RESEARCH OF SURFACE-PLANE AND SPACE-DEEP INTERACTION OF NEEDLE WITH SOIL

ИССЛЕДОВАНИЕ ПОВЕРХНОСТНОГО – ПРОСТРАНСТВЕННОГО ВЗАИМОДЕЙСТВИЯ ИГЛЫ С ГРУНТОМ

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Abstract: *The purpose is to reduce the energy costs of soil tillage by developing more accurate methods for assessing the effectiveness of surface-plane and space-deep interaction of the needle with the soil. It is noted that the result of the interaction of the round needle of rotary harrow with the soil, there is a hole of regular shape with an ellipse at the base. The change in the semi-axis of the ellipse formed at the soil-air interface is analyzed. The developed method improves the accuracy of forecasting and evaluating the effectiveness of the rotary harrow needle interaction with the ground. The method creates the prerequisites for improving the quality and energy indicators of the technological processes of soil treatment with rotary harrows*

KEYWORDS: *NEEDLE OF A ROTARY HARROW, INTERACTION OF NEEDLE WITH SOIL, COEFFICIENT OF SURFACE-PLANE INTERACTION, SPATIAL-DEEP INTERACTION*

1. Introduction

The natural and climatic conditions of the present are characterized by the formation of a dense soil crust on soils subject to wind erosion. This soil crust makes it difficult to germinate, damages the root system of plants, increases evaporation of moisture. For early-spring, pre-sowing and post-harvest small surface loosening of the stubble background, especially dense soil crust, effective tools with needle-like working bodies.

The reduction of terms and a significant improvement in the quality of execution of soil tillage technological processes are an important reserve for improving the efficiency of land resources and increasing the yield of agricultural crops [1]. Known implements with needle working units are intended for early-spring, pre-planting and shallow surface tillage of stubble in areas with soils that are prone to wind erosion. They have a low productivity, and an increase in the speed of their movement leads to a sharp decline in quality [2]. Rotary harrow tillage enhances soil organic C, total N and P and microbial C, N, and P stocks in comparison to moldboard plough management [3]. Soil processing is done without bringing from the depth wet soil layers to the surface, thus maintaining the humidity in the soil for good seed germination [4]. In studies [5] it was noted that with the increase in the depth of the tooth disc movement in the soil and the translational speed of the movement of the aggregate, the efficiency of the needle discs increases due to the increase in the vertical component of the total disk speed.

Existing needle harrows are not used in operations of the pre-emergence and after-sowing harrowing of cereals crops, as their working units are not adapted to working conditions at not great depths [6]. Therefore, the research is aimed at improving the qualitative and energy performance of soil tillage technological processes in needle harrows with variable angle of needle sharpening under conditions of their application for shallow surface fractures in the climatic zones that are prone to wind erosion.

The analysis of the condition of soil treatment with needle harrows showed that there are grounds to conclude that the selected directions are legitimate, the relevance and feasibility of carrying out research and the perspective of the formulated goals and objectives of research, which are aimed at improving the qualitative and energy performance of soil tillage technological processes in needle harrows with variable angle of needle sharpening, especially in the conditions of their application for small loosening of soil [7].

The work [8] deals with the motion of a disk whose axis is included in five disks with axes rigidly connected to the common axis holder, so that all disks move in the same direction and at the same height as the axis holder.

Under such conditions, the disk with the center C moves along with the other disks moves so that the velocity v_C of the center C is directed horizontally. The authors analyzed both the insignificant depth of immersion of needles in the soil, and the case from the deepening into the soil of two needles simultaneously (Fig. 1).

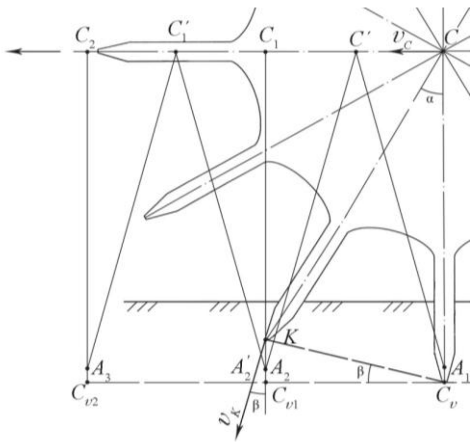

Fig. 1. *A scheme for analyzing the motion of a disk of a needle harrow, whose axis is connected to the axes of other disks and the depth of needle immersion, is significant*

It is noted that the smaller h_K, the smaller the angle β. As h_K is reduced to 0, the angle β becomes also equal to zero, and the velocity v_K will be directed vertically downward, that is the puncturing of the soil will be carried out vertically. Under such puncturing conditions, the friction force of the needle with the soil will be less than for the angle β greater than zero

Increasing the depth of processing does not lead to a change in the nature of the needle disk movement on the soil. However, the load on needles increases, which destroy a much larger number of soil particles than in cases of not significant depth of processing.

The velocity vector v_K of the point K (Figure 1) of the needle is directed at an angle β to the vertical. This angle β affects the conditions for puncturing the soil and is defined as:

$$\beta = \arcsin \frac{h_K}{2 \cdot r_D \cdot \sin \dfrac{\alpha}{2}}, \tag{1}$$

where: h_K – height of the point K above the line $C_{v2}Cv_1C_v$ (m);
r_D – radius of the harrow disk with the needles (m);
α – angle between the needles CK and CC_v.

The result of the harrow depends on the degree of synchronization of the needles of different disks on the soil. So, if the lower needles of the discs simultaneously sink into the soil, there will be a simultaneous piercing of the soil surface with these needles, and the pressure is equal to the soil resistance to deepening the needles. If the needles of different disks do not fall down into the soil at the same time, the needles of different disks will alternately sink into the soil, while the piercing pressure will also be equal to the soil resistance, but the puncturing of the soil will be random and depend on the position of the needle disks relative to each other before piercing.

It should be noted that in the case of using a harrow with synchronous operation of the disks in the section and small values gravity force of the discs with needles, turning the disks by 30° will result in several simultaneous punctures of the soil, and the rest of the time there will be no puncture of the soil. With such harrow work and rigid connection between the disc axes, the force acting on the needles during their immersion into the soil is equal to the gravity of the harrow section. And a force acting on each disc (and thus on the needle witch plunges into the soil) is equal to the section gravity force divided by the number of disks in it.

The angle of rotation of the disk for piercing the needle and leaving the needle is called the piercing angle. In existing harrows, this angle is theoretically equal to 30˚ of which half is used to dip the needle into the soil, and the other half is used to exit it. In general, this angle can be 36˚ or 45˚. However, at a piercing angle of soil 30˚, the piercing frequency is higher than in other cases (angles of 36˚ or 45˚). That is, the piercing angle 30˚ is the most rational.

In studies [6] the interaction of the needle harrow with the soil in the case when the needle pierces it and carries out the motion strictly vertically is considered in detail. This is a somewhat simplified view of the movement of the points of the needle as a result of its interaction with the soil. However, under certain conditions and at the phase of needle entry into the soil and at the phase of its exit, there may be processes that will differ from those taken. That is why research of the processes of interaction between the needles of a needle harrow and the soil under conditions when the phases of entry and exit from the soil are considered in a plane that differs from the general accepted idea (vertical movement of the needle at all phases of its movement in the soil) is quite important and urgent task.

According to the results of research [9], it was established that the main factors that influence the determination of the required force for deepening the needles of the needle harrow in the soil are: the depth λ of the needle immersion, the angle of friction of the needle along the ground, and the angle characterizing the taper of the needle. In addition, the force needed to deepen the needle into the soil depends on the hardness of the soil, that is, on its mechanical composition and moisture content. However, the existing technologies of mechanical tillage do not provide for the use of needles for high moisture soil values.

It is established that the work W is the larger, the more the number of disks, the number of needles on the disk, the pressure of the needles on the soil and the penetration depth λ [8].

2. Purpose of the study

The aim of the study is to reduce the energy costs of soil tillage by developing more accurate methods for assessing the effectiveness of surface-plane and space-deep interaction of the needle with the soil.

Based on the analysis carried out and in accordance with the purpose of this work, the following research tasks are formulated:

- determine the features of the interaction of the needle with the ground in phases, both the indentations and its exit from the soil;
- analyze the surface-plane and space-deep interaction of the needle with the soil, and develop a mechanism for evaluating such interaction.

3. Material and methods

The object of study is the technological processes of treatment, the soil and the working bodies of the rotary harrow, methods for evaluating the effectiveness of the interaction of the needle with the ground. The subject of the research is the interaction of the working bodies of the rotary harrow with the soil, the effect of its parameters on the indicators of the efficiency of the technological process of tillage.

Theoretical research are based on the basic principles of theoretical mechanics, the theory of mechanisms and machines, differential calculus and mathematical modeling of needle movement of any shape and design at various phases of its interaction with the soil (entry and exit from it)

The analysis of the operation of a needle harrow is carried out under such assumptions:

- the harrow with discs and needles is considered as a body moving along the traction unit (tractor) to the left horizontally, with the disk axes perpendicular to the plane of motion, and the disks with needles rotate counter-clockwise around their axes;
- the lower right needle that emerges from the soil does not affect it, and the force of attraction is transferred, mainly, to the needle that contacts the soil.

4. Results and Discussion

Consider the interaction with the ground points of the lateral surface of the needle, subject to moving its lower point along the vertical axis of symmetry formed by the needle hole.

The disk with needles of the needle harrow moves uniformly and rectilinearly with speed V_D. In Fig. 1 shows the scheme for piercing the soil with a needle. The moment of the beginning of the interaction corresponds to the instantaneous position *OA*. When the center of the disk *B* is moved to the position O_2, the needle is immersed to a depth y_1. This corresponds to O_1A_1 (Fig. 2). If the center of the disk occupies the position O_2, the needle will be deepened to the maximum depth y_{max} (O_2A_2). The vertical position of the needle ends the phase of its entry into the soil and it begins to move in the opposite direction. We note that the stage of penetration of the needle into the soil is characterized by a gradual increase in the resistance to movement of the needle. In position A_2 at depth y_{max}, these forces reach a maximum value. The exit of the needle from the soil (movement on the section A_2A) rightly does not take into account the influence of the resistance forces to the movement of the needle. Note that the section OO_2 – the distance that the disk passed in time t1 is equal to the distance AA_2= y_{max}= OO_2= V_D.

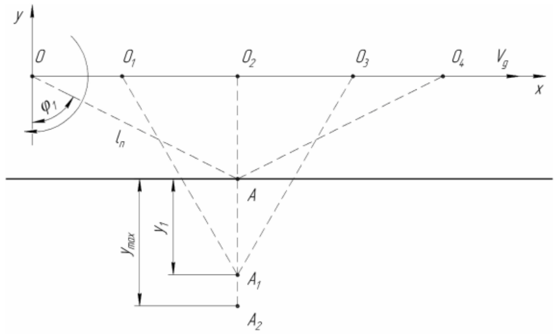

Fig. 2. *Trajectory needle OA given its interaction with the soil*

The peculiarities of the interaction of the needle with the soil on the phases, both the indentations and its emergence from the soil, include the presence of flattening (dents), which are formed on the soil surface in the direction opposite to the needle movement. In the case of the movement of the needle during the phase of entry into the soil, the observed flattening occurs from the side of the acute angle of contact with the soil. In the conditions of the needle exit from the soil, the flattening will appear on the other side of the funnel formed by the needle. In conditions of penetration of the needle into the soil in the form of a rod, a funnel (hole) formed by the results of such interaction can be represented as a cylinder. In case of penetration into the soil of a cone-shaped needle, the figure formed as a result of such interaction with the soil will represent a cone with a circle at the base. With increasing depth of penetration of such a needle, the area of the base of the cone will grow. According to the results of observations under conditions of real operation, the interaction of the needle of any shape and design with the soil leads to the appearance on its surface of a figure close in shape to the ellipse. Moreover, in the phase of the needle entering the soil in the direction opposite to the motion, a semi-ellipse is formed, whose small semi axis is equal to the radius of the conical (cylindrical) part of the needle that penetrated the soil. The semi major axis of the semi-ellipse depends on the parameters of the needle, their number on the disk, the depth of penetration of the needle into the ground. Leaving from the soil, the needle on its surface leaves the flattening in the form of the second part of the semi-ellipse. The needle forms a funnel (trace), which represents a cone with the vertex A_2, which is based on an ellipse.

In accordance with the known dependences [10] and our assumptions, we note that the doubled product of the small semi-axis of the ellipse is equal to the diameter of the needle, which is deepened into the soil. As is known, the ellipse is a closed figure in the plane, which can be obtained as the intersection of a plane and a circular cylinder, or as an orthogonal projection of a circle onto a plane. The circle is a special case of an ellipse [10].

In the case of the vertical position of the needle (O_2A_2) in Fig. 1 the area of its contact with the ground is a circle whose radius is equal to the radius of the part of the needle immersed in the soil.

The area of the ellipse (the hole formed by the penetration of the needle into the ground) will be determined by the dependence. The value of the area is affected both by the parameter a and by the characteristic of the needle (r_n). In general, the parameter a is the semi major axis of the ellipse depends on the characteristics of the needle, the depth of its immersion in the soil.

With Fig. 2 it follows that the beginning of the contact between the needle and the soil is characterized by the moment when the point A of the needle touches it. Under such conditions, it follows from the triangle ΔOAO_2 that, $OO_2=l_n \cdot \cos\varphi_1$, where φ_1 is the angle of inclination of the needle to the soil, characterizing the beginning of the contact of the needle with it. Then

$$y_{\max} = l_n \cdot (1 - \cos\varphi_1) \quad (2)$$

where: $y_{\max}$ – depth of penetration of the needle into the soil;

l_n – distance from the center of the disk to the top of the needle.

The process of interaction between the needle and the soil occurs in three directions. A flat figure (circle, ellipse) is formed on the soil surface and this interaction can be classified as surface-planar. Due to the penetration of the needle into the soil along the vertical axis of symmetry of the hole, space-deep destruction of the soil takes place. The evaluation of the functional capacity of the harrow should be carried out by the total (integral) exponent, which generalizes the two types of interaction. Surface-planar fracture can be estimated from the area of the near-flatness (the figure of an ellipse (circle) on the surface of the soil). The volume of the figure formed in the soil by the results of the penetration of the needle into it is an indicator characterizing the efficiency of the space-deep interaction of the needle with the soil.

According to the results of the interaction of the needle, which has a circular cross-section with the soil, a hole of regular shape is formed, at the base (on the surface of the soil) which will not be a circle, but an ellipse.

Let us consider the case of the interaction of a cone-shaped needle with the soil (a cone-shaped needle consists of a cone and a cylindrical part). Only the cone-shaped part of the needle penetrates the soil (Fig. 1). As noted above, the disc of a harrow with needles carries out a complex movement. Due to the realization of such a needle movement, its end (the extreme point of the needle) will constantly move along the vertical axis. The phase of the needle entering the soil (in Fig. 2) corresponds to the left part: the position of the needle O_1A_1 – the beginning of the contact, O_2A_2 – intermediate position, O_3A_3 – maximum immersion of the needle in the ground. The phase of needle exit from the soil corresponds to the right on the vertical axis in the part of the figure: O_4A_4 is an intermediate position. In the vertical position O_3A_3, point B_3 characterizes the point of contact between the needle and the soil. The penetration of the needle into the soil takes place in such a way that the movement of the extreme point of the needle A_1 is carried out along the vertical (y-axis), from the beginning of the contact of point A_1 (Fig. 2) to the position A_3 – the coincidence of the axis of symmetry of the needle and the vertical axis y. During the movement of the harrows section its needles carry out by a compound motion: translational with velocity V_D (center O_1) and rotational with angular velocity around center O_1. The beginning of the contact of the needle with the soil occurs at the moment when the point of the needle A meets the soil - position A_1 (Figure 2). After that, the axis of needle rotation will move to position O_2, and its lower point will occupy the intermediate position A_2. Under such conditions, the lateral surface of the cone-shaped part of the needle, deforming the soil, will occupy a position corresponding to the point B_2. We note that the trajectory of contact point between the needle and the soil at the air-ground interface will be characterized by the following features: first the distance from the point of the primary contact (A_3) to the left part of the needle will increase with penetrates into the soil (point B_2), then, reaching a maximum, this distance will decrease, and in the vertical position of the needle it will be determined by the radius of the circle of the cone-shaped part of the needle that penetrated into the soil. The contact of the needle with soil takes place in a circle with a radius equal to $A_1B_3=r_{nC}$ in the vertical position of the needle. The taper angle of the needle is $2\alpha_1$.

From the triangle $A_3B_3A_1$ we determine the depth of penetration of the needle into the soil:

$$A_1A_3 = y_{\max} = r_{nC} \cdot ctg\,\alpha_1 \quad (3)$$

where: α_1 – the angle between the altitude and slant height of cone of needle; r_{nC} – radius in the vertical position of the needle.
When the needle penetrates the soil, its O_1A_1 axis is inclined to the surface at an angle β_1, and the lateral surface is φ_1. That is $\beta_1=\varphi_1+\alpha_1$. In the intermediate position of the needle O_2A_2, the O_2A_2 axis is inclined to the soil surface at an angle β_2, and the lateral surface is φ_2 respectively (Fig. 3). And $\beta_2=\varphi_2+\alpha_1$. In the vertical position, the axis of the needle O_3A_3 coincides with the vertical, the angle $\beta_3=90^{\circ}=\varphi_3+\alpha_1$, where φ_3 is the angle between the lateral side of the conical part of the needle and the soil in the position of maximum needle location in it. Thus, the angle β varies in the interval:

$$\beta_1 \le \beta \le \beta_3, \text{ or } \varphi_1 + \alpha_1 \le \beta \le 90^{\circ} = \varphi_3 + \alpha_1 \quad (4)$$

where: φ_1 – the angle of inclination of the needle to the soil; α_1 – the angle between the altitude and slant height of cone of needle; β – angle of the needle axis to the soil surface at the time of penetrates; φ_3 – angle between the lateral side of the conical part of the needle and the soil in the position of maximum needle location.

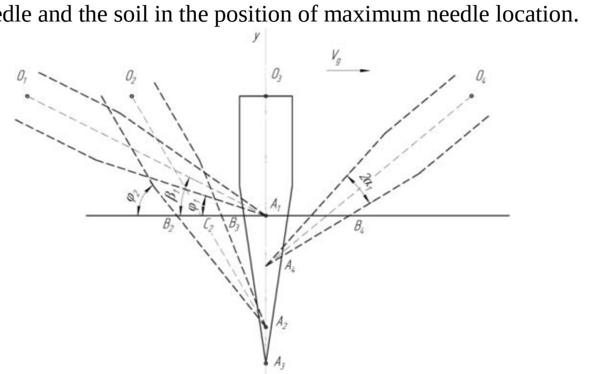

Fig. 3. *Regulation needle O_1A_1 given its interaction with the soil*

Using the known equation of the ellipse, and taking $b=r_{nC}$ is the radius of the needle part, plunged into the soil, a is the maximum distance from the point, plunged into the soil in a position where this point begins to enter the soil, that is the semi major axis of the ellipse, we get:

$$B_2A_1 \cdot ctg(90^{\circ} - \varphi_2) = C_2A_1 \cdot ctg(90^{\circ} - \beta_2) \quad (5)$$

where: β_2 – angle of the needle axis to the soil surface at the intermediate position; φ_2 – angle between the lateral side of the conical part of the needle and the soil in intermediate position

Using the notation that is inherent in an ellipse, we get: $B_2A_1=a$, and $C_2A_1=c$. Then, in accordance with the well-known dependence of the ellipse $a^2=b^2+c^2$, we get: $a^2 = (B_2A_1)^2 = b^2 + c^2 = r_{nC}{}^2 + c^2$. Whence

$$B_2A_1 = \frac{r_{nC} \cdot tg\beta_2}{\sqrt{tg^2\beta_2 - tg^2\varphi_2}} . \quad (6)$$

In accordance with accepted assumptions, the value of B_2A_1 determines the size of the semi major axis of the ellipse formed by the results of the interaction of the needle with the soil. This ellipse, as noted above, is formed at the soil-air interface. Parameter r_{nC} is varies from zero in the beginning position of the contact and to some value that characterizes the depth of penetration of the needle into the ground. The angle β_2 varies according to (4).

Determine the area of the ellipse as the area of the figure, which formed the needle by the results of penetration into the soil as

$$S_{el} = \pi \cdot a \cdot b = \pi \frac{r_{nC}^2 \cdot tg\beta_2}{\sqrt{tg^2\beta_2 - tg^2\varphi_2}} \quad (7)$$

where: S_{el} – area of the ellipse (m^2); a – semi-major axis of the ellipse (m); b – semi-minor axis of the ellipse (m).

The change in the area that was formed on the surface of the soil will be estimated by the index of the difference in the areas of the ellipse and the circle with the radius r_{nC}

$$\Delta S_{SP} = S_{el} - S_c = \pi \frac{r_{nC}^2 \cdot tg\beta_2}{\sqrt{tg^2\beta_2 - tg^2\varphi_2}} - \pi \cdot r_{nC}^2 = \pi \cdot r_{nC}^2 \cdot \left(\frac{tg\beta_2}{\sqrt{tg^2\beta_2 - tg^2\varphi_2}} - 1\right) \quad (8)$$

where: S_c – area of the circle with the radius r_{nC} (m^2). Adopt

$$k_{SP} = \frac{tg\beta_2}{\sqrt{tg^2\beta_2 - tg^2\varphi_2}} - 1 \quad (9)$$

where: k_{SP} – coefficient of surface-plane interaction of the needle with the soil. Expression (8) takes the form:

$$\Delta S_{SP} = \pi \cdot r_{nC}^2 \cdot k_{SP} = S_c \cdot k_{SP} \quad (10)$$

The space-depth interaction of the needle with the soil is estimated by the change in the volume of figures that were formed from the penetration of the needle into the soil.

$$\Delta V_{SD} = V_{KE} - V_{KC} = \frac{1}{3}\pi \cdot r_{nC}^2 \cdot y_{\max} \cdot k_{SP} = V_{KC} \cdot k_{SP} \quad (11)$$

where: ΔV_{SD}, V_{KE}, V_{KC} – the volume change, the volume of the cone with the base ellipse and the volume of the cone with the circle at the base, respectively (m^3).

It should be noted that the main factors that influence the determination of the required force for deepening the needles of the needle harrow in the soil are: the depth of the needle's immersion, the angle of friction of the needle along the ground, and the angle characterizing the taper of the needle. In addition, the force required to deepen the needle into the soil depends on the hardness of the soil, that is, its mechanical composition and moisture content.

It is established that the interaction of the needle of any shape and design with the soil leads to the appearance on its surface of figure close in shape to the ellipse. Moreover, in the phase of the needle entering the soil in the direction opposite to the motion, a semi-ellipse is formed, whose small semi axis is equal to the radius of the conical (cylindrical) part of the needle that penetrated the soil.

The semi major axis of the semi-ellipse depends on the parameters of the needle, their number on the disk, the depth of penetration of the needle into the ground. Leaving from the soil, the needle on its surface leaves the flattening in the form of the second part of the semi-ellipse. The needle forms a funnel (trace), which represents a cone with the vertex, which is based on an ellipse.

The developed method improves the accuracy of predicting and evaluating the efficiency of interaction rotary-harrow needle with soil. The method creates the prerequisite s for reducing the energy costs of soil cultivation.

The use of research results in the practice of agricultural enterprises makes it possible to solve the key task - to increase production efficiency through the management of technological processes, using machines and implements adapted for specific production conditions, as well as methods for their evaluation.

The developed theoretical background complements the existing experimental methods for determining the indicators of soil quality, thereby increasing the accuracy of assessment and experimental determination of the indicators of the quality of the implementation of the technological process of tillage.

4. Conclusions

1. It is noted that the result of the interaction of the round needle of rotary harrow with the soil, is a regular-shaped hole with an ellipse at the base.

2. Theoretically justified and noted that in the phase of needle entry into the soil in the direction opposite to the movement, a semi-ellipse is formed, the small semi-axis of which is equal to the radius of the conical (cylindrical) part of the needle, which penetrates the soil. The semi-major axis of the semi-ellipse depends on the parameters of the needle, their number on the disk, the depth of penetration into the soil. In the phase of emergence from the soil, the needle on its surface also forms a semi-ellipse.

3. The method has been developed and the coefficients for estimating of surface-plane and space-deep interaction of the needle with the soil are theoretically justified, which makes it possible to improve the accuracy of forecasting and evaluating the effectiveness of the interaction of the needle of rotary harrow with the soil. Space-deep interaction is estimated in terms of the change in the volume of a figure, which is formed from the results of needle penetration into the soil. The method creates the prerequisites for improving the quality and energy indicators of the technological processes of soil treatment with rotary harrows, especially under conditions of their application for the shallow surface soil fracturing in the climatic zones that are prone to wind erosion.

5. References

1. Gukov Ya.S. Drincha V.M. (2012): Resursy i prioritety agroinzhenernoj nauki [Resources and priorities of agroengineering science]. Kyiv: Feniks.

2. Zaika P.M. (2001): Teoriia silskohospodarskykh mashyn. Mashyny ta znariaddia dlia obrobitku gruntu [The theory of agricultural machines. Machines and tools for soil cultivation], Kharkiv: OKO.

3. Heinze S., Rauber R., Joergensen R.G. (2010): Influence of mouldboard plough and rotary harrow tillage on microbial biomass and nutrient stocks in two long-term experiments on loess derived Luvisols. Applied Soil Ecology, 46 (3): 405–412.

4. Vlăduţ D.I., Vlăduţoiu L., Marin E., Biriş S.Şt., Vlăduţ V., Găgeanu I., Mircea I.D. (2015) Aspects regarding the conservation soil tillage systems using on the world – a review. The Second International Symposium on Agricultural Engineering, 9th-10th October 2015, Belgrade–Zemun, Serbia: 1–15.

5. Kazakov V.I., Kazakov I.V. (2016): Kinematika i parametryi protsessa kacheniya rotatsionnyih rabochih organov kultivatora dlya pitomnika [Kinematics and parameters of rolling process for the rotary working bodies of the cultivator for nursery]. Lesotehnicheskiy zhurnal 3(23): 156–161.

6. Kravchuk V., Hajlis G., Shevchuk V. (2011): O kachenii diskov igolchatoj borony pri peremeshhenii po poverhnosti pochvy [About rolling disc harrows needle as you move through the soil surface]. Tehnika i tehnologija APK, 10: 23–25.

7. Hajlis G., Kovalev, N., Tolstushko, N., Shevchuk, V. (2014): Analiz raboty igl igolchatoj borony pri ih kachenij po pochve [Analysis of the operation of needle needles with their rolling along the soil]. Traktory i selhozmashiny, 5: 25–29.

8. Sheichenko V.O., Hailis G.A., Shevchuk V.V., Shevchuk M.V. (2016): Doslidzhennia tiahovoho oporu holchastoi borony [Investigation of the traction resistance of the needle harrow]. Mehanizacija i elektrifikacia selskogo hozjajstva, 3(102): 44–54.

9. Sheichenko V.A., Hajlis G.A., Shevchuk V.V., Dudnikov I.A., Pushka A.S. (2017): Jeksperimentalnye issledovanija igolchatoj borony [Experimental research of a needle harrow]. LAP LAMBERT Academic Publishing, Saarbrücken.

10. Korn H., Korn T. (1974): Spravochnik po matematike dlja nauchnyh rabotnikov i inzhenerov [A Handbook of Mathematics for Scientists and Engineers]. Moscow: Nauka.