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Productivity of the M-Planter Tree-Planting Device in Practice

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Need to mechanise tree-planting work have recently increased for many reasons. The newest planting and soil scarification device performing work in Nordic forests is the Finnish M-Planter. This study aims to clarify M-Planter's productivity in practice and show how various factors affect it. The follow-up data set covers 607 work shifts, of 13 operators with, in total, five M-Planters. The average productivity figures for the operators were 143 and 169 seedlings per effective working hour during the first and second planting season, respectively. Overall, the measured average productivity was 34.2% lower than that observed in an earlier work study of the M-Planter based on an experimental study design. On average, the operators learned to use the combination of the M-Planter and a base machine more efficiently while their experience in using it increased during the follow-up. Increasing number of stones and stumps as well as a thicker humus layer decreased productivity of the M-Planter. The study concludes that utilisation of the full productivity potential of the M-Planter requires not only good operators but also development of the whole planting service supply chain.

Keywords cost-efficiency, mechanisation, planting, seedling, silviculture, technology
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1 Introduction

The number of planting devices at work in Finnish forests has increased little by little in the 21st century, and currently stands at 30–35 planting units (Rantala et al. 2009). However, still under 5% of seedlings are planted mechanically in Nordic forests (Juntunen and Herrala-Ylinen 2009, Rantala et al. 2009). Most of the mechanically planted seedlings are container-grown Norway spruce (*Picea abies* (L.) Karst.) seedlings, but also some Scots pine (*Pinus sylvestris* L.) seedlings have been planted mechanically (Vartiamäki 2003).

Recently, call for mechanisation of tree-planting work have increased for many reasons. The labour shortage in forestry is expected to increase sharply after 2010 (Työvoiman saatavuus… 2005). The lack of labour will probably be especially keenly felt in tree planting, because forest-owners are less and less able and eager to do this work themselves (Karppinen et al. 2002). There is also a need to decrease silvicultural costs so as to maintain the profitability of forestry amid conditions of decreasing real stumpage values (Uotila 2005), and thus to preserve forest-owners' motivation for forestry (Harstela 2006). Mechanisation is aimed at both reducing the need of labour and attaining cost savings in planting (Rummukainen et al. 2002, Harstela 2006, Rantala et al.2009).

Conditions for mechanisation are also getting better for several reasons. Firstly, collection of slash and harvesting stumps for energy purposes is increasing in the Nordic countries. This makes work conditions in regeneration areas easier and therefore not only improves the productivity of current planting devices but also eases the work to develop new mechanisation concepts (Harstela 2006, Saarinen 2006, Rantala et al. 2009). Secondly, it appears that machine contractors will be more involved in silviculture in the future, because forest-industry companies are including silvicultural work under harvesting contracts (Strandström et al. 2009). Thirdly, it has been proved that the planting period of Norway spruce seedlings can be successfully extended to cover summertime in addition to traditional spring and autumn plantings (Luoranen et al. 2006).

The first Nordic planting machines were developed already in the 1970s, and numerous and varied mechanisation concepts were ideated and tested in the 1980s (Malmberg 1990, Ersson 2010). Today, the most commonly used planting device in the Nordic countries is the Swedish Bracke (Rantala et al. 2009). The newest planting device on the markets is the Finnish M-Planter (Rantala et al. 2009). The M-Planter carries out both soil scarification and tree-planting work; two parallel mounding blades invert pieces of soil, including humus and mineral soil, on undisturbed soil (spot mounding), after which a seedling is planted in the middle of each mound. Seedlings are stored in seedling cassettes placed on top of the device. The total capacity of the M-Planter's two seedling cassettes is 242 seedlings, and an operator loads seedlings manually from transportation packages into the cassettes (Rantala et al. 2009). The seedlings needed for a work shift are stored on a rack, usually located in back of the excavator (Härkönen 2008).

As a result of experimental time study, Rantala et al. (2009) reported that the mean productivity of the M-Planter was 33% higher than that of Bracke, and the higher productivity resulted in 23% lower unit costs of planting work. However, the difference between the devices got smaller when the density of stones or stumps increased. On the other hand, the greater the proportion of the regeneration area covered by slash, the bigger the difference between the devices (Rantala et al. 2009). The quality of the planting work of the Bracke and M-Planter seems to be at least as good as that of a combination of separate spot mounding and manual planting (Saarinen 2006, Härkönen 2008). According to Rantala et al. (2009), it seems possible to obtain cost savings by applying the M-Planter instead of manual planting work and separate spot mounding. Anyhow, when studying productivity of forwarders, Mäkelä (1979) observed that their productivity was clearly lower in practice compared to that measured in experimental time studies.

In addition to terrain-related work difficulty factors, both cognitive and physical skills, as well as the motivation of the machine operator, greatly affect the productivity of mechanised forest work (Murrell 1982, Sirén 1998, Ovaskainen et al. 2004, Kariniemi 2006, Rantala et al. 2009). In harvesting, for instance, experienced operators seem to reach significantly higher productivity than beginners do (Väätäinen et al. 2005). In addition to human factors, the economic result of mechanised forest work depends greatly on the technical reliability of the machine concept and success in the organisation of the work (Kuitto et al. 1994, Rantala et al. 2009, Strandström et. al. 2009). Taking all of the above-mentioned factors into account, one can see a lack of information on the M-Planter's productivity and factors affecting it, as well as on the functionality of work organisation in practice.

The aim of this study was to find out how work time with the M-Planter is, in practice, distributed between efficient work time and various interruptions. From the standpoint of work organisation and reliability of the device, also mechanical availability (MA), machine utilisation (MU), total utilisation (TU), degree of operation (OP), and degree of repair (REP) were calculated. The final goal was to clarify the M-Planter's real-world productivity and show how operators, their experience with the device, and prior experience in machine work, as well as work difficulty factors, affect it. In addition, planting work quality was measured.

2 Materials and Methods

Five machine units consisting of M-Planter and excavator (referred to below as A…E) were followed up on throughout the 2008 and 2009 planting seasons. During the follow-up, the machine units were driven by 13 operators (also referred to as A1…A4, B1…B2, C1…C2, D1…D4, and E1). Devices A, B, and C worked during the 2008 season and A, D, and E during the 2009 season. None of the operators had worked with the M-Planter before, but most of them had experience in working with either an excavator or harvester (see Table 1).

The operation of machine units was followed with paper forms on which operators marked work-shift-specific working hours, the number of seedlings planted, and interruptions in chronological order. The interruptions were classified in the following groups: operator's personal needs, maintenance or repair of the excavator, maintenance or repair of the M-Planter, filling of the seedling cassette, work organisation and planning of planting work, relocation of the machine unit, and other reasons – such as handling of seedling material. To control the reliability of the data, the planting units were equipped with vibration sensors during the first planting season.

In data analyses, work shifts that included a relocation were divided into two separate observation units, for obtaining work-shift-specific data match with inventory data measured from planted

Table 1. The regeneration area (ha) and the number of regeneration sites planted by the operators, as well as the number of work shifts, during the follow-up (operators with earlier excavator or harvester experience are denoted with a '*' symbol).

Machine unit	Regeneration area, ha	Regeneration sites, pcs	Operator*	Work shifts, pcs	Planting season
A	129.4	38	A1*	71	2008/2009
			A2	16	2008
			A3*	89	2008/2009
			A4*	72	2009
B	51.1	15	B1*	42	2008
			B2*	44	2008
C	15.0	6	C1	36	2008
			C2	20	2008
D	83.6	27	D1*	65	2009
			D2*	66	2009
			D3*	10	2009
			D4	20	2009
E	45.8	9	E1*	56	2009
Total	324.9	95	13	607	

regeneration areas. All told, the follow-up data consisted of 643 observations (from 607 work shifts). The number of work shifts per operator varied between 10 and 89. During the follow-up, 325 hectares were planted, on 95 regeneration sites (see Table 1).

The total working time (T_0) of the devices was divided into work place time (W_0), relocation time, and time used for maintenance and repair activities, on the basis of data collected with the paper forms filled in by the operators. W_0 was still divided into gross effective work time (E_{15}) and interruptions longer than 15 minutes. Further, E_{15} was divided into effective work time (E_0) and short (15 minute-or-under) interruptions (Nordisk… 1978, Harstela 1991, Kuitto et al. 1994). These time concepts were used to determine mechanical availability, machine utilisation, total utilisation, degree of operation, and degree of repair for the machine units.

Mechanical availability (MA) gives information on the reliability of the machine unit and illustrates the extent to which it is available for actual work; MA is the ratio of E_{15} to E_{15} added by maintenance and repair time plus other machine delays longer than 15 minutes. Machine utilisation (MU) is the ratio of E_{15} to E_{15} added by maintenance and repair time plus other machine delays longer than 15 minutes and all other work delay times such as relocation time and interruptions caused by other factors than the machine unit (Forest study… 1978, Harstela 1991, Kuitto et al. 1994). Total utilisation (TU) is the ratio of T_0 to calendar time, and degree of operation (OP) is the ratio of E_{15} to calendar time. Degree of repair (REP) represents the ratio of repair time to T_0 (Nordisk… 1978, Harstela 1991).

Work-shift-specific productivity figures were calculated for the operators on the basis of the paper forms. In addition, the forms were used to tally after each work-shift the cumulative number of seedlings that the operator had planted. In further analyses, the number of planted seedlings (× 1000) before the work shift under examination was used as a measure of the operator's experience in using the M-Planter.

A field inventory was carried out to estimate work difficulty factors and quality of planting work. The inventory was done after planting work in every regeneration area by measuring a systematic regular-shaped grid of the circular sample plots (r = 2.52 m). The number of sample plots and the distance between the plots was determined according to the area of the site; for sites of less than 2.0 ha, the grid consisted of 15 sample plots, whereas for larger sites a grid of 20 sample plots was applied. In regeneration areas larger than 10 ha, a further sample plot was measured for each half a hectare. In total, 1695 sample plots were measured. The sampling method is described in more detail by Saksa and Kankaanhuhta (2007).

Ground inclination, number of surface obstacles and stumps, stoniness, soil type, and thickness of the humus layer were estimated for each sample plot. A plot was classified as inclined if the difference in altitude of any opposite points on the perimeter of the plot was at least a metre. Stones extending more than 20 cm above the ground's surface, standing and fallen retention trees, ditches and other excavations at least 20 cm in depth, and stumps with a diameter of at least 20 cm and height of at least 20 cm were calculated as surface obstacles in the year-2008 measurements. In the year-2009 measurements, stumps with a diameter of at least 10 cm were considered separately from other surface obstacles. Surface obstacles and stumps less than half a metre from each other were treated as one. Existence of slash was subjectively evaluated at regeneration site level in the 2008 measurements but measured objectively for every sample plot in the 2009 measurements.

To estimate stoniness, six observations were done along the midline running north–south in each sample plot. Humus layer thickness was measured from the edge of the mound closest to the middle of the plot. The soil of every sample plot was classified as fine, coarse, very coarse, or peat. In further analyses, surface obstacles are presented as hectare density (ha^{-1}), stoniness as the percentage of the total area for which a stone is found at a depth of less than 20 cm, and humus layer thickness as the percentage proportion of plots with a layer over 10 cm deep. The sites' stoniness ranged from 0 to 60% and the proportion of the plots with a humus layer thicker than 10 cm from 0 to 100%. In the 2009 measurements, densities of stumps and surface obstacles varied from 0 to 575 and from 100 to 865 ha^{-1}, respectively (Fig. 1). In the 2008 measurements,

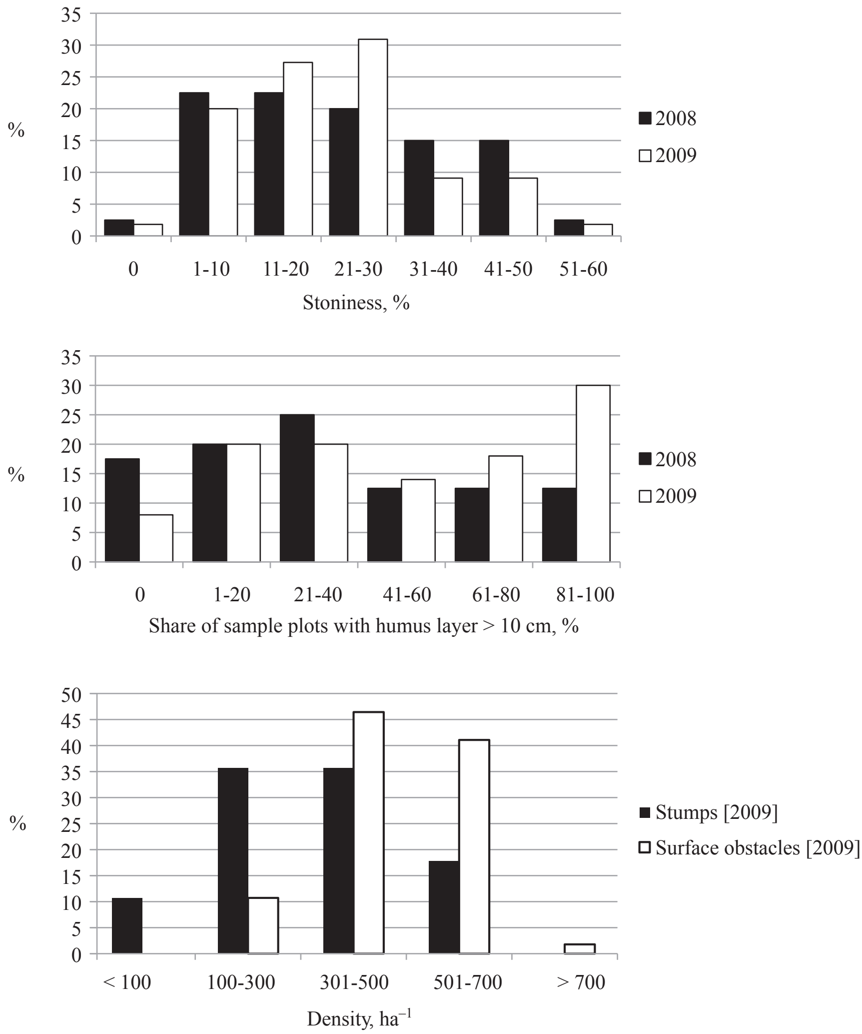

Fig. 1. Distributions of work difficulty factors: stoniness, humus layer thickness, and stump and surface obstacle density (2009) on regeneration sites planted during the follow-up.

the density of surface obstacles, including stumps, ranged from 125 to 733 ha^{-1}.

Quality of planting work was evaluated by measuring the density of planted seedlings. A planting service provider had set the target density of planting work at 1800 seedlings per hectare. Planted seedlings were subjectively classified as planted either in an acceptable spot mound or elsewhere. In addition, an evaluation was made as to whether stones, slash, or stagnant water decreased the quality of the planting point. Also evaluated were planting defects such as insufficient compaction of the soil around the seedling, and inappropriate planting depth, physical damage, and slantness of the seedlings, as well as the number, if any, of empty planting points or planting points with more than one seedling. All field measurements were made by the same researcher.

A linear mixed-effects model was used to examine how various work difficulty factors and operator, as well as an operator's prior experience of machine work and M-Planter use, affect productivity of planting work. Here, productivity y_{ij} is considered to be the sum of general mean productivity y and fixed α_i ($i=1,\ldots,k$) and random β_j ($j=1,\ldots,$n) effects, including a residual error e_{ij} caused by unknown factors (Eq. 1).

$$y_{ij}=y+\alpha_i+\beta_j+e_{ij} \quad (1)$$

In Eq. 1, the work difficulty factors were considered fixed variables, as were operator experience in terms of earlier experience of machine work (0/1) and number of seedlings (× 1000) planted with the M-Planter before each work shift, while the rest of the effects caused by the operators were considered random.

All machine units were assumed to be identical to each other. Hence, none of the variation in productivity was expected to be caused by the machine units. Although many variables were measured, only those with statistical significance are presented in the context of results, except surface obstacles and stumps that are presented in the model regardless of their significance because the inventory system was changed between the two planting seasons and therefore they cannot be presented separately from each other. The estimated mean productivity is expressed to illustrate the mean productivity of the M-Planter in average working conditions.

3 Results

Total working time (T_0) of the machine units varied between 403 and 1845 hours. Work place time (W_0) was, on average, 97.7% of T_0. Gross effective working time (E_{15}) used for planting ranged from 308 to 1613 hours, being 89.2% of W_0 and 87.2% of T_0, on the average. In total, the machine units (A…E) used 3994 work hours (E_{15}) to plant 592 320 seedlings during the follow-up.

On average, 67.6% and 12.5% of T_0 were spent on primary planting work and filling the seedling cassettes, respectively. Thus, the average proportion of E_0 relative to T_0 was 80.1%, with a range of 66.4% (machine unit C) to 88.5% (E). Of the remaining T_0, maintenance and repair of the M-Planter accounted for 6.0%, excavator-based interruptions 2.8%, and interruptions caused by personal needs of the operators 3.3%. The rest of the interruptions (7.8%) were classified as falling under other reasons. These included, for instance, short breaks (less than 15 minutes), relocation time, and interruptions caused by supervision of the planting work (Fig. 2).

Mechanical availability (MA) of the machine units varied from 78.6% (C) to 94.5% (E) and averaged 89.0%. Machine utilisation (MU) was the lowest in the case of unit C (59.8%) and the highest (76.5%) with unit E. The average MU was 70.3%. The total utilisation (TU) of unit E

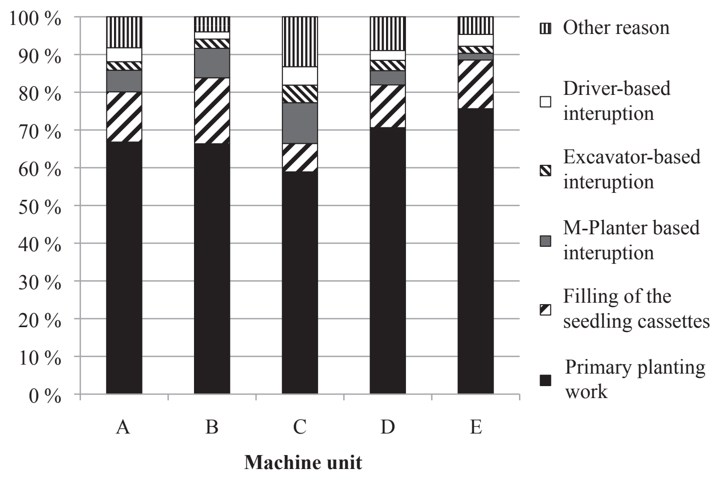

Fig. 2. Total working time (T_0) distributions of the machine units during the follow-up.

Table 2. Total work time (T_0), work place time (W_0), gross effective working time (E_{15}), and effective working time (E_0) of the machine units (A…E) during the follow-up.

Machine unit	T_0 (h)	W_0 (h)	E_{15} (h)	E_0 (h)
A	1845	1803	1613	1462
B	648	637	570	541
C	403	389	308	261
D	1200	1174	1072	983
E	481	472	432	420
Mean	915	895	799	733

Table 3. Mechanical availability (MA), machine utilisation (MU), total utilisation (TU), degree of operation (OP), and degree of repair (REP) of the machine units during follow-up.

Machine unit	MA, %	MU, %	TU, %	OP, %	REP, %
A	90.3	70.0	31.0	24.6	8.6
B	88.8	71.2	38.0	31.7	10.5
C	78.6	59.8	25.5	16.5	17.6
D	92.6	74.1	37.3	30.6	6.5
E	94.5	76.5	23.9	20.8	5.1
Mean	89.0	70.3	31.1	24.8	9.7

was the lowest (23.9%), because it was driven by only one operator. The average TU was 31.1%. Degree of operation (OP) varied between 16.5% (C) and 31.7% (B), being 24.8% on the average. The average degree of repair (REP) was 9.7% (Table 3).

The mean productivities measured for the machine units during the 2008 and 2009 planting seasons were 143 and 169 seedlings/hour (E_0), respectively. In total, the measured average productivity was 158 seedlings/hour (E_0). Productivity of planting work varied considerably between operators. The lowest mean productivity for an operator was only 75 seedlings/hour (E_0), whereas the most productive operator had a figure clearly more than double to that (201 seedlings/hour (E_0)). The four operators (A2, C1, C2, and D4) with no earlier experience in working with either an excavator or a harvester showed significantly lower productivity than did the rest of the operators (Table 4).

A linear mixed-effects model proved that certain work difficulty factors as well as operator experience (in terms of prior experience in machine work and number of seedlings planted with the M-Planter) significantly affect productivity. Increased stoniness ($p<0.01$), higher density of stumps ($p<0.01$), and a thicker humus layer ($p<0.06$) decreased the productivity of the planting work. The productivity of operators with earlier experience of machine work was, on average, 67.2 seedlings/hour (E_0) higher than that of those without such experience. Also the cumulative number of seedlings planted with the M-Planter before the work shift significantly increased productivity (Table 5).

Table 4. Mean productivities (seedlings/hour (E_0)) measured for work shifts during the follow-up.

Machine unit / operator	Productivity, seedlings/hour (E_0)	Min.	Max.	Std. dev.
A (mean)	159	0	324	41
A1	144	63	224	29
A2	99	50	144	24
A3	154	0	217	31
A4	196	128	324	35
B (mean)	181	57	360	41
B1	198	107	320	37
B2	164	57	360	39
C (mean)	92	20	207	34
C1	100	20	207	36
C2	75	32	115	23
D (mean)	156	32	223	29
D1	155	90	206	25
D2	168	127	209	19
D3	166	90	223	37
D4	111	32	154	27
E (mean)	201	140	311	39
E1	201	140	311	39

The estimated mean productivity of the M-Planter in average working conditions[1] was 160.8 seedlings per effective working hour. In the model, variance of the random operator effect

1) Parameters applied in the estimation are as follows: stoniness = 21.0%, humus = 47.9%, surface obstacles + stumps in 2008 = 147.9 ha^{-1}, stumps in 2009 = 204.3 ha^{-1}, surface obstacles in 2009 = 265.0 ha^{-1}, earlier experience of machine work = 0.85, and work experience with the M-Planter = 29 830 seedlings planted.

Table 5. A linear mixed-effects model for predicting the productivity (E_0) of the M-Planter in practice.

Variable	Estimate	Std. error	t	Sig.
Intercept	115.38	11.03	10.46	<0.001
Work difficulty factors				
Stoniness	–0.275	0.100	–2.77	<0.001
Humus	–0.087	0.047	–1.86	0.064
Surface obstacles + stumps [2008]	–0.027	0.013	–2.08	0.038
Stumps [2009]	–0.040	0.009	–4.34	<0.010
Surface obstacles [2009]	0.006	0.010	0.58	0.565
Operator variables				
Earlier experience of machine work [0=no; 1=yes]	67.21	11.74	5.72	<0.001
Planting experience with M-Planter [1000 × seedlings]	0.296	0.070	4.21	<0.001

Table 6. Planting density and the percentage of seedlings expressing some planting defect in regeneration areas planted during the follow-up.

Machine unit	Planting density, seedlings ha^{-1}				Planting defects, %			
	Mean	Min.	Max.	Std. dev.	Mean	Min.	Max.	Std. dev.
A	1845	1300	2300	228	28.4	6.5	59.0	13.6
B	1877	1550	2450	261	34.1	16.9	69.8	14.3
C	1833	1550	2050	197	23.8	6.6	47.3	18.4
D	1896	1550	2150	161	39.3	25.5	61.0	9.7
E	1861	1500	2300	272	30.5	15.0	43.3	10.0

was 333.1 (std. error 151.4), meaning the standard deviation of 18.3 seedlings per effective working hour. Variance of the residual error of the model was 932.2 (std. error 57.75), corresponding to a standard deviation of 30.5 seedlings per effective working hour.

The average proportion of seedlings that expressed some planting defect varied from 23.8% (machine unit C) to 39.3% (D), with the average being 31.2%. The most common planting defects were insufficient compaction of the soil around the seedling pot and too shallow a planting depth. Together these two reasons covered 74.3% of all planting defects. However, only 4.7% of all seedlings planted were not qualified as crop trees because of the planting defects. Planting density was between 1300 and 2450 seedlings per hectare, with the average density being 1865 seedlings per hectare (Table 6).

Almost all seedlings (99.6%) were planted in the mounds, and almost all mounds (96.5%) were placed such that stones, slash, or water did not adversely affect the growing conditions of the seedling. There was an appropriate mineral soil layer on top of three out of four (75.4%) mounds. On the other hand, 13.3% of mounds consisted only of peat or humus.

4 Discussion

This follow-up study aimed to determine the productivity level of M-Planter and factors affecting it in practice. The data is restricted to novice operators because none of the operators had used the device before the study started. It is also noteworthy that nobody had earlier experience on organization of planting work for M-Planter in a practical scale. Therefore, this study gives a description of an implementation of the new planting device in an operation environment of a planting service provider employing several planting entrepreneurs.

The data concerning division of total working time into different time elements was based on the paper forms completed by the operators. Therefore, the reliability of this part of the study relies on the integrity of the operators. Mäkelä (1979) states that there is a risk that operators overestimate their working time that leads to lower productivity figures in this kind of follow-up studies. In any case, to control the reliability, the planting machines were equipped with vibration sensors during the first planting season and the results from the sensors were quite consistent with those obtained from analysis of the paper forms. However, interruptions that included several different tasks were calculatory divided into separate work elements by the authors. Further, the share of the total working time used for relocations might be an underestimate because of difficulties in getting information on relocations carried out by other persons than the operators of the planting machines. The same problem might affect information on maintenance and repair times, which may be greater than the results show.

In the earlier study (Rantala et al. 2009), the mean productivity measured for the M-Planter was 240 seedlings per effective working hour. In this follow-up study, the measured productivities of the M-Planter were 40.4% and 29.6% lower than that figure during the first and second planting season, respectively. Altogether, the measured productivity of the M-Planter in the first two planting seasons was 34.2% lower than that measured in the experimental study setting (Rantala et al. 2009). This is similar observation to an earlier study (Mäkelä 1979) were the corresponding difference in the case of forest haulage by forwarders was as high as 53%. On the other hand, here the average productivity of the ten best work shifts during the follow-up was as high as 299 seedlings per effective working hour. Furthermore, the MA and MU of the M-Planter were quite similar to those of harvesting machines of the early 1990s (Kuitto et al. 1994).

The operators learned, on average, to use the combination of the M-Planter and a base machine more efficiently during the follow-up as their experience in planting work increased. However, a closer look at planting experience and operator variables indicates that there is great variation in learning effect between operators. Instead of this, earlier experience of working with either an excavator or a harvester explains a great amount of the variety in productivity among the operators; the mean productivity of the experienced operators was 64.8% higher than that of the beginners in average working conditions. In addition, the planting units that were used by the least experienced operators spent more time in repair and other activities outside efficient planting work.

The regeneration areas planted during the follow-up represented typical variety in the work difficulty factors affecting mechanised planting work in Nordic countries. Of all work difficulty variables measured, only stoniness, stumps, surface obstacles, and humus layer had a significant effect on the productivity of the M-Planter. Stones and stumps make it more difficult to find enough appropriate places for spot mounds, and the thick humus layer renders it more challenging to get a continuous mineral soil layer on top of the mounds. The significance of these work difficulty factors was well in line with the observations of Rantala et al. (2009), even though the variation in productivity as a consequence of changes in stoniness or in the density of stumps was less. This is a reasonable result: there are many other factors, such as weather conditions and operator motivation, that can be excluded from experimental work studies but that affect real-world work.

Although most of the seedlings were planted correctly in mounds of good quality, a significant proportion of seedlings expressed minor planting defects such as insufficient compaction and too shallow planting depth. In the opinion of the operators, rain is a factor that causes planting defects, as a wet root plug disintegrates easily while the seedling cassette rotates, and after that the seedling does not fall properly through the planting tube. Compaction of the soil after placement of a seedling on the mound did not work well either in soft peat lands or fine soil types where the planting tube was easily blocked up with soil. However, only a very small proportion of the defects were estimated to be fatal. In terms of the density of planted seedlings, the quality of the planting work can be regarded as satisfactory;

the density was 1600 or more seedlings per hectare in 91.6% of the regeneration areas.

This study proved that the mechanisation of tree planting requires much more than construction of a cost-efficient machine. It seems to be extremely important to take care of the proper guidance of operators in use of the device as well as instruction of work organisers in selection of suitable regeneration areas. Furthermore, it seems to be a great advantage if operators are familiar with a base machine before starting to learn usage of a new add-on device such as the M-Planter. Productivity of planting work could also be improved by comparing individual operators' work techniques and finding the most productive ways to use the device. Viewed from the standpoint of seedling logistics, the whole chain from production and packing of seedlings to their delivery to regeneration areas should be developed to match better with the needs of mechanised planting.

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References

Ersson, B.T. 2010. Possible concepts for mechanized tree planting in southern Sweden – an introductory essay on forest technology. SLU, Arbetsrapport 269. 51 p.

Härkönen, M. 2008. M-Planter- ja Bräcke-istutuskoneiden työn laatu. Abstract: Work quality of M-Planter and Bräcke forest planting machines. M.(Sc.) thesis. University of Joensuu, Faculty of Forest Sciences. 59 p. (In Finnish).

Harstela, P. 1991. Work studies in forestry. Silva Carelica 18. 41 p.

— 2006. Kustannustehokas metsänhoito [Cost-efficient silviculture]. Gravita Ky. 128 p. (In Finnish).

Juntunen, M.-L. & Herrala-Ylinen, H. 2008. Silviculture. In: Aarne, M., Herrala-Ylinen, H., Ihalainen, A., Juntunen, M-L., Mustonen, M., Mäki-Simola, E., Peltola, A., Toropainen, M., Torvelainen, J., Uotila, E. & Ylitalo, E. (eds.). Finnish Statistical Yearbook 2008. Finnish Forest Research Institute: 113–160. (In Finnish with English summary).

Kariniemi, A. 2006. Kuljettajakeskeisen hakkuukonetyön malli – työn suorituksen kognitiivinen tarkastelu. Abstract: Operator-specific model for mechanical harvesting – cognitive approach to work performance. Helsingin yliopiston metsävarojen käytön laitoksen julkaisuja 38. 126 p. (In Finnish).

Karppinen, H., Hänninen, H. & Ripatti, P. 2002. Suomalainen metsänomistaja 2000 [Finnish forest-owner 2000]. Finnish Forest Research Institute, Research Papers 852. 83 p. (In Finnish).

Kuitto, P.-J., Keskinen, S., Lindroos, J., Oijala, T., Rajamäki, J., Räsänen, T. & Terävä, J. 1994. Puutavaran koneellinen hakkuu ja metsäkuljetus [Mechanised cutting and forest haulage]. Metsäteho Report 410. 38 p. (In Finnish).

Luoranen, J., Rikala, R., Konttinen, K. & Smolander, H. 2006. Summer planting of Picea abies container-grown seedlings: effects of planting date on survival, height growth and root egress. Forest Ecology and Management 237(1–3): 534–544.

Mäkelä, M. 1979. Tilasto- ja aikatutkimustuotosten vertailua ainespuun korjuussa [Output in harvesting of industrial wood based on statistical data or time studies]. Folia Forestalia 378. 22 p.

Malmberg, C.E. 1990. Mekanisering av skogsodling [Mechanisation of artificial forest regeneration]. Styrelsen för Teknisk Utveckling, Stockholm. STU-info: 783-1990. 196 p. (In Swedish).

Murrell, H. 1982. Ihminen ja kone [Human–machine interaction]. Weilin+Göös, Espoo, Finland. 121 p. (In Finnish).

Nordisk avtale om skoglig arbeidsstudienomenklatur. 1978. Forestry Work Study Nomenclature. Nordiska skogsarbetsstudiernas råd (NSR). 130 p. (In English, Finnish, German, Norwegian and Swedish).

Ovaskainen, H., Uusitalo, J. & Väätäinen, K. 2004. Characteristics and significance of a harvester operators' working technique in thinning. International Journal of Forest Engineering 15(2): 67–77.

Rantala, J., Harstela, P., Saarinen, V.-M. & Tervo, L. 2009. A techno-economic evaluation of Bracke and M-Planter tree planting devices. Silva Fennica 43(4): 659–667.

Rummukainen, A., Tervo, L. & Kautto, K. 2002.

Ilves- ja Bräcke-istutuskoneet – tuottavuus, työnjälki ja kustannukset. Abstract: Ilves and Bräcke forest planting machines – productivity, quality of work and cost. Finnish Forest Research Institute, Research Papers 857. 75 p. (In Finnish).

Saarinen, V.-M. 2006. The effects of slash and stump removal on productivity and quality of forest regeneration operations – preliminary results. Biomass & Bioenergy 30: 349–356.

Saksa, T. & Kankaanhuhta, V. 2007. Metsänuudistamisen laatu ja keskeisimmät kehittämiskohteet Etelä-Suomessa. Metsänuudistamisen laadun hallinta hankkeen loppuraportti [Quality and the most essential development targets of forest regeneration in Southern Finland]. Finnish Forest Research Institute. 90 p. (In Finnish).

Sirén, M. 1998. Hakkuukonetyö, sen korjuujälki ja puustovaurioiden ennustaminen. Abstract: One-grip harvester operation, its silvicultural result and possibilities to predict tree damage. Finnish Forest Research Institute 694. 179 p. (In Finnish).

Strandström, M., Hämäläinen, J. & Pajuoja, H. 2009. Metsänhoidon koneellistaminen – visio ja T&K-ohjelma [Mechanisation of silviculture – vision and R&D programme]. Metsäteho Report 206. 24 p. (In Finnish).

Työvoiman saatavuus metsätaloudessa [Availability of labour in forestry]. 2005. [Online document]. Pöyry Consulting Ltd. 83 p. Available at: http://www.metsafoorumi.fi/dokumentit/tyovoima_raportti.pdf. [Cited 14 June 2010]. (In Finnish).

Uotila, E. 2005. Yksityismetsien hakkuuarvo ja metsänomistajien sijoitustuotto 1983–2003 [Stumpage price value and return on investment in private forests 1983–2003]. Metsätieteen aikakauskirja 1/2005: 57–65. (In Finnish).

Väätäinen, K., Ovaskainen, H., Ranta, P. & Ala-Fossi, A. 2005. Hakkuukoneenkuljettajan hiljaisen tiedon merkitys hakkuutulokseen työpistetasolla [The effect of tacit knowledge on harvesting result at the working point level]. Finnish Forest Research Institute, Research Papers 937. 100 p. (In Finnish).

Vartiamäki, T. Koneellinen metsänistutus vuonna 2003 – kyselytutkimuksen tulokset [Mechanical planting in the year 2003 – Results of a survey research]. Metsäteho Report 154. 14 p. (In Finnish).

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