Experimental Studies on the Improved Pneumatic Seeding Apparatus

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Abstract. This article defines the parameters of the seeding disk designed for clustered sowing in a pneumatic seeding apparatus. To ensure the tight placement of seeds in the cluster, the holes in the group must be positioned as closely as possible. However, excess seeds tend to stick more to closely spaced holes than to individual holes.
To remove excess seeds, design a fork-shaped seed singulator, which is the most effective and commonly used design, has been applied. In this design, the two prongs of the seed singulator are positioned along a circular row of suction holes, "bordering" the seeds adhered to the holes and pushing away the excess ones. A constructive solution was determined for removing excess seeds from the suction holes arranged in two or three rows for clustered sowing.
This apparatus includes three seed singulators that can be adjusted in two different ways. The seed singulators are mounted on the cover of the seeding apparatus. A system of seed singulators consisting of two radial and one central seed singulator is used to remove excess seeds adhered to the holes of the seeding disk.
To maintain the required vacuum density in the vacuum chamber of the seeding apparatus, a fluoroplast gasket is installed between the body of the apparatus and the disc. It is recommended to use a radial type centrifugal fan as an exhaust device.

Keywords: seed, disk, sowing apparatus

1 Introduction

It is well known that to achieve a high crop yield, seeds must be distributed evenly across the field, meaning they should be sown at a uniform depth and maintain specified intra-row and longitudinal distances. World practice favors the use of high-quality, prepared seeds, sowing them with a precise rate, often dropping a single seed per clusters[1,2].
In addition to general requirements, specific seeding conditions have been developed based on the climate and soil characteristics of each region. For example, in certain

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areas where soil crust formation occurs after rainfall during the spring sowing season, single-seeded crops may struggle to break through the hardened layer, risking their failure to emerge. Therefore, for bare cotton seeds or other crops, it is advisable to use clustered sowing, placing 2–3 seeds per cluster [3,4].
When using the clustered sowing method, it is essential to ensure that the number of seeds in each cluster matches the prescribed amount, and that the dispersion within the cluster is minimal meaning the seeds should be as closely packed as possible. As a result, developing a modern, energy-efficient pneumatic seeder that precisely sows row crops in both individual and clustered configurations has become a pressing issue.
In world practice agricultural experience has demonstrated that using vertically rotating seeding disks in pneumatic seeders is the most effective method. The majority of companies manufacturing pneumatic seeders have adopted this technology, equipping their seeders with such discs [5,6,7].

2 Materials and methods

To ensure clustered sowing, the suction holes on the seeding disc of the apparatus are grouped along two or three concentric circles, as mentioned in the theoretical section. The suction holes in each group are arranged along a straight line deflected at a certain angle relative to the disc's radius.

The distance between the circles depends on the size of the seeds, ensuring that seeds adhering to the holes in adjacent circles do not come into contact with each other. Figure 1 illustrates the scheme for determining this distance.

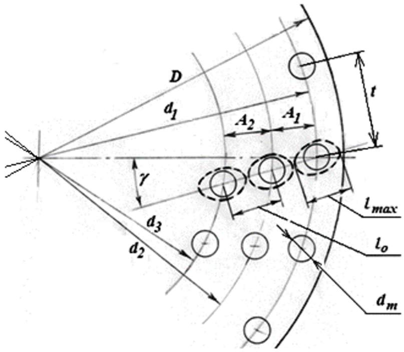

Fig. 1. Schematic for determining the distance between suction holes on the seeding disc.

To sow 3 seeds per cluster, the suction holes on the seeding disk are arranged along 3 concentric circles, while for 2 seeds per cluster, they are arranged along 2 concentric circles.
In the first case, the radial distance between the circles (relative to the disc) is determined using the following expressions [8]:

$$A_1=A_2=(d_1-d_2)/2= (d_2-d_3)/2=l_o\times\cos\gamma \quad (1)$$

Here A_1 – Radial distance between the first and second circles;

A_2 – Is the radial distance between the second and third circles;

d_1, d_2, d_3 – are the diameters of the centers of the suction holes in the first, second, and third rows, respectively.

When the suction holes on the seeding disc are arranged in two rows, the meaning of equation (1) remains unchanged, only A_2 va $(d_2\text{-}d_3)/2$ some terms are omitted.

From second side

$$l_o \geq l_{max} \quad (2)$$

Considering the length of cotton seeds grown in Uzbekistan as lmax = 11 mm and γ = 200 according to, substituting these values into the above expressions, the radial distance between the circles is determined as follows:

$$A_1 = A_2 = 10{,}34 \text{ mm}$$

Thus, the difference between the diameters based on the centers of the suction holes should be 20.68 ≈ 21 mm.

When the suction holes on the seeding disc are grouped along two or three concentric circles for clustered sowing, the issue of removing excess seeds adhering to the holes has not been fully resolved. To ensure a compact placement of seeds within the cluster, the holes within each group must be positioned as closely as possible [9,10].

On the other hand, an additional aspect that complicates the problem is that more excess seeds stick to closely spaced holes compared to a single hole.

The most effective and widely used seed singulator for removing excess seeds has a fork-shaped design. In this design, the two prongs of the seed singulator "border" the seeds adhered to the suction holes arranged along a circular path, pushing away the excess seeds [11, 12]. For clustered sowing, a constructive solution based on this principle has been developed to remove excess seeds from the suction holes arranged in two or three rows for group sowing is illustrated in Figure 2.

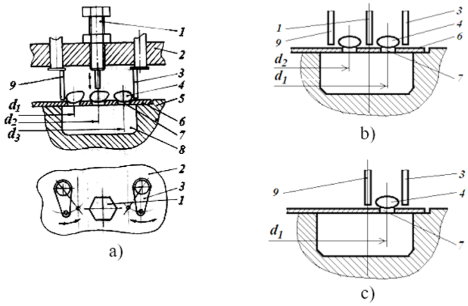

Fig. 2. Schemes for removing excess seeds:

a) For sowing three seeds per cluster; b) For sowing two seeds per cluster; c) For sowing one seed per cluster.

1 - central seed singulator ; 2 - apparatus cover; 3 - outer radial seed singulator ; 4 - seed; 5 – sowing apparatus; 6 - seeding disc;7 - seeding hole; 8 - suction chamber; 9 - inner radial seed singulator .

There are three seed singulators, which can be adjusted in two different ways. The central seed singulator (1) is designed as a threaded bolt (Figure 2a), with its tip machined to a smaller diameter. Using the thread, it can be moved closer to or further from the surface of the seeding disc. When the seeding disc (6) has holes (7) arranged in three rows, the central seed singulator (1) is aligned above the seeds adhered to the middle row of holes. It is adjusted and fixed at a distance from the seeding disc that corresponds to the seed size. In this setup, the central seed singulator (1) removes excess seeds stuck around the seeds adhered to the middle row of holes (with diameter d2). The outer (3) and inner (9) radial seed singulator s have a fork-like structure with one prong removed. They are installed on the apparatus cover (2) with two holes, allowing them to rotate around their own axis. When the outer radial seed singulator (3) is rotated around its axis, it can move closer to or farther from the holes positioned at diameter d1 relative to the center of the disc. This allows fine adjustment to remove excess seeds adhered to the holes.

The inner radial seed singulator (9) is responsible for removing excess seeds adhered to the holes positioned at diameter d3.

In figure 2b, the working principle of the seed singulators for a seeding disc with two rows of holes is illustrated. In this configuration, the outer (3) and inner (9) radial seed singulators continue to function as before. They act on the outer and inner sides of the seeds (4) adhered to the two rows of holes (7), pushing away any excess seeds. However, the central seed singulator (1) now operates differently. Instead of acting from above, as in the previous case, it functions from the side, similar to the radial seed singulators. The tip of the central seed singulator (1) is adjusted using its thread to be as close as possible to the surface of the seeding disc (6) without touching it. Positioned between the first and second rows of holes, it pushes away any excess seeds that may have adhered to these holes.

In this design, when the seeding disc has a single row of holes, meaning the seeds are sown in a single-file row, the working principle is illustrated in figure 2c.

The central seed singulator is not used (it is either removed or adjusted away from the seeding disc so that it does not interact with the seeds). The inner radial seed singulator (9) pushes excess seeds from the inner side of the holes (7), while the outer radial seed singulator (3) acts from the outer side, ensuring that only the correct number of seeds remain attached before sowing.

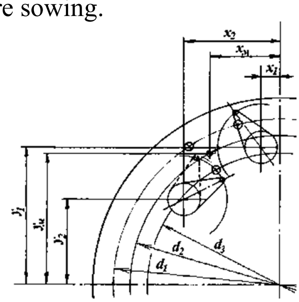

Fig. 3. Diagram for determining the placement coordinates of the seed singulators.

We install two radial seed singulators into these holes and determine constructively the radius by which the seed singulator legs should have the ability to rotate (Figure 3). The outer radial seed singulator is placed at the hole with coordinates x_1 and u_1 and the inner radial seed singulator is placed at the hole with coordinates x_2 and u_2.

For the outer radial seed singulator to remove excess seeds from the holes located along the diameter d_l from the outside, the rotation radius of the seed singulator leg must meet the following condition:

$$r_{t1}=(d_1+l_{max}+d_0)/2+\Delta- \sqrt{(x_1^2+ y_1^2)} \quad (3)$$

Here r_{tl} – the rotation radius of the outer radial seed singulator leg.

d_0 – the diameter of the singulator leg.

Δ – the allowance from the seed singulator leg's outermost contact point with the seed (a precautionary additional distance). We assume this value to be 2 mm.

The inner radial seed singulator must remove excess seeds adhered to the holes located on the d_3 diameter from the inner side. Additionally, when the holes on the planting disc are arranged in a single row (for row planting), the inner radial seed singulator should also remove excess seeds adhered to the holes located on the d1 diameter from the inner side. In figure 3, the pivot point of the inner radial seed singulator is positioned closer to the holes on the d_3 diameter compared to those on the d1 diameter. Therefore, when determining the rotation radius of the seed singulator leg, we consider the requirement of removing excess seeds adhered to the holes on the d1 diameter. This condition must be satisfied by the following equation:

$$r_{t2}=(d_1-l_{max}-d_0)/2+\Delta- \sqrt{(x_2^2+ y_2^2)} \quad (4)$$

Here r_{t2} – the inner radial seed singulator leg's turning radius.

We substitute the above-mentioned coordinate values into equations (3) and (4), assume the seed singulator leg diameter as $d_0 = 3$ mm from a structural perspective, and perform the calculations. As a result, we obtain r_{tl} = 26,65 mm and r_{t2} = 18.48 mm. To ensure interchangeability of the outer and inner radial seed singulators, we round up the larger value, meaning the turning radius of the radial seed singulator legs should be 27 mm.

$$r_{tl} = r_{t2} = 27 \text{ mm.}$$

Based on the dimensions of the housing and cover of the pneumatic seeding apparatus being developed, we accept the length of the radial seed singulator legs as 22 mm.

To determine the coordinates (x_m and u_m) of the central seed singulator, we use figure 3. The requirements are as follows: the central seed singulator must align with the suction holes positioned along the d_2 diameter. It must not obstruct the free rotation of the outer and inner radial seed singulator legs.

The outer radial seed singulator leg interacts only with the first-row holes and, as shown in the figure, does not extend to the second-row holes, which fall within the operating zone of the central seed singulator.

Thus, we accept $u_m = u_l$, and the value of the x_m coordinate is determined as follows:

$$x_m = \sqrt{([d_2/2]^2- y_m^2)} \quad (5)$$

If we substitute the given values, x_m = 37,523 mm ≈ 37,5 mm it follows that. Thus, um = 84 mm, x_m = 37,5 mm.

The diameter of the central seed singulator leg is also equal to that of the radial seed singulator s, i.e., 3 mm, and the size of the threaded part is assumed to be M8. To determine the length dimensions of the central seed singulator, we refer to figure 2a. It is known that the thickness of the apparatus cover 2 is 23 mm, and the distance between the cover and the housing is 38 mm. The length of the part of the seed drill seed singlator inside the apparatus is 34 mm. Based on these values, the maximum insertion of the central seed singulator into the apparatus is 34 mm, the length of the machined tip is 10 mm, and the total length of the seed singulator should be 80 mm.

To plant seeds one by one into the cluster, the diameter of the circular arrangement of suction holes on the disc remains d_l= 205 mm. However, to plant seeds two at a time into the cluster, the diameters of the circular arrangements of suction holes on the disc need to be calculated. In this case, the central seed singulator must pass between the holes of both circles at a minimal distance from them. Using the known coordinates of the central seed singulator, we determine the diameter dm of the "drawing" circle from the center of the apparatus.

$$d_m=2\sqrt{(x_m^2+y_m^2)} \quad (6)$$

As seen in figure 2b,

$$d_l=2\sqrt{(x_m^2+y_m^2)}+(d_o+l_{max})/2 \quad (7)$$

and

$$d_2=2\sqrt{(x_m^2+y_m^2\ )}-(d_o+l_{max})/2 \quad (8)$$

By substituting the known values into these expressions, it follows that for planting seeds in pairs into the clusters, the suction holes on the disc should be located on circles with diameters of d_l = 191 mm and d_2 = 177 mm.

As a result of the initial laboratory studies and additional calculations, the previously determined parameters were refined. From a structural standpoint, the vacuum groove was designed with a width of 24 mm and a depth of 10 mm. In this case, the outer diameter of the groove is 216 mm, while the inner diameter is 168 mm.

The starting section of the vacuum groove, which is cut into the apparatus housing, can have an arbitrary shape. However, its end section, where the vacuum effect on the seeds ceases (the lower part of the apparatus), must have a specific shape and parameters. The reason is that at this point, the seeds adhering to the sowing disk must detach due to the loss of vacuum pressure and fall downward into the sowing furrow under their own weight. The consistent dropping of seeds from the disk holes at the same position relative to the housing ensures smooth and even sowing. When the holes on the disk are grouped, the sequential dropping of seeds from each group determines the formation of seed clusters in the soil. This sequence of seed dropping depends on the shape of the vacuum groove's end section. For proper alignment, the straight line connecting the centers of a hole group must be placed at an angle of γ = 20° against the direction of disk rotation relative to the disk radius.

Preliminary laboratory studies have shown that the central seed singulator should pass along the side of the seeds rather than above them to effectively remove excess seeds.

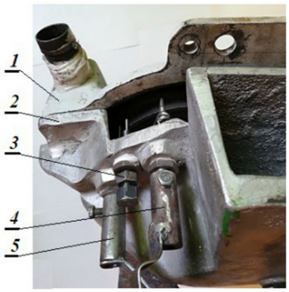

Fig. 4. Assembled condition of the

seed singulators (Sowing disc not installed):
1 - apparatus body; 2 - apparatus cover; 3 - central seed singulator ; 4 - radial seed singulators

Figure 4 illustrates the assembled state of the seed singulators, which are designed to remove excess seeds adhered to the sowing disc holes.

The diameter of the sowing disc is 230 mm, and based on structural considerations and the disc’s diameter, the outer diameter of the vacuum groove in the apparatus housing is set to 216 mm.
As seen in figure 1, the holes on the outermost circles must be positioned slightly inward, approximately halfway between the outer and inner edges of the vacuum groove. As a result, the diameters of the circles where the suction holes are positioned are: first row: d_1= 205 mm; second row: d_2= 184 mm; third row: d_3 = 163 mm.
The inner diameter of the vacuum groove is calculated as: 152 mm, resulting in a groove width of 32 mm. The seed singulators are mounted on the cover of the seeding apparatus. The design includes two fork-shaped seed singulators, which are installed in two holes in the cover. These seed singulators can rotate around their axes and be adjusted using linkage mechanisms.
The diameter of the holes in the cover is 20 mm, and their coordinates relative to the center of the sowing disc are provided in figure 3, as follows: x_1 = 12 mm; x_2 = 59,5 mm; u_1 = 52 mm and u_2 = 84 mm.

3 Conclusion

Based on the conducted research, the following conclusions and recommendations can be made. The width of the vacuum groove in the seeding apparatus body should be 24 mm, its depth should be 10 mm, with an outer diameter of 216 mm and an inner diameter of 168 mm. The end line of the vacuum groove should be positioned parallel to the vertical axis of the housing and shifted at a 20° angle towards the front of the apparatus. To remove excess seeds adhering to the sowing disc holes, a system consisting of 2 radial and 1 central seed singulator should be used. To ensure proper vacuum chamber sealing, a fluoroplast gasket should be installed between the housing and the sowing disc. A centrifugal radial-type fan is recommended as the exhauster. The fan’s impeller diameter should be 430 mm, and its optimal rotational speed should be 3500 rpm.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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