INVESTIGATION OF MACHINES FOR SOIL PROCESSING AND SOWING BIOENERGETIC CROPS UNDER CONDITIONS OF CHANGEABLE RELIEF

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Abstract: *Problematic issues of tillage on slopes are distinguished and methodological aspects of theoretical analysis and experimental researches and production testing of tillage and sowing machinery under the given conditions, in recognition of preservation of soil fertility, are represented. It is considered that sloping lands can be terraced to reduce water erosion of soil, but it is not always expedient to apply this anti-erosion measure, especially on slopes with low steepness, where the usage of special tools for soil-protective non-moldboard tillage is preferable. The theoretical background to make calculation of sowing machines that are engineered for the system of precise/specific/accurate farming in fields with a complex terrain is presented.*

KEYWORDS: *SOIL, CROPS, TILLAGE MACHINES, SLOPES, SOWING EROSION, TERRACING.*

1. Introduction

Mechanized technological processes in plant growing on flat, horizontal fields under the optimal values of humidity and firmness of soil by existing agricultural machines are basically conducted satisfactory. Herewith, quality, energy and economic indicators correspond with the norms of agrotechnics and business. Farm scale trial shows that it is not possible to perform technological work properly on sloping lands even with slight steepness.

The main factor that affects work of agricultural units on sloping lands is the terrain, which is characterized by steepness and configuration of the cultivated areas, and state of soils as well. The preparation of fields (terracing of slopes, the organization of anti-erosion facilities, usage of No-Till, Strip-Till technologies, etc.) for carrying manufacturing processes of crop cultivation has great influence/impact on work of agricultural machines. To prevent erosion on the slopes it is preferably to carry out tillage operations, sowing, spacing cultivation horizontally (crosswise the slopes).

In Ukraine, in particularly in some south-western regions, sloping lands/slopes of varying steepness occupy large areas [1]. About 10,5 million. ha (31,7% out of all arable land) are eroded. Among them 7,8 mln. ha (74,2% out of the total area of eroded lands (TAEL)) are poorly eroded; 2,2 mln. ha (21,0% out of TAEL) are mid-eroded; and 0,5 mln. ha (4,8% out of TAEL) are highly eroded lands. Typically/as a rule, the slopes of more than 10° steepness are eroded by more than 60 % [2]. Water erosion starts if the steepness of a slope is 0,5° [3]. Investigations show that intensity of water erosion increases greatly with the increasing of slope steepness. Conditions of lowland and slope agriculture significantly differ in relation to agrotechnics, the specifics of conducting mechanized processes, methods of land development (preparing lands for reclamation and conducting land clearance operations, regulating moisture regime of soil), etc. [1, 2, 3].

Agricultural crops, that can accumulate solar energy to a large extend/considerably, take/have a special place in the agricultural sector of the Ukrainian economy. These are sugar beet, corn, small grains (wheat, triticale), which are used as primary produce for producing bioethanol, and oil plants (rapeseed, sunflower, soybean, etc.), which are used for the production of biodiesel [4, 5]. The technological process of sowing occupies an important place in the complex of works on growing bioenergetic crops. Erosion processes of soil, following effective mechanized operations and, eventually, the yield of these crops and the profit for agribusiness depend on the correctness and accuracy of sowing processes. Although, growing bioenergetic crops on sloping lands, especially tillage and sowing are not investigated properly, that’s why it is an urgent scientific and industrial problem that should be solved comprehensively.

2. Prerequisites and means for solving the problem

Conditions of work of agricultural machines on the same hilly field vary due to the moving direction: uphill, downhill, across a slope or on a hillside. To minimize erosion on sloping lands tillage machines should move across the slope.

Moreover, it should be considered that while moving across the slope spontaneous withdrawal of tires can be caused by the cross-wind component of a machine weight, and the difference of/in rolling resistance of lower and upper support parts of the machine on slopes as well. Alongside the spontaneous withdrawal of tires, sliding of machine wheels and its working parts should be taken into account. It mainly depends on magnitude of a slope angle, wheel load, physical and mechanical characteristics of soil and tire grip. As the result of side movement and sliding, rectilinear stable moving of agricultural machines on a slope gets interrupted.

While tillage and seeding on sloping lands are in process, both motion stability and quality indicators (especially, agroecological ones) should be taken into consideration. Thus, for example, when plowing slopes of 4º steepness soil shifts up the hill, partial inversion of soil layer by shellboards of a plough bottom; and while working on soil turned to the footslope, soil shifts down the hill that is equal to the soil loss of 12 m^3/ha [3, 7].

In general, intensity of soil loss per area unit in a time unit, i.e. t/ha per year or mm/yr., is computed assessing erosion processes. These units are for assessing speed of soil forming, too. Comparing intensity of soil loss and speed of soil forming we can evaluate the level danger of erosion. If the intensity of erosion lower than the speed of soil forming, then the erosion of this field is not dangerous, although it occurs quite rare.

3. Solution of the examined problem

According to steepness of slopes conservation cropping system of contour land reclamation intends usage of soil/lands differentially, due to what arable lands are divided into 3 groups. The first group of lands is plains and slopes of up to 3º steepness. These are used for grain and hoed crop rotation. Sowing of hoed crops decreases and sowing of grains and herbs increases on the farmlands with greatly rugged terrain. It is because of different soil-protecting efficiency of these crops. The second group of lands is slopes of 3 to 7º steepness. It is recommended to use them for soil-protective crop rotations with sowing of winter and spring grains, one year and perennial grasses, and not hoed crops. The third group of lands is slopes of more than 7º steepness. They are sown by perennial grasses. The complex of tillers and sowing machines to use depends on the type of crop, sowing of which in turn depends on the slope steepness.

According to the profile of the slopes they are concave, convex and convex-concave. In the concave slope steepness gradually diminishes from the middle to the base. The soil on it becomes more fertile as you approach the valley. On the convex-concave slopes the steepest portion is spaced near the base. Over the steep part of the slope is again a flat area on which is deposited the fine earth, carried from the upper part of the slope.

Cultivation of the soil without turning the soil formation, is widely used in soil conservation technologies of land processing and it includes such operations: metal-cutting blades surface treatment, treatment by combined units, chisel tillage, chisel processing, slotting, milling, deep-hole digging.

Metal-cutting blades tools better perform their function in the light and medium soils. On heavy soils they work worse, form lumps, don't move steadily. For quality work of metal-cutting blade tools the soil should not be over-wet. On heavy soils and at higher moisture content it is recommended a wider use of rippers and chisel cultivators, gap-makers, narrow holes tools, cutters.

When designing metal-cutting blades, you can implement a large number of options for the location of the working bodies, as the soil formation at work does not move to the side and does not turn around. But because these tools work on stubble backgrounds, containing a significant amount of crop residue on the field surface, it is important that the distance between the steel paws was enough for the free passage of plant debris and carrying out the process without jamming the soil.

Soil treatment without recourse to the reservoir was carried out with a chisel ploughs working bodies in the form of rippers with interchangeable bits of different designs. As a result of deep soil loosening and mixing 20-30% of crop residues with the surface layer 2-3 times increased its watersoaking effect that prevented water erosion. Chisel hoeing to a depth of 50 cm was carried out during the rotation of planting the seeds. Because of the depth of treatment below the arable layer, the energy intensity of the process of loosening the soil increased sharply.

On sloping lands the system of the non-plough tillage included slotting the soil to a depth of 60 cm, with gaps of 3-4 cm in width and the distance between them more than 120-150 cm. Working bodies of the narrow holes maker worked in a cutting blocked mode.

Economically feasible is the use of combined units, which consist of a set of tools and execute within a single pass three or more basic operations − cultivation, disking of the soil, leveling, harrowing, compacting surface, etc. Each of these tools can be used individually for the intended purpose. Needle harrow BIG-3, for example, effectively loosens the soil in the spring to perennial grasses of the 2nd, 3rd year of cultivation.

The most beneficial to have the stabilization of movement for the tillage and sowing machines which is carried out by the lateral soil reaction on the working bodies of the machine and wheels. Dimensions of the running wheels of tillers depend on soil conditions, implement design features, durability requirements.

A wheel experiences a radial load P_r and P_o axial force applied to the bottom of the rim by the gauge. The magnitude of the axial force can be taken as

$$P_o = P_r \varphi_c, \qquad (1)$$

where φ_c – friction coefficient. The axial force creates $P_o D/2$ point, which acts on the wheel, causing a bending stress. To increase traction with the ground applied spurs or flanges [10].

Pneumatic wheels mounted on the soil cultivated tools and compared over metal ones have several advantages: they have somewhat lower traction resistance; they are less damaging to crops. Furthermore, application of pneumatic tires can improve speed and durability of the machine unit, due to the decrease of intensity in shocks and bumps. Besides this a tread of the tire must meet the following requirements: a good longitudinal and lateral grip on the rolling surface, sufficient self-cleaning grooves.

The centuries-old practice of growing different crops on the slopes with the steepness 5 ... 25° shows that these lands cannot get lower yields when you hold the plain and a soil moisture and on a slope.

Effective way to protect the soil from water erosion is terracing slopes [2].

Professor J.K. Kyrtbaya proposed formulae for calculating elements terraces where sizes of terraces set in such a way that the volume of soil excavation is an apparent volume after shrinkage of the soil.

Tilt bandwidth necessary for the construction of terraces set parameters determined by the formula: (2)

$$L = B\frac{\sin(\beta+\gamma)\sin(\varphi-\alpha)+\sqrt{\sin(\beta+\gamma)\sin(\varphi-\alpha)\sin(\varphi+\gamma)\sin(\beta-\alpha)}}{\sin(\beta-\alpha)\sin(\varphi-\alpha)\left[1+\sqrt{\frac{\sin(\beta+\gamma)\sin(\varphi-\alpha)}{\sin(\varphi+\gamma)\sin(\beta-\alpha)}}\right]}+a,$$

where B – width of the canvas (Fig. 1);

α – steepness of a slope;

β – long well inclined angle of the slope to the horizon;

γ – angle of the angled cross-section to the horizontal position of the canvas;

φ – angle of repose of a bulk;

a – berm width.

The width of the dredging on a canvas

$$b = B\frac{1}{1+\sqrt{\frac{\sin(\beta+\gamma)\sin(\varphi-\alpha)}{\sin(\varphi+\gamma)\sin(\beta-\alpha)}}}. \quad (3$$

The width of the excavation of a soil slope [2]

$$c = B\frac{\sin(\beta+\gamma)}{\sin(\beta+\alpha)\left[1+\sqrt{\frac{\sin(\beta+\gamma)\sin(\varphi-\alpha)}{\sin(\varphi+\gamma)\sin(\beta-\alpha)}}\right]}. \quad (4)$$

For terraces that have an angle cross-section the canvas down the hill, in all formulae before γ should be put a minus sign

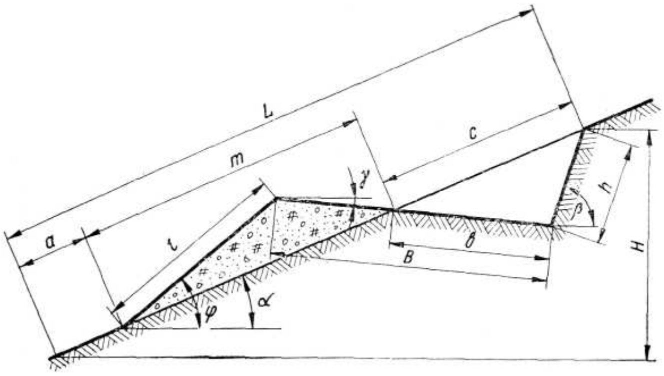

Fig. 1 Scheme of stepped terrace

Bulk of many terraces is being compacted by the tractor tracks during its soil processing. Therefore, when calculating it is appropriate to use the settings that are obtained after shrinkage of the soil, and do not consider the ratio of hollow soil during creating a formula. This ratio is expedient to consider while fulfilling a normalization process for the construction of terraces, where the volume of compacted soil should be multiplied by a factor of availability of the hollow soil.

The movement of particles on rough surfaces of the agricultural machines is analyzed in details in the works by Vasilenko P.M. [8] as well as other sources.

Design of many agricultural machines, their working bodies, including seeding machines, is impossible without the determination of kinematic and dynamic parameters of movement of material on the working surface. [6, 9]

When talking about the sowing machines it is necessary to understand that moving particles can occur without interaction with other seeds, but because the definition of trajectories of individual particles, determining the parameters of its interaction with moving surfaces of the machine is an important scientific task, it is allowing the design phase to ensure high standards for their accuracy.

Let's us consider moving a cone surface of the sowing machine with a casing diameter D_0 in the cylindrical coordinate system $O\rho\theta z$, rotating with angular velocity ω (Fig. 2) [6].

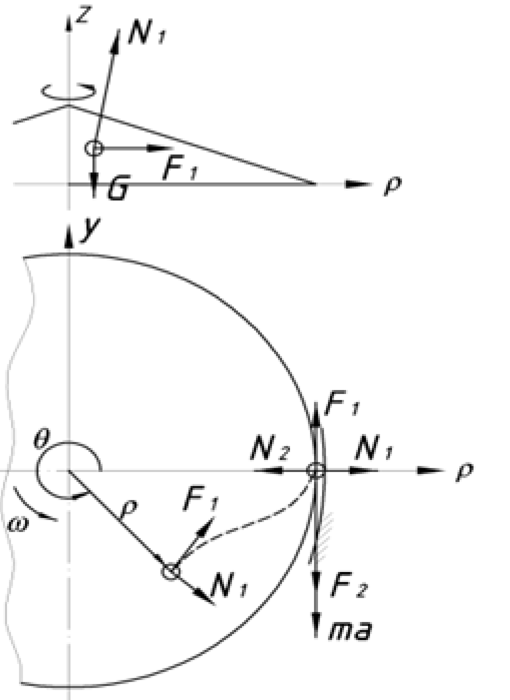

Fig. 2 Estimated traffic pattern of a single seed on the surface of the seed sowing disc

The equation of this surface is in the cylindrical coordinate system

$$\rho_1 = u; \quad \theta_1 = \varphi_1; \quad z_1 = u_1 \mathrm{ctg}\beta. \tag{5}$$

Equation on a cylindrical surface casing:

$$\rho_1 = D/2; \quad \theta_1 = \varphi_1; \quad z_2 = u_2, \tag{6}$$

where u_1 and φ_1 – respectively linear and angular parameters which are independent on each surface.

According to the law of conservation of energy to grains during rolling the equality happens [6]:

$$\frac{mv_c^{\,2}}{2} + \frac{I\dot{\phi}_e^{\,2}}{2} + \frac{k_t\dot{\phi}_e^{\,2}}{2} = mg\Delta h, \tag{7}$$

where m − grain weight; v_c − the velocity of the center of mass of grain; I − moment of inertia around the ellipsoid axes around the central axis of rotation; k_t − dissipative energy dissipation rate; Δh − grain level placement for working height range, $\Delta h = -y_{oc}$.

Value of a module angular velocity ellipse:

$$|\omega| = \sqrt{\frac{-mgy_{0c}}{\frac{m\sqrt{\left(\dot{x}_{0c}\right)^2 + \left(\dot{y}_{0c}\right)^2}}{2} + \frac{I}{2} + \frac{k_t}{2}}}, \tag{8}$$

The changes in angular velocity are according (8) defined linear speed of grains.

Depending on the derived data it enables to determine the trajectory of the center of mass cone surface grain on the sowing machine and the variation speed of the particles, for which are developed the appropriate algorithms and software.

Using the principle of d'Alembert equation, the flow of grains has the following form:

$$\overline{N}_1 + \overline{F}_1 + \overline{N}_2 + \overline{F}_2 + \overline{G} - m\overline{a} = 0 \tag{9}$$

where $\overline{N}_2$ and $\overline{F}_2$ – are the vectors of force with normal reaction to the cylindrical surface of the housing and the friction force because of its action, $\overline{F}_2 = \mu_2 N_2$. Vector resultant in reaction on the disk surfaces (*i=1*) and a cylindrical casing (*i=2*) in a polar coordinate system is similarly recorded as:

$$\overline{R}_i = \overline{N}_i + \overline{F}_i = \left\{\alpha_{\rho i}N_i; \alpha_{\theta i}N_i; \alpha_{zi}N_i\right\}, \tag{10}$$

where $\alpha_{\rho i}, \alpha_{\theta i}$ and α_{zi} – are the relevant factors (amount of the direction cosines vectors and to the angles on the coordinate system). For the proposed case

$$\alpha_1 = \{\sin\beta; \mu_1; \cos\beta\}; \tag{11}$$

$$\alpha_2 = \{-1; -\mu_2; 0\}.$$

Components of the absolute speed and acceleration of a grain during its movement on the surface of the enclosure under the drive of a disc [6]:

$$v_\rho = 0; \quad v_\theta = u \cdot d\theta / dt; \tag{12}$$

After appropriate transformations and reactions on a disk surface the casing is determined according to defined dependencies:

$$N_1 = mg / \cos\beta;$$

$$N_2 = m\left(D_0 / \dot{\theta} / 2 + gtg\beta \right). \tag{13}$$

The equation of motion of a particle in expanded form looks like:

$$\ddot{\theta} - 2\mu_1 g / \left(D_0 \cos\beta\right) + \mu_2\left(\dot{\theta}^2 + 2gtg\beta / D_0\right) = 0. \tag{14}$$

For the set motion when $\ddot{\theta} = 0$, under the condition that the angular velocity of the circular flow of grains is provided $\dot{\theta} \lhd \omega$) is equal [6]:

$$\omega_A = \dot{\theta} = \sqrt{2g(\mu_1 - \mu_2 \sin\beta) / \left(\mu_2 D_0 \cos\beta\right)}. \tag{15}$$

As a result of researches the model of a particle seed, which allows determining the kinematic and power parameters when interacting with a conical seed and seeding flat disks. We can obtain the analytical dependence for determining the trajectory of the grains on the surface of a rotating disk, the angular velocity array of seeds and reaction of the surfaces and a drive enclosure. The described above is a scheme and a principle of work for a mechanical precision seeding machine [5] .

A method of structuring mechanical constructions precision seeding machines and methods to improve them are based on the study of the properties of elements of the structure according to the synthesis theory of hierarchical groups using morphological analysis [5].

The above written scientific principles have important prerequisites for research and development activities of agronomic problems crop on fields with difficult terrain of crops, including promising bioenergetics groups − sugar beet, corn, wheat, triticale [5].

4. Results and discussion

In all soil protection technology is appropriate to include measures which are related to improving soil fertility by application of organic and mineral fertilizers. Therefore, while developing the tillers and seeding machines for work on slopes should be considered an opportunity to add fertilizers, organic mulch, as well as performing terracing of the slopes and develop seeding machines for precision farming in fields with rough terrain.

5. Conclusion

The theoretical and experimental studies have made it possible to clarify certain provisions of the peculiarities of soil cultivation on slopes, and to obtain new scientific results in this direction. In particular, the theoretical substantiation system tillers, their interaction of working organs and working elements running with the soil, taking into account the saving of soil fertility. Slopes terracing of the ground 2-4 times reduces the soil erosion. The model of a particle seed is developed, which allows to determine the kinematic and power parameters when interacting with conical seed and flat seeding disks. Due to all these activities were obtained analytical dependences for determining the trajectory of the grains on the surface of a rotating disk angular velocity array of seeds and reaction of the surfaces and a drive enclosure.

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