Justification of the Parameters of the Working Organ of the Device for Planting Seedlings of Perennial Plants

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Abstract. For each type of forestry area, special soil cultivation is required, a specific type and size of seedlings for planting, and a planting scheme. Applied to forestry seedling planting machines according to agrotechnical requirements. The general requirements for them are as follows: proper placement of seedlings and root parts of seedlings at planting sites, ensuring planting depth and density, maintaining the specified distance between seedlings in the row (planting stage) and not damaging the seedlings. In the following years, artificial forest plantations began to be created on large areas by planting large-sized seedlings. In such conditions, tractor-mounted hole diggers, as well as special digging machines for planting and transplanting large seedlings with soil, are aimed at widespread use.

Keywords: forest, forestplanting, seedling, machine, coulter, parameter, width, height

1 Introduction

Depending on the category of forest crop areas, forest crop seedling machines are divided into the following groups: for establishing nurseries, for cutting, for field protection, for establishing forests, on sandy and rocky soils, for planting and transplanting large-sized seedlings.

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For each category of forest-cultural areas, special soil preparation, specific types and sizes of planting material, and crop placement schemes are necessary. Relevant requirements are imposed on forest planting machines. The general requirements for them are as follows: proper placement of seedlings and seedling root systems in planting furrows, ensuring the required depth and density of burial, maintaining the specified distance between plants in the row (planting pitch), and not damaging the planted seedlings [1-28].

It is known that the task of the planter of the forest planting machine is to prepare a planting furrow for placing the roots of the seedling or cuttings [4].

Currently, the method of preparing a planting furrow in the form of a continuous planting is widespread, which creates the most favorable conditions for mechanized planting and subsequent burial of root systems. In this case, a number of requirements are imposed on the seeding furrow picker:

- stable movement of the seeding furrow along the depth during operation;
- prevent the accumulation of soil near oneself;
- minimal energy expenditure should be required to form a furrow of specified width and depth [2,3].

2 Materials and methods

In the existing designs of forest planting machines, several types of furrowers are used - namely, box-type, disc-type, and combined sliding furrowers [5]. Each of these mechanisms performs soil opening to create furrows for planting forest seedlings or cuttings. However, when planting seedlings and cuttings of forest plants, the planting process requires digging to a depth of at least 45 cm to ensure proper root placement and soil compaction. This requirement imposes a limitation on the use of disc and combined sliding furrowers. Their design, although effective for shallow planting, becomes impractical for deeper planting due to excessive structural dimensions, increased material consumption, and considerable weight. These drawbacks make such furrowers unsuitable for deep planting in loose or sandy soils, where maneuverability and balance are also crucial factors. The technological process of automated planting of seedlings follows a specific operational sequence. In a traditional forest planting machine, a specialized automatic device is installed to deliver seedlings to the planting mechanism's grips or holders. This device ensures the timed and precise transfer of plants either from special seedling cassettes or directly from cuttings, depending on the planting method used. The continuous and synchronized functioning of the delivery mechanism with the planting apparatus determines the overall performance and uniformity of planting. The task of the automatic system is not only to feed the seedlings reliably but also to position them correctly in the furrow at the required depth and orientation, ensuring their optimal growth conditions after planting. In the existing mechanized systems, the process requires human supervision and coordination at several stages. Typically, such machines must be operated by a crew of four people - a tractor driver, two seedling operators, and one distance operator who monitors the alignment, spacing, and continuity of the technological process. This staffing requirement significantly limits the economic efficiency of mechanized planting operations, particularly in large-scale reforestation and sand stabilization projects. Therefore, one of the primary objectives in developing an automated seedling planting machine is to reduce labor requirements while maintaining or even improving planting quality and productivity.

The proposed automated forest planting unit should ideally require only two operators - a tractor driver and one operator responsible for monitoring and maintaining the smooth functioning of the technological process. This represents a reduction in manpower by 50%, which directly translates into labor cost savings and improved operational efficiency. Moreover, automation minimizes human error in seedling placement and spacing, thereby enhancing the uniformity of planting and the survival rate of seedlings. In addition to the labor reduction, automation contributes to a substantial increase in productivity - by an estimated factor of 1.3 to 1.5 times compared to existing mechanized methods. This improvement arises from continuous operation, reduced downtime, and precise control of planting parameters. The machine's design should ensure stable performance under challenging field conditions, particularly in mobile sand areas where traditional machines struggle with traction and depth control. Reliability of the furrowing and planting mechanisms in such conditions is essential for effective afforestation and sand-fixing efforts. The economic effect of introducing such an automated planting machine is significant. Fuel and lubricant consumption is reduced due to optimized motion and reduced idle time. Additionally, by improving root system quality and ensuring proper soil contact around each planted seedling, the survival rate of plants can be increased by 15–20%. This higher survival rate means fewer replanting operations are required, resulting in additional cost savings. Current estimates suggest that eliminating the need for repeated planting or filling gaps among existing crops can reduce overall costs by 20–30%. Beyond economic advantages, the social and ergonomic benefits of this technology are also considerable. Reducing the number of workers directly engaged in heavy field labor improves working conditions and safety. Automation minimizes exposure to harsh outdoor environments, fatigue, and repetitive manual tasks, thus enhancing job satisfaction and reducing occupational health risks. Altogether, the development and implementation of an automated seedling planting machine represent a major advancement in forestry mechanization - increasing efficiency, ensuring environmental sustainability, and improving both economic and social outcomes for production workers.

3 Results

To achieve these goals, we use the principal scheme of the seedling planting machine. The schematic diagram of a seedling planting machine (Fig. 1.) is the basis for designing many other types. It includes a transverse beam with a fastening mechanism 2, a main frame 4, on which a landing device 5 is installed, compression rollers 6, a receiving table 7, seedling seats 8, supports 9. A coulter 3 is attached to the upper frame. For gears, it is implemented through 10 chain wheels 11. In this construction, the movement is carried out from one of the compression rollers equipped with a star.

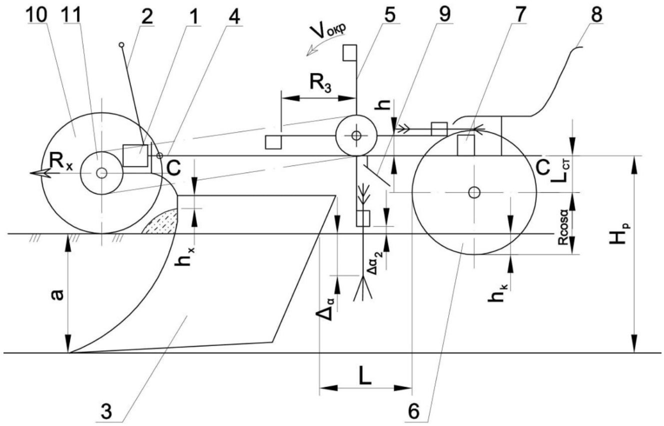

Figure 1. Classical diagram of a forest planting machine.

In the existing designs of forest planting machines, box, disc, and combined sliding furrowers are used [5]. Since planting seedlings and cuttings of forest plants requires sowing to a depth of at least 45 cm, the use of disc and combined furrowers for the developed unit is not advisable, as this is associated with significant dimensions and the weight of the design.

For example, for a disc plowshare with a soil penetration depth of 30 cm, the disk diameter must be at least 80 cm, and for a soil penetration depth of 45 cm, the disk diameter must be at least 120 cm. This leads to an increase in the size and mass of the forest planting machine.

With an increase in the depth of penetration of the disc plowshare into the soil, its sliding increases, which leads to the accumulation of soil and plant residues in front of the plowshare. This leads to a deterioration in the quality of seedling furrow formation, root burial, and other negative consequences, even disrupting the planting process [5,6].

Therefore, when justifying the type of furrow formation for planting seedlings, we focused on a box-shaped furrow opener with an angle of entry into the soil, which is facilitated by the simplicity of the construction design, as well as reliability in operation. The main parameters of the furrow opener (Fig. 2) are: the angle of entry into the soil α, the angle of opening of the working edges 2γ, the angle of rear cutting ε, the height of the side wall H, the length of the side wall L_{δ}, and the total length of the furrow opener L.

According to the design of the front part of the furrow opener, if the angle of entry into the soil is sharp, the seeding furrows will meet the requirements. Planting furrows with an obtuse angle of entry into the soil compact it. For the penetration and uniform movement of such seeding furrows, the mass of the section must be heavy. With a sharp entry angle, the furrow opener easily splits the soil, and in terms of energy consumption, the resistance to splitting is significantly less than the resistance to crushing. In addition, planting furrows have a steady path along the depth and reduce the density of the furrow walls [7,8].

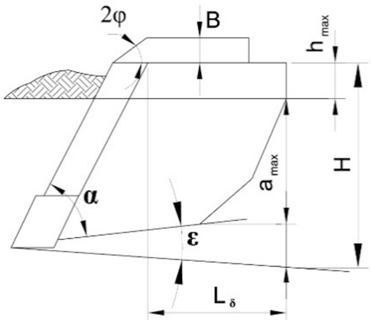

Figure 2. Scheme for substantiating the main parameters of furrow formation.

Based on the foregoing, a furrow opener with an acute angle of entry into the soil α was adopted. To comply with the self-cleaning condition of the furrow opener, the angle of entry into the soil must be greater than the angle of friction, i.e., $\alpha \geq \varphi$, where φ is the angle of friction, degrees.
As a result of the research, it was established that the angle of entry of the furrow cutter edge into the soil for loose sandy soils is in the range of 14-19°, for sandy cohesive soils - 26-35°, taking the average value obtained from half the sum of the minimum and maximum values of the boundaries occurring during the operation of the furrow former, we obtain $\alpha \geq 25°$ [5,7]. On the other hand, the condition $\alpha < 90 - \alpha$ must be maintained for the furrow former. According to studies, the cutting force of the soil increases sharply in the range of $\alpha = 45 - 60°$, with an increase in the angle α, the cutting force decreases, and the stability of movement along the depth increases. However, the nose of the furrow former extends too far forward, which increases the friction force, the dimensions, and the mass of the former. Considering the unbound nature of sierozem soils and their lower crack resistance compared to bound soils, the angle of entry into the soil for the calculated furrow former is assumed to be $\alpha = 65^0$, which does not significantly affect the increase in energy consumption indicators [7]. The opening angle of the chest part of the furrow moldboard is selected from the condition of sliding the soil along the edges of the two-sided wedge and is performed on the basis of the following conditions:

$$\gamma + \alpha \leq 90^o, \text{ from where } \gamma \leq 90 - \alpha. \quad (1)$$

According to the research, the optimal opening angle 2γ is in the range of 30-60°, and if the opening angle 2γ is greater than 60°, a compacted soil layer forms in front of the column and the resistance of the furrow former increases, and at small values, friction on the edges increases. The optimal opening angle of the furrow moldboard's chest section is $2\gamma = 45°$, determined analytically [4,5] Therefore, we assume $2\gamma = 45°$. The distance between the edges of the furrow moldboard B is determined by the dimensions of the root systems of the seedlings to be planted and the grips of the planting apparatus, or by the diameter of the outlet of the mechanism for transporting and directing planting material. It is in the form of a vertically installed clamp, the diameter of which is equal to the length of the seedlings directed into the furrow-forming cavity. The calculations are carried out taking into account the condition of free passage of the clamps of the planting apparatus with seedlings in the cavity of the furrow formers, taking into account a distance of 4 cm from both sides of the furrow formers.

In this case, we can accept:

$$B = d_{max} + \Delta_z + b_z \qquad (2)$$

where: d_{max} - the largest diameter of the roots of seedlings in the cross-section, according to studies, does not exceed 10 cm [5].

Δ_z - gap between the seeder walls and the seeding apparatus gripper;

b_z - working width of the seeding apparatus, b_z = 10-14 cm.

Consequently, the width of the furrow former will be B = 0.26 m.

The height H of the furrow former (Fig. 2) depends on the depth of the furrow being formed, the height h_{max}, the unevenness of the furrow former along the chest and depth, and is determined by the following equation:

$$H = a_{max} + h_{max} + a_1 + h_1, \qquad (3)$$

where, a_{max} - planting depth of seedlings, cm;

h_{max}-height of the front chest of the furrow former, cm;

a_1-height of the furrow former tip, cm;

h_1 - uneven movement of the ridges formed during the movement of the furrow former along the depth, cm. With a furrowing depth of 0.3-0.35 m, the maximum height of the pre-socket ridge is also 12-14 cm. Considering that the clearance depth in barchan sands should be 45 cm, it is 1-3 times deeper than the movement depth of existing seeding machines, and we assume h_{max}=18 cm.

a_1 is determined from Figure 2 by the following expression:

$$a_1 = L tg\, \varepsilon, \qquad (4)$$

In turn, the lateral length L_b can be determined by the following formula (Fig. 3):

$$L_b = l_1 + L_1, \qquad (5)$$

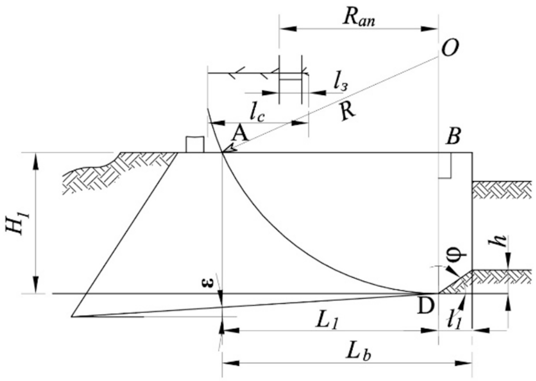

Figure 3. Diagram for determining the length of the side of the furrow former

Point O - axis of rotation of the sowing apparatus;

OD - maximum height of the planting apparatus axis above the soil;

AO =R - radius of rotation of the planting apparatus.

The length L_1 of the side of the furrow former is determined from triangle *Δ* AOB:

$$L_1 = \sqrt{R^2 - (2R - H_1)^2} \quad (6)$$

Then:

$$L_b = l_1 + \sqrt{R^2 - (2R - H_1)^2} \quad (7)$$

$$R = R_{an} + l_c + l_z \quad (8)$$

where R_{an} – radius of rotation of the seeding apparatus, m

l_c - cuttings or seedling length

l_z – length of the working part of the sowing apparatus, m.

During the movement of the furrow former, the soil spills into the rear part (Fig. 1.3), and at low speeds, it penetrates into the internal cavity of the furrow former and is located at a natural angle of inclination φ'. When the speed of motion is minimal, l = hctgφ'. In the general case, the coordinate of the planting point is determined as follows:

$$L_1 = l - Vt, \quad (9)$$

Substituting the given expression into equation (7), we obtain:

$$L_b = l - Vt + \sqrt{R^2 - (2R - H_1)^2} \quad (10)$$

where l is the longitudinal dimension of the soil dumped after the furrow former passes, m.

V - speed of the unit, m/s.

t - sand spillage time, s.

From Figure 1.2 $H_1 = a_{max} + h_{max} = 630$ *mm*; $h_1 = 30$ *mm*; $R = 800$ *mm*; $L_δ$ =750 mm; $L = 1200$ mm; $φ' = 30^o$; $δ' = 38^o$.

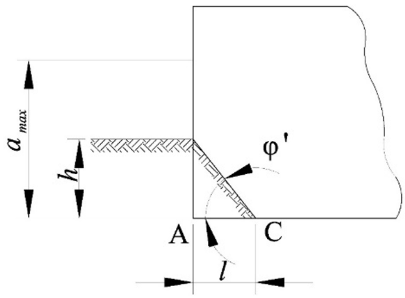

Figure 4. Diagram of sand spillage after passing the plowshare (longitudinal section).

We determine the value of a_l = L ctg E = 258 mm.
The total height of the plowshare is H = H_l + a_l + h_l = 913 mm.

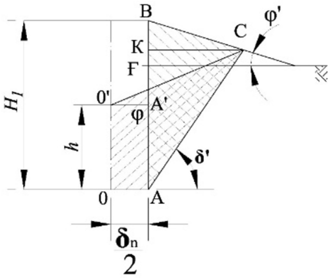

Figure 5. Diagram of sand unloading after passing the plowshare (cross-section).

Thus, the type and parameters of the coulter of the developed forest planting unit were theoretically substantiated. This allows for deep planting of cuttings and seedlings of desert and forest plants, which fully meets the requirements of the agrotechnology for deep planting of cuttings and seedlings of sand-fixing plants in the conditions of moving sands.

4 Conclusion

As a result of theoretical studies, the types and parameters of the furrow formers intended for soil cultivation, the shape and dimensions of the bunker, as well as its location in the general design scheme, the types and parameters of the receiving-guiding mechanism and the gripping-sowing organs are substantiated.
A furrow-forming machine with an angle of entry into the soil α =65°, length of the side part L_δ =750 mm, opening angle of the chest part 2γ =45°, height of the coulter H= 630 mm, width B = 260 mm, adopted as the optimal type and parameters, is proposed.

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