RESEARCH ON NOVEL PLANTING SYSTEM DESIGNED FOR AFFORESTATION OF DESERTIFIED LANDS

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Abstract. Creating forest curtains on sandy or highly compacted lands affected by desertification necessitates precise control, given the challenges associated with the soil management in these regions. The mechanisms designed for planting forest seedlings face significant challenges: the working apparatus responsible for handling seedlings during planting can inflict notable damage to the stems, particularly through scratching or crushing. This issue usually arises from the design solution and the shape of the mechanical organ handling the seedlings. Moreover, it is highly important to improve the control over the seedling positioning in the soil, action that often encounters issues such as inadequate planting depth or improper planting angles. The present research evaluates a novel modular planting system, which can have excellent effects for areas with difficult or desertified lands. The objective was to obtain a precise control over seedling planting, by enabling the mechanism to automatically adjust its grip and force according to root dimensions, stem characteristics, and seedling size. This ensures effective protection of the seedlings and enhances the overall planting process. The mechanism demonstrated excellent performance and successful adaptation to challenging sandy terrain conditions. The proposed solution offers several technical advantages, including: the precise adjustment of the clamping force on the sapling during planting, based on the condition and size of the woody stem and a better adjustable spacing between the gripping jaws.

Keywords: planting mechanism design; afforestation of arid soils, seedling protection.

Introduction

Desertification is becoming a critical socio-economic and environmental challenge on a global scale [1-4]. Understanding the science behind reversing desertification phenomena, particularly the specific processes and mechanisms, is highly valuable for ecological restoration in arid and semiarid regions [5]. Vegetation is a key component of terrestrial ecosystems, and holds significant role in the reversal of desertification, especially the trees [6-8]. There is an increasing demand to incorporate forested areas bordering agricultural crops, aiming to protect against erosion and establish buffer zones to mitigate snow accumulation and regulate microclimates [9; 10]. To achieve this goal, it is imperative to conduct research aimed at designing more efficient equipment for planting forest curtains [11]. The most effective approach to implementing these principles involves the adoption of automated machinery in forestry operations [12], particularly for tasks traditionally reliant on manual labor – such as planting, which demands significant energy input [13-15]. This transition not only addresses the challenges of modern forestry but also mitigates issues like scarcity of available workers, particularly for labor-intensive seasonal tasks conducted in unfavorable weather conditions [16].

Several planting machines are currently researched, providing a high degree of automation, however they still require a significant amount of manual operation [17-19]. Furthermore, these systems often lack a focus on adequately protecting the seedlings during planting, and they seldom address the challenges posed by difficult terrains as planting environments. Typically, these devices/machines are either mounted onto agricultural tractors or are attachments affixed to construction excavators.

A full automated prototype for forest regeneration and afforestation of post-agricultural and reclaimed areas is described in [11]. The proposed system enhances the reliability of seedling collection and incorporates significantly more advanced technology, necessitating a more powerful control unit with enhanced computing capabilities.

Several studies identified problems in the time spent by operators to load the planting material into the machine carousel [20], that is why a simplistic approach to feeding should be considered. A commonly used design in Nordic countries is crane-mounted planting equipment [21], known for its large circular container equipped with cavities designed for holding seedlings. Research conducted in Latvia indicated that mechanized planting could prove to be too costly as a forest management method.

It is therefore a need to develop a planting system that demonstrates robust performance even in challenging terrains characterized by steep inclines or susceptible to the impacts of climate change. Such an innovation is essential to enhance planting efficiency significantly within these regions, ensuring the successful establishment of vegetation despite adverse environmental conditions [22; 23].

The objective of the present research was to create an improved system for planting forest saplings on sandy or compacted lands, affected by desertification, by offering a more precise control over the sapling during planting (avoiding damaging stems and roots), and ensuring at the same time a more efficient positioning of the plant. In addition, the designed heavy-duty mechanism of soil processing and the irrigation installation may offer significant advantages to the desertified regions.

Materials and methods

The mechanized planting system for forest saplings, developed and constructed by the INMA Institute (Fig. 1), consists of three mechanisms that can operate collectively or independently: a soil tillage mechanism, a planting mechanism, and an irrigation mechanism. These components are towed by an agricultural tractor.

Fig. 1. **Experimental installation design for planting forest saplings on difficult and desertified lands:** 1 – soil processing equipment; 2 – seedling planting equipment; 3 – seedling irrigation equipment; 4 – agricultural tractor

The versatile machinery concept is designed for mechanizing afforestation tasks, aimed at reestablishing forest cover in lowland and hilly terrains, creating protective barriers, and establishing orchards or nurseries. These works refer to tilling the soil, up to a depth of max. 30 cm in strips, with a width of max. 60 cm. After the seedlings are established in the soil, the planting material is irrigated to enhance the success of the process. The towing equipment used must have a minimum power of at least 140 kw (190HP). The equipment is designed to allow single or combined works (tilling the soil, planting the saplings, and administration of the water), to improve the versatility of the system.

The planting depth adjustment is performed by modifying the hole dimensions, excavated with the digging mechanism. This step ensures that the sapling is positioned at the right depth for optimal growth. Once the hole is suitably configured, then the planting mechanism is calibrated according to the dimensions of the seedling and the depth of the hole. Water from the irrigation basin is directed through a hose to the sapling root, an important action that ensures the success of planting in arid regions. This process ensures that the sapling receives the essential hydration needed for its survival and growth in challenging environmental conditions. By strategically directing water directly to the root zone, optimal moisture levels are maintained, fostering resilience and vitality in the young plant.

Evaluating root coverage when testing the planting mechanism involved determining the extent to which the plant roots are covered by soil. This assessment involved manual measurement, excavating around the plant base to reveal its roots and determining the depth of their anchorage.

In addition, the proposed mechanism introduces an innovative seedling gripper, consisting of a plunger that operates two sets of clamping jaws, allowing for separate handling of the sapling roots and stems during planting. These clamping jaws independently grip the root and stem of the plant. They utilize a spring-based fastening system that applies varying pressures, facilitating automatic adaptation to the size and condition of the woody sapling.

It is important to apply different clamping forces to various parts of the plant, in order to achieve enhanced control over sapling planting. This allows for adjustments in force based on the plant characteristics, root, stem and height size, ensuring their protection during planting. Figure 2 illustrates how the planting mechanism works. A version of the mechanism for planting forest seedlings with controlled gripping was submitted to OSIM (Romanian State Office for Inventions and Trademarks) as Patent Application No. A-00765/2023 and was financed through Nucleu Project PN 23 04 02 01: Innovative Technology for Biofertilizer Production Aimed at Restoring Soil Biodiversity and Mitigate the Drought Effects on Agricultural Lands.

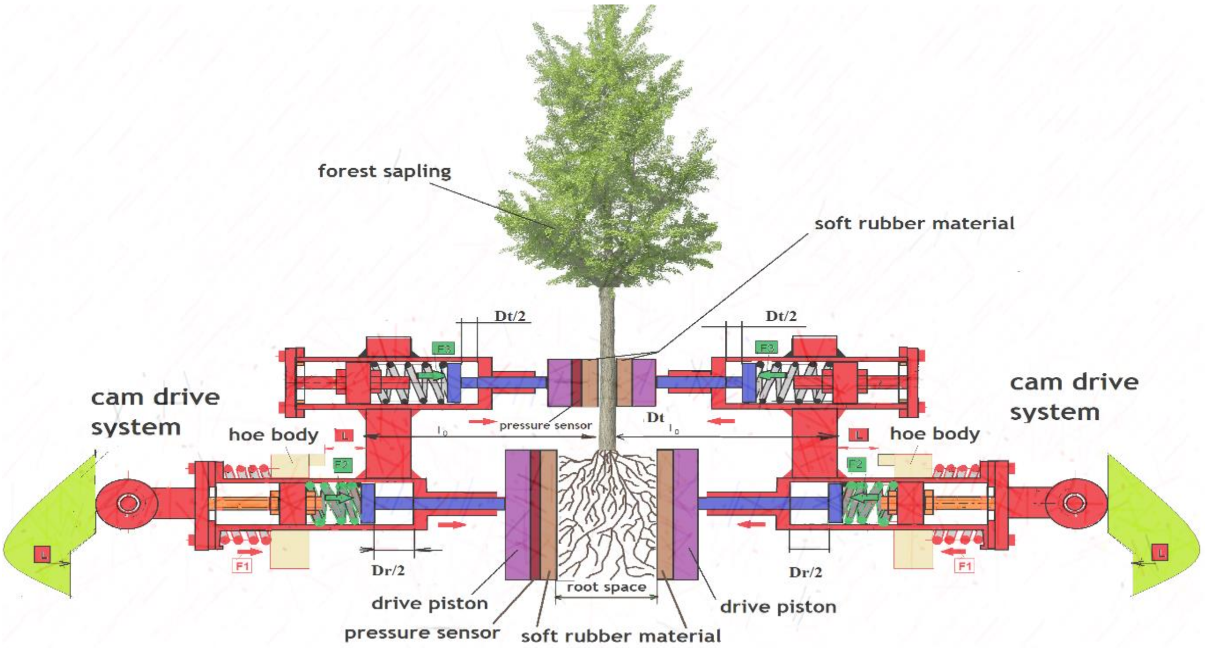

Fig. 2. **Kinematic diagram illustrating operation of the mechanism for planting forest seedlings with controlled gripping - Closed position with sapling:** F1 – tension force of the spring maintaining plunger A in the initial position; F2 – tension force of the spring maintaining jaw J1 in the pushed position; F3 – tension force of the spring maintaining jaw J in the pushed position

Figures 3-5 depict detailed views of the three component elements comprising the planting system. These mechanisms can operate either grouped together or independently, as illustrated in the images.

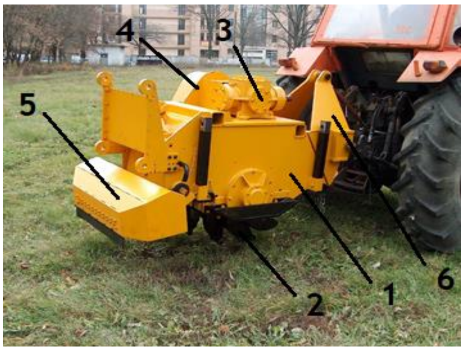

Fig. 3. **Soil tillage mechanism prior to planting:** 1 – casing; 2 – rotor; 3 – reducer; 4 – intermediate transmission; 5 – compactor; 6 – coupling triangle

Fig. 4. **Mechanism for planting forest saplings:** 1 – frame; 2 – planting mechanism; 3 – transport train; 4 – watering pipe; 5 – mechanism for holding forest seedlings; 6 – seedling boxes

Fig. 5. **Irrigation mechanism during planting**: 1 – reservoir; 2 – passage valve; 3 – transportation hose; 4 – dispenser

In contrast to conventional soils, challenging terrains may exhibit extreme hardness with large boulders, or sandy textures prone to clumping. Hence, the equipment utilized must effectively process different types of soil, necessitating reliable and robust machinery. For this, before planting, a module is used to process and loosen the soil, which works on the basis of a rotor-type tiller (Fig. 6), composed of several rotating knives (Fig. 7) and a rotor shaft (Fig. 8).

Fig.6. **Rotor-type tiller**

Fig.7. **Rotating knives**

Fig.8. **Rotor shaft**

Another important characteristic in terms of planting in desertified areas is the mechanism of watering the saplings. As a result, the 200-liter basin (depicted in Fig. 9) distributes water via gravity through a hose, with the flow rate controlled by a flow adjustment valve (Fig. 10), along with a dispenser positioned near the planting area (Fig. 11).

Fig. 6. **Basin for storing irrigation water**

Fig. 7. **Flow adjustment valve**

Fig. 8. **Water dispenser**

The tests were carried out in Romania, in an area subject to desertification from Ilfov County. Testing was performed across a 0.5-hectare area, employing a speed of 2.5 $km \cdot h^{-1}$ and a planting area width of 11 cm. Evaluation criteria included assessing the root coverage, monitoring plant damage throughout the processes, and analyzing any deviations from the desired planting depth.

Results and discussion

Given the fundamental influence of soil conditions on forest vegetation, the primary focus when considering afforestation initiatives is on soil preparation.

Mechanizing soil preparation with the proposed system for afforestation offers several benefits, including reduced physical exertion, soil conservation through decreased compaction, and a 38-44% reduction in fuel consumption per hectare compared to traditional methods. Moreover, it enhances labor productivity, leading to shorter afforestation campaigns and improved work quality.

Fig. 9. **Afforestation system during planting of saplings**

Fig. 10. **Result of the afforestation action**

The experimentation encompassed an area of 0.5-hectare vulnerable to desertification, the agricultural tractor operated at a speed of 2.5 km·h^{-1} with a planting area width spanning of 11 cm. Within the designated planting zones, three rows comprising 20 saplings each were selected for comprehensive evaluation. Before testing, the systems were adjusted according to the conditions of the land and the sizes of the saplings. The length of the saplings varied from 30 to 70 cm. Criteria for assessment aimed the determination of the following qualitative indices: the average planting depth of the forest saplings (cm), width of the planting area (cm); degree of root coverage (%); degree of plant damage (%), and the degree of planting depth deviation (%). The assessments involved carefully excavating the saplings and conducting a thorough analysis to ensure adherence to the optimal planting depth, proper soil coverage of the roots, and minimal injury sustained by the saplings during the process. The calculations were made in Microsoft Excel by processing the obtained data, according to 60 total measurements. The results are presented in Table 1.

Table 1

Obtained data processing results

No.	Working speed, km·h^{-1}	Planting area width, cm	Root coverage, %	Plant damage, %	Deviation from the planting depth, %
1	2.5	11	99	0,2	5.5
2	2.5	11	100	0,3	4.3
3	2.5	11	100	0,5	5.1
4	2.5	11	99	0,2	4.9
5	2.5	11	100	0,2	5.2

The planting depth averaged 26-30 cm with the anchor-type coulter set at an obtuse angle, ensuring a high-quality planting operation at this depth. The root coverage when using the technology was highly satisfactory (Fig 11).

Fig. 11. **Coverage of planted saplings**

The plant damage level is satisfactory, most of the plant injuries were caused accidentally, by the lack of skills of the operator. The deviation in the planting depth is also acceptable, relative to the operating depth of the planting section.

Due to the modular nature of the system, additional subsystems can be incorporated and tested to facilitate a more comprehensive comparison. The comparative evaluation of the results obtained when the system is equipped with the mechanism for planting forest seedlings with controlled gripping and the system that uses a classic mechanism can be seen depicted in Figure 12.

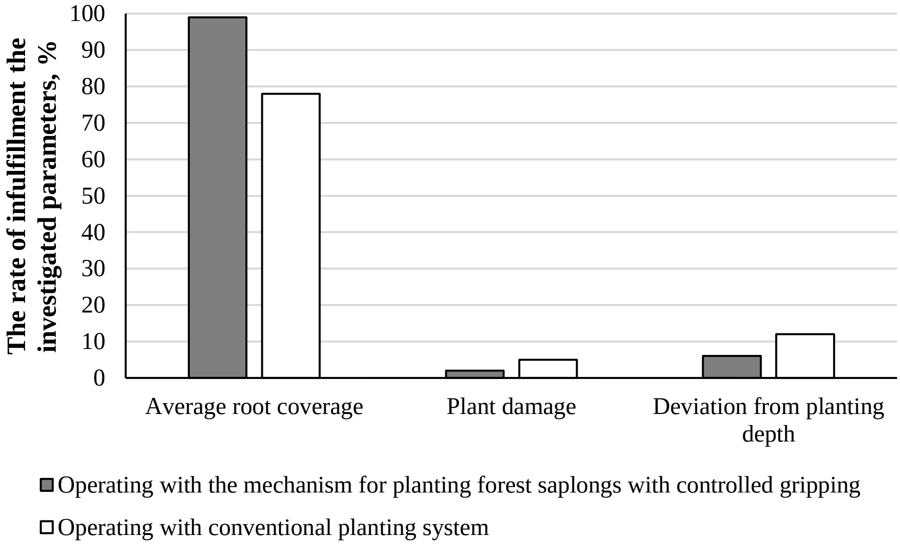

Fig. 12. **Coverage of planted saplings**

The previous picture shows that the innovative mechanism that assures controlled plant-gripping associated with the installation is particularly effective in terms of reducing sapling damage and ensuring a better coverage of the plant roots.

The assessment also took into account the satisfaction of several specific requirements outlined by the farmers, as detailed in Table 2.

Table 2

Specific requirements outlined by the farmers

No.	Requirements imposed in operation	Values determined experimentally
1	2.5 km·h^{-1} working speed	2.5 km·h^{-1}
2	Changing the working knives on the rotor can be done quickly	Ease of changing knives (however, the equipment is robust and does not require frequent changes of knives)
3	Positioning of the planting machine can be carried out easily	The fact that the elements are modular have brought major benefits in positioning and transporting the machine
4	Adjusting horizontality of the planting machine and the tillage equipment can be done easily	Adjustments were made much easier than in the case of other installations, especially due to the modularity of the system
5	Repair and maintenance operations of the equipment must be carried out easily	Operations of greasing and checking the working bodies were performed easily
6	All working bodies, in rotational motion, must be protected with guards	All working bodies that are in rotational motion are protected with protective guards

The afforestation system has proven to be efficient in planting a wide range of sapling sizes on difficult lands, subject to desertification. Unlike other planting systems that are extremely complex [24-27], the proposed version is versatile and can be easily pulled by an ordinary agricultural tractor. In addition, the system proposed in this paper is modular, the elements can be used both grouped and separated, which gives a high level of versatility. The objectives of watering the saplings during planting and safeguarding the planting material resulted in a remarkable success rate, with 96,66% of the saplings thriving – 58 out of the 60 initially planted.

Conclusions

1. The operational components of the planting system achieved work quality indices consistent with agrotechnical specifications. The area cultivated by the anchor-type working body with an obtuse angle exhibits a consistent appearance resembling a longitudinal trench. The area processed by the soil subsidence components displays a uniform appearance.
2. Precise control of the seedling tightening force was achieved during planting, especially when the mechanism that ensures controlled plant-gripping was used. As a result, the saplings were much less injured in the planting process.
3. The technology offers better vertical planting of a wide range of small, medium or large saplings, without changing the mechanism settings.

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Author contributions

Conceptualization, N.F., M.C., V.I., C.R.; methodology, N.F., M.C., V.I., C.R., and A.V.; software, C.R.; validation, N.F., M.C., and V.I; formal analysis, N.F., and M.C.; investigation, C.R.; data curation, N.F., M.C., V.I., C.R.; writing – original draft preparation, N.F., M.C.; writing – review and editing, N.F., M.C.; visualization, N.F., M.C.; project administration, N.F.; funding acquisition, A.V. All authors have read and agreed to the published version of the manuscript.

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