Mathematical prerequisites for improving the method of sowing crops on sloping lands

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Abstract. The technological process of traditional grain production includes some operations: tillage, fertilizing, sowing, crop care, harvesting. Performing the above operations requires many energy-saturated and metal-intensive equipment, repeatedly moving around the field. This negatively affects its structure and, as a result, leads to crop shortages. An effective way to reduce costs in the crop production is to combine several operations in one unit pass such as softening the soil and applying basic fertilizer, preparing the soil and sowing. The article proposes a new method of sowing grain crops, as well as a mathematical justification for the formation of a furrow and the placement of fertilizers and seeds therein to improve the process of sowing grain crops on slopes, namely using a cutting disc creating a furrow in the form of an isosceles triangle instead of a duck-foot sweep that formed a trapezoid in the transverse plane.

1. Introduction

One of the problems of preserving the fertile horizon on sloping lands, which are subject to flushing of the fertile soil layer and fertilizers, as well as the destruction of its biological component due to floods and torrential rains, is the development and implementation of more advanced methods of tillage, as well as the creation of modern tillage and sowing machines for combined sowing of crops which will have a more gentle effect on the fertile soil horizon and simultaneously increase productivity.

Western countries have a faster pace in the development and implementation of new technology with many significant positive factors relating to human interaction with soil, which consists of minimal mechanical impact on it. The most responsible technological process for producing crop products is sowing, inextricably linked with the preparation of the soil for seed planting. Surface tillage without turnover of the reservoir with the preservation of crop residues on its surface contributes to resource-saving (moisture, humus, fuel) and protection from erosion [1, 2, 3, 4].

The new production method of sowing differs from the traditional ones by the absence of the agricultural machinery impact on the field in the post-harvest period and the implementation of sowing according to the background mulched with crop residues, which protects the soil from blowing, contributes to snow retention in the winter and moisture preservation during the growing season of plants. An alternative to the applied farming systems is the No-till technology translated as “no ploughing” from English. This technology eliminates other types of machining, even on the formation of the seedbed. Features of this technology: the soil structure is not disturbed until sowing; all crop residues remain on the surface of the...
field. These features preserve soil moisture and protect the soil from erosion processes [3, 5, 6]. Such technology during sowing has partial destruction of the surface layer by combined coulters based duck-foot sweeps or discs. Seeder disc coulters have a more gentle effect on the soil. Direct sowing needs special seeders with higher strength characteristics.

2. Results and Discussion.
We based the method of sowing grain crops on the idea of preserving the moisture of floods and showers in artificially created depressions on the soil surface, the volume of which can be a potential volume of water accumulation. We combined this idea with the process of sowing spring and winter crops, namely across the slope, a sowing machine with coulters based on duck-foot sweeps performs furrows with a depth equal to the sowing depth. The duck-foot sweep has a shape that provides a furrow with the form of a trapezoid in cross-section. Its smaller base faces down. The seed laying process has the following sequence: seeds are fed through seed delivery pipes whose ends are brought out to space under the duck-foot sweep, they fall into the corners of the furrow, where the distance between the corners corresponds to the row spacing, the soil that has come off the sweep returns to the furrow and covers the seeds, the roller going behind compacts the soil over seeds. The positive factors of the considered method of sowing crops include the following factors: cutting weed vegetation in the furrow and the formation of a compacted sowing bed, one coulter sows two rows, the possibility to place a row of mineral fertilizers between rows of seeds.

The idea is a way to form a furrow by replacing a special sweep with a flat disk or a turbo disc. Observations show that when the disk moves, the soil in the front part is compressed and tends to fall as a result of friction on its lateral sides, and in the rear side, on the contrary, friction forces push the soil outward, which leads to chipping along the outer planes on both sides of the disk. This results in the furrow formation of loosened soil with a cross-section in the form of an isosceles triangle, turned apex down (Figure 1) with an angle \( \beta \) at apex equal to \( \beta = 22^\circ \). The shape of the furrow indicates the feasibility of placing fertilizers at the bottom of the furrow at the apex of an isosceles triangle, and on the sides, at a shallower depth, it is more advisable to place two rows of seeds covered with loose soil.

![Figure 1: Diagram of the formation of the furrow and the placement of fertilizers and seeds](image)

- \( h_y \) – filling depth of the main fertilizer; \( h_c \) – filling depth of seeds;
- \( b \) is the row spacing; \( \alpha \) – soil cleavage angle; • - fertilizers; ● - seeds

Intra-soil fertilization, sowing seeds of agricultural crops have specific width of row spacing, the depth of placement of both in the soil, the location of the seeds relative to the row of fertilizers in horizontal and vertical directions. We are reasoning in relation to the sowing of grain crops (winter wheat) in the Central Black Sea zone. According to the recommendations set forth in [4, 7, 8], the depth of fertilizer placement should be \( h_y = 0.12 ... 0.15 \) m, the row spacing should be \( 0.15 ... 0.30 \) m, and to the side and below the row of seeds it should be \( 0.02 ... 0.07 \) m. Now we define the parameters of the furrow under fertilizers and seeds formed by a flat disk. We proceed from the fact that the agrotechnical requirements determine the depth of placement of a row of fertilizers and seeds, and they are constant, i.e. [9, 10]: \( h_y = \text{const} \) and \( h_c = \text{const} \).

Thus, the width of the furrow \( B_\delta \) will depend on the depth of immersion of the disk, it is also the depth of placement of fertilizers \( h_y \) and the cleavage angle \( \alpha \) (see Figure 1).

We will determine the furrow width \( B_\delta \), the segment \( CD \) represents it in Figure.

\[
CD = 2MD = 2hy \cdot \tan \alpha
\]

(1)

where \( S_\delta \) is the cross-sectional area of the furrow determined by the area of the triangle ACD (see Figure 2)
\[ S_{ACD} = S_8 = \frac{1}{2} CD \cdot h_{y0} = h_{y0} \cdot 2h_{y0}\tan \alpha \cdot \frac{1}{2} = h_{y0}^2 \cdot \tan \alpha \]  \quad (2)

Then, the volume of decompressed soil \( V_\delta \) per hectare is the product of the length of the furrow and its cross-sectional area:

\[ V_\delta = \frac{10000}{b} S_8 \]  \quad (3)

We take the unconsolidated soil volume \( V_\delta \) as the potential volume of moisture accumulation per hectare, but since we are talking about sowing grain on the slopes, the potential volume of moisture conservation \( V_B \) on the slope (Figure 2) will be determined by the dependence [11, 12]:

\[ V_B = V_\delta \cdot K, \]

where \( K \) is the coefficient of moisture accumulation, \( K \leq 1 \).

The potential volume of accumulated water in the grooves on the slope will be proportional to the area of the ACL triangle (see Figure 2), the expression has the form:

\[ S_{ACL} = S_{ACD} - S_{CDL}. \]  \quad (4)

where \( S_{ACL}, S_{ACD}, S_{CDL} \) are the squares of the triangles ACL, ACD, and CDL.

\[ \text{Figure 2: Scheme of the accumulation of the potential volume of water in the furrows made on the slope} \]

We denote the angles at the vertices of the triangle CDL:
- \( C \) is the angle of the field slope \( \beta \);
- \( D = (90 - 2\alpha) \);
- \( L = (180 - 90 + 2\alpha - \beta) = (90 + 2\alpha - \beta) \);

The CDL triangle is wrong, to determine its area we apply the sine theorem:

\[ \frac{CD}{\sin(90+2\alpha-\beta)} = \frac{DL}{\sin \beta} = \frac{CL}{\sin(90-2\alpha)}. \]

In the CDL triangle, the known side is the segment CD, we find the length DL:

\[ DL = CD \cdot \frac{\sin \beta}{\sin(90+2\alpha-\beta)}. \]  \quad (5)

Given the formula (1), the area of the triangle CDL will be determined by the dependence:

\[ S_{CDL} = DL \cdot CD \cdot \sin(90 - 2\alpha) = CD^2 \cdot \frac{\sin \beta}{\sin(90+2\alpha-\beta)} \cdot \sin(90 - 2\alpha). \]  \quad (6)

And the area of the triangle SACL will be determined by the expression:

\[ S_{ACL} = S_{ACD} - S_{CDL} = h_{y0}^2 \cdot \tan \alpha - 4h_{y0}^2 \cdot \tan^2 \alpha \cdot \frac{\sin \beta \cdot \sin(90-2\alpha)}{\sin(90+2\alpha-\beta)}. \]  \quad (7)

The obtained expression shows that the potential amount of moisture accumulation in the furrows on the slope depends on the depth of fertilizer \( h_{y0} \), the soil cleavage angle \( \alpha \) and the field slope angle \( \beta \).

We will conduct a comparative assessment of the proposed method of furrow formation for fertilizers and seeds, based on the volume of unconsolidated soil. The use of a cutting disk for this purpose, in comparison with traditional methods, for example, disking, cultivating, ploughing, will be more effective. The diagram shows it (Figure 3). The sum of the areas of the right-angled triangles ABC and DKM is only part of the cross-sectional area of the formation per furrow to accommodate one row of fertilizers and two rows of seeds.

If the width of the furrow does not exceed the width of the row spacing, then the fraction of the volume of loose soil \( \gamma \) after the passage of the disk knife will be only:
\gamma = \frac{ABC+MDK}{h_B} = \frac{(h_y t g_a + h_y t g_a) h_y}{h_B} = \frac{2 h_y t g_a}{B}, \quad (8)

For the case when the furrow width is equal to the row spacing, the volume of loosened soil formed after the passage with a cutting disk will be half of the volume per furrow [13].

Figure 3: A plan diagram of the formation of a furrow hollow in a flat disk and placement of seeds and fertilizers in it (b is the row spacing; \( h_y \) is the depth of fertilizer placement; \( h_c \) is the depth of seed placement; \( \alpha \) is soil cleavage angle.)

3. Conclusions.
A row width exceeding the furrow width is likely to reduce energy consumption by less than half. This indicates the advisability of using disk as a cultivator of soil when sowing, which will make it possible to almost halve the energy costs of furrow formation.

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