D2.2 Site preparation adjusted for mechanized planting

A comparative study with three different soil preparation machines including scarification, traditional mounding and a centre-mounted device for inverse soil preparation

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EFFORTE project objectives

The Efforte project is built on the idea that forests and forestry provide a great potential to meet challenges of tomorrow by providing the Bio-based industry with efficiently processed raw material resulting in low carbon footprint.
To realize this and systematically replace fossil fuels and other non-renewable raw materials it is of great importance to find novel technologies and methods to improve and guarantee sustainability within the forestry.

The project is built on three different areas of development

- Trafficability (Better knowledge on soil properties, in particular soil mechanics)
- Efficiency in sustainable forest management and silviculture (development and utilization of novel technology, planning- and decision tools)
- Precision forestry (in mapping, characterizing, planning and operations by using information from different sources such as terrain maps and models, harvester data models for predicting detailed yield and operational cost and additional information from earlier sylvicultural and harvesting operations)

Background

Mechanization is common in Swedish forestry, particularly in activities relating to thinning, final felling and soil preparation. However, seedlings are still mostly planted using manual methods. Despite many trials, mechanized planting has yet to make a breakthrough in Swedish forestry. There are many reasons, but the main ones involve technical bottlenecks in prototypes and commercial planting machines that have made it difficult for the mechanized systems to compete with manual planting. There are thus great potentials in improvements of soil preparation methods, logistics and technical development. Back-Tomas Ersson (2014) concludes in his doctoral thesis that there is high potential for technical improvements that increase the productivity and lower the planting costs of today's tree planting machines. Such improvements will likely include faster seedling reloading via tray-wise-loaded carousels or band-mounted seedlings, multi-headed planting devices that produce high quality planting spots using adapted soil preparation methods, and sensors that aid the operator in choosing microsites.

EFFORTE has opened the door to renewed initiatives in this field through the work package on increasing efficiency in silviculture, WP2. The general aim of the EFFORTE projects was to develop a concept for automatic mechanized planting of container seedlings, integrated with environmentally sound and efficient soil preparation. The work was to be carried out in several independent projects, each of which generated its own results, development and innovation. The projects involve systematic problem solving, with the aim of finding solutions in three areas:

1. Testing and evaluating a new concept that aims for inverse soil preparation with a continuously moving machine equipped with centre-mounted flat scarification arms, the Kovesen.
2. Evaluating potential in improved logistics and develop new solutions concerning the interface between nursery and planting machine planter
3. Develop and evaluating new solutions for semi automation in mechanized planting

This study aims to the first of these areas

1. Introduction

This report summarise result of a study aimed at developing continual inverse soil preparation method. The study was based on three trials set up in Västerbotten in northern Sweden. The Kovesen machine was compared with two other soil preparation machines in terms of soil disturbance as well as number and quality of planting spots on soils with differing degrees of difficulty.

The machines used in the study were a modified Bracke T26 disc trencher (scarification), a Bracke T25 mounder (mounding), and the Kovesen machine where centre-mounted discs invert the humus which is then driven over and compacted by the bogie.

The Kovesen (two heads) **The Scarification machine (three heads)** **The Mounding machine (three heads)**

The Kovesen sometimes failed to create inverted humus spots; at these points the soil preparation can be described as a compacted ridge. The mounder compacted the ridge to a certain extent, but the trencher did not compact the ridge at all.

In the trials, two occations in the year for planting were used, one in the autumn directly after soil preparation and the other in the spring when the prepared soil had been left over the winter. Planting directly after soil preparation simulates the conditions that would apply for mechanical planting incorporated with a soil preparation machine. Spring planting is similar to the conditions that are most common for planting after soil preparation.

2. Materials and methods

Soil preparation was carried out with the instruction given to each operator that at least 2100 approved planting spots per ha should be created. Before the work started, trial runs were carried out outside the plot to ensure that the machines were correctly adjusted. At three different localities (Passagen, Kråken and Åshällan) with different difficulties concerning the terrain, the soil was prepared along six strips per machine. The strip lengths varied between 120 and 150 metres in the different localities, and the strips were six metres apart.

On one 70-metre strip, a planting trial was set up in which half of the length was planted directly after soil preparation in the autumn and the other half at the end of May the following year. In each row, seedlings were planted a minimum of one metre and a maximum of three metres apart. The goal of planting was to make optimal use of the best soil preparation area for all machines.

After planting, a survey was made of soil disturbance, stoniness, obstacles and number of approved planting spots with a minimum distance of one metre along a 20-metre section in all rows.

During the planting in autumn and spring, the same batch of pine seedlings grown at Gideå nursery was used, the only difference being that the seedlings planted in the spring had been stored in a refrigerator during the winter.

At the end of shoot growth in the autumn after the plantation, vitality, damage, colour of needles, and height was recorded for all plants, and a sample of stem base diameter of all plants in two blocks of 12. Because there were visual differences in size between the seedlings planted in autumn and spring that could not be explained by height and stem base diameter, side shoots were collected and needle length and dry weight recorded. At one of the localities, there was a relatively extensive pine weevil infestation, and for these plants the proportion of the stem circumference that was damaged was recorded.

Description of test sites

The test sites are presented in Table 1. All three localities had been cleared of logging residues before soil preparation.

Table 1. Description of test sites.

Locality	Latitude	Harvest	Soil type, texture	Boulders	Site quality
Kråken	63°31’	2014	Sandy-silty moraine	No data	T23
Passagen	64°08’	2014	Sandy-silty moraine	Few boulders	T21
Åshällan	63°59’	2015	Sandy-silty moraine	Many boulders	T22

Description of plant material

In conjunction with quality assurance checks of Holmen’s plant batches, information was obtained about the plant batch used both in autumn and spring (Table 2). In addition, a lab-test showed that the roots had high vitality, and a trial cultivation showed that the plants were undamaged after winter storage.

Table 2. Description of plant material.

Tree species	Pine
Batch reference	1504 T8 Dal
Tray	Starpot
Substrate volume	50 cc

Mean height	7.9 cm
Mean diameter	2.1 mm
Dry weight, shoot	0.70 gram
Dry weight, root	0.35 gram
Nitrogen content	2.2 DM weight %

Assessment of soil preparation

The method used complied with the SCA instruction for self-assessment of soil preparation and is described in Table 3, with some additions and adjustment for practical implementation in the trials. In addition to soil disturbance and preparation spots, other factors recorded were thickness of humus layer, stoniness, and any brushwood piles and dead trees that could affect the result of soil preparation in the sections planted in autumn and spring.

Table 3. Classification of planting spots from 5 (highest quality) to 0 (lowest quality).

Classification of planting spots	
5 points	Inverse, i.e. the mound is inverted in its own cavity
5 points	Inverted humus layer with more than 2x2 dm mineral soil and a thickness of at least 3 cm
5 points	Inverted humus layer with more than 2x2 dm mineral soil cover and a thickness of at least 1x1 cm
3 points	Mineral soil min 2x2 dm and max 7x7 dm over or at ground level
3 points	Inverted humus layer without or less than 1x1 dm mineral soil cover max 7x7 dm
3 points	Humus remains on mineral soil in track or spot max 7x7 dm
2 points	In mineral soil clearly below ground level in track or spot
0 points	Humus undisturbed by machine

Soil disturbance

Soil disturbance was recorded both horizontally and vertically along 20-metre sections in the in all planted rows. A total of twelve 20-metre sections were surveyed per machine and trial for the two planting times. Soil disturbance along the operational strips was measured as the proportion of the 20-metre section disturbed by the machine (Table 4).

Soil disturbance perpendicular to the strips was measured along five transects at predetermined intervals per 20-metre section, which gave 60 observations per machine and trial for each planting occasion. Soil disturbance was recorded if there was the slightest visible disturbance of the soil/humus cover caused by the machine.

Obstacles were brushwood piles, large stumps and stones, and dead trees and residue wood that made it impossible to create planting spots.

The measurements were carried out following the same instruction, but by different people, in autumn and spring. Soil disturbance was measured according to the following instruction.

Table 4. Measuring of soil disturbance.

Variable	Where	How
Disturbed soil along planted row	In 20-metre sections along the planted row, starting every 35 metres	Proportion of 20-metre section showing soil disturbance
Approved planting spots	In 20-metre stretches along the planted row starting every 35 metres	Number of approved planting spots with minimum distance 1 metre
Ground stoniness	Between the rows, every metre, i.e. 20 measuring points	Probe touching a stone counted as a hit
Obstacles: brushwood piles, boulders, stumps, dead trees	In 20-metre stretches along the planted row starting every 35 metres	Proportion of 20-metre length containing obstacles
Soil disturbance (vertical) along planted row	Vertical at 2 6 10 14 18 m over planted row	Proportion from the centre of the operational strip to 3 m of soil disturbance
Disturbed soil, highest point	At highest point of planted row after 2 6 10 14 18 m	Height from ground level to highest point
Disturbed soil, lowest point	At lowest point of planted row after 2 6 10 14 18 m	Height from ground level to lowest point
Thickness of humus layer	Between the rows at 2 6 10 14 18 m	Thickness of humus layer in dm with probe

Measurements at planting spots

For each plant, soil preparation type in which the seedling had been planted, and whether this was deemed an approved soil preparation spot, were recorded. Soil humidity was recorded in four classes, and the thickness of the humus layer at the nearest point showing no soil disturbance was also recorded.

Because the Kovesen drives over and compacts the ridge with the bogie, thinner layers of mineral soil are accepted in Classes 5 and 6 and small amounts of humus remains in the mineral soil in Class 5.

Measurement of plants after one growth season

At the end of shoot growth in the autumn the year after plantation, all plants in the trials were measured. For each plant, vitality, damage, colour of needles and height were measured. In two blocks per trial, the stem base diameter was measured on all plants. At Passagen, side shoots were cut from approximately 30 of the plants with yellow-green or blue-green needles. Length, diameter, length of needles, and dry weight of the shoot were measured, and nutrient content analysed in needles of each colour. In the trial at Åshällan, pine weevil damage was recorded separately.

Variables measured:

- Height, measured from ground level to top bud in cm
- Vitality, four classes
0 = dead or dying
1 = severely reduced vitality
2 = significantly reduced vitality
3 = no or insignificant reduction in vitality
- Needle colour
1 = pale green to yellow
2 = green
3= dark green to blue-green
- Damage
1 = snow blight
2 = Brunchorstia disease
3 = drought
4 = drowned
5 = vegetation that brushes against or covers the plant
6 = mechanical damage, e.g. caused during planting
7 = pine weevil
8 = frost heaving
9 = unknown or other damage
- Pine weevil damage was assessed as the degree of ring barking
1 = 1-25% of the circumference
2 = 26-50% of the circumference
3 = 51-75% of the circumference
4 = 76-100% of the circumference
-Stem base diameter: measured in tenths of a mm.

3. Results

The surveys carried out in autumn and spring revealed certain differences. The biggest difference concerned soil stoniness. There were also some differences in the obstacles recorded, but here the differences were within localities.

The number of approved planting plots at Åshällan was an average of 20% lower in spring compared with autumn, and it was soil prepared by the trencher and Kovesen that decreased most.

For other parameters, such as soil disturbance and approved planting spots, the results between the two survey times were similar.

Soil disturbance

The trencher clearly caused most disturbance to the soil, both horizontally and vertically, followed by Kovesen and then the mounder. However, if we calculate how many operational strips are needed to make 2100 approved planting spots, the mounder needed more strips to attain the target, so the difference is less.

If, instead, we calculate the size of the area needed to make an approved spot, the Kovesen performs best (1.7 m²), closely followed by the mounder (1.8 m²) and then the trencher (2.1 m²). At Åshällan, where there were most obstacles and stones, soil disturbance was greatest per approved planting spot for all machines, but here both Kovesen and the mounder caused distinctly less disturbance than the trencher (see Figure 1).

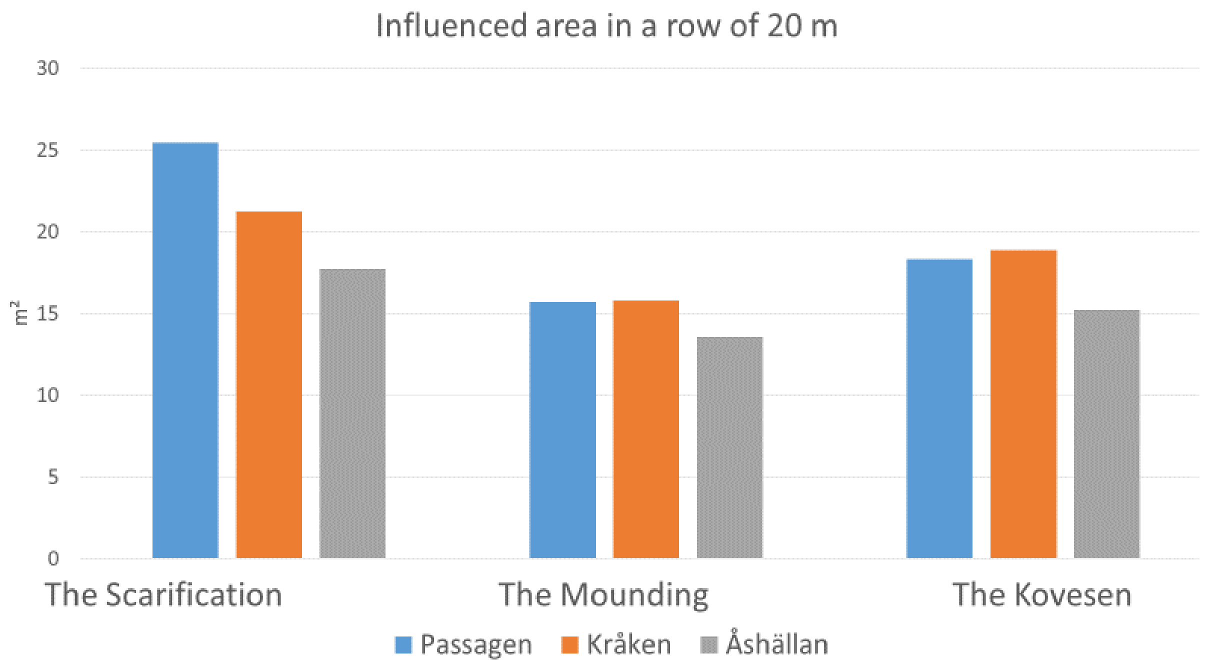

Figure 1. Amount of soil disturbance in a row over a 20-m section.

The task for each operator was to make at least 2100 approved planting spots per ha. The average spacing between the rows along the operational strip was 2.8 metres for the trencher, 2.4 metres for Kovesen and 2.0 metres for the mounder. If we assume a fixed spacing between the rows on an area of 100x100 metres, the trencher must make 36 rows (18 strips), Kovesen 42 rows (21 strips) and the mounder 50 rows (25 strips). At Passagen, all machines made at least 2100 approved planting spots, but at Åshällan none of the machines reached the target (Figure 2).

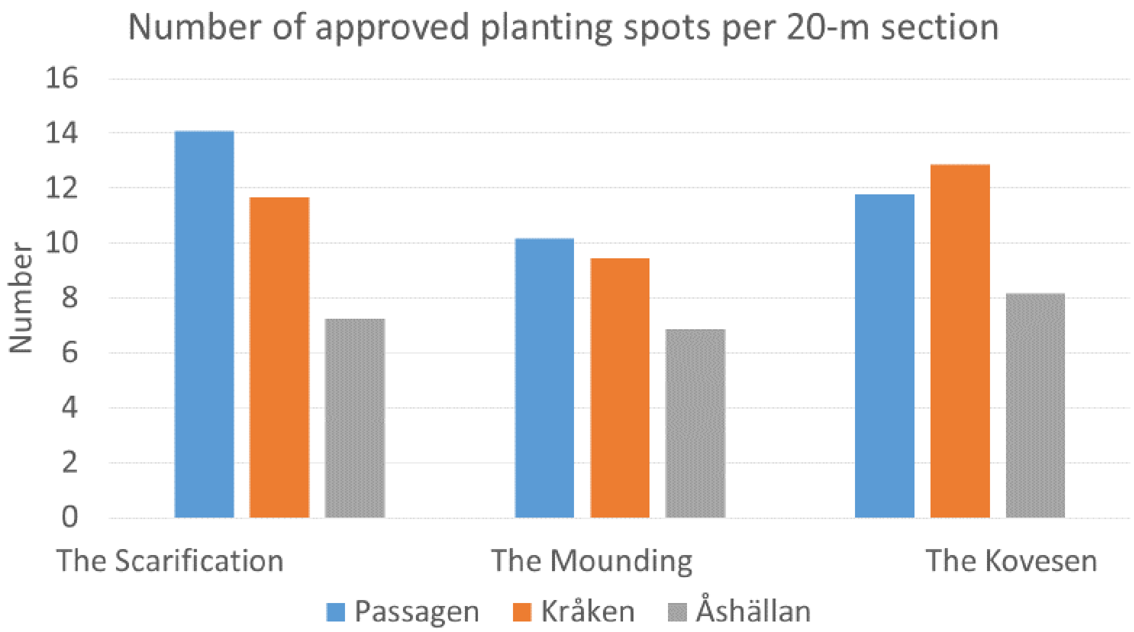

Figure 2. Number of approved planting spots per 20-m section.

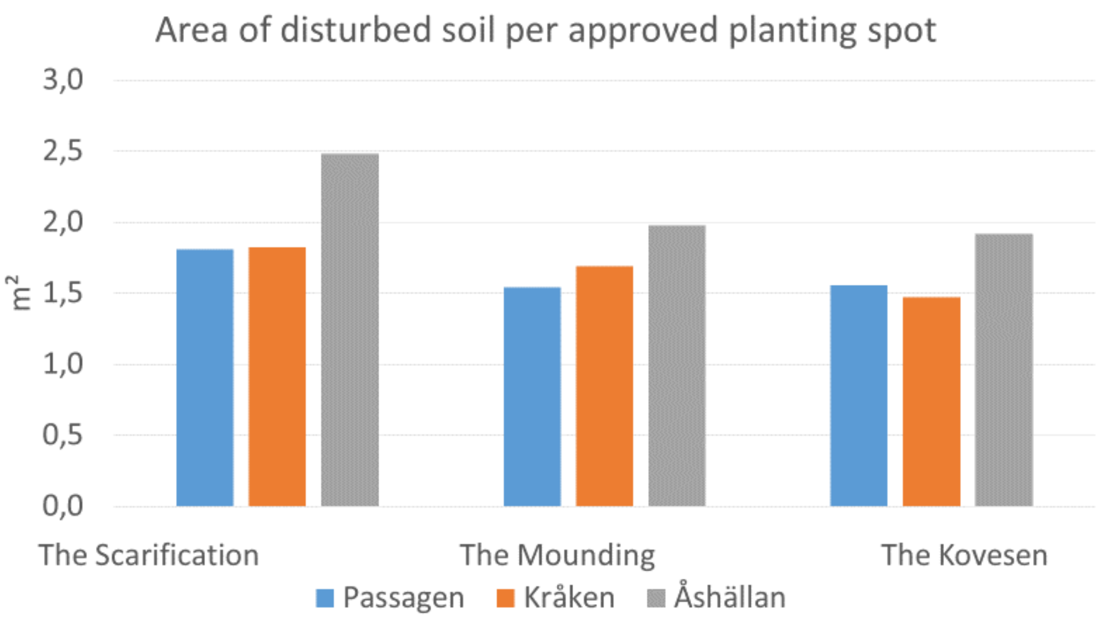

Figure 3. Area of disturbed soil per approved planting spot.

On average, for the machines to make 2100 approved planting spots per ha, soil disturbance was needed on 45% of the area for the trencher, 38% for the mounder and 36% for Kovesen. At Åshällan, the most difficult soil, the trencher would have needed 31 operational strips (62 rows). The distance between rows would then have been 1.64 metres, and 55% of the humus cover would have been disturbed by the trencher to produce 2100 approved planting spots. Corresponding figures for the humus cover would have been 44% for the mounder and 42% for Kovesen.

Quality of planting spots

Machine performance in terms of quality of planting spots varied between localities (Figure 4). At Passagen, the trencher had the highest proportion of high-quality planting spots, but Kovesen had most high-quality planting spots at Kråken and Åshällan.

There was an correlation between soil disturbance, number of planting spots, and the quality of planting spots. At Passagen, the locality where the trencher operated with the strongest pressure and disturbed the largest area, the most approved spots were made per section, and had the highest proportion of seedlings planted in inverted humus with mineral soil (Figure 4).

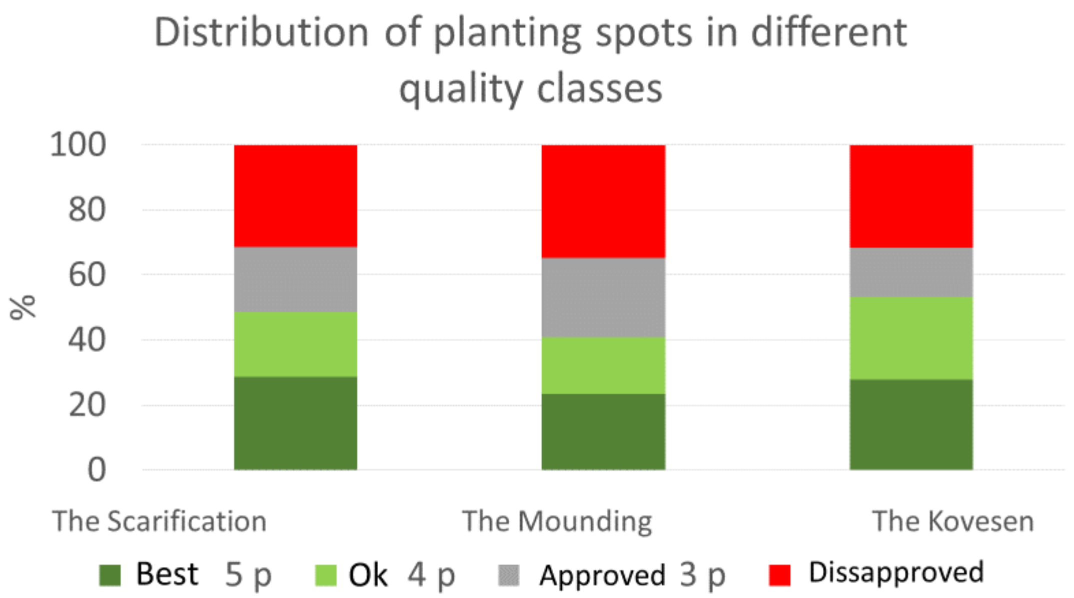

Figure 4. Distribution of planting spots in different quality classes.

At Åshällan, the most difficult locality, the trencher produced the smallest number of approved planting spots, and Kovesen the most. Of the seedlings planted in moist ground, or ground with a thick humus layer, more were placed in approved planting spots where the soil had been prepared by Kovesen compared with the other machines (Table 5).

Table 5. Number of approved planting spots on moist ground or ground with a thick humus layer.

Machine	Planting in humus cover >2.5 dm	Number approved	Percentage approved	Planting in moist soil >2	Number approved	Percentage approved
Trencher	55	31	56	99	58	59
Mounder	77	46	60	105	58	55
Kovesen	79	64	81	122	95	78

In general, the number of approved spots with mineral soil decreased between autumn and spring for all machines, with the greatest difference noted at Åshällan.

For approved spots of inverted humus with mineral soil, the distance varied between 2.9 and 7.2 metres depending on locality and preparation method, and for any approved spot the corresponding distance varied between 2.2 and 4.5 metres.

Plant survival and growth

After one growth season, the seedlings planted in autumn were generally thicker and greener, but shorter, than those planted in spring (Figures 5 and 6). Mortality was 4 percentage points higher for the seedlings planted in the autumn compared with those planted in the spring (Figure 7).

Differences in mortality, height, diameter, and needle colour were found between different types of planting spots. Mortality of seedlings planted in unprepared, pure mineral soil was compared with seedlings planted in inverted humus with mineral soil and ridges. Mortality was clearly greatest in unprepared soil, but similar in mineral soil and ridges. The high mortality found at Åshällan was mainly caused by pine weevils, where 60-70% of the mortality was in unprepared soil, and 10-20% in mineral soil and ridges.

Plants were higher in mineral soil than in unprepared soil and ridges. This is probably because the plants may have been planted slightly deeper in the ridges. Plants were thickest in the ridges and thinnest in unprepared soil.

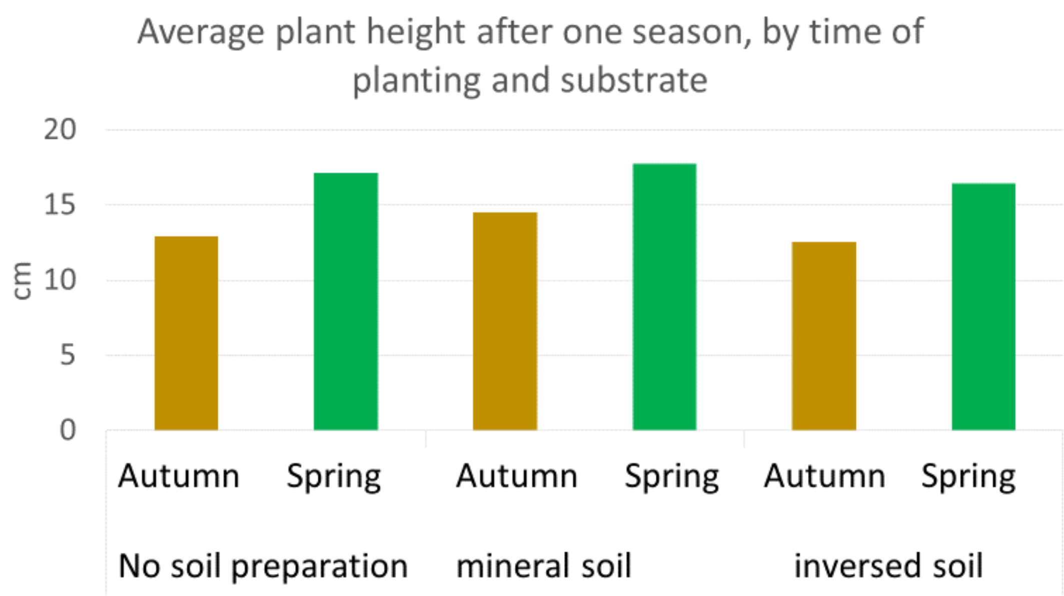

Figure 5. Average plant height after one season, by time of planting and substrate

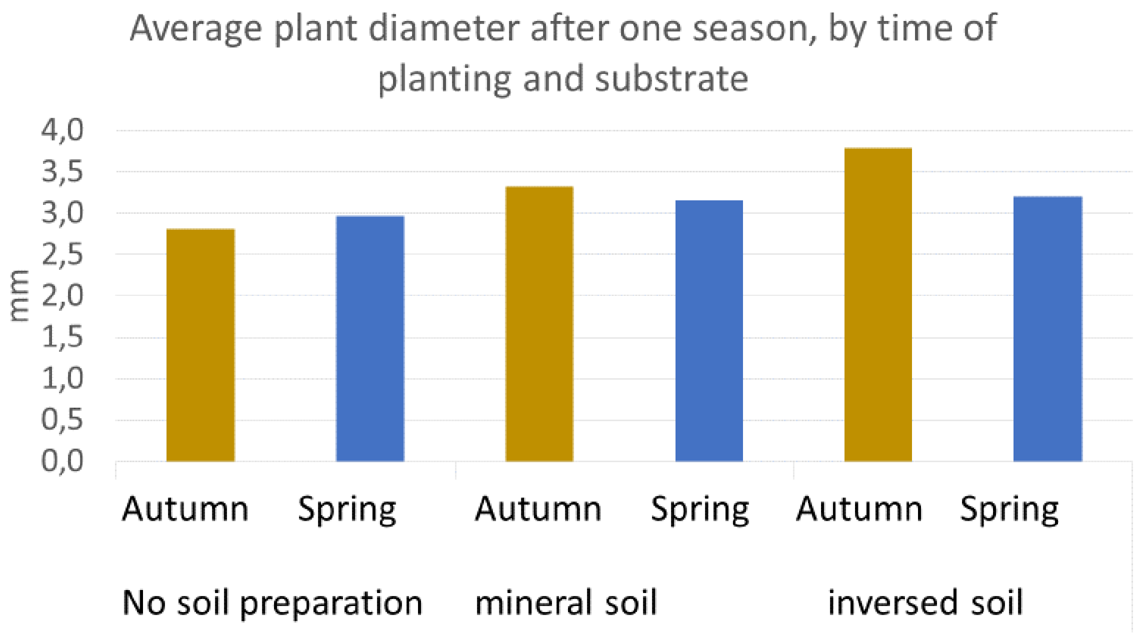

Figure 6. Average plant diameter after one season, by time of planting and substrate.

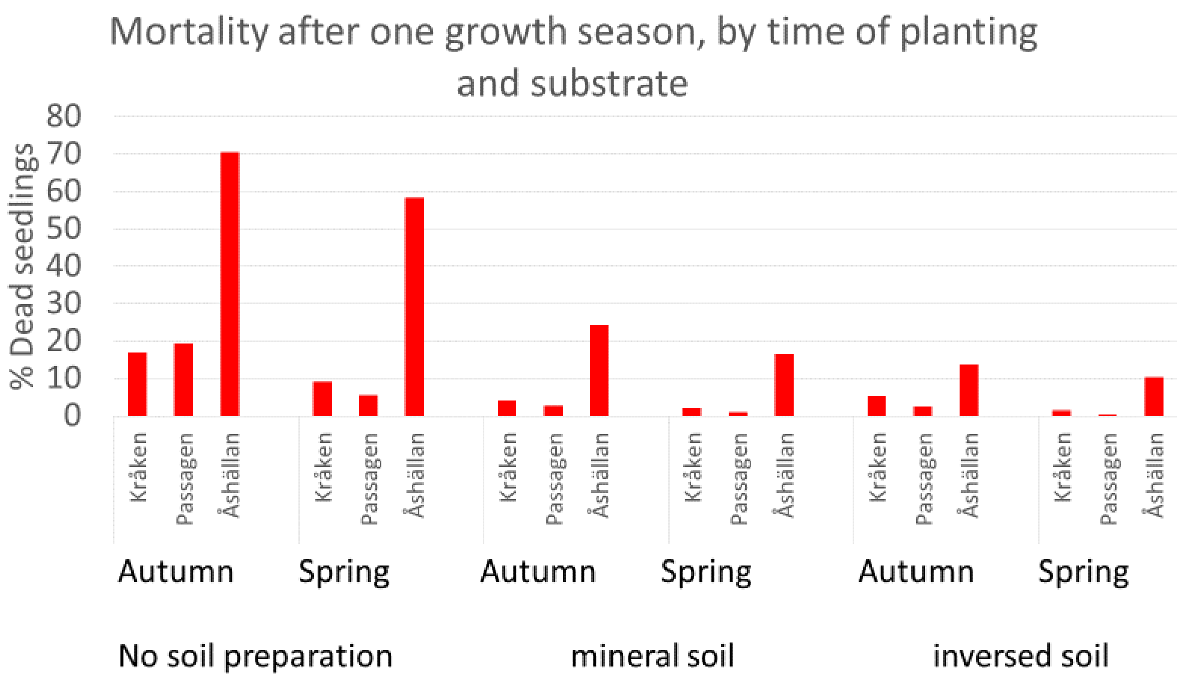

Figure 7. Mortality after one growth season, by time of planting and substrate.

Needle colour is an indicator of nitrogen content, and seedlings planted in ridges were greenest (highest nitrogen levels) and those in the unprepared soil were yellowest (lowest nitrogen levels). Analysis of shoots collected from plants with blue-green and yellow-green needles showed considerably more biomass and nitrogen content in the blue-green needles compared to the yellow-green (Table 6).

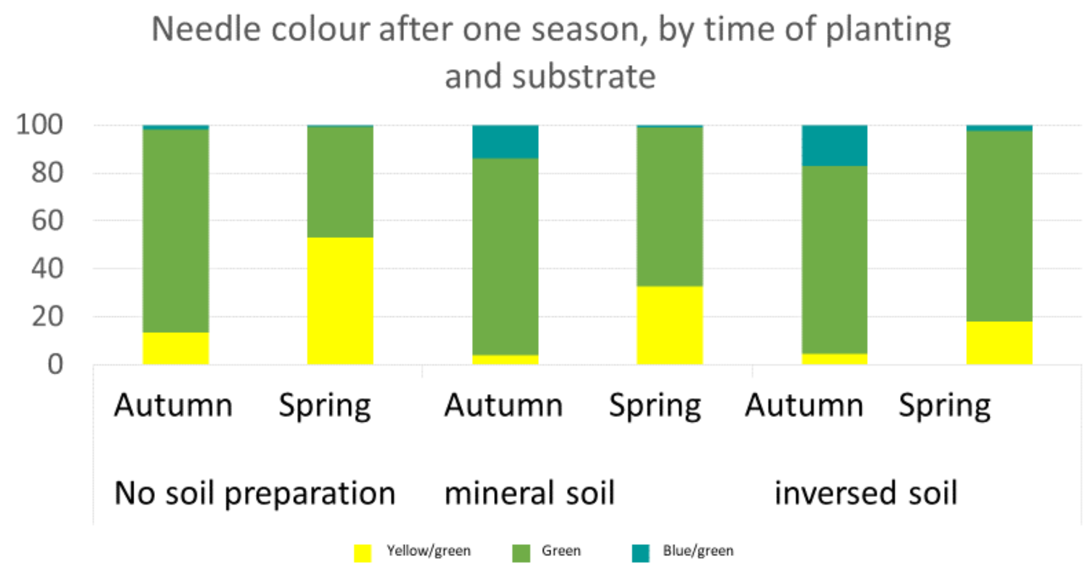

Figure 8. Needle colour after one season, by time of planting and substrate.

Table 6. Measurement of side shoots from plants with different needle colour.

Needle colour	Shoot length (mm)	Needle length (mm)	Diameter (1/10 m)	Fresh weight (g)	Dry weight (g)	DM weight % nitrogen
Yellow-green	53.5	36	1.4	0.67	0.25	0.8
Blue-green	46.5	79	2.3	2.31	0.83	2.4

Figure 9. Yellow-green plant (left), most commonly found in spring planting, and blue-green plant (right), most commonly found in autumn planting.

4. Discussion

The trencher's discs and teeth are unable to invert humus with mineral soil, and many of the planting spots in the mineral soil clearly ended up below ground level. Kovesen was clearly better than the trencher and the mounder in terms of producing inverted humus with mineral soil classified as the best spots, i.e. the highest number of approved planting spots.

If machine performance on sections with moist soil and/or thick humus cover is added, the results indicate that the Kovesen technology creates a greater number of approved planting spots on difficult soils.

The total number of approved planting spots decreased between autumn and spring. This may be because of tougher assessment in classification in spring but also because mineral soil was eroded from ridges during the winter snowmelt, thereby reducing the number of approved spots of inverted humus with mineral soil.

In addition to the soil disturbance by the machines in terms of area, there was also disturbance in a vertical direction. Vertical disturbance is more visible from a distance and is regarded as unattractive by the public. One of the objectives of the Kovesen project was to produce a more attractive soil surface after preparation, i.e. with as little visible disturbance as possible in depth and height from the ground surface.

Differences were observed in plant development and survival depending on whether they were planted in the autumn at the time of soil preparation or in the spring after a winter. Seedlings planted in the spring generally had longer top shoots than those planted in the autumn, which is why the plants were also longer. After one growth season, seedlings planted in the autumn were thicker than those planted in the spring.

Seedlings planted in unprepared soil and mineral soil were longer than those planted in inverted humus with mineral soil, but this was probably because these were planted deeper to ensure that they reached the humus layer. Stem diameter growth was also greater in higher-quality planting spots.

Analyses of side shoots from plants with yellow-green and blue-green needles showed that shoots on the blue-green plants were shorter but three times heavier than those from the yellow-green plants. In addition, the blue-green plants contained three times more nitrogen by weight than the yellow-green, 2.4% versus 0.8%. Of the seedlings planted in autumn, on average more of the plants were blue-green and fewer were yellow-green than those planted in the spring, regardless of the planting spot quality.

There is also a logical difference in needle colour between plants in the three types of site: unprepared – mineral soil – inverted humus with mineral soil. In the unprepared soil, more plants were yellow-green due to greater competition for nutrients and water, and in inverted humus with mineral soil more plants were green and blue-green, where there was best supply of nutrients.

Seedlings planted in the autumn seemed to have longer needles and generally greater biomass than those planted in the spring, but this could not be confirmed because height and diameter measurements are not sufficient to determine the biomass of small pine plants. Instead, the length of the needles, in combination with the diameter, provided more information about the plant's biomass.

The overall results suggest that the roots of seedlings planted in the autumn had time to become established in the surrounding soil before the winter, despite the lateness of planting. This meant they were thicker and had more access to water and nutrients in 2016 than the seedlings planted in the spring. The clearest and best effect of autumn planting is shown by the growth in diameter of plants in the highest-quality planting spots (inverted humus with mineral soil), where the seedlings planted in autumn were 15% thicker (3.8 mm) compared to the spring-planted plants (3.2 mm).

5. Conclusions

Soil preparation with Kovesen results in less soil disturbance, both horizontally, vertically, and in terms of area, than the trencher per approved planting spot. Results from the most difficult soil conditions show that Kovesen's soil preparation technology creates more high-quality planting spots than the trencher and the mounder.

There is no difference in survival for plants after the first growth season attributable to type of machine, but the different types of planting spots were significant.

Differences found between plants in terms of size and nutrient content were attributable to time of planting, with the results generally more positive for seedlings planted in the autumn than for those planted in the spring. This could indicate that autumn planting, and thereby planting direct after soil preparation with integrated mechanical planting, could improve vitality and growth in the new stand.

References

Ersson, Back-Tomas, 2014. Doctoral Thesis. Swedish University of Agricultural Sciences, Faculty of forest Sciences Department, Umeå 2014.