Estimating the Theoretical Development Potential of a Boom-tip Forest Planting Machine

ARTO RUMMUKAINEN[1], KARI KAUTTO[2] AND LEO TERVO[2]
Finnish Forest Research Institute, [1]Vantaa Research Centre
Pl 18, FIN-01301 Vantaa, [2] Suonenjoki Research Station, FIN-77600 Suonenjoki, Finland

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Forest tree-planting devices, which are installed on the boom-tip of a loader, are at present the most important planting machines in Nordic Countries with stony moraine and peat-land soils. The principle that the driver directs the planting device with a hydraulic boom to each planting spot is an advantage as he can choose each spot individually according to biological preferences. The working speed of the hydraulic boom sets the maximum limits for work productivity. Effective working patterns for the Ilves planting device – agricultural tractor –combination were constructed according to results of actual productivity models. The productivities of these patterns were simulated by extrapolating results of field studies and arranged experiments of loader speeds. The maximal improvement of productivity with advanced working patterns could be increased by a third. Using advanced working patterns prerequisite more covering soil preparation than today's average. The development of the planting device's plant feeder offers an extra 20 percent productivity improvement option. A longer boom theoretically offers better productivity only when combined with a two-headed planter device.

Key words: forest regeneration, planting machines, work productivity

Introduction

Nordic moraine and peat-land soils have made difficult the use of simple ploughing planting machines common elsewhere in Europe and America. After many unsuccessful attempts to build a fully automated planter (Kaila 1984, Hallonborg *et. al.* 1995), a new type of planting machine appeared on the market ten years ago. This is based on the manual planting tube. A cone-headed tube is pressed into the soil, the cone is opened and the seedling is dropped into the hole through the tube. The tube is lifted up and the seedling is pressed into the hole with pads. Seedlings are stored on a table above the tube where they are transferred to the tube by a moving chain or a revolving cassette.

The planting device is mounted on the tip of an hydraulic boom. The driver chooses the planting spot and directs the planting device onto it with the hydraulic boom. This mode of operation is the advantage of the device, as the driver chooses each planting spot individually. On the other hand, the controlling speed of the hydraulic boom also sets the maximum work speed.

The Bräcke-Planter produces a planting mound with a turning blade (von Hofsten 1993). The Eco-Planter mills and accumulates humus and top mineral soil for a planting spot with a rotating chisel wheel (Åhlund 1995). The Ilves-device is a plain planter, which requires preliminary soil preparation using another machine (Arnkil & Hämäläinen 1995). These three machines are now the most common planting machines in Finland, Norway and Sweden. The planting speed of these machines does not appear to exceed manual planting and mechanical soil preparation. The higher capital costs of planting machines increase the total planting cost to the level of manual planting (Kautto 1997). The organisation of mechanical planting as a turn-key reforestation entrepreneurship may yield some savings compared to the common system arranged by Forest Management Associations. The Ilves planting device mounted on a heavy agricultural tractor has shown to be an economical choice in Finnish conditions compared to other Bräcke and Ilves combinations (Kautto 1997).

The aim of this study was to find the development potential of the Ilves planting device - agricultural tractor –combination. An "ideal" working pattern was constructed by simulating the productivity and behaviour of the device beyond the validity field measured on actual site.

Materials and methods

The Ilves planting device was mounted on the tip of an eight-meter-long hydraulic knuckle boom timber loader. The loader was built on an extra axle chassis on the back of a 75 kW agricultural tractor. The closest working distance was two metres and furthest eight metres, measured from the vertical pylon of the loader. The working sector was 250 degrees.

The machine was studied on four sites over a period of two years. However only the last site was chosen as the base for development because the productivity of the same driver increased by over 20% between the first and the last sites. The driver was also the inventor of this planting device. The site was a well representative fine moraine clear-cut area located at Tuohikotti, near Kouvola, in southern Finland. Fairly even surface with stumps and slash was mounded by a tractor-excavator in the spring of the planting year. 1300 two-growing-season-old pine container seedlings were planted. Working conditions and time consumption of the site can be seen on Tab. 1 in column 2.

The effective time consumption of planting can be calculated with the formula:

$$E_0 = E_s + E_p + E_m + E_f \quad (1)$$

where: E_0 = total effective time consumption of planting, cmin/seedling, E_s = time consumption of directing planting device to planting spot, cmin/seedling, E_p = time consumption of planting the seedling, cmin/seedling, E_m = time consumption of moving the tractor to the next working point, cmin/seedling, E_f = time consumption of filling the plant table, cmin/seedling

To find the maximal productivity, an "ideal" planting pattern was determined by drawing different patterns on paper (Fig. 1) and simulating their time consumption using the equations in Table 2 and equation 2. The criterion for drawing was to plant as many seedlings as possible in one working point. Target planting density was 2,000 seedlings per hectare, with minimum 1.5 metres and maximum 2.5 metres distance between adjacent seedlings. The loader's revolving movements were used as much as possible to gain speed. Seedlings planted in sequential working points should cover the whole width of one working zone.

Results

At the Tuohikotti site, the time consumption of one effective planting sequence was 24.2 cent minutes per seedling (coefficient of variation 217 %, number

Table 1. Work productivity of machine planting by various working patterns. Directing times of the loader are calculated using the equations in table 2 and moving times of the tractor using equation 2

Measurement criteria									
Number of planting heads	1	1	1	1	2	1	1	1	2
Reach of loader, m	8	8	8	11	11	8	8	11	11
Min. planting distance from machine, m	2	2	2	3	3	2	2	3	3
Calculation basis for table filling time	Measured	Measured	Measured	Measured	Measured	One tenth of measured	One tenth of measured	One tenth of measured	One tenth of measured
Calculation basis for other work phases	Measured	Estimate	Estimate	Estimate	Estimate	Measured / estimate	Estimate	Estimate	Estimate
Description of working pattern (see also fig. 4)									
Working pattern	Miscellaneous	Full outer arc	Full inner arcs	Full outer arc	Full outer arc	Miscellaneous	Full inner arcs	Full outer arc	Full outer arc
Row space, m	Variable	2.5	2.5	2.0	2.5	Variable	2.5	2.0	2.5
Number of seedlings: -outer row		12	9	14	18		12	14	18
-outer centre row		-	-	11	14		-	11	14
-inner centre row		7	9	6	10		7	6	10
-inner row		3	4	3	4		3	3	4
Seedlings per point	8.7	22	22	34	46	8.7	22	34	46
Distance between points, m	6.9	6.3	7.0	9.0	10.5	6.9	6.3	9.0	10.5
Density, seedlings/ha	1,725	1,969	1,969	1,956	1,957	1,725	1,969	1,956	1,957
Time consumption, cmin/seedling									
Moving the loader and planting act	15.1	12.6	11.4	12.7	9.3	15.1	11.4	12.7	9.3
Moving between working points	4.6	1.7	1.8	1.3	1.0	4.6	1.8	1.3	1.0
Filling the plant table	4.5	4.5	4.5	4.5	4.5	0.45	0.45	0.45	0.45
Total, cmin/seedling	**24.2**	**18.8**	**17.7**	**18.5**	**14.8**	**20.2**	**13.6**	**14.4**	**10.7**
Productivity values									
Productivity of effective working time, seedlings/hour	**248**	**320**	**340**	**325**	**407**	**298**	**441**	**416**	**561**
Comparison to meas. productivity, %	100	130	137	131	164	120	178	168	226
Productivity of effective working time, ha/hour	**0.14**	**0.16**	**0.17**	**0.17**	**0.21**	**0.17**	**0.22**	**0.21**	**0.29**

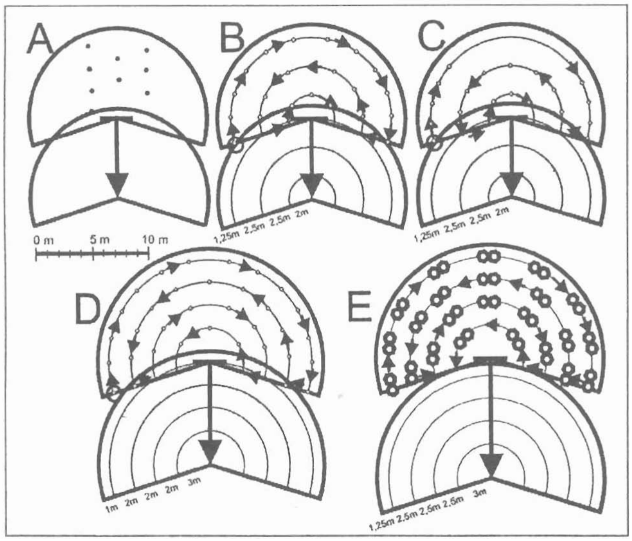

Figure 1. Planting patterns of the Ilves-agricultural tractor combination machine. A is the realized pattern used in the Tuohikotti site. B and C are "ideal" patterns, where as many seedlings as possible are planted in one working point. B is called "full outer arc and C "full inner arcs". D is an "ideal" pattern, where the reach of the loader is 11 metres. E is an "ideal" pattern, where the reach of the loader is 11 metres and where the planting device has two simultaneously operating planting tubes.

of observations: 1,300), which corresponds to 248 plants per effective work hour. Directing the planting device from one planting spot to the next is the most critical and time-consuming phase in the work (Tab. 1). The driver chooses the planting spots and makes decision when to move to an other working point. At Tuohikotti, he planted on average 9.8 seedlings per working point (coefficient of variation 36 %, number of observations 151). The average moving distance between working points was 6.9 metres (coefficient of variation 18 %). The seedlings were evenly planted, but planting density (1,725 seedlings per ha, coefficient of variation 20 %, number of observations: 8) fell below specifications (2,000 seedlings per ha). The main reason for this was shortage of mounds because of insufficient soil preparation. The plant table needed to be filled after 102 seedlings, which meant filling on average every 11 working points.

The properties of the hydraulic loader determine the maximum speed of directing the planting device from one planted spot to the next. Naturally the quality and location of soil preparation also determines the possible spots. The directing speeds of the loader in the radial direction and in the direction of the revolving arc were measured in an arranged test on an even surface. Time consumption models of directing the planting device in different directions are shown in Table 2 and in Figure 2. The boom movement in the

Table 2. Time consumption models for directing the loader and planting device in the direction of boom-radius and in the direction of the loader's turning radius arc.

	Moving in the direction of radius	Moving in the direction of the turning radius arc
Type of model	y=1/(a+bx)	y=ax^b
y	Time consumption, cmin/m	Time consumption, cmin/m
x	Length of the movement, m	Length of the movement, m
Number of observations	30	130
R^2 (Square of correlation coefficient), %	90.94	91.32
p-value	0.0000	0.0000
Confidence level	***	***
Value of constant a	0.115359	6.3110
Value of coefficient b	0.0466	-0.7118
Average, cmin/m	4.10	2.42
Variation coefficient, %	30.0	46.3

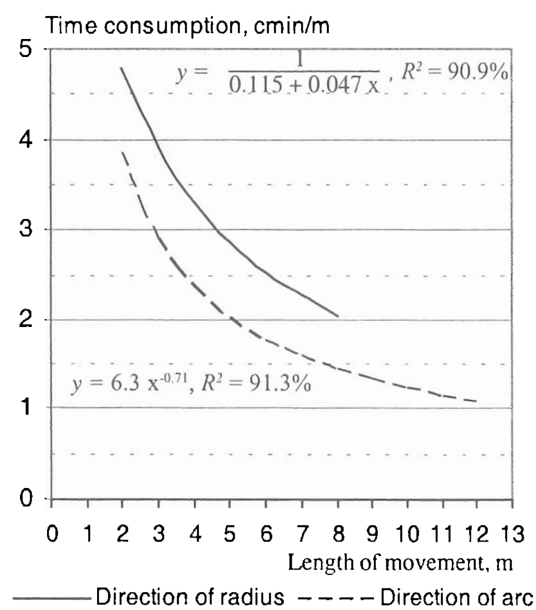

Figure 2. The time consumption models on moving the loader in the directions of boom's radius and the loader's turning radius arc. Time consumption of 16 different movements was measured with ten repetitions on a hard even surface according to a previously made sketch

direction of the turning radius is about 25% faster than the movement in the direction of the boom. Thus, using radial movements of the loader as much as possible could intensify the speed of work.

The time consumption of moving the tractor from one working point to another depends on the moving distance and the speed of tractor. According to the Tuohikotti data, the equation of time consumption is the following:

$E_m = 25.99 + 1.91 * D_w$ (2)

where E_m = time consumption of moving the tractor to next working point, cmin/seedling, D_w = distance between working points, m.

This linear equation 2 was used as an example even it's square of correlation coefficient was only 3%. The p-value of the model was 0.0306 according to which the model is significant at confidence level of 99.9% (**). Number of observations was 151.

As the planting act itself is automated, its development requires radical constructional changes. In the Tuohikotti data, the average time consumption of the planting act was 3.3 cmin/seedling. The time consumption of filling the plant table depends on the capacity of table and the feeding method. In the Tuohikotti data, the average time consumption of feeding the plant table was 4.5 cmin/seedling.

In addition to determining the "ideal" working pattern, the effects of increasing the reach of the boom, of using two simultaneously working plant tubes and of filling the plant table faster were simulated. The typical reach of a harvester loader is 11 metres. Working on the outer limits of boom's reach is less accurate, or achieving the same accuracy increases the time consumption. This has been taken into consideration by increasing the planting time for longer boom (Table 1 columns 5, 6, 9 and 10). Using two adjacent plant tubes increases the planting time, but at the same time the number of boom stops on planting spots decreases (Table 1 columns 6 and 10). In difficult terrain conditions, a short distance between two planting heads may be an advantage. The lower limit could be 0.5 metre, which enables both trees to produce pulpwood. Good wood quality is one benefit for pine, but it may produce the opposite for spruce and birch, which however are the most commonly planted tree species. Till the effects of planting on short interval on the quality of wood are cleared up, it would be useful, if the distance between planting heads could be adjustable.

The filling of the plant table has already been improved in practice by one entrepreneur, by enlarging the table area to carry 150 seedlings instead of 102. Two levels of faster feeding were taken in the calculations: decreasing the feeding time to a half or to a

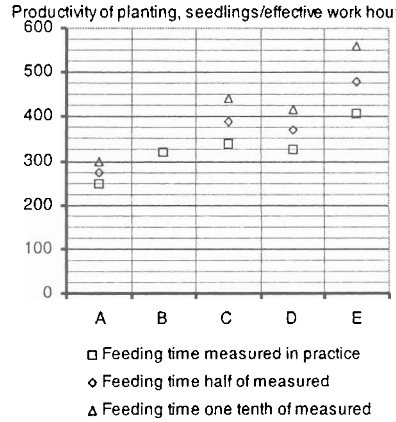

Figure 3. The productivity of effective work time with different planting patterns. The patterns are marked with capital letters, whose explanations are given in Figure 1

tenth of the original. Simple enlargements may achieve the first alternative, but the second alternative is possible only with sophisticated automation. The latter increases investment and service costs.

The use of an "ideal" working pattern could according to simulations increase the productivity of effective working time at the most by one third (Table 1 and Fig. 3). The use of a longer boom (11 metres) is estimated to decrease the accuracy of work so much that the productivity appears to be lower than that of an eight-metre boom. If it is possible to build a planting device with two simultaneously working plant tubes and an 11-metre- long boom it may at its best double the productivity. The use of an automated plant feeder, which decreases the filling time to one tenth of the original, could increase the productivity by 20%. The advantage is even larger when an "ideal" working pattern is used. Even the decreasing of the plant table's filling time to half increases the productivity with one tenth.

Discussion and conclusions

The actual time studies for this report were made on fine moraine soil clear cutting area, which would be the most common work environment for mechanical planters in Finland. On fairly similar conditions Arnkil & Hämäläinen (1995) measured productivity of 190 and Kautto (1997) 184 seedlings per effective work hour for Ilves planting device – forwarder – combination. The position of loader and pylons restrict the working space and thus the productivity in forwarder based planting machine. According to Arnkil & Hämäläinen (1995) increased stoniness will decrease the productivity and weaken the quality of work.

Systematic use of the fastest movements of the Ilves planting device – agricultural tractor – combination's hydraulic loader may increase the planting productivity with up to 35%. This can be achieved with no extra development of planting device. This "ideal" working pattern prerequisites that the soil preparation produces sufficiently planting spots. Continuous methods, like scarification, produces more alternative planting spots than, for example, mounding, but the latter is often more preferable because of better growing conditions and less effects on nature. The higher cost of more intensive soil preparation has to be taken into account when planning to use the "ideal" working patterns. Stony soils also decrease the usefulness of "ideal" working patterns, as enough good planting spots cannot be found on the radial course of the loader.

Rebuilding the planting device cost extra money, but it enables increased productivities. According to simulations building an automated plant feeder increases the productivity with maximum 20% compared to original situation. Combined with "ideal" working patterns, the productivity increment of automated feeding is up to 75%. Using an 11 meter long boom instead of 8 meter increases the productivity by up to 30%. This result is however more uncertain, as no measurement of the speeds of a longer loader was made in practice. The effects of weaker visibility and less accurate operation at the limit of reach of the boom could be only estimated in these calculations.

Even more uncertain are the results of productivity increment with more than hundred per cent, by using the device with automatic feeding and two simultaneously working planting tubes on top of long boom. There is also the questions of soil preparation and how much the productivity increment demands extra cost as price of structural changes and higher maintenance of planting device. The productivity of two headed Eco-planter with milling cutter soil preparation reach up to 500 seedlings per effective work hour (Ahlund 1995).

These simulations emphasizes the importance of more systematic working patterns, using as much as possible the loader's higher radial speed and planting more dense than today. Adequate soil preparation requirements and criteria and driver training makes these advantages possible. The structural changes of planting device offer also productivity improvements, but they should be analysed bearing in mind the extra cost they require. The quality of soil preparation is important, but even that can not hold up the productivities in very stony conditions.

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ОЦЕНКА ПОТЕНЦИАЛА ТЕОРЕТИЧЕСКОГО УСОВЕРШЕНСТВОВАНИЯ ЛЕСОПОСАДОЧНОЙ МАШИНЫ ТИПА КРАНОВОЙ СТРЕЛЫ

А. Риммукайнен, К. Каутто, Л. Терво

Резюме

Лесопосадочные орудия, монтируемые на устройствах типа крановых стрел, в настоящее время являются основными лесопосадочными машинами в северных странах. Преимуществом этого типа машин является принцип их управления, где оператор с помощью гидравлической стрелы направляет лесопосадочное орудие в желаемое посадочное место, имея в виду биологические преимущества данного места. Рабочая скорость гидравлической стрелы определяет пределы максимальной продкутивности работы.

Эфективная рабочая модель для сочетания Илвес лесопосадочное орудие – сельскохозяйственный трактор, была создана по фактическим результатам продуктивности данной модели. Продуктивность этих сочетаний была имитированна с помощью экстраполяции результатов полевых исследований и упорядочиванием экспериментов скорости устройста. Максимальная продуктивность данного сочетания может быть увеличена на треть с применением прогресивных рабочих сочетаний. Применение прогресивных рабочих комбинаций требует более интенсивной подготовки почвы. Усовесршенствование механизма подачи саженцев на лесопосадочном орудии позволяет дополнительно на 20 % увеличить производительность. Применение более длинной стрелы теоретически позволяет повысить производительность, но только с применением лесопосадочного орудия с двумя головками.

Ключевые слова: лесовосстановление, лесопосадочные машины, продуктивность работы.