ANALYSIS OF COMB FORMATION PROCESS FOR SOWING SUGAR BEETS ON HEAVY SOILS

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Abstract. Improving the efficiency of sugar beet production is possible by developing alternative technologies for growing root crops and substantiation of rational parameters of advanced technological processes and tools for pre-sowing tillage. In particular, these areas of research are relevant and have scientific priority in sowing of sugar beet seeds and their cultivation on heavy soils. Based on the analysis of known technologies, a ridge method of sowing sugar beet seeds and a technical device (cultivator-comb-former) for the formation of pre-sowing ridges on heavy soils are proposed. The technological process of field surface profiling in autumn is considered, the analytical analysis of the geometric model of ridge formation by cultivator-comb-former is developed and given. The constructive-technological scheme of the cultivator, its comb sections is substantiated. At the analytical level, the design parameters of the working body for the formation of the profile of pre-sowing ridges from the condition of stabilizing the movement of the working body of the comb sections of the cultivator at a given depth are analysed. Experimental studies of the process of forming the profile of the ridge of the proposed cultivator are conducted in the soil channel modeling the soil environment in the form of heavy soils. The regression equation of the dependence of the change in the depth of the working body of the cultivator and the height of the formed ridges on the length of the leash and the stiffness of the spring of the parallelogram mechanism of the comb sections developed. It is established that the rational geometric parameters of the ridge surface when sowing sugar beet seeds on heavy soils with row spacing 0.45 m will be: substantiated: the length of the leash of the parallelogram suspension is 0.27 + 0.01 m; the height of the crest 0.12 ± 0.01 m; the depth of the ridge gap relative to the ridge depression 0.08 ± 0.01 m.

Keywords: tillage, cultivator-comb-former, comb section, field profiling, ridge, ridge height, empirical model.

Introduction

Scientific and practical experience shows that during the formation of ridges in the spring it is necessary to carry out the whole complex of technological operations of surface tillage. This leads to drying of the soil and reducing the germination of seeds, and in accordance with the additional costs and poor yield.

In the implementation of the alternative proposed method, the number of spring operations of surface tillage is reduced, drying and re-compacting of the soil is reduced, which is especially true for heavy mechanical soil. The comb technology accelerates the spring warming of the soil, reduces the number of passes of aggregates across the field, provides storage of moisture needed for seed germination and plant growth and development. Sowing can be carried out earlier, which leads to an increase in the growing season. Therefore, conducting research, creating technical facilities and implementing this technology and technical support is an urgent scientific and practical task [1; 2].

In the scientific works [3; 4], regularities of the influence of the design parameters, working depth and speed of movement on the cost of power of the soil tillage process (tiller, bentleg and paraplow) have been established. Forecasting and design requirements for the tillage unit have been found to be important factors that influence picking of the tillage equipment and the corresponding tractor for specific agricultural production conditions [5]. Therefore, the evaluation and implementation of the forecasting project were investigated during field trials [6].

The ASABE D497.6 standard [7] provides one of the basic mathematical expressions for determining the power cost required for cultivating soil in different soil conditions. However, this standard does not provide a design for some tools, such as a paraplow and bent leg. It should be noted that most of the regression equations used to design and predict different tillage and machine alignment tools were developed using data obtained during the field experiments [8].

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Materials and methods

An important indicator that characterizes the effectiveness of ridge formation in the fall to minimize spring tillage is the ability of the ridges to withstand weather conditions in the autumn and winter. In order to reduce non-capillary voids, especially in the upper layer 0.5 … 1.0 cm, a protective crust should be created. The formation of ridges also creates conditions for more free penetration of moisture into the soil, for which at the bottom of the furrows slits are cut to a depth of 5 … 10 cm. Taking into account the above requirements, a geometric model of the profiled surface was created (Fig. 1). Taking into account the requirements of the formation of ridges, uniform in height, the structural and technological scheme of the sections cultivator-comb-forming (Fig. 2) is substantiated.

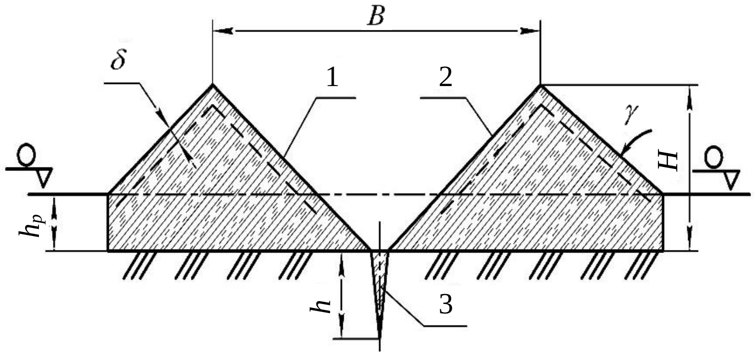

Fig. 1. **Geometric model of the profiled surface of the field:** 1 – depth of sealing of the slopes of the ridge cat, δ = 0.5 … 1.0 cm; 2 – bulk part of the comb; 3 – slit; – level of the surface of the field before combing; h_p – depth of travel of the mount; h = 5 … 10 cm – depth of travel of the slit cutter; B – row spacing of ridge vertices; γ – angle of inclination of the ridge; H – height of ridges

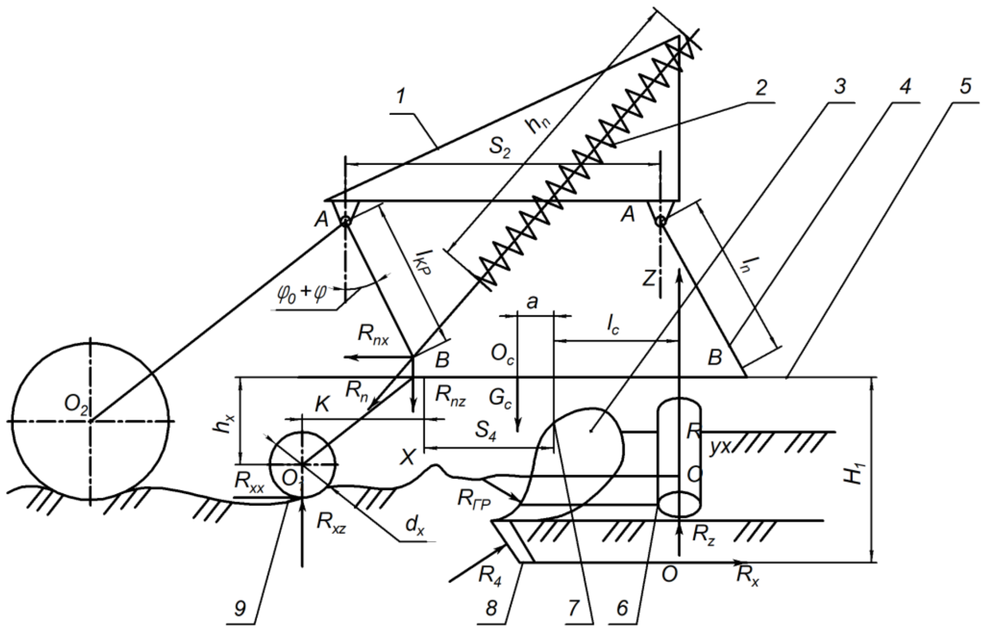

Fig. 2. **Structural and technological scheme of section of cultivator-comb-forming:** 1 – frame of the cultivator; 2 – compression spring; 3 – wings of the crest formation; 4 – parallelogram suspension; 5 – section sections; 6 – sealing device; 7 – working body; 8 – slit cutter; 9 – support wheel of section; 10 – cultivator support wheel

Also, one of the important conditions for the technological process of ridge formation is the uniform formation of ridges in height. The uniformity of the molding depends on the stabilized stroke of the working body at a given depth.

To determine the deviation of the working body ΔH from the specified depth of the cultivator section, an equivalent scheme was developed (Fig. 2).

The movement of the cultivator sections is considered relative to the fixed coordinate system with the axes *Ox* and *Oz*, the reference of which is at the point *O*. The frame of the cultivator-combinatory copies the supporting wheels of the field surface and moves according to the law close to the sinusoidal. Assume that the center of gravity of the sections of the ridge is at the point O_C, and the coordinates at the initial moment ($t = 0$) of motion can be expressed through X_{O_C} and Z_{O_C}:

$$X_{O_C} = l_C + a \,;\; Z_{O_C} = H_1, \tag{1}$$

where X_{O_C}, Z_{O_C} – coordinate points O_C along the axes *Ox* and *Oz*, m;

$(l_C + a) = OO_C$ – distance from the starting point of the coordinate system (point *O*) to the point O_C (center of gravity of the cultivator), m;

H_1 – distance from the end of the slit cutter 8 (Fig. 2) to the point O_C (center of gravity of the cultivator), m.

In the case of a uniform movement of the cultivator-ridge for time t it will move in the direction of the axis *Oh* by an amount equal to $\vartheta_k t = X_1$, where ϑ_k – cultivator speed, m·s^{-1}. The projections of the velocity of displacement of the center of gravity of the ridge section on the coordinate axis through the angle of rotation of the sections $(\varphi_0 + \varphi)$ will be:

$$\dot{\vec{X}}_1 = \vec{\vartheta}_k - \dot{l}_n cos(\varphi_0 + \varphi) \,;\; \dot{\vec{Z}}_1 = \dot{l}_n\, sin(\varphi_0 + \varphi), \tag{2}$$

where φ_0 – initial angle of the point O_C, deg.;

φ – angle to which the area will return under the action of the perturbing moment in time *t*, deg.;

l_n – length of compression of the cross section of the parallelogram mechanism of the cultivator section, m.

For the independent generalized coordinate we assume the angular displacement φ of the suspension. Under this condition, the problem is to determine the angle of rotation φ as a function of time *t*.

To compile the differential equations of motion of the sections of the comb-forming we use the Lagrange equation of the second kind

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}}\right) - \frac{\partial T}{\partial \varphi} = Q_\varphi q, \tag{3}$$

where T – kinematic energy of the system, J·(N·m)$^{-1}$;

Q_φ – generalized force applied to the system, N;

q – moving the system in time *t*, m.

The kinematic energy *T* of the system as a result of mathematical transformations is determined by the formula

$$T = \frac{1}{2} m \left[\vartheta_k^2 - 2\vartheta_k l_n \left(\frac{d\varphi}{dt}\right) cos(\varphi_0 + \varphi) + \left(\frac{d\varphi}{dt}\right)^2 \left(l_n^2 + \frac{1}{2} I_c\right)\right], \tag{4}$$

where m – mass of the ridge section, kg;

I_c – static moment of inertia of the cultivator section relative to the axis passing through the center of mass perpendicular to the plane of the section, m^2.

After substituting expression (4) in the left part of equation (3) and after transformation and refinement we have

$$m\left(\frac{d\varphi}{dt}\right)^2 \left(l_n^2 + I_c\right) = Q_\varphi q\,. \tag{5}$$

The principle of possible displacements of a mechanical system is used to determine the generalized force. After determining the reactions and forces of the components of the generalized force, received

$$L_r = R_z\left[l_c + S_1 + l_n\,sin(\varphi_0+\varphi)\right] + R_x\left[H_1 + l_n\,cos(\varphi_0+\varphi)\right] - G_c\left[S_1 + l_n\,sin(\varphi_0+\varphi) - a\right] + \\ + c_{np}\left[fh_n + 0.5\,fd_n + fl_n\,cos(\varphi_0+\varphi) - l_{kp} - l\right]\left\{l_n\left[cos(\varphi_0+\varphi) - cos\,\varphi_0\right] + \mu\,sin\,\lambda\left[l_n\,sin(\varphi_0+\varphi) - k\right]\right\} - \\ - R_{npx}l_{kp}\,cos(\varphi_0+\varphi) - R_{npz}l_{kp}\,sin(\varphi_0+\varphi) - R_n n_o \tag{6}$$

where R_x, R_z – horizontal and vertical reaction of the force applied to the wing of the comb, slit cutter, seal, N;
G_c – force of gravity of the crest formation section, N;
c_{np} – stiffness of the compression spring, $N \cdot m^{-1}$;
f – stiffness coefficient;
h_n, d_n – length and diameter of the spring, m;
R_{kx}, R_{kz} – horizontal and vertical components of forces applied to the support wheel, N;
R_{npx}, R_{npz} – horizontal and vertical component of the force from the action of equal spring stiffness, N;

Differential equation (7) is solved by linearization, as a result of which the angle φ (rad.) of rotation is determined

$$\varphi = \frac{a_1}{a_2}\left(1 - cos\sqrt{\frac{a_2 t}{I_n}}\right) \tag{7}$$

where a_1, a_2 – coefficients, which are determined as a result of substitution in solving the equation, $kg \cdot m \cdot s^{-1}$;
I_n – dynamic moment of inertia of the system, $kg \cdot m^2$.

Equation (7) characterizes the influence of each design parameter of the working body on the deviation of the ridge section from the initial angle φ_0. The linear value of the deviation of the working body from the specified depth of travel in the vertical plane, which depends on the angle of rotation ($\varphi_0 + \varphi$), will be written as follows

$$\Delta H = l_n\left(cos\,\varphi_o - cos(\varphi_0+\varphi)\right). \tag{8}$$

At the first stage, one-factor experiments were implemented to optimize the depth of the working body and the height of the ridges depending on the speed of the cultivator ϑ_k, the length of the spring h_n and the angle α of the cutter section. The optimization parameters were evaluated by the value of the standard deviation of σ and the coefficient of variation V. To conduct experimental studies to determine the influence of active factors (the cultivator speed ϑ_k, the leash length l_n, the stiffness coefficient of the compression spring c_{np}, which were measured by standard methods [9]) on the deviation of the depth of the working body and the height of the formed ridges, a program of experiments was developed. Experiments were performed in the soil channel.

The planned three-factor experiment of PTFE 2^3 type was implemented, i.e. the three-factor experiment at two levels (upper and lower) of factor belief [10].

The experimental data were processed according to standard methods, the approximation function was set at the highest value of the coefficient of determination D [11], the unknown coefficients of the approximation model were determined by the method of least squares, and the adequacy of the regression model was checked by F-Fisher's test [12].

Results

According to equation (8), the dependence of the change in the depth of deviation of the working body of ΔH from the length of compression of the cross section of the parallelogram mechanism of the cultivator section l_n and the angle φ, to which the area will return under the action of the perturbing moment in time t at the initial angle φ_0 = 10 deg, as a function is constructed $\Delta H = f_{\Delta H}(l_n;\varphi)$ (Fig. 3).

Based on the analysis of the graphic constructions (Fig. 3), it is established that the main array of deviations of the depth of the stroke ΔH of the working body are in the range from (-0.01 m) to 0.02 m. The greatest influence on the value of ΔH has the length of the leash l_n – for changes in n from 0.15 to 0.35 m deviation of the depth of the stroke averages 0.015 m.

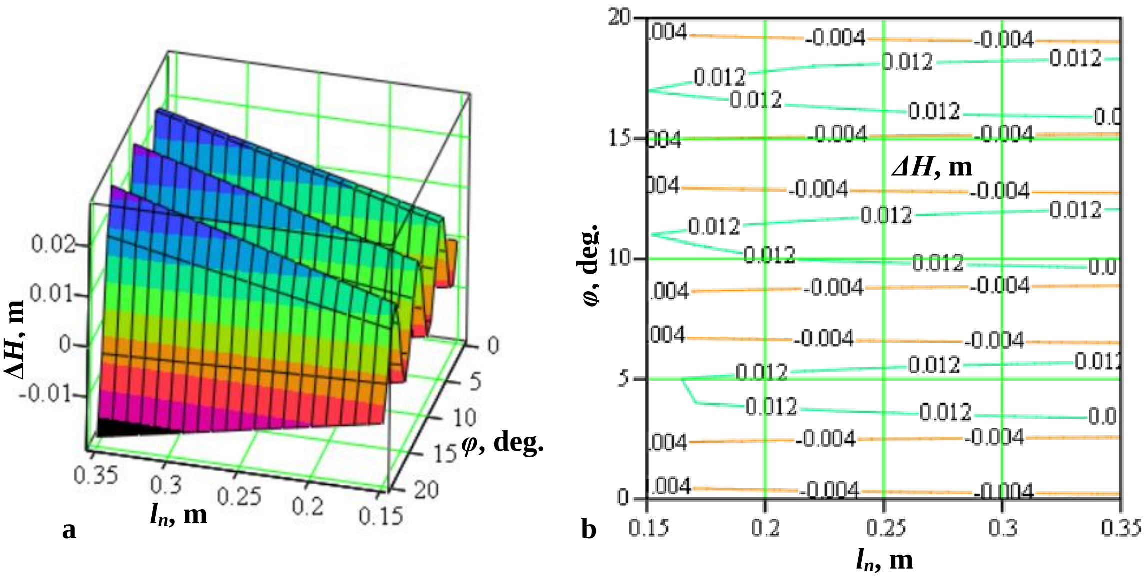

Fig. 3. **Dependence of deviation of the depth of the stroke of the working body as a function of $\Delta H = f_{\Delta H}(l_n;\varphi)$ (a) and the two-dimensional cross section of the dependence of $\Delta H = f_{\Delta H}(l_n;\varphi)$ (b) when φ_0 = 10 deg**

According to the results of the classical one-factor experiments it is established that:

- at the depth of the cutter h_p = 0.06 m the height of the two tops of the ridges did not meet the initial conditions for sowing sugar beet seeds, and at h_p = 0.14 m the parameters of the ridges were close to rational, but part of the soil overturned on the sides of the ridges and came to the bottom of the furrow;
- the rational height of the ridges is achieved by the depth of the cutter section h_p = 0.1 + 0.02 m;
- with an increase in the angle of the cutter α from 135 to 155 deg, the coefficient of variation I of the stroke depth increases, and a further increase α to 175 deg leads to a decrease in the coefficient of variation V (Fig. 4a);

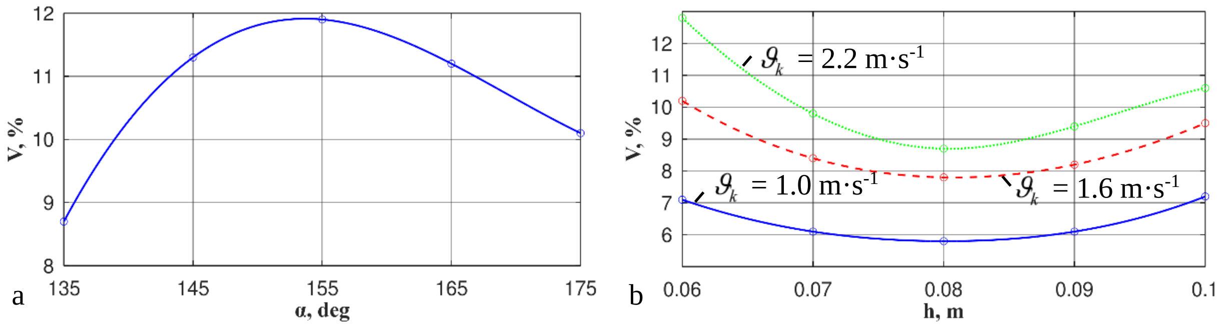

Fig. 4. **Dependence of change of coefficient of variation on depth of the course**

- at α more than 175 deg. there is an increase in the effect of soil slip, which causes a change in the direction of the force of soil resistance. Therefore, it is advisable to set the cutter at an angle α = 135 deg;
- the rational length of the cutter section, at which the height of the formed ridges meets the initial requirements is in the range $h = 0.08 \pm 0.1$ m.

As a result of processing of experimental data mathematical models in the form of regression equations are received:

$$h_p = 4.4 + 14.25 l_n + 0.003 c_{np}\,;\;\; H = 8.4 - 13.5 l_n + 0.003 c_{np}\,. \qquad (9)$$

Conclusions

According to the results of the research, the main rational parameters of the cultivator section for ridge sowing of sugar beets have been established. The proposed technology minimizes the number of passes of pre-sowing units in the field.

Rational structural and kinematic parameters of the cultivator-comb-former for ridge sowing of sugar beet seeds with a row spacing width of 0.45 m are substantiated: the length of the leash of the parallelogram suspension is 0.27 + 0.01 m; the initial angle of installation of the cutter section 15 ± 5 deg.; stiffness of the compression spring 150 …180 $N \cdot m^{-1}$; the speed of the cultivator from 1.5 to 2.2 $m \cdot s^{-1}$; length of the cutter blade 0.08 ± 0.01 m; depth of the section from 0.01 ± 0.01 m.

The obtained results complement the methodology and techniques for optimizing the parameters of tillage machines.

Author contributions

Conceptualization, V.T.; methodology, V.P. and V.L.; software, M.I.; validation, A.K. and V.P; formal analysis, A.K. and V.K.; investigation, V.T., V.P., V.L. and M.I.; data curation, A.K., V.T. an V.K.; writing – original draft preparation, V.T.; writing – review and editing, V.P. and V.L.; visualization, M.I., V.K.; project administration, M.I.; funding acquisition, V.L. All authors have read and agreed to the published version of the manuscript.

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