Parameters and operating modes of the coulter group of the sod seeder

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Abstract. For the implementation of strip overseeding, they are used by seed drills with disc cutters. Improving the sowing quality due to the compaction of the seed bed and the creation of a soil layer between the seeds and fertilizers is possible when removing the working bodies of seeds and fertilizers of the from the area of the circular knives. To ensure the incorporation of seeds and granulates at different soil levels, it is stage to determine the length of the fertilizer coulter cheeks and the permissible distance between working bodies. Dependencies for calculating rational parameters and operating modes of the developed coulter group are obtained. The calculated parameters make it possible to ensure the minimum spread of fertilizer granules along the planting depth and high stability of the soil layer thickness between the fertilizer and seeds. In the range of operating speeds of the seeder, the rational parameters of the coulter group have the following values: the angle at the top of the fertilizer coulter in the horizontal plane is 15-20°, the lip of the fertilizer coulter is 0.040-0.045 m, the width of the coulter bell is 0.02 m, the minimum distance between the coulters is 0.14-0.16 m.

1. Introduction
Most technologies for improving natural forage lands are based on a combination of chemical suppression of plants in the existing ecosystem with herbicides, followed by mechanical cutting of narrow grooves in the sod and sowing grass seeds in them with special seeders or combined units [1-2].

The development of ecological farming has led to the widespread use of technologies for increasing the productivity of natural forage lands. This technology consists in sowing grass in strips with mechanical processing in the sod of the strips. At the same time, the size of the stripes ensures the successful development of seedlings without the use of chemicals [3-4].

Along with high-quality soil cultivation, a special place in creating the starting conditions for germination and further vegetation of plants is occupied by an increase in the uniformity of planting seeds and fertilizers in the soil. This provides equal access of sown seeds to the main growth factors [5].

The quality of the seed placement in the soil is determined by the work of the opener group of the tillage and sowing units. Numerous studies of tillage and seed-making working bodies have shown the advantage of their installation on elastic stands or the use of spring-loaded suspension mechanisms for this [6-8].

The design of a universal coulter group for tillage and sowing units (Patent RF no. 2641073) has been proposed. The tillage part of this device provides high quality pre-sowing tillage. This allowed the use of torsion springs as coulter leashes. The combination of the functions of fastening, protection and relief copying in one structural element (torsion spring for single-row installation of keeled openers) ensures
compactness and low metal consumption of the opener group. In the future, this coulter group can be used both for strip sowing of grass seeds in the sod with SDK seeders and for row sowing.

The aim of the study is to theoretically determine the parameters of the opener group of a seeder for strip sowing of grass seeds into sod with the introduction of a starting dose of mineral fertilizers.

2. Materials and methods

To increase the efficiency of the process of direct strip sowing of grass seeds into the sod with SDK seeders, it was proposed to remove the working bodies for seeding seeds and embedding fertilizers from the operating zone of disc cutters. In this case, it is necessary to combine the fertilizer and seed coulters into a single coulter group. Removing the coulter group from under the protective casing of the milling furrow-opener of the seeder (figure 1, b) will reduce the soil sticking to the space under the casing and exclude the influence of casing vibrations on the coulters from impacts of clods earth. Reducing sticking of the disc cutter casing is important in conditions of high humidity, and eliminating the influence of casing vibrations on the coulters from impacts of clods of earth will improve the uniformity of the seeding depth of mineral fertilizer granules and seeds. This method includes pre-sowing strip processing of the sod with disc cutters, leveling the soil, applying mineral fertilizers and sowing seeds on a compacted seeding bed along the axis of the treated strip 0.01-0.02 m above the depth of fertilization (figure 1, a). In this case, a double opener is installed for fertilizers and grass seeds. Torsion springs are used to mount the coulter group. When driving in a milled strip of soil, the fertilizer coulter creates a furrow into which mineral fertilizers are sown. After the coulter has passed, the furrow walls crumble and cover the fertilizer. This ensures an optimal soil layer between mineral fertilizers and seeds. Further, the opener compacts the seedbed over the granules of mineral fertilizers and grass seeds are sown. Compaction of the soil is carried out by a packer roller.

![Figure 1](image-url)

**Figure 1.** The technological scheme of the sod seeder of strip sowing (a) and its coulter group (b): 1 - packing roller, 2 - seed coulter, 3 - fertilizer coulter, 4 - hopper for seeds and fertilizers, 5 - disc milling cutter; 6 - suspension mechanism of coulter group; 7 - protective casing.

One of the main indicators of the quality of sowing is the stability of the depth of incorporation of mineral fertilizers and seeds, as well as their size of the soil layer among themselves. For a minimum spread of mineral fertilizer granules along the seeding depth when they fall from the fertilizer opener into the formed furrow, it is necessary that they have time to move to the water of the furrow [9, 10].

In this regard, it is necessary to determine the optimal length of the cheeks A of the fertilizer coulter, which delay soil shedding from the walls of the furrow. To ensure the optimal size of the soil layer between the granules of mineral fertilizers and the seeds, it is necessary to find the minimum allowable distance l between the fertilizer and seed coulters. Determination of this distance l makes it possible to achieve complete cover of the granules with soil crumbling from the walls of the furrow.

To determine the length of the cheeks A of the fertilizer coulter, the movement of fertilizer granules along the furrow walls was studied. The furrow profile is formed by two inclined planes. Therefore, let
us consider the “boundary case” of falling fertilizer particles into the upper point of the furrow wall. To obtain a minimum spread of fertilizers along the seeding depth, the length $A$ of the side walls of the fertilizer coulter should be such that the granules that fell into the furrow had time to slide to the bottom before they were closed by the earth that fell from the walls of the furrow.

Let us consider the movement of the granule along the wall of the furrow and determine the time it takes to reach its bottom (Fig. 2, a). When a granule hits the furrow wall, it has a falling speed $V_n$ and it is affected by gravity $mg$, friction force $mg \cdot \tan \varphi$ and reaction force $N$ of the soil. Let us compose the equation of motion of the granule along the groove wall in the coordinate axes $\tau-N$:

$$m \frac{d^2 \tau}{dt^2} = mg \cdot \cos \gamma - mg \cdot \sin \gamma \cdot \tan \varphi.$$  \hspace{1cm} (1)

The solution to the differential equation (1) has the form:

$$V_\tau = g(\cos \gamma - \sin \gamma \cdot \tan \varphi) \cdot t + C_1,$$ \hspace{1cm} (2)

Where $\gamma$ – angle at the apex of the opener, deg.;

$C_1$ – constant of integration;

$t$ – granule sliding time, s;

$\varphi$ – angle of friction of the soil against the side face of the opener, deg.

The nature of the movement of the granule along the wall of the groove is largely determined by the shape of its transverse profile. It depends on the value of the angle $\gamma$ at the apex of the opener shaft in the vertical-transverse plane. There are two types of movement of granules in the groove: with reflection from the groove wall and with sliding along it. In our case, the second option is most acceptable. To completely eliminate the rebound, it is necessary that the force of the impact recovery does not exceed the component of the granule mass per normal $N$ or its normal acceleration equal to $a_n \leq g \sin \gamma$ [10].

Then, at the moment the fertilizer granule falls onto the furrow wall at $t = 0$, its initial velocity is equal to $V_\tau = V_n \sin \delta$ and the equation for the speed of the granule along the furrow wall, taking into account the initial conditions, can be expressed by the following expression:

$$V_\tau = g(\cos \gamma - \sin \gamma \cdot \tan \varphi) \cdot t + V_n \cdot \sin \delta,$$ \hspace{1cm} (3)

Where $\delta$ – angle of incidence of the granule, deg.

Analysis of equation (3) shows that the speed of movement of the granule along the furrow wall depends on its speed $V_n$ of fall and the angle of fall $\delta$, the coefficient $\tan \varphi$ of friction of the granule against the soil, as well as on the value of the angle $\gamma$ at the apex of the opener in the vertical-transverse plane.

The solution to equation (3) with the initial conditions: $t = 0$ s, $\tau = 0$ m, is expressed as:

$$\tau = g(\cos \gamma - \sin \gamma \cdot \tan \varphi) \frac{t^2}{2} + V_n \cdot \sin \delta \cdot t.$$ \hspace{1cm} (4)

The distance traveled by the pellet before it slides to the bottom of the furrow after time $t$

$$\tau_t = \frac{b}{2 \sin \gamma}.$$ \hspace{1cm} (5)

Where $b$ – coulter socket width, m.

To determine the length of the cheek $A$ of the opener, we calculate the time $t$ of movement of the granule along the plane of the furrow wall during which it reaches the bottom, using expressions (4) and (5):

$$\frac{g(\cos \gamma - \sin \gamma \cdot \tan \varphi)}{2} \cdot \frac{t^2}{2} + V_n \cdot \sin \delta \cdot t - \frac{b}{2 \sin \gamma} = 0$$ \hspace{1cm} (6)

Solving the second order equation (6), it is possible to determine the time $t$ required to move the granule to the bottom of the furrow. The calculated length of the fertilizer coulter jaws is

$$A = V_\tau \cdot t.$$ \hspace{1cm} (7)
When finding the minimum allowable distance $l$ between the fertilizer and seed coulters to create a layer of soil between mineral fertilizers and seeds, we determine the relative speed of movement of soil particles bordering the lateral edges of the fertilizer coulter, based on the condition of complete cover of the fertilizer granules with soil crumbling from the furrow walls.

When the keeled fertilizer coulter moves, which has the shape of a straight flat wedge in the longitudinal-horizontal plane, the following forces act on a soil particle in contact with the side face of the opener at point $O$ (Fig. 2, b):

- $P_x$ - lateral pressure of bulk material,
- $F_{tr}$ - friction force of soil particles along the coulter shaft and
- $F_{in}$ is the dynamic pressure force caused by soil inertia thrown to the sides by the side face of the coulter and directed opposite to the absolute velocity $V$ of movement of soil particles thrown by the side face of the coulter [10].

Let us decompose the force $N$ into the components $P_x$ and $P_x\tau$, acting in the direction of the speed $V_c$ of the coulter movement and on its working surface. A soil particle will slide on the wedge surface under the action of the force $P_x\tau > F_{tr} + F_{in}\tau$.

The force of dynamic soil pressure $F_{in}$ on the side face of the opener is determined by the expression:

$$
F_{in} = \frac{2m}{S} \cdot V_c^2 \cdot \sin \frac{\Delta}{2}
$$

(8)

Where $m$ – soil mass thrown by the side face of the opener, kg;
$\Delta$ – angle at the apex of the shank opener for fertilizer, deg.

The differential equation of motion of a soil particle along the inclined edge of the opener:

$$
\frac{md^2x}{dt^2} = mg \cdot \tan \beta - mg \cdot \tan \varphi - \frac{2 \cdot m \cdot V_c^2}{S} \cdot \sin \frac{\Delta}{2}
$$

(9)

Where $\frac{mg}{2\tan \alpha} = P_x$ soil force on the side face of the opener, N;
$V_c$ - coulter speed, m/s;
$\alpha$ – particle stacking angle, deg.;
$\beta$ - angle between the direction of the coulter speed and the normal, deg.

Integrating expression (9), we find the equation for the velocity of soil particles along the inclined surface of the opener head, taking into account that the time of movement of particles along the inclined side of the fertilizer coulter is $t = \frac{Scos\Delta}{V_c}$:

$$
V_x = \frac{g \cdot S \cdot \cos \Delta}{2 \cdot \tan \alpha \cdot V_c} (\tan \beta - \tan \varphi) - 2V_c \cdot \cos \Delta \cdot \sin \frac{\Delta}{2}
$$

(10)

After the soil particle passes to the side face of the opener, it will begin to move along the coulter cheek (Fig. 2, b), where the following forces act on it: $F_1$ is the friction force between the soil and the side face of the opener and $F_2$ is the friction force between soil particles. The equation of motion of a particle along the cheek of a fertilizer coulter after integration has the form:

$$
V_x = \frac{gt}{2\tan \alpha} [\tan \varphi - \tan \varphi_1] + C_1,
$$

(11)

Where $\varphi$ – angle of friction between soil particles, deg.

Under initial conditions $t = 0$, the speed of soil particles on the side face of the opener:

$$
V_x = \frac{gt}{2\tan \alpha} [\tan \varphi - \tan \varphi_1] + \frac{g \cdot S \cos \Delta}{2 \tan \alpha \cdot V_c} (\tan \beta - \tan \varphi) - 2V_c \cdot \cos \Delta \cdot \sin \frac{\Delta}{2}
$$

(12)

Equation (12) allows you to find the soil speed when coming off the edge of the fertilizer coulter. Its value depends on the forward speed $V_c$ of the coulter and its geometrical parameters: angle $\Delta$ at the apex of the opener and the length $S$ of the inclined surface of the opener.

After the coulter has passed, the soil layer bordering on the side walls of the coulter falls under the influence of gravity. Time $t_f$ of closing the furrow after the coulter pass is:
\[ t_1 = \sqrt{\frac{2h}{g}}, \]  

(13)

Where \( h \) – depth of the fertilizer coulter stroke, m.

Due to the small width of the fertilizer coulter bell, it is assumed that the fall of the soil layer bordering on the side walls will ensure the closure of the furrow with granules of mineral fertilizers. In this case, the distance traveled by the soil particle during shedding will be \( B = V_0 \cdot t_1 \), and the value of the path traversed by the opener group of the seeder during this time is \( B_1 = V_c \cdot t_1 \). Then the minimum distance between the fertilizer and seed coulter is determined as:

\[ l = \sqrt{\frac{2h}{g} \left( V_c - \frac{g \cdot t}{2tg\alpha} (tg\varphi - tg\varphi_1) - \frac{S \cdot cos\Delta}{2tg\alpha \cdot V_c} (tg\beta - tg\varphi) + 2V_c \cdot cos\Delta \cdot sin\frac{\Delta}{2} \right)}. \]  

(14)

By varying the values of other parameters of the fertilizer coulter, such as the angle \( \gamma \) at the apex of the opener in the vertical-transverse plane and the width of the socket \( b \), as well as the technological parameters of the sowing process, it is possible to find rational values of the parameters under consideration in relation to the operating conditions of the coulter group.

3. Results and Discussion

To study the influence of the main parameters and operating modes of the coulter group on the length of the cheek of the \( A \) tuck coulter, a graphical solution to equation (7) was constructed for the following parameters: \( \varphi = 30^\circ \), \( \gamma = 20^\circ \), \( \delta = 45^\circ \) and \( V_n = 1.6 \) m/s (figure 2).

![Figure 2](image2.png)

**Figure 2.** Influence of the width \( b \) of the coulter bell on the length \( A \) of the fertilizer coulter sides (a) and the angle \( \Delta \) at the apex of the shank fertilizer coulter in the horizontal plane by the minimum permissible distance \( l \) between the fertilizer and seed coulters (b).

An increase in the width \( b \) of the flare of the fertilizer coulter and its speed \( V_c \), regardless of the initial speed \( V_n \) of the fall of the granule, cause an increase in the required length \( A \) of the coulter cheeks. Changing the width \( b \) of the bell from 0.01 to 0.03 m at a fixed speed \( V_c = 2.0 \) m/s requires lengthening the coulter cheeks \( A \) from 0.008 to 0.023 m in the case of a pellet falling from a height of \( h_n = 1.0 \) m \((V_n = 4.4 \) m/s\)) and from 0.022 to 0.058 m at \( h_n = 0.125 \) m \((V_n = 1.6 \) m/s\)). An increase in the angle \( \gamma \) at the apex of the opener \( t \) more than \( 20^\circ \), as well as the height of fall \( h_n \) of the granule, can change the nature of the granule movement, going from sliding to multiple reflection from the walls, at which the time \( t \) required to move the granules to the bottom of the groove will significantly increase.

To minimize the spread of mineral fertilizer granules along the planting depth, it is necessary to limit their free fall height and ensure the formation of the lower part of the furrow with a small opening angle. This will allow you to use the most compact fertilizer coulter design. Subject to the optimal nature of the movement of the granules along the walls of the furrow for a sod seeder for strip sowing in the range of operating speeds up to 2.0 m/s, the rational parameters of the fertilizer coulter are the angle at the top...
of the shank in the vertical-transverse plane $\gamma = 20^\circ$, the width of the bell of the opener $b = 0.02$ m. Then, he calculated coulter cheek length $A$ is then $0.040-0.045$ m.

In order to identify the relationship between the value of the minimum allowable distance $l$ between the fertilizer and seed coulters and the design and technological parameters of the coulter group, the solution to equation (14) is graphically illustrated (Fig. 4, b) with the following values of the variables: $\alpha = 25^\circ$, $\varphi = 30^\circ$, $\varphi_1 = 35^\circ$, $\beta = 65^\circ$, $h = 0.03$ m, $t = 0.02$ s, $S = 0.03$ m. This corresponds to the sowing conditions on medium loamy sod-podzolic soils.

With an increase in the speed $V_c$ of the coulter group and an increase in the angle $\Delta$ at the apex of the fertilizer coulter, the distance required for complete closure of mineral fertilizers increases. This is explained by the fact that the relative velocity of soil particles $V_s$, bordering on the edges of the opener, increases. Thus, an increase in the coulter speed from 1.0 to 2.2 m/s at a fixed value of the angle $\Delta = 20^\circ$ leads to an increase in the distance between the coulters $l$ from 0.06 to 0.26 m. A change in the value of the angle $\Delta$ causes changes of a similar nature, but expressed less significant.

An increase in the length $S$ of the inclined sidewall opener wall slightly reduces the required distance between the openers. So, according to calculations, at a coulter speed $V_c = 2.2$ m/s, its elongation from 0.01 to 0.03 m reduced the value of the permissible distance $l$ by 5-12%.

To increase the compactness of the design of the coulter group while maintaining a high stability of the size of the soil layer between the sown granules of mineral fertilizers and seeds, it is necessary to use a fertilizer coulter with the minimum permissible width of the opener. In the range of operating speeds of the sod seeder up to 2.0 m/s, the rational parameters of the coulter group are the angle at the top of the fertilizer coulter in the transverse horizontal plane $\Delta = 15-20^\circ$, the length of the inclined wall of the coulter $S = 0.03$ m, the distance between the coulters $l = 0.14-0.16$ m.

4. Conclusion
The structural and technological scheme of the opener group of the sod seeder, consisting of fertilizer and seed openers, which are installed on fastening leashes in the form of trailers of torsion springs, is theoretically substantiated. Mathematical dependencies have been obtained that make it possible to calculate the parameters and operating modes of the opener group, ensuring the minimum spread of mineral fertilizer granules along the seeding depth and the stability of the soil layer between the mineral fertilizer granules and seeds.

For the range of operating speeds of the strip sod seeder, the rational parameters of the coulter group were calculated: the angle at the top of the fertilizer coulter in the transverse horizontal plane $\Delta = 15-20^\circ$, the length of the lip of the fertilizer coulter $A = 0.040-0.045$ m, the width of the fertilizer coulter bell $b = 0, 02$ m, the distance between the fertilizer and seed coulters $l = 0.14-0.16$ m.

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