IMPROVING SCOTS PINE REGENERATION ON STAGNATING SITES THROUGH SOIL PREPARATION

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Abstract. Forest regeneration is crucial for sustainable forestry, shaping future stand composition. Clear-cutting can create unfavourable conditions for young trees due to excessive soil moisture, compaction, vegetation competition, and nutrient deficiencies, particularly in acidic coniferous stands. These factors hinder regeneration, causing establishment failure or growth stagnation. Soil preparation, such as spot mounding and inverting, can mitigate these issues by improving nutrient availability, aeration, and moisture balance. This study examined three clear-cut areas with poor Scots pine (*Pinus sylvestris* L.) regeneration. The soil was treated with spot mounding, inverting, or left unprepared (control), followed by planting containerized seedlings. The work time was recorded, planting spot quality assessed, and tree survival monitored annually over three vegetation seasons. The tree height, annual growth, and root collar diameter were measured after the third season. The results showed persistently acidic soils across all sites. Inverting required more time but created a larger scarified area than spot mounding. Both methods provided suitable planting conditions, ensuring at least 90% survival, compared to 71% in the control. The tallest trees with the largest root collar diameters were found in inverted soil treatments. While soil preparation enhances regeneration in stagnating environments, additional soil amendments may be necessary to maximize the tree growth potential.

Keywords: spot mounding, inverting, forest planting.

Introduction

After clear-cutting, unfavourable environmental conditions for forest regeneration may arise, often associated with increased groundwater levels [1]. In coniferous forests, non-optimal pH levels may also be present [2]. However, for regeneration of Scots pine, clear-cutting is the best option, as this tree species requires sunlight for successful growth [3].

One way to enhance the growth and survival of young trees is through soil preparation methods [4]. Preparing the soil before planting improves soil aeration, nutrient availability and water management, and reduces competition with surrounding vegetation [5; 6]. This increases the likelihood of tree survival while also improving their growth, thereby boosting forest productivity [7].

Several soil preparation methods are available, among which two notable options are by using an excavator equipped with either a bucket or a specialized soil preparation device for spot mound formation and inverted turf creation [8; 9]. Mounding creates a raised planting spot with a small hill and an adjacent pit, improving drainage and aeration, with an organic layer inside of mound. In contrast, inverting involves flipping the organic topsoil layer upside down, exposing the mineral soil while burying the organic layer. This method creates a scarified surface that helps reduce competition from surrounding vegetation [10].

One key factor for choosing a soil preparation method is work productivity, as it is essential to prepare the soil in all planned forest areas under resource-constrained conditions. In hilly areas both methods could be used depending on the water table.

Materials and methods

Research was conducted to evaluate the effects of different soil preparation methods (spot mound, inverting) on the success of Scots pine forest regeneration in four stagnating pine stands managed by the Latvian state forests. All four young stands (702-103-39, 702-127-5, 702-65-48, 702-65-17) are on mineral soils representing *Vacciniosa* forest types. The study areas are located in the northwestern part of Latvia, within a 3 km radius of this point (57.56159, 22.15625). The study included time tracking of soil preparation, measurement of prepared planting spots, and assessment of the tree survival rate after each growing season over three years after tree planting, and after the third growth season also the diameter at the root collar and each year height were measured. Data were collected from circular plots with a radius of 4 meters. All trees with visibly green needles were recorded as living, while measurements were carried out only on those with an intact main stem. The tree height and diameter were analysed using one-way ANOVA to assess the effect of soil preparation. Tukey's HSD post-hoc tests were applied to identify significant differences between soil variants ($\alpha = 0.05$). Assumptions for ANOVA (normality and homogeneity of variances), were tested and met. Statistical analyses were performed in RStudio (R version 4.4.2, 2024-10-31 ucrt). Chemical analyses were performed to determine groundwater pH levels with Ysi Pro DSS Probe.

A comparison was made between the productivity and quality of different soil preparation techniques (spot mound, inverting) in the northwestern part of Latvia. Soil preparation using the spot mound and inverting methods was carried out in all four sites and for control an unprepared area was left. The experimental sites were established and measured during implementation of the JSC Latvia's State Forests research programme "Working methods and technologies for restoration, planting, care and protection of forest stands" (agreement No. 5-5.9.1_007o_101_21_77). After soil preparation Scots pine containerized seedlings were planted.

Before soil preparation, in July 2021, groundwater wells were installed in sample plots within each treatment at a depth of approximately 1.5 m. Groundwater samples were collected in the autumn after growing seasons to assess pH values.

The productivity of planting spot preparation was monitored in two forest sites (702-65-10 and 702-65-17). To compare the productivity of spot mounding and inverting the soil the preparation process was divided into five steps, which are as follows:

1. Moving in site.

Time was recorded for machine movement within the site between stopping points. Multiple planting spots were typically created from a single stopping point. This activity includes pure work time spent on movement from one point to another but excludes entry and exit times from the site. The start of the operation is considered to be the beginning of the excavator track movement, and the end of the operation is stopping of the track movement.

2. Manipulator movements.

Time recorded for manipulator operations that do not involve movement, planting spot preparation, or other activities. The activity ends when another task begins.

3. Planting spot creation.

Time recorded from the moment the bucket touches the soil to the completion of planting site formation, ends when the mound is compacted, and the bucket is lifted from the ground.

4. Other Activities.

Additional tasks related to soil preparation, including minor repairs, technical inspections, and short technical pauses.

5. Pauses. Non-work-related activities, such as phone calls, conversations, and rest breaks.

The base machine used for operations was an excavator with a standard excavator bucket. After preparation, the mounds were measured. Spot mound dimensions (length, width, height) and pit parameters (width, length, depth) were recorded. For inverting, the width and length of the prepared planting spot were measured.

Results and discussion

The overall trend in all stands showed an acidic environment, with pH values ranging from 3.86 to 5.87. Results from 2021 to 2024 indicate that groundwater remains acidic across all sample plots, with minor fluctuations. The lowest pH values were slightly below 4, while the highest were slightly above 5. The acidic groundwater conditions negatively impact pine seedling development by limiting essential nutrient absorption, because the optimal condition for Scots pine is 5-5.5 pH [11].

Productivity and quality of planting spots.

The average preparation time for a spot mound in plot 702-65-10 was 15.5 seconds, whereas in plot 702-65-17, it was 14.8 seconds. The average preparation time for a single inverted spot in site 702-65-10 was 20.8 seconds, while in 702-65-17, it was 18.8 seconds. The overall average preparation time for a single spot mound across both sites was 15.2 seconds, whereas for an inverted spot, it was

19.8 seconds, what is 4.7 seconds (23.5%) longer. Assuming that 1600 planting spots need to be prepared, the preparation of classic mounds would take 6.7 hours, while the preparation of inverted planting spots would take 8.8 hours, requiring 2.1 hours more.

In both soil preparation methods, the largest proportion of time was spent on planting spot creation, accounting for an average of 55-59% for spot mounds and 68-72% for inverting of the total time consumed. The manipulator movements for spot mounds accounted for 17-22% and moving in site for 14-21% of the total soil preparation time. For inverting, the manipulator movements accounted for 15-17% and movement in site for 13-14% of the total time. Other activities and pauses in both soil preparation methods accounted for up to 4% of the total work time, that did not significantly affect productivity, Fig. 1.

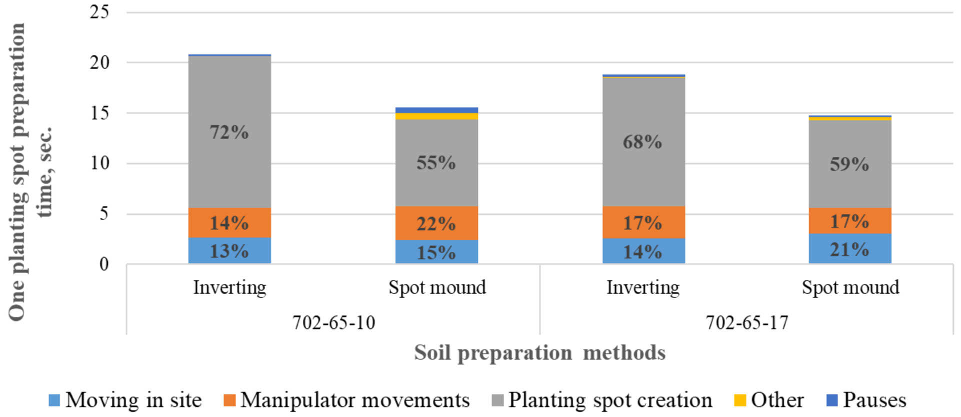

Fig. 1. **Time productivity preparing plating spots**

The amount of the counted spot mounds varied between 600 and 1000 per hectare, while the number of the inverted planting spots ranged from 1000 to 1400 per hectare.

Spot mound dimensions must meet certain quality standards. According to the guidelines developed by the Latvian state forests (JSC) the minimum dimensions of a mound after compaction should be a width of 0.5 m, a length of 0.6 m, and a height of 0.15 m, but they can be in larger dimensions [12].

The average length of spot mounds was 1.26 m, which is 0.66 m (111%) above the recommended minimum, whereas the average length of inverted spots was 2.21 m, which is 1.61 m (268%) above the JSC minimum planting spot length requirement of 0.6 m. The average width of spot mounds was 1.03 m, which is 0.53 m (105%) above the JSC minimum requirement, while the average width of inverted spots was 0.95 m, which is 0.45 m (89%) above the JSC minimum planting spot width requirement of 0.5 m, Fig. 2. The average height of spot mounds was 0.3 m, which is 0.15 m (100%) above the JSC minimum mound height requirement.

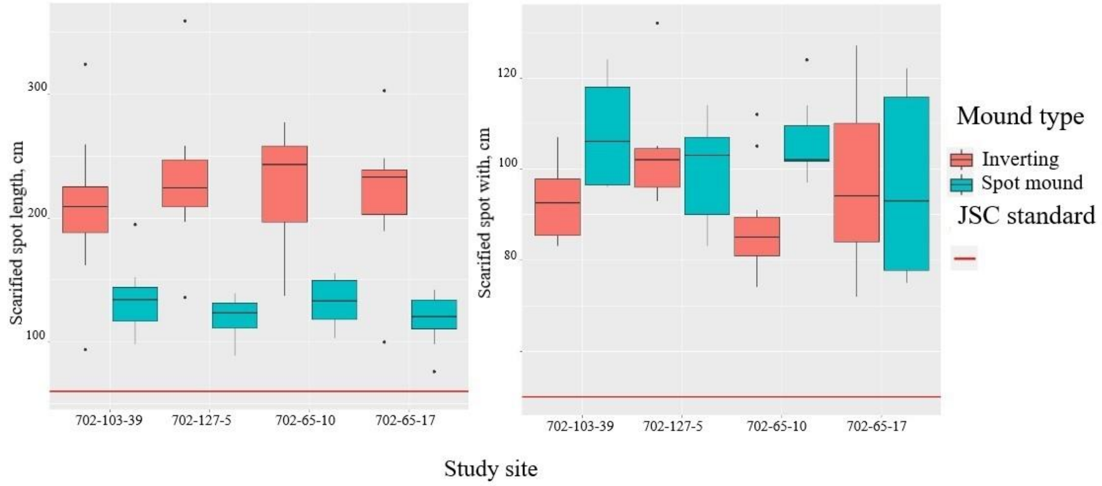

Fig. 2. **Length and width of planting spots**

The average parameters for mound pits are not specified in the JSC guidelines. However, the dimensions of the pits influence the ease of movement during forest tending and agrotechnical care operations [13]. The average pit length was 1.19 m, width 0.82 m, and depth 0.4 m, Fig. 3.

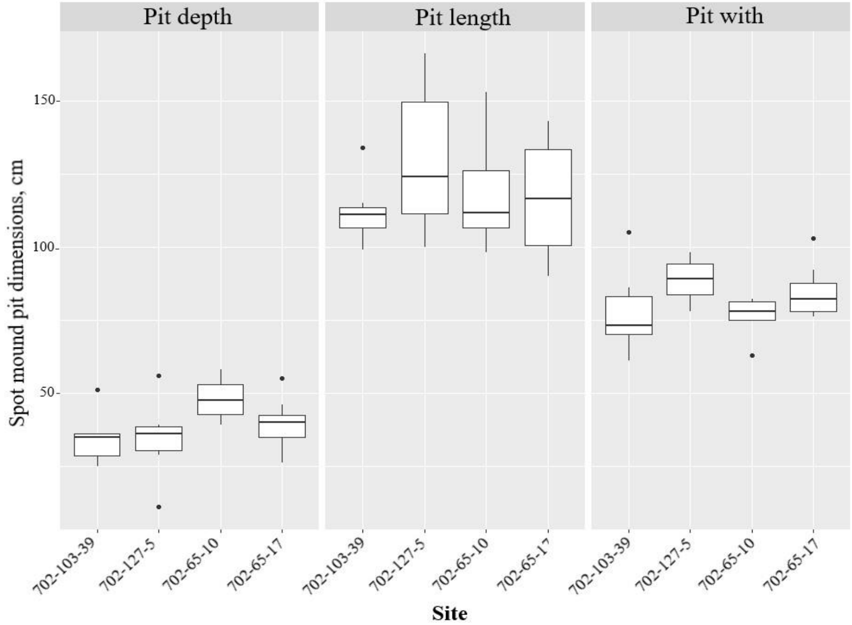

Fig. 3. **Dimensions of spot mound pit**

In the trial sites, the average scarified area for inverted spots was 37%, and for spot mound and pit together 33%. The total scarified area for different soil preparation methods, depending on the number of planting spots, is shown in Fig. 4. Latvian forestry regulations stipulate a minimum of 2000 Scots pines per hectare for successful stand regeneration [14], defining the required number of planting spots in the absence of natural regeneration.

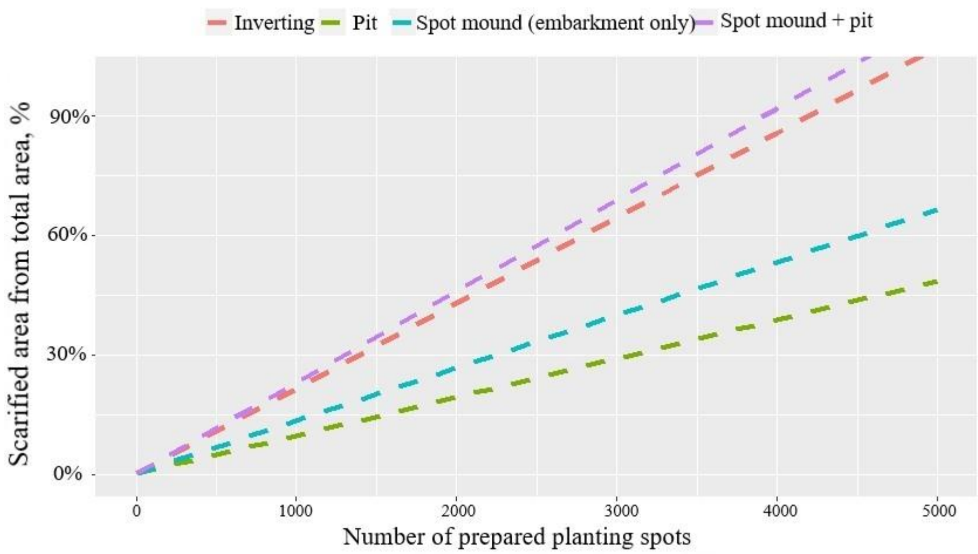

Fig. 4. **Scarified area depending on the number of planting spots**

Impact on pine survival and growth

The tree survival rate after the first and second growth seasons after outplanting was 100% in all three soil preparation variants, but during the third season some pines died back and alive were 96% in spot mounds, 92% in inverted parts of study sites and in the control variant only 71%, and many authors mention that increasing survival rate is one of the main reasons for soil preparation [15; 16].

Soil preparation can impact tree growth, including radial increment. In our study sites there was a significant difference between the prepared soil and the control variant, which coincides with the results of other studies [17]. The most significant root collar diameter was in inverted sites 10.6 mm, 8.75 in spot mounds and only 5.18 in unprepared soil.

Regarding the pine height, significant differences between variants were only observed after the third growth season after outplanting, when pines in inverted sites reached a significantly higher height 47.9 cm versus 39.6 cm in spot mounds and 38.3 cm in the control variant, Fig. 5. The same relationship other authors have gained about *Pinus contorta* and *Picea abies* [18]. These results show that the soil preparation has not created optimal conditions for pine growth, because under favourable environmental conditions Scots pine annual growth can exceed 0.5 metres annually [19].

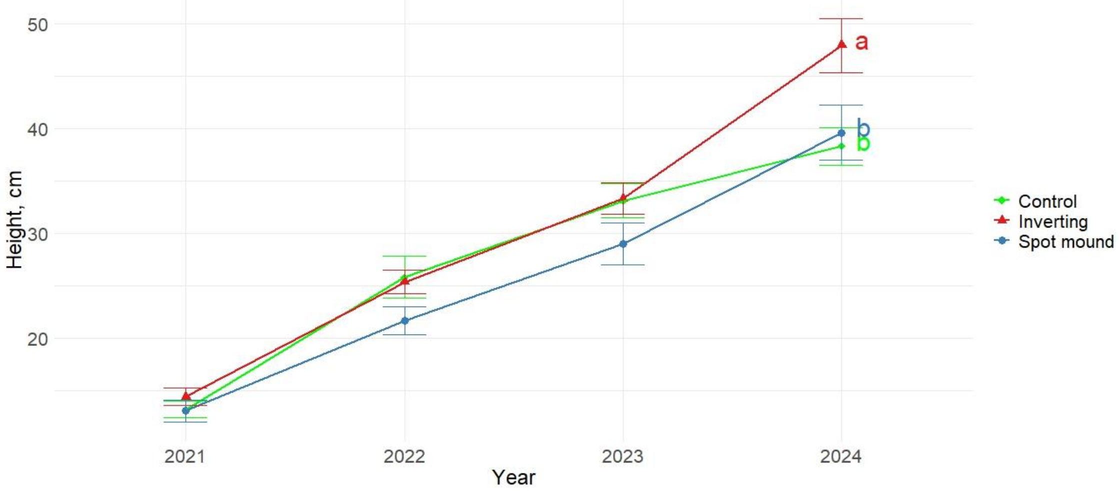

Fig. 5. **Tree height depending on the soil preparation method used, significant differences are indicated by different letters (*p* < 0.05)**

Conclusions

1. By the third growing season, soil preparation improved Scots pine survival in stagnant stands, with survival reaching 96% in spot mounds and 92% in inverted plots, compared to 71% in the control.
2. In inverted mounds Scots pine reaches larger height and diameter dimensions compared to unprepared soil and spot mounds.
3. Soil preparation in spot mounding can be completed more rapidly than in inverted scarified spots. Mounding is, on average, 23.5% faster than inverting, with the most significant time difference observed during the preparation of the planting spot itself.
4. There is no significant variation between the two methods in terms of the scarified area produced, and both methods surpass the minimum planting spot standards established by the JSC Latvia's State Forests. The preparation of 2000 planting spots results in a scarified area of 46% when using spot mounding, whereas the same number of inverted planting spots produces a scarified area of 43%.

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Author contributions:

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