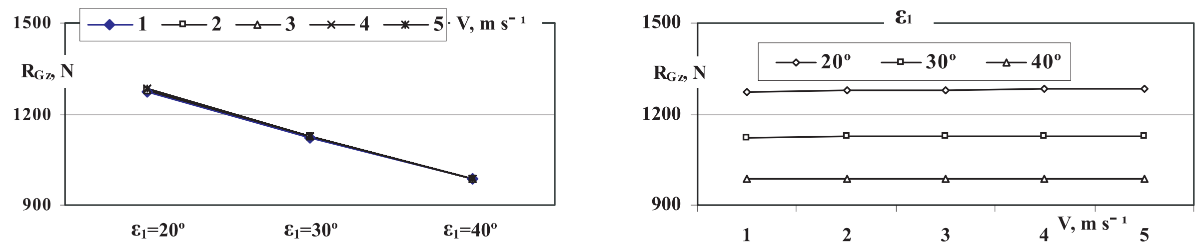

Figure 6. Reaction of the lower supporting surface caused by the gravity of the soil slice depending on the initial lifting angle ε_1 and speed ν.

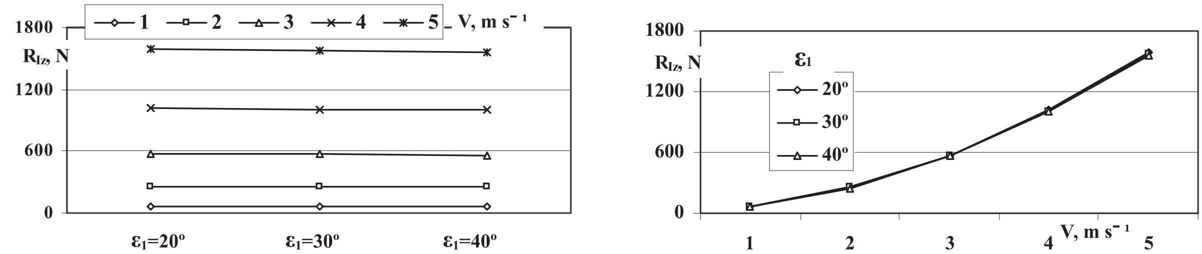

Figure 7. Reaction of the lower supporting surface caused by soil inertia forces depending on the initial lifting angle ε_1 and speed ν.

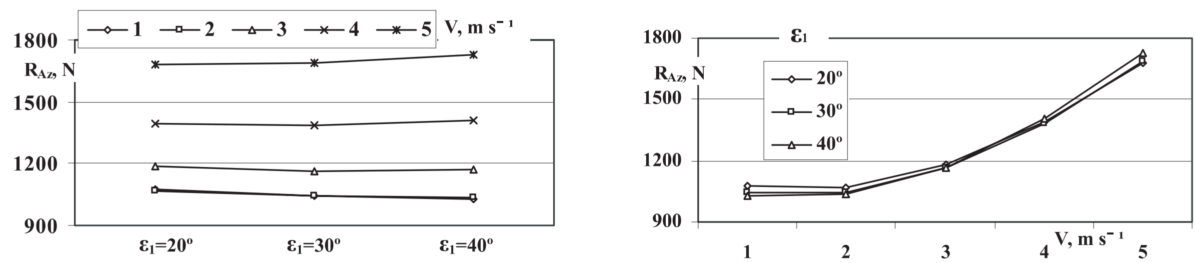

Figure 8. Reaction of the lower supporting surface caused by soil adhesion depending on the initial lifting angle ε_1 and speed ν.

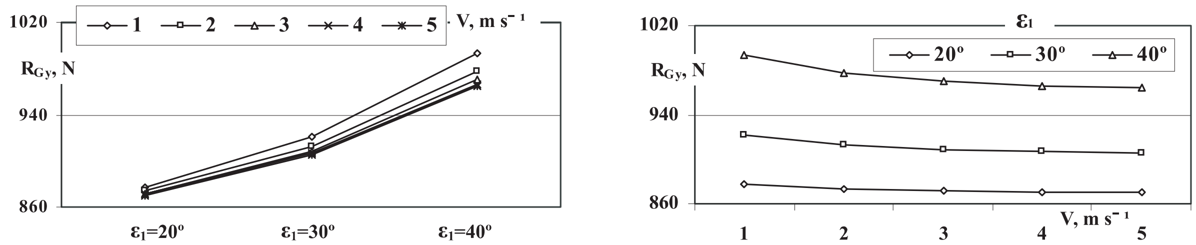

Figure 9. Reaction of the lateral supporting surface caused by the gravity of the soil strip depending on the initial lifting angle ε_1 and speed ν.

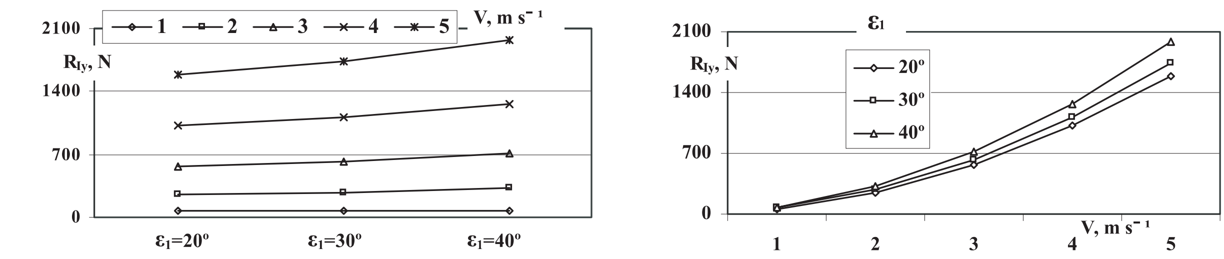

Figure 10. Reaction of the lateral supporting surface caused by soil inertia forces depending on the initial lifting angle ε_1 and speed ν.

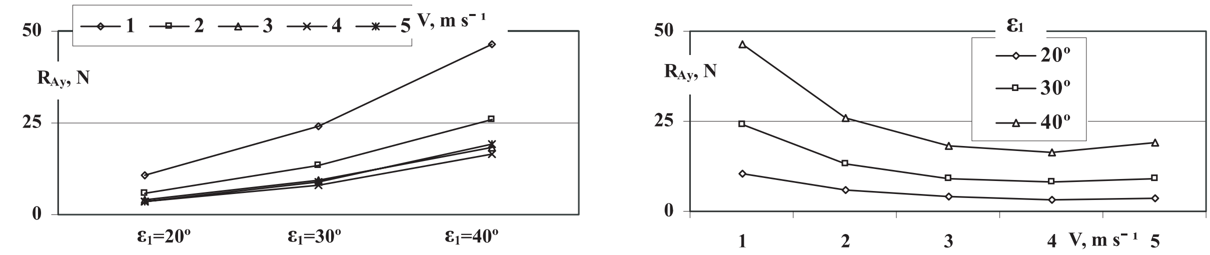

Figure 11. Reaction of the lateral supporting surface caused by soil adhesion depending on the initial lifting angle ε_1 and speed ν.

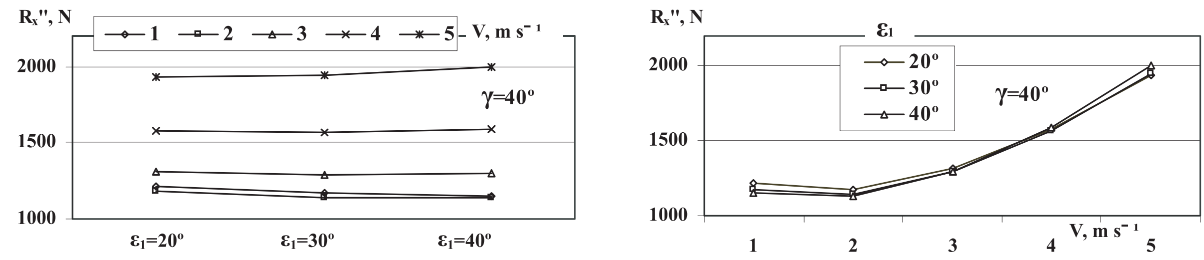

Figure 12. Summary draft resistance of the plough body supporting surfaces depending on the initial lifting angle ε_1 of the soil strip and speed ν.

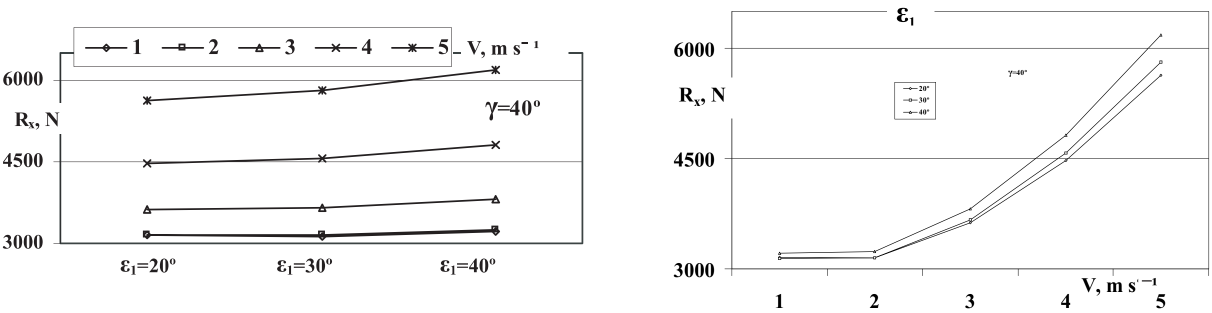

Figure 13. Total draft resistance of the plough body depending on the initial lifting angle ε_1 of the soil strip and speed ν.

supporting surface) caused by soil strip gravity, has less influence on it of the forces caused by inertia and adhesion (Figs. 6 - 8) and leads to increasing of the lateral reactions caused by all theses forces (Figs. 9 – 11). In connection with that the change of the share inclination angle has insignificant influence on the draft resistance $R^{//}_x$ of the supporting surfaces (Fig. 12).

Changes in of the total draft resistance of the plough body depend on the mode of operation. If the plough is working in a floating mode, then increasing of the share inclination angle increases the draft resistance R_x of the plough bodies from 2% to 10% (Fig. 13), but if the plough is working with a power regulation means, the changes in the total draft resistance may be followed by the draft resistance changes in the share-mouldboard surface (at lower values of the total resistance the floating mode of operation).

The resistance component R_{px} to the cutting of a soil strip is not included into total resistance of the plough body, which is not dependent on the ploughshare inclination but on its sharpness (thickness of the cutting edge).

The materials of the calculations which were carried out using the correlations given 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 and the working speed. Possibilities to reduce the tillage energy requirement have been clarified.

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 strip (the angle between the share and the furrow bottom) must have a minimal value – 24…30°. A smaller inclination angle is not desirable because of the wear 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. For safer work in hard loamy soils its optimal value may be approximately 30° (28…32°).

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.

The use of bodies having optimal parameters allows obtaining good ploughing quality, reduce draft resistance by 12…20% and to raise correspondingly the efficiency, to save fuel and financial resources for ploughing (Ruciņš et al., 2004).

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 strip, 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. By increasing the initial lifting angle ε_1 (inclination angle of the share toward furrow bottom), the draft resistance increases. For safer work in hard loamy soils its optimal value may be approximately 30° (28…32°).

5. 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 resources for ploughing.

References

1. 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.
2. 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.
3. 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.
4. Vilde A., Rucins A. (2004) The impact of soil physical and mechanical properties on draft resistance of ploughs. In: TEKA Commission of Motorization and Power Industry in Agriculture, Volume IV. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp. 243–248.
5. Vilde A., Cesnieks S., Rucins A. (2004) Minimisation of soil tillage. In: TEKA Commission of Motorization and Power Industry in Agriculture, Volume IV. Polish Academy of Sciences Branch in Lublin. Lublin, Poland, pp. 237 – 242.
6. Rucins A., Vilde A. (2005) Modelling forces acting on the plough body. Simulation in Wider Europe. 19th European Conference on modelling and Simulation ECMS 2005 June 1-4, 2005 Riga, Latvia. Riga, pp. 414-419.
7. Rucins A., Vilde A. (2005) 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, pp. 36-42.