DEVELOPMENT OF AGRICULTURAL MECHANICS

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Abstract. A brief review is given on the research carried out in the field of agricultural mechanics. Agricultural mechanics is a subdivision of science about the functional relations of agricultural technological processes and machinery, which provides the possibility to improve the motivation, productivity and effectiveness of the mechanisation of agricultural production. Their cognition provides a possibility to improve the mechanisation issues of agricultural production in a more motivated, economical and faster way. A considerable development in agricultural mechanics was achieved in soil tillage (terra mechanics), field crop growing, beet harvesting, the design of broad-grip machines and aggregates by finding new relations between technological processes and functioning of machines and their working parts. The obtained correlations allow to apply a method of simulation and modelling technological processes and function of machine working parts, and to determine the optimal parameters of the operating parts for machines and the draft resistance in connection with the technological properties of soil and working mode. A study has been carried out of probable plant spacing in the field crop and vegetable plantations and their corresponding yields by sowing seeds at exact intervals and growing them without thinning. Mathematical coherences for the determination of the plant spacing density and their distribution were obtained. It is stated that the plant spacing density is a function of the seed germinating power in the field.

Keywords: agricultural mechanics, terra mechanics, mechanics of the broad-grip machines, optimisation of parameters, plant density, plant spacing.

Introduction

Nothing is more practical like a good theory. This cognition has been constantly leading in the research work for the authors of this paper. That is why the studies in soil tillage mechanics have been unofficially conducted already since the time the Institute started its operation, but officially became a theme of research in 1997.

Agricultural mechanics is a subdivision of science about the functional relationships of agricultural technological processes and machinery. Their cognition provides a possibility to improve the mechanisation issues of agricultural production in a more motivated, economical and faster way. Since 1990 the research work at the Institute is connected with investigations in soil mechanics, the choice of energy-saving rational technologies for the production of agricultural crops. Studies have been conducted to raise the quality of soil tillage, to reduce the energy requirement and costs.

The paper was presented (in the Latvian language) at the 3rd Latvian World Congress in Jelgava at the Latvia University of Agriculture on October 26, 2011 and was recommended to be published.

The purpose of the research: to find out objective relations between agricultural technological processes, function of working parts, machines and aggregates as well as to develop their design and optimisation of parameters, to clarify mathematical coherences between the plant spacing density, their distribution and desired amount of yields.

Materials and Methods

Development of agricultural mechanics is connected with problems and tasks of extension and perfection of mechanised agricultural production.

Approaches have been formulated and motivated concerning the course of the soil tillage technological processes and of energy requirement. In contrast to the previous views, a hypothesis was advanced and proved by Vilde that the draft resistance of the operating parts of the machines and the respective soil tillage energy requirements depend on the impact of dual forces upon them: the forces which are determined by the mechanical properties of soil (the mechanical strength (hardness) which cause resistance to the penetration of the operating parts into soil, as well as resistance to its deformation, and the forces that depend on the physical properties of soil (the forces of weight and inertia caused by the transferred mass of soil, as well as resistance to friction and adhesion). Guided by this conclusion, relations of the strength of materials and theoretical mechanics are applied for analytical determination of the forces acting upon the operating parts of the machines and their elements. The obtained analytical relations are used for the determination of the optimal parameters of the operating parts of the machines and the draft resistance in connection with the technological properties of soil and mode of working.

Theoretical and experimental research has been carried out to obtain the relations of the plant density, their spacing and crop yields. The theories of probability and mathematical statistics were used in these investigations. The results of theoretical research carried out to clear up the relationships of the plant density and their spacing have been affirmed with experimental data.

Results and Discussion

Development of agricultural mechanics is connected with problems and tasks of extension and perfection of mechanised agricultural production. It proceeded in the nine main directions:

- soil tillage mechanics (terra mechanic);
- mechanics of sugar beet diggers;
- mechanics of cutting device for beet haulm;
- mechanics of sugar beet cleaning devices;
- mechanics of broad-grip machines and aggregates;
- mechanics of soil sliding along the surfaces of the operating parts;
- mechanics of motion stability;
- simulation and modelling technological processes and functions of machine working parts;
- modelling plant spacing and yields of crops.

Energy–saving soil tillage technologies and machines. The theoretical and experimental research of the energy requirement for the soil tillage processes, as well as the technical solutions and recommendations for its reduction have been included into several dozens of publications with a common subject matter in Latvian, Russian, and, since 1997, also in the English language. Approaches have been formulated and motivated concerning the course of the technological processes of soil tillage and energy requirements.

The results of the research undoubtedly confirm the hypothesis advanced by us.

The obtained analytical relations are used for the determination of the optimal parameters of the operating parts of the machines and the draft resistance in connection with the technological properties of soil. These methods and the obtained relations allow motivation for the solution of an energy–saving technology and design of the operating parts, the development of highly efficient, economic machines and aggregates for the basic soil tillage and its pre-sow preparation, as well as finding ways of their efficient application [1; 2].

Approximately half of the draft resistance of the soil tillage machines (ploughs) arises due to the resistance of soil sliding along the surfaces of the operating parts. In order to study this phenomenon more extensively and intensively, a computerised tribometric stand was developed in 2003 and used by the students of the Master and Doctoral studies for working out the promotion papers, as well as for other research connected with the tillage and the physic–mechanical properties of soil. It will be used for investigations of the friction resistance of other materials, too.

Motivated by more efficient energy saving technologies, machines have been developed on the basis of the research materials for the basic and pre-sow tillage of soil. 16 kinds of machines are developed for more efficient soil tillage under zonal conditions, for example: ploughs with a gently sloping helicoidal or semihelicoidal share-mouldboard surface of their bodies [2], cultivators having a S-type spring tooth with a narrow frontal surface and shallow adjust angle of the shovel, rotary knife harrows, drag-harrows, combined machines and aggregates, and others. The developed and recommended solutions are applied in the machine designs at the enterprises of Latvia and other countries (CIS) [3].

A new improved method has been worked out for the optimisation of the functional parameters of soil tillage aggregates. The optimum parameters: the speed and the working width of the machine to gain maximum efficiency of the soil tillage aggregates with minimum energy (fuel) consumption, the relations of the draft power of the tractor and the specific resistance (power) of the machines being as the functions of speed. In order to achieve high specific efficiency of the soil tillage aggregates with a minimum consumption of energy, machines should be used with a low coefficient of the dynamic resistance. By means of this method optimal parameters of harrowing, ploughing and cultivation are determined. They are applied to substantiate the working width of the designed machines and aggregates, as well as to choose and complete sets of machines for high–speed and powerful tractors.

The obtained analytical relations are used for the determination of the optimal parameters of the operating parts of the machinery and the draft resistance in connection with the technological properties of soil and mode of working. There we have received nine certificates on inventions.

The mechanics of sugar beet diggers developed by A. Vilde is a subdivision of terra mechanic. There is explicated the theory of functioning and energetics of one share and two share diggers [4]. For beet harvesters a haulm cutting apparatus with adjustable correction of the cutting height that improves the quality of its work was constructed by A. Vilde [5]. There we have received two certificates of invention. A. Vilde has made improvements to the mechanics of sugar beet digging, transportation and cleaning devices for working in rocky soils (three certificates of invention), that increase their working safety under the Latvian conditions [6].

For efficient introduction and for using big high powered tractors, A. Vilde, U. Pinnis, A. Cesnieks, U. Berzins had established the main principles of designing broad-grip high speed soil tillage and seeding machines and aggregates for the work on uneven rugged terrain fields [3; 7 – 9]. Under the Latvian conditions the best machines are mounted ones, also many-unit wide aggregates during the operation of which it is possible to transfer their extra weight (in order to perform technological operations) to the tractor using the automatic control system of the tractor hydraulic hitch-up device, hydraulic loaders or other analogous means. For this purpose original constructions and modes of functioning of machines, couplings and aggregates were created, earning 15 certificates of invention.

Mathematical methods and computer algorithms were worked out for the simulation of soil tillage processes allowing calculations of the forces acting upon the machine operating parts and their optimal design (including the plough body) for qualitative soil tillage with minimum energy consumption [1; 2; 10]. By using the methods of the probability theory and mathematical statistics distribution relationships of the plants and their density were theoretically determined in the sugar beet plantations, as well as their impact on the expected yield, which were confirmed in the experimental research. It was discovered that the distribution irregularity of the plants was functionally dependent on the germination power of the seeds on the field: the higher their germination power, the higher their homogeneity of distribution, and vice versa [11]. For example, estimation of the draft resistance and optimal parameters of the plough body are given (Fig. 1).

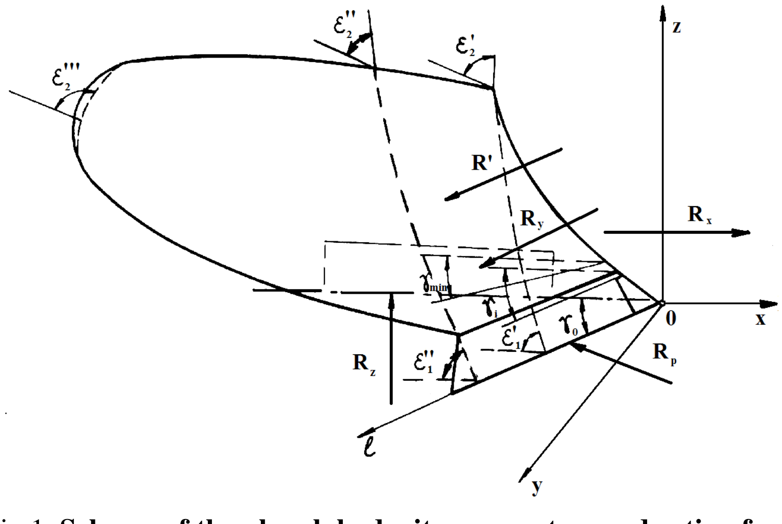

Fig.1. **Scheme of the plough body, its parameters and acting forces**

According to the research the draft resistance R_x of the plough body is determined by the share cutting resistance R_{Px}, the resistance caused by the weight R_{Gx} of the strip lifted, by the inertia forces R_{Jx}, by the soil adhesion R_{Ax} and by the 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.

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

$$R_x = R'_x + R''_x = \sum R'_{ix} + f_0\,(\sum R_{iz} + \sum R_{iy} + p_{Axy}\,S_{xy} + p_{Axz}\,S_{xz})\,, \tag{2}$$

where f_0 – coefficient of soil friction along the working and supporting surfaces of the operating part;
p_{Axy}, p_{Axz} – specific adhesion force, respectively, to the lower and the lateral supporting surfaces of the operating part;
S_{xy}, S_{xz} – surface area of the lower and the lateral supporting surfaces of the operating part.

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

$$R'_{Px} = k_p \rho_0\,\omega = k_p \rho_0\, ib\,, \tag{3}$$

where k_p is the coefficient involving the impact of the shape of the frontal surface of the ploughshare edge;
i, b – the thickness and width of the edge.

At a sharp ploughshare (the rear bevel is absent):

$$R_{Pz} = 0. \tag{4}$$

At an inclined ploughshare the lateral reaction R_{Py} arises, its value being affected by the friction reaction. 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 total cutting resistance :

$$R_{Px} = k_p \rho_0\, ib\,[1 + f_0\,\mathrm{ctg}\,(\gamma_0 + \varphi_0)]. \tag{5}$$

Forces caused by the weight of the lifting soil strip:

$$\begin{aligned} R'_{Gx} \approx\ & q\delta g k_y r \sin^{-1}\gamma\,\cdot \\ & \cdot\{\,[(\sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma)e^{f_0\sin\gamma(\varepsilon_1-\varepsilon_2)}\ - \\ & -(\sin\gamma\cos\varepsilon_2 + \cos^2\gamma\sin^{-1}\gamma)]\cos\varepsilon_1 + \\ & +(\cos\varepsilon_1 e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)} - \cos\varepsilon_2)(\cos\varepsilon_1 - f_0\sin\varepsilon_1\sin\gamma)^{-1}\,\cdot \\ & \cdot\sin\varepsilon_1\left[\sin\varepsilon_1\sin\gamma + f_0(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right]\} \end{aligned} \tag{6}$$

$$R_{G_z} \approx q\delta g\, r\sin^{-1}\gamma\,(\varepsilon_2 - \varepsilon_1)\ ; \tag{7}$$

$$R_{G_y} \approx q\delta g\, r\sin^{-1}\gamma\,(\varepsilon_2 - \varepsilon_1)(\varepsilon_1 + 0.52)\ ctg\,\gamma\,; \tag{8}$$

$$R''_{Gx} = f_0\,(R_{Gz} + R_{Gy}) = F''_{Gx} \tag{9}$$

Forces caused by the soil inertia:

$$\begin{aligned} R'_{Jx} = q\,\delta\, v^2 k_y^{-1}\sin\gamma\{\ & (\sin\gamma\cos\varepsilon_1 + \cos^2\gamma\sin^{-1}\gamma)\,\cdot \\ \cdot e^{f_0\sin\gamma(\varepsilon_1-\varepsilon_2)} & - (\sin\gamma\cos\varepsilon_2 + \cos^2\gamma\sin^{-1}\gamma) + \\ +(\cos\varepsilon_1 & - f_0\sin\varepsilon_1\sin\gamma)^{-1}e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)} \\ \sin\varepsilon_1 & \left[\sin\varepsilon_1\sin\gamma + f_0\,(\sin^2\gamma\cos\varepsilon_1 + \cos^2\gamma)\right]\} \end{aligned}\ ; \tag{10}$$

$$R_{Jz} = q\,\delta\, v^2 k_y^{-1}\sin\gamma\sin\varepsilon_2\ e^{f_0\sin\gamma(\varepsilon_2-\varepsilon_1)}\,; \tag{11}$$

$$R_{Jy} \approx q\,\delta\,v^2 k_y^{-1} \sin\gamma\cos\gamma\,(1-\cos\varepsilon_2)\,; \tag{12}$$

$$R''_{Jz} = f_0(R_{Jz}+R_{Jy}) = F''_{Jx} \tag{13}$$

Forces caused by soil adhesion:

$$\begin{aligned} R'_{Ax} &= p_A\, b\, r \sin^{-1}\gamma\,(e^{f_0 \sin\gamma(\varepsilon_2-\varepsilon_1)}-1)\cdot \\ &\cdot\{\ \sin\gamma\cos\varepsilon_1+\cos^2\gamma\sin^{-1}\gamma+(\cos\varepsilon_1-f_0\sin\varepsilon_1\sin\gamma)^{-1}\cdot; \\ &\cdot\sin\varepsilon_1\left[\sin\varepsilon_1\sin\gamma+f_0(\sin^2\gamma\cos\varepsilon_1+\cos^2\gamma)\right]\ \} \end{aligned} \tag{14}$$

$$R_{Az}=0\,;\ R_{Ay}\approx 0\,;\ R''_{Ax}=f_0\,(p_{Axy}\,S_{xy}+p_{Axz}\,S_{xz})=F''_{Ax}\,. \tag{15, 16, 17}$$

where q – cross section area of the strip to be lifted;
δ – density of soil;
k_y – soil compaction coefficient in front of the operating part;
f_0 – soil friction coefficient against the surface of the operating element;
v – speed of the movement of the plough body;
p_A – specific force of soil adhesion to the operating surface;
b – 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 following diagrams show the change of the draft resistance of the share- mouldboard surface and the total resistance of the plough body (Fig. 2 and 3).

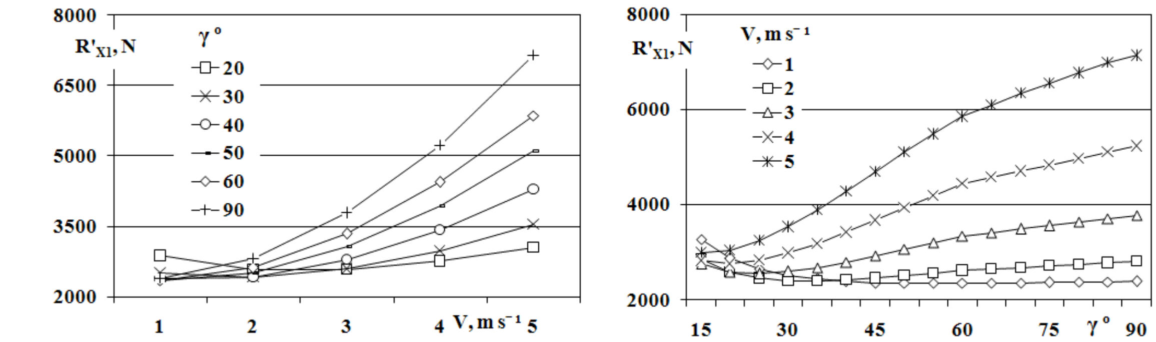

Fig. 2. **Draft resistance of share-mouldboard surface caused by soil slice gravity, inertia and adhesion forces in dependence on working speed *v* and inclination angle *γ* of generatrix (horizontal shape lines)**

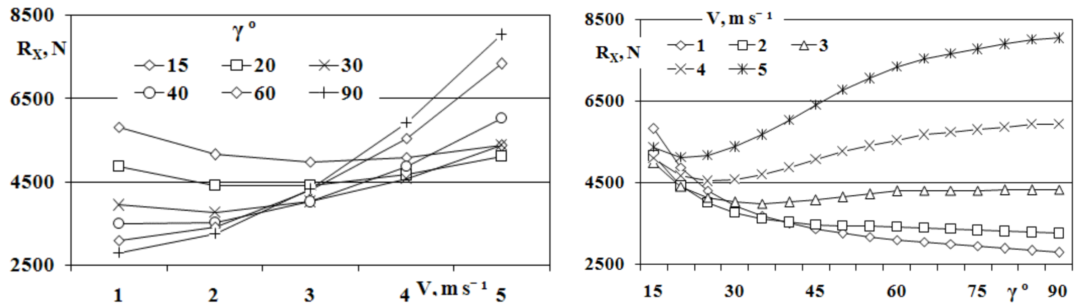

Fig. 3. **Total draft resistance of plough body in dependence on working speed *v* and inclination angle *γ* of generatrix (horizontal shape lines)**

Increasing the inclination angle γ of the horizontal generatrix (shape lines) leads to decreasing the draft resistance caused by the soil slice gravity and adhesion, but to increasing the resistance caused by the inertia forces. In the results the draft resistances of the share- mouldboard surface and plough body have minimum, that at greater working speed is moving on lesser values of the inclination angle γ of the generatrix. So, increasing the speed from 1 $m \cdot s^{-1}$ the optimal value of the inclination angle γ of the generatrix decreases from 50º to 25º (Fig. 2.)

Conclusions

1. Agricultural mechanics is a subdivision of science about the functional relationships of agricultural technological processes and machines. Their cognition provides a possibility to solve the mechanisation issues of agricultural production in a more motivated, economical and faster way.
2. The deduced analytical correlations and the developed computer algorithm enable simulation of the soil coercion forces upon the operating surfaces of the working parts of machines, determination of the specific draft resistance depending on its working parameters and soil properties and motivation of the optimal values of the parameters.
3. The obtained analytical relations are used for the determination of the optimal parameters for the operating parts of the machines and the draft resistance in connection with the technological properties of soil and mode of working.
4. The use of working parts having optimal parameters allows obtaining a good working quality, reduction of the draft resistance by 12…20 % and a corresponding rise in the efficiency, saving fuel and financial means.
5. Mathematical coherences are obtained for the determination of the plant spacing density, their distribution as well as yields. They enable to prognosticate plant spacing irregularity in the rows depending on the expected seed germinating power and to specify their sowing ratios.
6. The plant spacing frequency is a function of the seed germinating power in the field. The lower the germinating power of the seeds, the lower the regularity of the sprouts, i.e., the number of the longer intervals increases.

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