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Arrangement of Spherical Disks for Frontal Harrows

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Abstract. Disk-type spherical working tools are widely used in soil-cultivating machines, where they serve as an element base for combined units and disk harrows, including the multi-row ones with disks on individual racks. The tools are used in the implementation of traditional technologies based on reversible plowing, with surface tillage after late-harvested predecessors, for example, corn, sunflower, and also in NO-TIL technologies. (Research purpose) To determine the arrangement of working tools on the disk harrow frame, which reduces the required number of disks and improves the quality of soil cultivation. (Materials and methods) The authors have analyzed the arrangement of disk harrow working tools and determined their rational arrangement and mutual positions in the rows, which increases the tillage width between adjacent soil strips, thus improving the completeness of soil shearing and loosening over the entire operating width with simultaneous decreasing of the required number of disks. (Results and discussion) The authors have determined the interrelated arrangement of disks in their rows, aimed at improving soil shearing, so that the number of strips tilled into a ridge by adjacent disks increases. It has been shown that the arrangement of working tools of the consecutive row determined by the orientation of the adjacent disks of the previous row, allows to economize one working tool for every 400 mm of its operating width when shearing the soil all the way across the entire width of the disk harrow. (*Conclusions*) It has been established that when soil is tilled with a disk and moved toward the already processed adjacent strip, the technological width of the disk coverage increases due to the deformation of soil tearing and shearing. The authors have proposed the arrangement order of spherical disks and their mutual orientation, which improves the quality of soil cultivation, the completeness of soil shearing along the entire operating width, and leads to a reduction in the number of disks.

Keywords: soil cultivation, disk harrow, disks arrangement, reduction of the number of disks, completeness of soil shearing.

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Agrotechnical requirements for soil cultivation by disk harrows depend on its purpose: pre-sowing tillage after reversible plowing, or basic surface tillage, or other type. In this case, the most important requirement for a disk harrow is the completeness of soil shearing and shifting the soil layer along the entire operating width. This requirement should be met by multi-row harrows with front disks on individual racks. The parameters for arranging disks in such harrows are selected experimentally. Increasing the number of disks per unit of width increases their cost as compared to traditional battery-type harrows, and worsens the stability of their performance in heavily foul fields.

The research purpose is to improve the quality of soil cultivation and reduce the necessary number of disk working tools by correcting their arrangement on the harrow frame.

Materials and methods. When a flat disk with an approach angle α is operating, the soil is subject to the deformation of compression and shearing. When a conical or spherical disk deviated from the vertical plane by the angle β is used, there is a kind of tear and shear deformation. This makes it easier to lift the soil layers up along a spherical or tapered disk. A single disk, as a rule, loosens the monolithic soil only by the width of a strip cut in it by a section in the form of a segment of an ellipse with a chord at the soil surface level (*Fig. 1*) [1-3].

However, the lateral tear and shear stresses made by the disk can destroy an additional strip of soil produced by the front disk between the tilled and already treated soil.

The length of shearing elements formed as a result of tearing and shearing depends on the width of the soil strip between the strip cut by the disk in the monolith and the soil with a structure broken by the front disk processing the adjacent strip. This length should be less than the average chip length, since the disk moves in the longitudinal direction, and lateral destruction of the additional soil strip occurs only as a result of the temporary action of normal stresses on the partition

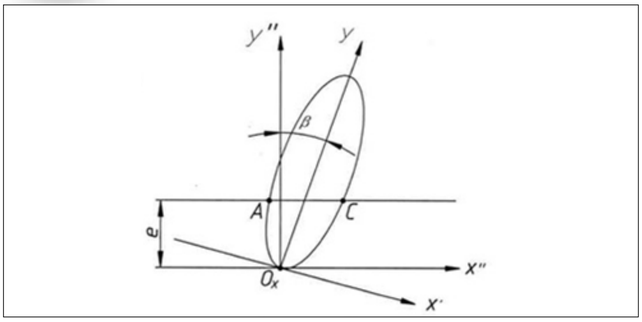

Fig. 1. The profile of the soil cut out of a monolith with a spherical (concave) disk with an approach angle α and inclination angle β (e is the depth of treatment)

wall until the first shearing element is formed in the lateral direction (*Fig. 2*).

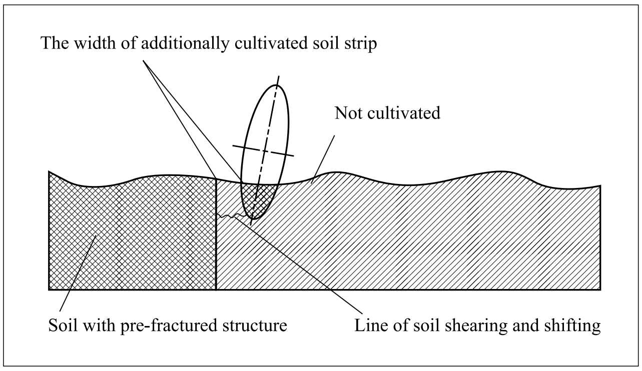

Fig. 2. An increase in the width of the strip tilled by the disk due to tearing and shearing between the strips of tilled and already cultivated soil

Thus, two disks located one after another in different rows till adjacent strips of soil, while the second disk makes soil ridges or pushes the soil aside in the same direction as the first one. Then, with the same parameters of both disks, the second one can till the soil of a larger width than the first one by the length of one shearing element. The length of one fragment depends on the soil type and structure, its moisture, hardness, the presence of root residues, operating modes and parameters of the disk tool (tillage depth, unit travel speed, an approaching angles and disk inclination), the values of which vary on the same field and have a random character [4, 5].

To clarify the correction factor of the planned disk operating width, depending on their location relative to the adjacent front disks, the authors have conducted experimental studies and recommended rational arrangement of working tools.

Results and discussion. Disk harrows with individual fastening of working tools to the frame, despite the small inter-disk distance, leave untilled strips on the dense soil [6]. This is the result of incorrect arrangement of working tools on the frame. The width of the strip b tilled separately by the mounted disk is [8, 9]:

$$b = \sqrt{4e_n \sin^2 \alpha (2R\cos\beta - e_n)\cos^2\beta}, \qquad (1)$$

where $e_п$ is the agrotechnically permissible height of the longitudinal ridge formed between adjacent runs of two disks; R is the disk radius; α is the approaching angle of the disk; β is the slope angle of the disk. The width of the tilled soil strip.

Figure 3a shows a fragment of the technological scheme of most frontal multi-row disk harrows with individual fastening of the working tools. The variants of the mutual arrangement of pairs of working tools that till adjacent soil strips (pairs 1-2, 2-4, 3-4 and 1-3). Their characteristic feature is that only in one pair (3-4) the disk located at the rear part tears and shifts the soil towards the furrow open in front of the disposed disk of the same pair. Such a pair is called an effective pair. In the technological layout of the working tools proposed by the authors (*Fig. 3b*), there are three effective pairs (1-4, 2-3, 1-2) and one non-effective – (3-4).

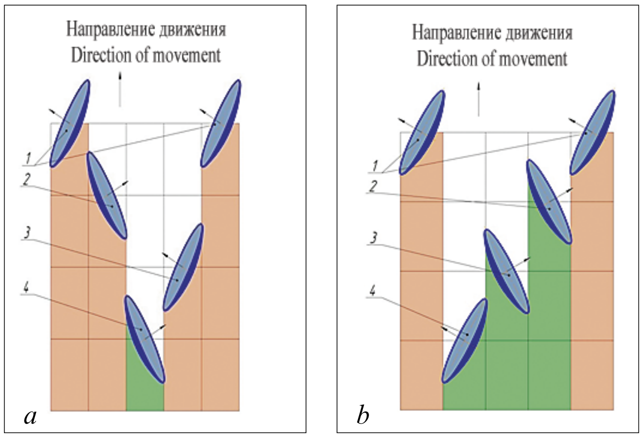

Fig. 3. Fragments of the technological schemes of disk harrows: with the approaching angle, the disks opposite to the approaching angle in the previous row (a), and with the soil tillage as a result of its tear or shear deformation (b)

The results of the calculations and experimental studies have shown that when mounting disks with a diameter of 560 mm at a distance of 400 mm in one row according to the scheme (1-4-3-2), the technological width of the effective pairs of disks was an average of 50%. The effective operating width is given by:

$$b = k\sqrt{4e_n \sin^2 \alpha (2R\cos\beta - e_n)\cos^2\beta}, \qquad (2)$$

where k is the coefficient of an increase in the width of the tilled strip.

It is larger than that of conventional inefficient pairs and depends on soil conditions and disk parameters. If the technological width b of the strip tilled in the monolith is 80 mm, then taking into account tearing off or shifting in the transverse direction, the pair of disks will process a strip with a width of 100-130 mm, that is wider by 20-50 mm. For a full 4-row disk harrow of a four-meter-long operating width, 32 disks instead of 40 are sufficient for the entire width of the soil area. With their traditional arrangement, complete soil shearing is not achievable, and with the recommended arrangement, a smaller number of disks are provided [10].

Conclusions

1. When arranging working tools on disk harrows, it is necessary to take into account the dependence of the technological width of the tilled strip on each working element on the relative position of a pair of disks that tills adjacent strips of soil.

2. When the soil is tilled with a disk, moving it towards the already cultivated adjacent strip, the disk operating width increases by a factor of 1.3-1.7 due to the manifestation of the tear and shear soil deformation.

3. For a wide-spread 4-row disk harrows with disks of 560 mm in diameter with an approaching angle of 18° and an inclination angle of 10-11°, the number of disks can be reduced by 25%.

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Conflict of interest.
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