Comparative analysis of soil discarding by spherical disks

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Abstract. The article presents data on the influence of various types of spherical disks on the discarding of soil in the horizontal and vertical planes during its processing. These studies were conducted in order to optimize the selection of working bodies of disk tillage machines in terms of resistance and processing quality. Three types of disks were used in the comparative analysis. Two types of discs with cutouts and one solid spherical disc. On one type of disk, the cutouts are made in the form of circular arcs, and on the other-in the form of arcs of a logarithmic spiral. The conducted studies have shown that within the working surface of the disk, the trajectories of movement of soil particles under the influence of the three types of disks under study differ little from each other. Although it can be noted that the steeper rise of the trajectory in the vertical plane provides a solid disk, and the smallest rise of the trajectory - at the disk with cutouts in the form of a logarithmic spiral. In the horizontal plane, the longitudinal movement of the soil mass is less in disks with cutouts, especially in a disk with cutouts along the arc of a logarithmic spiral. As a result of these studies, it was revealed that the disk working bodies with cutouts on the cutting edge in the form of arcs of a logarithmic spiral showed the best quality and energy indicators.

1. Introduction
In modern agricultural engineering, a significant place is occupied by tillage machines with disk working bodies. The simplicity of the design, high productivity, low tendency to clogging with plant residues, the ability to easily overcome obstacles, relatively low wear of the working bodies, the ability to provide surface tillage and other advantages make disk tillage machines preferred, and in some cases the only possible applications [1-3].

In the practice of operation of disk tillage tools, disk working bodies of various sizes and shapes of cutouts have been used [4-6]. The working bodies of disk tools must ensure the proper quality of tillage, and the minimum energy consumption of the process performed. The problems of reducing costs and reducing energy intensity during tillage, as well as combining several types of operations during tillage, have always been in agricultural production [7-9].

In this paper, the influence of various working bodies of disc harrows and mulchers on the cutouts of soil in the longitudinal-transverse and longitudinal-vertical planes is studied.

2. Materials and methods
Experiments to determine the trajectories of the movement of soil mass were carried out on the experimental field of Belgorod State Agrarian University on medium-loamy slightly alkaline chernozem according to the method developed by P. S. Nartov. To conduct the experiment, a horizontal grid of labeled wooden cubes with a size of 10x10x10 mm was placed in the ground. The grid was laid to a
depth of 40 mm. The grid consists of eight rows of cubes. The number of transverse rows was selected
in such a way that at the time of moving the disk battery in the area with marked cubes, it could occupy
a position in which part of the cubes would still remain in the undeformed layer of soil, and part would
be in the layer laid on the surface of the field. The distance between the cubes in the longitudinal row
was 100 mm, and in the transverse row – 60 mm.

As working bodies, three disk batteries were used, assembled from solid and cut-out disks. Two types
of disks were used as cut-out disks: with cut-outs made in the form of arcs of circles, and with cut-outs
made in the form of an arc of a logarithmic spiral. The batteries consisted of eight disks each. The
distance between the disks is 220±2 mm, the diameter of the disks is D=660 mm. The angle of attack of
the disk batteries is 15°.

The grid was laid as follows. First, the surface of the field on which the grid will be installed was
leveled. Next, a welded metal grid (frame) with a size of 480×1100 mm and a cell size of 60×100 mm
was placed on the aligned section (Figure 1).

Then, at the intersection of the transverse and longitudinal rows of the frame, marked cubes were
laid out. The marking of the cubes was done as follows. All faces of the cubes will be marked ij. Here i
is the number of the longitudinal row of the cube (from 1 to 8), and j is the number of the cross row of
the cube (from 1 to 9). For example, 11,12,13...19 or 21,22,23...29 and so on. Then, using a special
device (Figure 1), all the cubes of the grid were lowered to a depth of 40 mm. The movement of the disk
batteries was carried out in such a way that the first disk of each disk battery passed through the place
where the grid was laid. Then the unit was stopped. The measurement of the spatial coordinates of the
marked cubes after their excavation was carried out using a coordinator-profilometer.

3. Determination of the longitudinal and transverse movement of the soil mass by solid and cut-
out disks
Experimental studies were carried out in order to obtain specific data on the influence of the disk
parameters and a number of other factors on the placement of the soil mass on the field surface after the
impact of the working bodies on it. Disks assembled in batteries were used as working bodies. One disk
battery consisted of solid disks, the second of cut-out disks with cutouts in the shape of a circular arc,
and the third of cut-out disks with cutouts made in the shape of a logarithmic spiral (Figure 2).

The position in space of each cube of the longitudinal row at the moment of stopping actually
determines the position of the same cube at various points in time. The line connecting the locations of
the cubes represents the trajectory of the soil particle relative to the translational movement of the unit.
The measurement of the spatial coordinates of the marked cubes after their excavation was carried out
using a coordinator-profilometer.
Figure 2. Types of disk working bodies used in research: a - solid working edge; b - cutouts in the form of circular arcs on the cutting edge; c - cutouts in the form of a logarithmic spiral on the cutting edge.

The obtained data were used to construct projections of the trajectories of soil particle movements on the XOY and YOZ planes (Figure 3).

Figure 3. Trajectories of movement of soil particles: a – longitudinally-vertical plane YOZ; b – longitudinally-horizontal plane XOY.

From the experimental data presented in Figure 3, it can be seen that within the working surface of the disk, the trajectories of movement of soil particles under the influence of the three types of disks under study differ little from each other. Although it can be noted that the steeper rise of the trajectory in the YOZ plane is for a solid disk, and the smallest rise of the trajectory is for a cutout disk with cutouts in the shape of a logarithmic spiral. In the XOY plane, the trajectory of the soil movement by the disk with cutouts along the arc of the logarithmic spiral is more strongly deflected towards the OY axis. This is caused by the shape of the disk cutouts, which allows the movement of soil particles along a more gently sloping trajectory.

The longitudinal movement of the soil mass is undesirable from the energy and agrotechnical points of view. It entails an increase in the working resistance of the unit.

The range of movement of soil particles along the OX axis varies greatly depending on the geometric parameters of the disk and on the position of the soil particle on the cross-section of the soil layer.

When studying the longitudinal movement of the soil mass by various disk working bodies, we found the value of the longitudinal movement of the center of gravity of the cross-section (midpoint) of the soil layer. To do this, we used 8 cubes, which were laid in the soil with an interval of 220 mm from each other across the direction of movement of the investigated disk battery of the unit. The depth of laying the cubes varied depending on the depth of tillage. After passing the disk battery of the soil layer in
which the cubes were located, the unit stopped. The positions of the cubes before and after passing the unit were recorded by the coordinator-profiliometer.

Figure 4 shows the dependence of the longitudinal movement of the midpoint of the soil layer (Xst) on the type of disks, the angle of attack and the depth of the disk stroke.

![Figure 4](image)

**Figure 4.** The dependence of the longitudinal movement of the midpoint of the formation (Xst) on the angle of attack, the type of disks and the depth of processing.

From the data in Figure 4, it can be seen that with an increase in the angle of attack $\alpha$, the longitudinal movement of the midpoint of the formation (Xst) along the OX axis also increases. An increase in the processing depth also entails a certain increase in the value of the Xst. It can also be concluded that the longitudinal movement of the midpoint of the soil layer when installing disk batteries at an angle of attack of 9° from 3 times for disks with cutouts in a logarithmic spiral to 4 times for solid disks is less than when installing disk batteries at an angle of attack of 21°. This is because as the angle of attack increases, more soil and plant residues accumulates in front of the disk battery. And the difference in the values of the longitudinal displacement of the midpoint of the soil layer in solid and cutout disks is caused by the presence of cutouts in the latter. The value of the longitudinal movement of the Xst in disks with cutouts made in the form of an arc of a logarithmic spiral in the range from 9° to 18° varies slightly, in contrast to solid disks and disks with cutouts along the arcs of circles. And in the range from 18° to 21°, there is a sharp increase in the longitudinal displacement of the soil layer.

![Figure 5](image)

**Figure 5.** Dependence of the transverse movement of the midpoint of the soil layer (Yst) on the angle of attack, the type of disks and the depth of processing.

The movement of the soil mass to the side (Yst) is one of the main indicators that determine the quality of tillage. The final position of the soil layer depends on the distance to which the soil particles located at different points of the cross-section of the soil layer will move in the transverse direction. In some cases, there is a rotation of the soil layer, in others-a shift without rotation, and in the third, the fall
of the soil layer into a furrow or the shedding of a loose layer of soil. Figure 5 shows the dependence of the transverse movement of the midpoint of the soil layer (Yst) on the type of disks, the angle of attack and the depth of the disk stroke.

According to the experimental data shown, it can be concluded that the type of disks does not have a special effect on the transverse displacement of the soil layer. The slight difference in the curves is due to the presence of cutouts on the disks, as well as the appearance of these cutouts. The depth of processing affects the displacement of the soil layer Yst. At the same time, with an increase in the depth of tillage, the transverse displacement of the soil also increases. It was also found that the particles located at a greater depth for all types of working bodies studied are displaced in the transverse direction by a smaller distance than those located closer to the surface of the field.

The qualitative analysis of the cast samples’ structures has shown that we have not succeeded in detecting a significant difference in the eutectoid amount under various concentration of the modifier. By means of the metallographic studies it has been found that the change in the eutectoid content is not so significant as it was during the influence of different cooling rates on the same bronze. The maximal difference (a decrease from 15 % to 10 %) was detected in case of the sample, which contained 0.75 % of the modifier. At that, the samples with 0.75 and 1.5 % addition of the modifier possessed such vastly branching morphology of eutectoid that it did not allow determining a spericity coefficient and an average size for them.

4. Conclusion
Disc working bodies perform a complex movement in the soil. They, in contrast to the ploughshare-footed working bodies, not only move translationally together with the tool, but also rotate under the action of reactive moments around the axis. The rotational motion changes the trajectory of movement of the soil mass on the working surface of the disk and beyond, and also affects the disposition of cutting the soil with the cutting edge of the disk working bodies. Ultimately, this is reflected in the magnitude and direction of the reactive forces on the working surface of the disk from the soil layer side. In the process of tillage with disk working bodies, the soil is scattered and partially mixed.

The trajectories of movement of soil particles by different types of disks are obtained. In the vertical plane, they are a parabola. The smallest longitudinal and transverse movement of the soil was recorded by disks with notches in the shape of an arc of a logarithmic spiral of 118 mm and 97 mm, respectively.

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