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Planting and tending productivity comparison in mounds and disc trenches using containerized and bareroot coniferous seedlings

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Abstract. In 2016 more then 40,300 ha of forest was regenerated in Latvia, where 13,000 ha were seeded or planted and 30,300 ha were left in natural regeneration. Before planting, usually one of two soil preparation methods are used – mounding or disc trenching. In areas with optimal water regime, disc trenching is used, while in wet areas mounding is used. Tree planting and after planting tending is done manually by hand tools. The aim of the study was to compare planting and tending productivity in different soil preparation methods (mounding and disc trenching) by planting different stocktypes (containerized and bareroot seedlings). Planting time studies were done in 12 sites and tending time studies in 8 sites. In planting time studies, different planting operations were measured and compared. In tending time studies, GPS devices were used, where area, distance and working time (productive and rest) was counted from GPS data. Average planting time for containerized seedlings in disc trenches was 10.3 seconds, while in mounds 9.2 seconds per seedling, an 11% improvement. Average planting time for bareroot seedlings in mounds was 28.3 seconds, while in trenches – 18.2 seconds, a 35% improvement. Tending in trenches was done faster than in mounds. On average, one hectare tending time in mounds was 8.4 hours, while in trenches 7.4 hours, an 11% improvement. Walked distance for 1 hectare tending in mounds was 5.4 km, 7% shorter than the distance of 5.0 km in trenches. Factors that influence planting and tending productivity are soil preparation quality, logging residue, and water level on the site. Data from planting and tending time studies could be used for better plan work activities and select suitable planting material for a particular soil preparation method.

Key words: planting time studies, planting productivity, tending time studies, tending productivity, planting in mounds, planting in trenches.

INTRODUCTION

Forest in Latvia cover 3.3 million hectares of land, or 52% of the country territory. In 2016 more than 40,300 ha of forest was regenerated in Latvia, where 13,000 ha were seeded or planted (artificial regeneration) and 30,300 ha were allowed to regenerate naturally (Central Statistical Bureau of Latvia 2018). Natural regeneration occurs by sprouting or leaving the seed trees on the cleared area. Artificial regeneration happens through planting or seeding and consists of soil preparation, planting, and later tending. Planted forest stands, in most cases, have higher productivity compared to naturally regenerated, achieved through use of tree breeding and better soil preparation (Nordborg

et al., 2003; Heiskanen et al., 2013; Jansons et al., 2015). Before planting two main soil preparation methods are used: mounding and disc trenching (Fig. 1).

Mounds Disc trenches

Figure 1. Examples of the forest soil preparation methods used in Latvia before planting. These site preparation techniques are done during the autumn before planting (photos from our study sites).

In mounding, a hole with excavator bucket is scoped into the soil, turned upside down and placed next to the hole. The new pile is called a mound. In trenching, a disc is towed behind forest tractor to form a long trench. Soil preparation with trenchers is cheaper, faster, and more widely used compared to mounding method. On average, trencher productivity for one hectare of soil preparation is 1.0–1.8 hours (UOT-2000 Forest Trencher, 2019), while in mounding, when 2,000 planting spots per hectare are prepared, average productivity is 5.9–6.9 hours (Lazdina et al., 2018). Average trenching service costs are 120–180 EUR ha^{-1}, while mounding costs 450–550 EUR ha^{-1} (Lazdina, 2017). Besides using seeds during direct seeding, three different seedling types are used in artificial regeneration: bareroot, bareroot-container hybrids, and containerized seedlings (Latvian State Forests, 2015). Bareroot seedlings have an open root system that is not specially designed. These seedlings have a limited planting time, and the possibility of roots drying in the soil is not ruled out. Bareroot-container hybrid seedlings have an open, vertically oriented, compact root system. During the first half of the year they are grown as containerized seedlings in a greenhouse and in the second half of the year (middle of summer) they are transplanted to an open field where they are grown an additional one or two years. As a result, these seedlings have a robust root system that accelerates plant growth in the first years after planting. The possibility of roots drying out is very low, but these seedlings also have a limited planting time. Containerized seedlings have a closed, vertically oriented, compact root system included within the soilless (peat) substrate. Containerized seedlings can be planted almost through the whole vegetation period and seedlings do not dry out when transported and planted. Joint Stock Company 'Latvia's State Forest' with 9 nurseries is the main seedling producer in country. Of the 49.9 mil. seedlings grown in 2017, 8% were bareroot, 43% were bareroot-container hybrids, and 49% were containerized seedlings.

All planting is done manually with planting tubes for containerized seedlings and by spades for bareroot seedlings. In tending all competing vegetation that suppresses tree growth is removed using bush saws. Average planting service costs in 2017 were 85–120 EUR ha^{-1} and tending 124–160 EUR ha^{-1} depending on location and forest type (Central Statistical Bureau of Latvia, 2018).

Previous time studies of forest establishment in Latvia were more related to planting mechanization (Liepins et al., 2011; Lazdina et al., 2018) and early thinning operations (Lazdins et al., 2013; Lazdins et al., 2016; Petaja et al., 2018). In one such study, where tending in similar conditions was done, the main conclusion was that tending on sites prepared by mounding was as effective as on sites where disc trenching was used, and speed of the operation was unaffected by soil preparation method (Dzerina et al., 2016). This study did not, however, analyze time spent for different operations of manual planting and or the distance of walking during tending operation.

The planting cycle consists of actions or elements that directly make up the act of planting a tree and interruptions that occur as planting proceeds. Some undesirable planting activities are also outside the planting cycle, but remain to overall affect planting productivity (Vyse, 1973). Actions such as site preparation, planting, stumping, and walking in site are elements that are directly connected to tree planting. Pauses and other breaks are not directly related to planting, but will affect planting if they continue for a longer time period. Other elements, like driving to the site, driving between different sites, or seedling transportation to the site can influence productivity over a longer time period.

In Finland, approximately 60% of the conifer forest stands are judged to require early cleaning (substantial 37.2%; high 21.2%) (Uotila et al., 2012). In Latvia, where forest soils are more fertile, tending mostly starts in the year of reforestation if the competitive overgrowth (canopy competition) interferes with successful tree growth. Tending continues several years after planting, one or more times per year, depending on overgrowth intensity. Tending intensity depends on tree species, soil fertility, and weather conditions.

Main tending productivity influencing factors are overgrowth intensity, tree species, forest type, and working methodology (Zimelis et al., 2011). In Finnish forests, early cleaning or tending substantially reduced canopy competition and, consequently, the mean diameter of released spruce grew 21–32% faster depending on the site. Finnish forest scientists reported that tending activity can reduce the cost of pre-commercial thinning, because tending reduces the estimated time needed for subsequent management by 18–49% and offers an economically viable young stand management option (Uotila & Saksa, 2014). To ensure high quality of stands at the felling age, intense thinning of young stands should be used (Zālītis et al., 2017). Despite the fact that mounding is more costly than disc trenching, at the interest rate of 3%, the investment in spot mounding had a 329 EUR ha^{-1} higher net present value than the investment in disc trenching (Uotila et al., 2010).

MATERIALS AND METHODS

On our study sites, disc trenching and mounding soil preparation methods were used. Study sites were located in the central part of Latvia in JSC 'Latvian State Forest' managed areas. In sites with optimal water regime, trenching was was done with a forest machine with attached disc trencher. On wet sites, mounding was down with an excavator and a conventional bucket. In total 12 sites were chosen, where soil preparation was done in the previous autumn.

Planting time studies

Planting was done on 12 sites. On 6 sites the soil preparation method was mounding and on 6 sites it was disc trenching. In each soil preparation method, 3 sites were reforested with pine (*Pinus sylvestris*) and 3 sites with spruce (*Picea abies*). Pine was planted as containerized and bareroot seedlings, but spruce as containerized, bareroot, and bareroot-container hybrid seedlings (Table 1).

Table 1. Planting and tending operations in study sites. Stocktypes include bareroot (BR), bareroot-container hybrid (BRCH), or containerized (C) seedlings

Soil preparation method	Site	Species	Stock-type	Planting		Tending			
				Number of workers monitored	Number of devices used	Number of workers monitored		Number of devices used	
				2017		2017	2018	2017	2018
Mounding	1	Spruce	BR	2	1	-	1	-	1
	2	Spruce	BRCH	3	1	-	2	-	2
	3	Spruce	C	2	1	3	2	3	2
	4	Pine	C	2	1	1	-	1	-
	5	Pine	C	3	1	-	-	-	-
	6	Pine	C	3	1	-	-	-	-
Disc trenching	1	Spruce	BRCH	1	1	-	1	-	1
	2	Spruce	BRCH	1	1	1	1	1	1
	3	Spruce	BRCH	2	1	1	1	1	1
	4	Pine	C	3	1	-	1	-	1
	5	Pine	BR	2	1	-	-	-	-
	6	Pine	C	1	1	-	-	-	-

Table 2. Monitored activities in planting time studies

No.	Activity	Activity description
1.	Planting spot preparation	Planting spot prepared by cleaning away branches, roots, and other logging residues.
2.	Seedling separation/sorting	Seedling separation and sorting before planting activity.
3.	Planting	Planting bareroot seedlings; this activity includes hole digging, planting, and stamping. Planting containerized seedlings, this activity includes seedling insertion in planting tube, planting, and stamping.
4.	Moving in the site	Moving between planting spots.
5.	Going after seedlings	Going after new seedlings, when all picked/carried seedlings from planting basket are planted. Usually 50–100 seedlings are carried with worker in one planting session. Containerized seedlings are more compact and usually in one session 100 seedlings are planted, where usually 50–70 bareroot seedlings are planted in one session. Seedlings usually are stored in edge of planting site and distance to them can greatly vary in different sites. This activity was monitored, but excluded from productivity calculations, because of huge differences between sites.
6.	Other activities	Non-planting activities during planting (talking on the phone, talking to each other, small pauses, etc.).

Time studies for planting were carried out in spring of 2017. Time spent planting one seedling was set as one working cycle. To compare planting productivity on different sites, several planting activities within a working cycle were counted (Table 2). The time study was done using the SDI 1.2. time keeping program (Haglof Sweden AB) that was installed on an Allegro CX field computer (Juniper Systems, USA). During time studies, if possible, data was recorded from several field workers on the site in order to obtain more objective results.

Tending time studies

Time studies for tending were conducted from autumn 2017 until autumn 2018. Tending was implemented on the same sites where planting was done (Table 1). Tending was done on 8 sites, 4 sites were prepared with mounding and 4 sites with disc trenching. On 3 sites, tending was done twice, once in 2017 and once 2018.

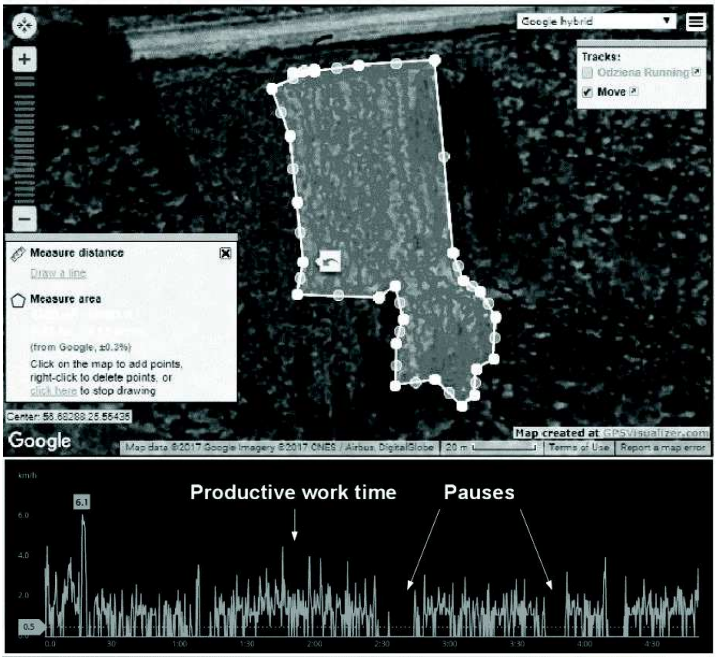
Tending was monitored using GPS devices that were attached to workers. For data recording, simple and freely available GPS sport devices were used to test if these devices could be used in tending time studies. Devices were not selected based on any specific parameters, but were chosen because they were available at this particular moment. We used one unit of each device, and in total 3 different devices were used: Garmin 610 and Garmin F25 (Garmin, Kansas, USA) and Suunto GPS Pod (Suunto, Vantaa, Finland) (Fig. 2).

Figure 2. GPS devices used to quantify tending activities.

If on one site one worker did the tending, a GPS device that was available at this particular day was attached to the worker. If on one site several workers did the tending, available GPS devices were attached to the workers. We did attempt to compare the different devices. During the working time, GPS devices provided non-stop data recordings, where worker walking speed and location was recorded. Tended area was calculated in a 'GPS Visualizer' program, which is free software program available at: http://www.gpsvisualizer.com.

Working time and distance for tending was taken from GPS movement data. (Fig. 3).

Productive work time was considered, when workers were moving and doing tending operation. Pauses included larger breaks, bush saw maintenance, and refueling. In Fig. 3, tending was done in trenches where containerized pine seedlings were planted. Tending was done by one worker and total tended area was 0.46 ha with total time 4 hours and 32 minutes, what converted to one hectare tending time is 9 hours and 51 minute.



Total Area	0,46 ha
Tending time	4:02:00 h
Pauses	0:30:00 h
Total time	4:32:00 h
1 ha	**9:51:00 h**

Figure 3. Working time calculation in tending.

RESULTS AND DISCUSSION

Planting productivity

On average, it took less time to plant container seedlings than bareroot seedlings, regardless of site preparation technique. The average planting time for one bareroot seedling was 23.2 seconds while for containerized seedlings it was 9.8 seconds, which is 57% faster. Containerized seedling planting is faster because of the different seedling root system and planting technique. Containerized seedlings are planted using planting tubes that make planting more effective because main work operations can be done faster than using spades to plant bareroot seedlings. Average bareroot planting spot preparation takes 4.1 seconds, while in containerized seedlings 0.9 seconds, which provides 78% time efficiency. The same applies for the overall planting operation, moving between planting spots and seedling sorting, where time efficiency is 57%, 59% and 18% in favor of containerized seedling planting. Planting with planting tube is physically easier then planting with spade, that is one reason it is easier to maintain steady planting productivity throughout the whole workday, while in bareroot planting the productivity tends to decline in the latter half of working day.

On average, for containers, it took slightly less time to plant mounds than trenches, but for bareroot the result was opposite: planting mounds took much more time than did planting disc trenches. Planting time for one containerized seedling in mounds on different sites varied by 23% and ranged from 7.9 to 10.3 seconds per seedling. The fastest planting was on sites with well-prepared mounds and with moderate ground water level. More variability in planting speed was observed when seedlings were planted in disc trenches, where it varied by 67% and ranged from 4.3 tp 13.9 seconds per seedling.

On average, planting one bareroot seedling in a mound required 28.3 seconds, while in trenches 18.2 seconds per seedling, which is 35% faster. Bareroot seedling planting in mounds was done on one site. Bareroot seedling planting time in trenches on different sites varied by 37% and ranged from 13.5 to 21.4 seconds per seedling. Bareroot planting is slower because it takes more time to find a good planting spot and it takes extra time to clear the for planting, prepare for planting, insert the seedling, and stamp the hole closed (Fig. 4).

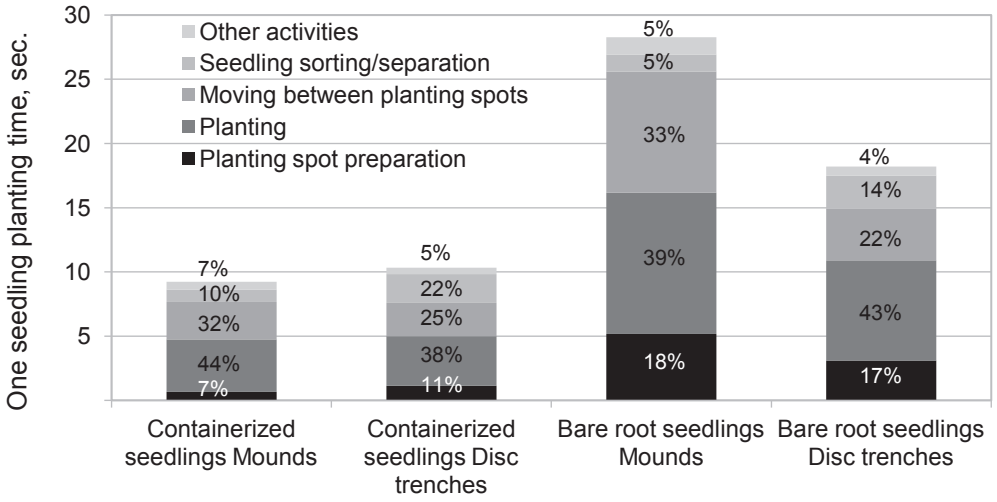


Figure 4. Planting productivity in different soil preparation methods with different coniferous seedlings.

Slower planting occurred on sites with wet trenches and in sites with high logging residues concentration. More time was spent on sites, where soil preparation quality was poor because such sites require extra searching time for proper planting spot and removing logging residues If the soil is prepared properly, no extra time is spent on planting spot preparation. In both soil preparation methods, most of the time was spent on planting operation. Seedling sorting and insertion speed into the planting tube is important when containerized seedlings are planted. Time spent on this activity can be reduced by placing the seedling in the planting tube while moving between planting spots, which leads to a faster planting rate and higher planting productivity in general. Seedling separation is more common in bareroot planting because of root mingling. In containerized seedling planting, this activity mainly is related to seedling withdrawal from plant box and sorting in planting basket.

When planting container seedlings, it was faster to plant spruce at 2,000 per ha than pine at 3,000 per ha. When bareroot-container hybrid spruce seedlings were planted, it was faster to plant seedlings on mounds than in disc trenches. In larger scale (production conditions) planting productivity is measured in hours per hectare. One hectare planting time was calculated from time studies and depends on planted tree species. According to Latvian Forest Law, for pine at least 3,000 and for spruce at least 2,000 seedlings should be planted per hectare to recognize the site restored. Planted tree number is the

same for both seedling types: containerized and bareroot. In one hectare planting, time spent for seedling transportation to the site, bringing them into the site, lunch time and other brakes, which are inevitable in planting, were excluded from productivity calculations (Fig. 5).

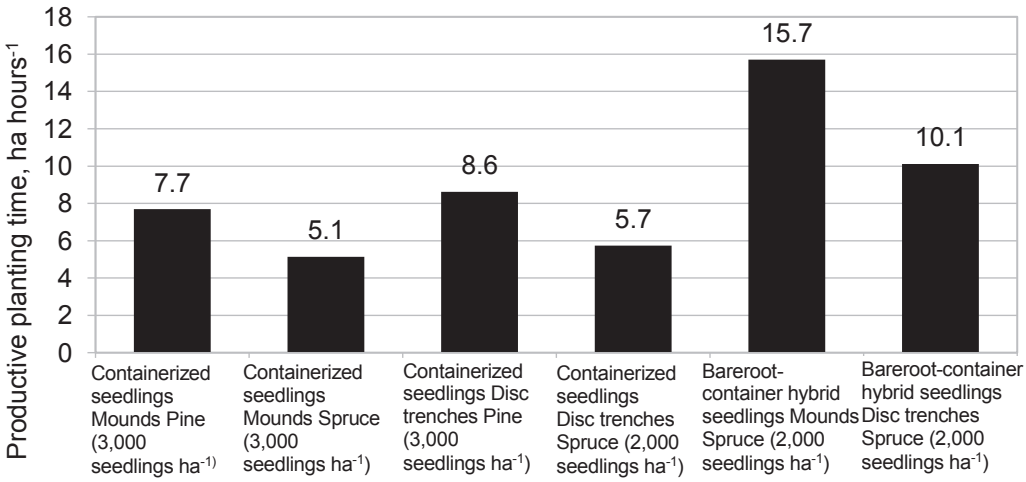


Figure 5. Planting productivity in different soil preparation methods with different tree species.

In this experiment the only bareroot seedlings were spruce seedlings. Although bareroot spruce was planted the most rapidly on disc trenching sites, twice as many container spruce could be planted in the same amount of time. Based on planting time studies, the fastest planting was when containerized spruce seedlings were planted on mounds (5,1 hour per hectare) and the slowest when bareroot spruce seedlings were planted on mounds (15,7 hours per hectare), which is about 60% longer. Previously, time studies for mechanized planting and mounding operation were done in very similar conditions. From these studies mechanized containerized seedling planting on mounds (planting density 2,000 seedlings ha^{-1}) with an M-Planter averaged 11.9 hours per hectare. In other studies (planting density 2,500 seedlings ha^{-1}) with a double-headed M-Planter was 9.6 hours per hectare (Liepins et al., 2011). In mechanized planting, mounding and planting is done at the same time. In our study, when manual planting time is combined with mounding time, average planting productivity for mounding + manual planting was 11.2 hours per hectare (Lazdina et al., 2018).

Manual planting time studies were done in different sites with different soil preparation quality. Crucial factor for fast planting in trenches is water level and logging residues. In wet soils covered with logging residues, planting in trenches is slower due the extra time spent searching for a planting spot and preparation before planting. Planting speed on mounds mostly depends on preparation quality. If the mounds are poorly prepared, it is hard to plant in the middle of the mound and difficult to move between mounds. If mounds are not pressed well so that they have air chambers, planting should be done in the edge of mound but this could cause problems finding seedling during tending.

Tending productivity

Time studies for tending were done to compare tending productivity in mounds and disc trenches. Productive working time, which included only mowing, averaged 81% of the total working time, where pauses, rest breaks, refueling, and maintenance averaged 19% of the total working time. Working time distribution (productive working time vs. pauses, refueling, etc.) with certain exceptions does not change significantly depending on different soil preparation methods (mounds or trenches), planted tree species (pine or spruce), forest type, and level of competition (see. Fig. 6).

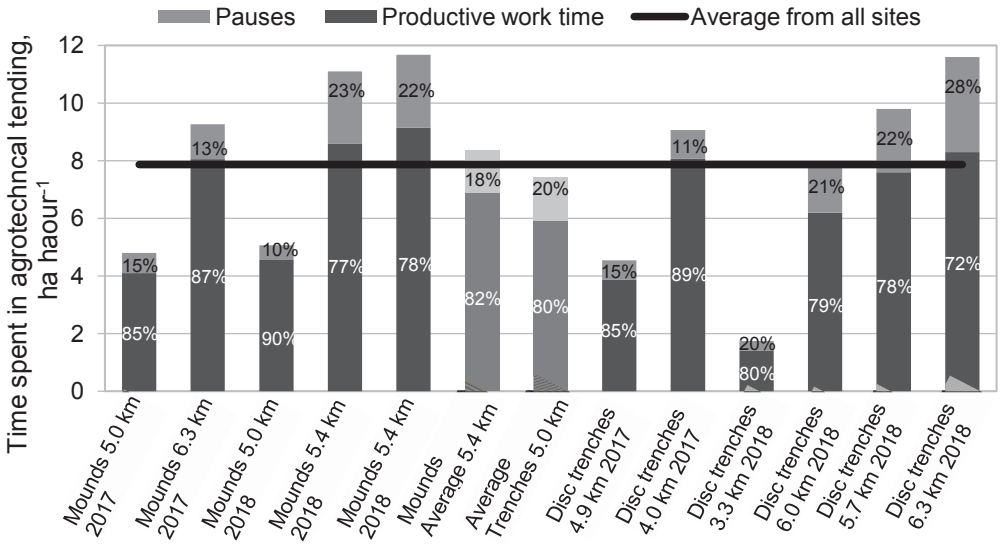


Figure 6. Tending time and walked distance in different soil preparation methods, 2017–2018.

Average time for tending across sites was 7.9 hours per hectare. Time for tending in disc trenches was 1.7–11.6 hours and for mounds 4.8–11.6 hours per hectare. On average, one hectare tending time in mounds was 8.4 hours, while in trenches 7.4 hours, which is 11% faster. These results are similar to those of Dzerina et al. (2016) where tending productivity in mounds was 8.0 hours and in disc trenches 7.7 hours per ha. In Zimelis et al. (2011), where time studies were done in 30 sites and tending was done in trenches, productivity in strips was 5.5 hours per hectare and in continuous (full) tending 7.3 hours per hectare. Previous studies show that seedlings in mounds are protected from surrounding vegetation competition for a longer time period compared to seedlings in trenches (Lehtosalo et al., 2010). Differences in tending productivity depends on the level of competition, worker professionalism, and working organization skills. Overall, tending in trenches is fastest.

Average walked distance for 1 hectare of tending was 5.4 km. Walked distance for tending in mounds was 5.0–6.3 km and for trenches 3.3–6.3 km per hectare. Overall less walking was needed when tending trenches. On average, the walked distance for 1 hectare tending in mounds was 5.4 km but only 5.0 km in trenches, which is 7% shorter. Difference in moving distance depends on worker organizational skills, which

allows the worker to choose the shortest distance on a site and plan to exclude walking without mowing.

Tending in trenches is faster because less time is spent deciding on the route and to look where tending has already finished. Workers admit that moving in trenches is easier because they simply follow the trench and moving is mostly on a flat surface. Walking in mounds requires extra attention because of pits between mounds, which could be full with water and logging residues. If the seedlings are not planted in the center of the mound, extra time and attention is spent locating seedlings.

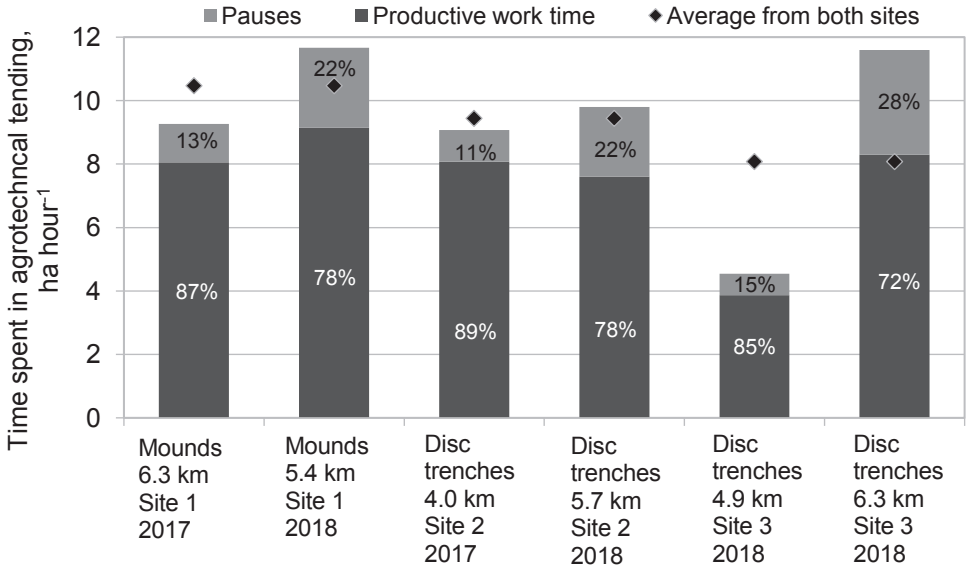


Figure 7. Tending time and walked distance in different soil preparation methods and years.

In 3 sites tending was done twice, in 2017 and 2018 (see. Fig. 7). In all 3 sites more time was spent during the second tending compared to the first one. In all sites, competiton during the first year was smaller compared to second year, and this is the main reason for the drop in tending productivity. Walking distance is not related to tending repetition and is more related to worker professional skills.

CONCLUSIONS

Comparing the productivity of planting speed for containerized and bareroot seedlings, when planting is done in different soil preparation methods (disc trenching and mounding) with different tree species, better results, in terms of productivity, were made by planting containerized seedlings. Comparing containerized seedling planting in different soil preparation methods, better results in terms of productivity were observed when planting on mounds than in trenches. When bareroot planting productivity was compared in different soil preparation methods, planting was more efficient in disc trenches. Workers' professionalism and previous experience is crucial in achieving more productive work. For containerized seedling planting productivity improvement,

seedling load in planting tube should be done during the movement between planting spots. Soil preparation quality is important to ensure high planting productivity in both soil preparation methods.

On sites where disc trenches were used, tending productivity was higher and walked distance shorter compared to sites where mounding was used. On sites where tending was done two years in a row, in second year tending took more time, compared to first year.

Our results show that reforestation can be more effective in terms of planting and tending productivity, when species and stocktype are matched to site preparation techniques.

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