The experimental determination of the diameter of a flat disk in a ridge seeder

Evgeny Zykin*, Vladimir Kurdyumov, Svetlana Lazutkina and Sergey Albutov

Department of Agrotechnologies, Machines and Life Safety, Ulyanovsk State Agrarian University, Ulyanovsk, Russia

*evg-zykin@yandex.ru

Abstract. The article gives an outline of the development of a method for sowing row crops and the design of a ridge seeder for its implementation. The use of the latter makes it possible to carry out the pre-sowing cultivation in one pass, the sowing of seeds in a moist soil layer on a compacted bed. It also helps to form a soil hummock of the required size above the seeds and by rolling the soil hummock from three sides one can finally form a ridge of the soil of the required size and density. The optimal diameter of a flat disc of the working part in the ridge seeder has been theoretically and experimentally substantiated proceeding from the conditions of its reliable rotation in the soil with minimal sliding and rolling resistance, as well as cutting soil clods, weeds and pushing the soil from the inter-row space on to the sown seeds.

1. Introduction

Having analyzed all known ways of pre-sowing preparation of the field and ridge cultivation of row crops [1, 2], we can conclude that the soil ridges during sowing are formed with various means of mechanization including active and passive working bodies and, in particular, flat disks. However, the problem of high-quality formation of soil ridges with flat disks has not been solved yet, therefore, it is necessary to justify the optimal design and operational parameters of the ridge seeder equipped with new working bodies that include flat disks.

To implement the ridge method of sowing row crops [3, 4], a ridge seeder [5, 6, 7] was designed that simultaneously performs the following tasks: pre-sowing cultivation, sowing seeds in the moist soil layer on a compacted bed, forming the required size of the earth hummock over the seeds, rolling the soil ridge from three sides and the final formation of the soil ridge of the required size and density.

On each sowing section (Fig. 1) of the ridge seeder, there is a shovel-coulter, two working bodies with flat disks and a ridge-forming roller. The working bodies are mounted in such a way that their flat disks are pointed at an acute angle in the direction of movement of the ridge seeder.

2. The study objects and research methods

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Figure 1. Sowing section of a ridge seeder: 1 - parallelogram mechanism; 2 - beam; 3 - support wheel; 4 - shovel-coulter; 5, 6 - working parts with right and left flat disks; 7 – ridge roller.

When the ridge seeder is moving, the wings of the shovel-coulter raise the soil layer 2...3 cm thick, move it in different directions, forming a moist compacted bed on which the seeds are paced. The working parts that follow with the wings of A blades also raise the soil and throw it with the right and left flat disks from the inter-row space towards the longitudinal symmetry axis of the beam (on sown seeds).

The process of rectilinear movement and rotation of a flat disk with the radius $R, m$, in the soil at a depth of $h, m$, should take place in such a way that when it meets with soil clods or lumps, a flat disk grips them between its cutting edge and the soil and cuts them. In this case, the contact angle $\theta$ with the soil is the grip angle [8] (Fig. 2).

In the interaction of the cutting edge of a flat disk with the soil clod $A$, two normal forces arise: $N_1 = N \tan \beta$ - one tending to push out a clod of the soil, and $N_2 = N / \cos \beta$ - perpendicular to the cutting edge of a flat disk. The resulting force $N = N_1 + N_2$ - tends to push the clod of soil out of the cutting edge aperture and the soil surface in the direction of the positive part of the Ox axis.

Between the surfaces of the soil clod and the soil the friction force $F_1$ arises and force $F_2$ – between the cutting edge of the flat disk and the soil. The resultant force of friction $F = F_1 + F_2$ goes to the direction opposite the direction of the flat disk rotation [9, 10].

From fig. 2 it follows that:

$$F_1 = N_1 \tan \varphi_1,$$  \hspace{1cm} (1)

$$F_2 = N_2 \tan \varphi_2,$$  \hspace{1cm} (2)
where $\varphi_1$ – the angle of friction between the cutting edge of the flat disk and the soil clod, deg.; $\varphi_2$ – the angle of friction between surfaces of the soil clod and the soil, deg.

The pressing of the soil clod between the cutting edge and soil will take place if

$$F_1 + F_2 \cos \theta \geq N,$$

or

$$N_1 \tan \varphi_1 + N_2 \tan \varphi_2 \cos \beta \geq N.$$  

(4)

Having substituted the values $N_1$ and $N_2$, in equation (4), taking account that $\beta = 90^\circ - \theta$, we will obtain:

$$\tan \varphi_1 + \tan \varphi_2 \geq 1.$$  

(5)

If $\tan \varphi_1 + \tan \varphi_2 < 1$, then the soil clod will be thrown out of the aperture between the cutting edge of the flat disk and the soil surface.

To rotate a flat disk in the soil with minimal slip and rolling resistance, it is necessary to justify its diameter. A flat disk with an optimal diameter should ensure reliable cutting of soil clods and weeds and provide a removal of a certain amount of the soil from the inter-row space on to sown seeds.

Since the flat disk of the working part is mounted with the angle of attack $\alpha$, deg., to the movement direction of a ridge seeder, then in the longitudinal and vertical plane the projection of the flat disk represents the ellipse with the semi-axes $R$ and $R \cos \alpha$.

The canonic equation of the ellipse

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1,$$

where $a = R \cos \alpha$ – the minor axis of the ellipse, m; $b = R$ – the major axis of the ellipse, m.

Taking account of the flat disk parameters we will write equation (6) in the following way:

$$\frac{x^2}{R^2 \cos^2 \alpha} + \frac{y^2}{R^2} = 1.$$  

(7)

From equation (7) we will express the value of $y$:

$$y = \sqrt{R^2 - \frac{x^2}{R^2 \cos^2 \alpha}} = \sqrt{R^2 \cos^2 \alpha - \frac{x^2}{\cos \alpha}}.$$  

(8)

To determine the angle $\theta$ formed by the force $N$ in the direction of the axis $Ox$ and tangent line to the cutting edge of the flat disk it is necessary to distinguish expression (8) in the variable value $x$:

$$\tan \theta = \frac{dy}{dx} = \left( \sqrt{R^2 \cos^2 \alpha - \frac{x^2}{\cos \alpha}} \right) = -\frac{x}{\cos \alpha \sqrt{R^2 \cos^2 \alpha - x^2}}.$$  

(9)

To determine $x$ it is required to take account that in the point $A$ of the contact between the cutting edge of the flat disk and soil clod is

$$y = -(R - h).$$  

(10)

Then, having substituted expression (10) in equation (7), we will obtain:

$$\frac{x^2}{R^2 \cos^2 \alpha} + \frac{(R - h)^2}{R^2} = 1.$$  

(11)

Expressing the variable value $x$ from equation (11), we will obtain:

$$x = \pm \cos \alpha \sqrt{2hR - h^2}.$$  

(12)

By applying expression (12) in equation (9), we will obtain:

$$\tan \theta = -\frac{\pm \cos \alpha \sqrt{2hR - h^2}}{\cos \alpha \sqrt{R^2 \cos^2 \alpha - \left( \pm \cos \alpha \sqrt{2hR - h^2} \right)^2}}.$$  

(13)

We will square both sides of equation (13), taking into account that $\tan \theta = \tan \varphi_1 + \tan \varphi_2$ and, having performed the corresponding transformations, we will obtain the quadratic equation:
\[ R^2 \left( \tan \alpha_1 + \tan \alpha_2 \right)^2 \cos^2 \alpha - 2hR \left[ 1 + (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha \right] + h^2 \left[ 1 + (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha \right] \geq 0. \] (14)

Having expressed \( \left[ (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha \right] \) through \( i \), and \( \left[ 1 + (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha \right] \) through \( j \), and solving equation (14) in respect to the radius \( R \) of the flat disk, we will obtain:

\[ R_i \geq \frac{hj_i - h\sqrt{j(j-i)}}{i_i} \] and \[ R_2 \geq \frac{h\sqrt{j(j-i)}}{i_i} + \frac{hj_i}{i_i}, \] (15)

or

\[ R_{i,2} \geq \frac{h(j \pm \sqrt{j(j-i)}}{i_i}. \] (16)

Having made the return substitution of the variables \( i \) and \( j \), we will determine the optimal diameter of the flat disk of the working part in a ridge seeder proceeding from the conditions of its reliable grip on the soil and minimal slip:

\[ D \geq \frac{2h \left[ 1 + (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha \pm \sqrt{1 + (\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha} \right]}{(\tan \alpha_1 + \tan \alpha_2)^2 \cos^2 \alpha}. \] (17)

The friction angle between the cutting edge of a flat disk and the soil clod (or the soil friction angle over steel) for black soils is \( \varphi_1 = 20 ... 24^\circ \), and the friction angle between the surface of the soil clod and soil is \( \varphi_2 = 48^\circ \). Then, with the cutting depth of the working part with a flat disk \( h = 0.06 \) m, the minimum diameter of a flat disk with the angle of attack of \( \alpha = 5^\circ \) will be \( D = 0.08 ... 0.26 \) m, with \( \alpha = 35^\circ \) - \( D = 0.07 ... 0.32 \) m.

3. Research results

The geometric dimensions of the soil hummock formed during sowing by working parts with flat disks, in addition to the diameter \( D \) of flat disks and their angle of attack \( \alpha \), also depend on the speed \( v \) of the ridge seeder. The studies were carried out in the tillage bin with the soil moisture 19...23 % with the diameter of flat disks being 0.2; 0.25; 0.3 and 0.35 m. The cutting depth of the working bodies with flat disks was 0.06 m, because it is given by agrotechnical requirements for pre-sowing cultivation. As a result of search experiments, the ranges of variation of the main independent factors of the process of formation of the soil hummock were determined: the speed of the section of the seeder with the working bodies was changed from 1.2 to 2.4 m / s with an interval of 0.4 m / s; the angle of attack of flat disks to the direction of movement of the unit is from 5 ° to 30 ° with an interval of 5 °.

When the soil is moved from the inter-row space on to sown seeds, flat disks should provide the required dimensions of the soil hummock for its subsequent high quality compaction. Therefore, as a criterion for optimization, we adopted a coefficient of conformance to the \( k_{cs} \) standard, which allows us to characterize the quality of the formed soil hummock from the position of correspondence to its profile established by agrotechnical requirements.

The coefficient of conformance to the standard can be expressed as the following dependence:

\[ k_{cs} = 1 - \frac{|S_{cs} - S_h|}{S_{cs}}, \] (18)

where \( S_{cs} \) – the cross-sectional area of the standard soil hummock, the dimensions of which are specified in the agrotechnical requirements for sowing, \( m^2 \); \( S_h \) – the cross-sectional area of the soil hummock formed after the passage of the working bodies, \( m^2 \).

After implementing the experiments and processing their results with the help of the Statistica PC program, mathematical models of the process of forming the soil hummock in natural values of factors were obtained.

The equation of the response surface from the interaction of the speed of the unit and the angle of
attack of flat disks with a diameter of 0.2; 0.25; 0.3 and 0.35 m has the following form (equations 18, 19, 20 and 21, respectively):

\[ k_{cs} = 0.0994 + 0.1358v + 0.0527\alpha - 0.0558v^2 - 0.0002v\alpha - 0.0011\alpha^2, \quad (19) \]
\[ k_{cs} = -0.655 + 1.2591v + 0.0568\alpha - 0.2724v^2 - 0.021v\alpha - 0.0006\alpha^2, \quad (20) \]
\[ k_{cs} = -0.7615 + 1.4606v + 0.041\alpha - 0.34v^2 - 0.0146v\alpha - 0.0005\alpha^2, \quad (21) \]
\[ k_{cs} = 0.1922 + 0.5632v + 0.0212\alpha - 0.1635v^2 + 0.0005v\alpha - 0.0005\alpha^2, \quad (22) \]

where \( k_{cs} \) – the coefficient of conformance to the standard; \( v \) – the speed of the unit, m/s; \( \alpha \) – the angle of attack of each flat disk, deg.

By differentiating equations (19-22), we determined the coordinates of the extremum at which the maximum value of the optimization parameter is achieved:

from equation (2): \( v = 1.2 \) m/s and \( \alpha = 24 \) deg., \( k_{cs} = 0.81 \).
from equation (3): \( v = 1.5 \) m/s and \( \alpha = 21 \) deg., \( k_{cs} = 0.89 \).
from equation (4): \( v = 1.85 \) m/s and \( \alpha = 14 \) deg., \( k_{cs} = 0.87 \).
from equation (5): \( v = 1.76 \) m/s and \( \alpha = 22 \) deg., \( k_{cs} = 0.92 \).

From the presented calculations, it follows that the maximum value of the coefficient of conformance to the standard \( k_{cs} = 0.92 \) is achieved at a unit speed of 1.76 m/s and angle of attack of flat disks \( \alpha = 22 \) degrees with their diameter of 0.35 m.

The response surface corresponding to equation (21) is shown in Fig. 3.

Having analyzed equations 18-21, we can conclude that in order to achieve the maximum value of the coefficient of conformance to the standard \( k_{cs} = 0.92 \) when forming a soil hummock, it is necessary to use flat disks with a diameter of 0.35 m, with the aggregate speed of 1.76 m/s (6.34 km/h), that corresponds to the agrotechnical requirements of sowing row crops (6...8 km/h), and to set them to the direction of movement of the unit at an angle \( \alpha = 22 \) degrees.

![Figure 3](image_url)

**Figure 3.** The response surface from the interaction of the speed of the unit and the angle of attack of flat disks.

4. Conclusions

Thus, the optimum diameter of a flat disk in the ridge seeder depends on the depth of penetration \( h \) of the working body specified in the agrotechnical requirements, the angle of attack \( \alpha \) of a flat disk, the physical and mechanical properties of the soil, and the speed \( v \) of the ridge seeder.

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