Time Consumption, Work Quality and Cost of Mechanised Precommercial Thinning

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Abstract

Costs of precommercial thinning (PCT) have increased quite steadily in Finland for a long time. Therefore effective PCT methods must be developed. Although there is still development potential in manual PCT, mechanisation has been considered as a solution to decrease costs of PCT.

Machines haven't become common in PCT yet. The most important reason for this is low productivity resulting in high operation costs. If mechanised PCT becomes real business for entrepreneurs and machine manufacturers, technical problems are most likely to be solved.

In this study two prototypes of boom-mounted cleaning devices were studied. Prototypes were manufactured by private entrepreneurs. Productivity, work quality and operation costs of these cleaning devices were estimated. Average time consumption of both machines was around 7.5 effective hours/ha in a pine-dominated stand with total density of around 7 000 stems/ha and average cutting diameter of stems around 5 cm. Costs of mechanised PCT in this study were over two times higher than those of manual work.

Key words: mechanized precommercial thinning, cleaning, cleaning device, time study

Introduction

Aim of the precommercial thinning (PCT) is to control the density, tree species admixture and quality of trees in young stand. (Hyvän metsänhoidon... 2001). PCT is done to guarantee growth of trees of good economical value. In PCT naturally emerged secondary stems and excessive main stems are being cut. According to silvicultural recommendations PCT is done at 4–5 m dominant height in spruce stands and 5–8 m dominant height in pine stands. Recommended number of remaining trees after PCT is 1 800–2 000 trees/hectare (Hyvän metsänhoidon... 2001).

The need for PCT in Finland is estimated in a National Forest Inventory. According to the latest inventory results around 2.4 million hectares of young stands need treatment within 10 years. The same inventory data reveal that in about 470 000 hectares PCT is already late. This means that on average the annual area of PCT should be over 200 000 hectares to maintain the current silvicultural level of young stands. (Tomppo *et al.* 1998, 1999a, 1999b, 1999c, 1999d, 2000, 2001a, 2001b, 2003, Korhonen *et al.* 2000a, 2000b, 2000c and 2001).

PCT was carried out in 136 000 hectares in Finland during year 2002 (Metsien hoito... 2004). This number includes tending young stands of 0-8 cm average diameter ($d_{1.3}$) in private, forest industry and state owned forests. The area of PCT was 98 000 hectares in 1997 so there has been almost 40 % increase in five years. State subsidies play a big role in tending young stands in Finland and the future development of PCT areas is most likely to be dependant on those subsidies. State subsidy for PCT varies from 84.5 to 177.1 €/ha depending on location of stand and method of implementation (Tuet taulukkona... 2004).

In Finland practically all PCT work is carried out motor-manually using brush saws. In private owned forests self-employed forest owners have carried out about half of the PCT work (e.g. Immonen 2003). The rest is being carried out by forest workers. Average cost of PCT was 231 €/ha in 2001 (Metsien hoito...2004). Costs have increased steadily and since 1985 the real costs of PCT have more than doubled. At the same time mechanisation has decreased cost of timber harvesting by 30 % (Figure 1). Costs of PCT now form a greater share of total costs of forest growing's than before.

Mechanization has been considered as a solution to decrease costs. Small thinning harvesters equipped with cleaning devices were tested in the 1980's and 1990's in Finland and in Sweden (e.g. Freij 1991, Kaivola 1995). Later in the 1990's and 2000's more spe-

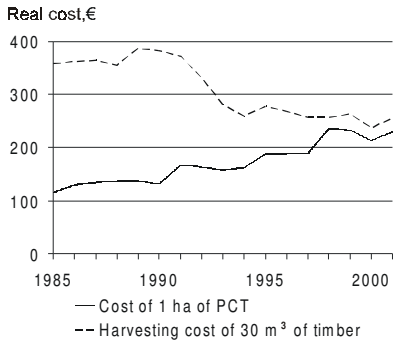

Figure 1. Cost development of harvesting and precommercial thinning in 1985–2001 (Metsien hoito... 2004)

cialized machines have been developed (e.g. Vimek 404... 2004, Reikä-perkaaja... 2004). Earlier machines straddled the remaining trees and thus were capable of working without damaging the remaining trees only in quite young stands. Swedish Vimek is an example of a small machine that can drive between the remaining trees. Also corridor-type of PCT is being researched in Sweden (Bergkvist and Glöde 2004). The most important reason why PCT is still carried out mostly motor-manually is low productivity of machines resulting in high operating costs.

The aim of this study was to find out if increased costs of manual work and technical development of thinning harvesters have improved the cost-competitiveness of totally mechanised and selective PCT method. Focus was on stands with high density and high diameter of trees because cost of motor-manual work is high in those conditions.

Materials and methods

Cleaning devices, base machines and working method

Two thinning harvesters, Farmi Trac 5000 T and FMG 0470 were equipped with cleaning devices mounted on boom tip. Farmi Trac 5000 T was a tracked machine with the weight of 10 tons and width of 2.2 m. It was equipped with a knuckle-boom crane of 8.5 m maximum reach (Figure 2). FMG 0470 was a four-wheeled machine with the weight of 6 tons and width of 2.3 m. It was equipped with a knuckle-boom crane of 7.0 m maximum reach (Figure 3).

Both cleaning devices were prototypes and manufactured by private entrepreneurs. Cleaning device in Farmi Trac machine unit was manufactured by Risto Kvist and it was made of two round discs and two flail-type blades between the discs. Device had a cutting width of 130 cm. Cleaning device in FMG 0470 was manufactured by Kari Järvenpää and it was a circular saw with cutting diameter of 60 cm. Both cleaning devices had a hydraulic motor as a power source.

Both machine units' working method was totally mechanized and selective PCT. Machine operators chose the trees to be felled. Clearing the strip roads was made simultaneously with thinning the area between the strips. From single strip road the machines could clean an area of 14–17 m width. Planned amount of the remaining trees was 1 800 - 2 000 stems/ha according to silvicultural recommendations.

Figure 2. Farmi Trac 5000 T and cleaning device

Figure 3. FMG 0470 and cleaning device

Stand characteristics

All time studies were carried out in pine-dominated stands of *Vaccinium* site class (Cajander 1949) and they were untreated before PCT (Table 1). Farmi Trac 5000 T machine unit was studied in two di-

rectly seeded stands with age of 22 and 37 years in Rovaniemi, Finland in August 2002 and August 2003. Although stand 2 had pine as a dominant species there were a lot of smaller birch stems in the stand. FMG 0470 machine unit was studied in planted stand aged 18 years in Mouhijärvi, Finland in May 2003. Studies were carried out in total of 25 rectangular sample plots. The area of plots varied from 300 to 700 m^2 depending on strip road spacing. Stand characteristics within time study plots were estimated from 6-8 circular 25 m^2 sample plots (Figure 4).

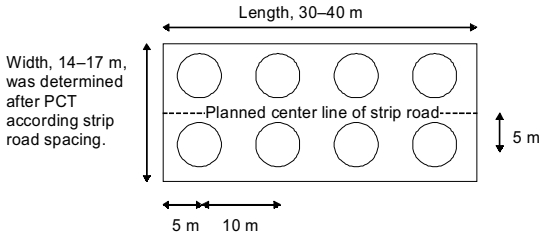

Figure 4. Rectangular time study plot and circular plots for estimating stand characteristics

Table 1. Stand characteristics before precommercial thinning, x is average and s is standard deviation

Machine & Stand	Number of sample plots	Density, stems/ha		Proportion of pine stems, %		Dominant height, m		Diameter ($d_{1.3}$), cm	
		x	s	x	s	x	s	x	s
Farmi Trac 5000 T with "disc-flail" cleaning device									
Stand 1	15	7 300	1 550	97	2.9	5.9	0.5	4.9	1.1
Stand 2	5	18 250	9 950	15	9.0	5.5	0.7	2.8	0.5
FMG 0470 with "circular saw" cleaning device									
Stand 3	5	7 050	1 600	85	6.5	6.7	0.2	6.5	1.0

Before PCT center line of strip road was marked. Number of stems and dominant height was recorded by tree species from each circular sample plot. Average diameter of trees was estimated by measuring the diameter of thinnest, thickest and medium tree.

Time consumption

In time study both effective time and delay time were recorded with help of Husky Hunter 16 handheld computer and Siwork 3 data collecting program. Effective time consumption was divided into moving and cleaning time. Moving time was recorded when machine moved from working point to another and cleaning was the rest of time.

Effective time consumption (E_0) of PCT was changed to operating time consumption (E_{15}) by multiplying effective time by coefficient of 1.393 (Rieppo 2001). This was done partly because delays in rather short time studies tend to differ from actual work and partly because of working conditions tend to vary more in actual work than in time study.

Removal and work quality

After PCT each sample plot was re-measured. Number of remaining trees and average height was recorded by tree species. Removal was considered as difference in number of stems between measurements before and after PCT. Average cutting diameter in each circular sample plot was estimated by measuring cutting diameter of three stumps that were closest to the centre of sample plot.

Three damages were measured from rectangular zone, the width of which was 10 % of time study plot's length. Three damages were divided into stem and root damages. The number of damaged trees was counted as well as size and cause of the damage. The number of stems to be removed for silvicultural reasons but left uncut was recorded. These stems were not potential crop trees and typically they were over 2 metres lower than the main stems, different species than the main stems and grew very close to the main stems resulting in difficulties in cutting them. The width of strip road was estimated as sum of distances of a nearest tree to the centre line of strip road on both sides of strip road.

Cost calculations

Operating costs of machine units were set at 50 €/E_{15} per hour. This is about 0-5 €/E_{15} lower than cost that is being commonly used in cost calculations of medium-sized forwarders (e.g. Sirén and Aaltio 2003, Laitila *et al*. 2004 and. Rummukainen *et al.* (2002) presented an operating cost of 48.44 €/E_{15} per hour for mechanised planting with forwarder-based machine unit. For small-sized harvesters operating costs of 50–55 €/E_{15} /h has been presented (Sirén and Aaltio 2003).

Costs of mechanised PCT were compared to the costs of motor-manual PCT. Cost of 156 €/day was used as a daily cost of forest worker to an employer (Laitila *et al*. 2004). This includes wage and all side costs. Time consumption of motor-manual PCT was estimated by piece wage tables in collective labour agreement of forest workers (Metsäalan palkkaus 2000).

Results

Time consumption

Effective time consumption of mechanized PCT in time study stands is presented in Table 2.

Removal of trees affected relatively much to the time consumption (Figure 5). However, cutting diameter of stems had no significant effect on time con-

Table 2. Removal, average cutting diameter and effective time consumption of mechanized PCT in time study stands

Machine & Stand	Removal, stems/ha	Average cutting diameter of stems, cm	Effective time consumption, E_0 hours
Farmi Trac 5000 T with "disc-flail" cleaning device			
Stand 1	5 600	4.9	7.1
Stand 2	17 100	5.6	8.8
FMG 0470 with "circular saw" cleaning device			
Stand 3	5 500	2.9	7.5

sumption. Correlation coefficient between removal of trees and cutting diameter was rather high in each stand varying from -0.57 to -0.92. Thus the regression models presented in Figure 4 only include removal as an independent variable. Average removal and average time consumption of FMG 0470 machine unit in stand 3 did not differ from those of Farmi Trac 5000 T machine unit in stand 1 (p=0.87 & p=0.37). Thus only two regression models were formulated.

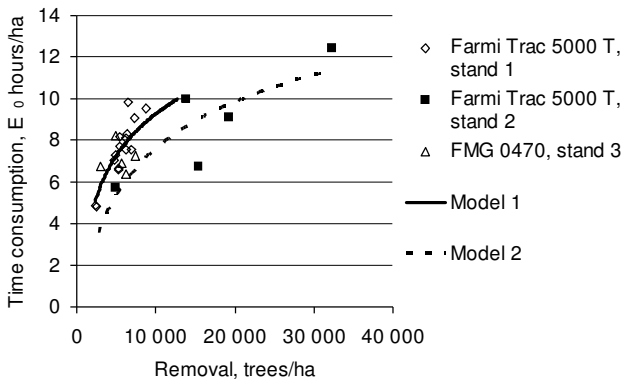

Figure 5. Effective time consumption of mechanized PCT in time-study plots and nonlinear regression models. Model 1 for Farmi Trac 5000 T and FMG 0470 machine units in pine stands: E_0 *hours/ha = 2.9162 * Ln(*N_r*) - 17.581,* (R^2=0.598). Model 2 for Farmi Trac 5000 T unit in mixed stand of pine and birch: E_0 *hours/ha = 3.2201 * Ln(*N_r*) - 22.061,* (R^2=0.7034). N_r is removal, stems/ha

Moving time was 7.4 % of total effective working time for Farmi Trac 5000 T machine unit and 18.3 % for FMG 0470 machine unit. Cleaning time was 92.6 % and 81.7 % respectively. Although delay times were also recorded they were very low - 0.7 % of total operating time for Farmi Trac 5000 *T* machine unit and 0.0 % for FMG 0470 machine unit.

Silvicultural results

The number of remaining crop trees after mechanized PCT was somewhat lower than aim (Table 3). The number of trees that should have been cut and that were left uncut was relatively low.

Table 3. Number of stems and average height of remaining trees and trees that should have been cut silviculturally but that were left uncut

Machine unit	Stand	Remaining crop trees		Remaining secondary stems	
		Density, 1/ha	Average height, m	Density, 1/ha	Average height, m
Farmi Trac 5000 T	1	1800	5.1	160	2.8
Farmi Trac 5000 T	2	1200	5.8	150	4.8
FMG 0470	3	1600	5.6	300	3.2

The number of tree damage varied quite a lot (Table 4). All of the damage were stem damage and almost all were caused by cleaning device touching the remaining trees. Only very few damage was caused by crane or base machine. There were only insignificant damaged trees in the data and results of tree damage are approximate.

Table 4. Number of tree damage, average height of damaged trees and average size of damage

Machine unit	Stand	Tree damages		
		Number of stems, 1l/ha	Average height of damaged trees, m	Damage size, cm^2
Farmi Trac 5000 T	1	140	5.5	14.8
Farmi Trac 5000 T	2	190	5.7	9.6
FMG 0470	3	24	5.5	50

The width of strip roads was a little greater with Farmi Trac machine unit than with FMG (Table 5). Strip road spacing was quite low and strip roads covered quite big proportion of stands area. No ground depression existed in time study stands.

Table 5. Width of strip roads and strip road spacing

Machine unit	Stand	Width of strip roads, m	Strip road spacing, m	Area covered by strip roads, %
Farmi Trac 5000 T	1	3.1	15.0	21
Farmi Trac 5000 T	2	3.5	13.3	26
FMG 0470	3	2.8	13.2	21

Costs of mechanized PCT and comparison to motor-manual work

Costs of mechanized and motor-manual PCT in time study stands are presented in Table 6.

Table 6. Cost of mechanised and motor-manual PCT and relative difference of costs in time study stands

Machine & Stand	Cost of mechanised PCT, €/ha	Cost of motor-manual PCT, €/ha	Mechanised PCT cost more than motor-manual PCT, %
Farmi Trac 5000 T with "disc-flail" cleaning device			
Stand 1	526	215	145
Stand 2	612	239	156
FMG 0470 with "circular saw" cleaning device			
Stand 3	495	219	126

Costs of mechanized PCT were greater than cost motor-manual work in every time study plot. Removal had no effect on cost difference between the methods (Figure 6).

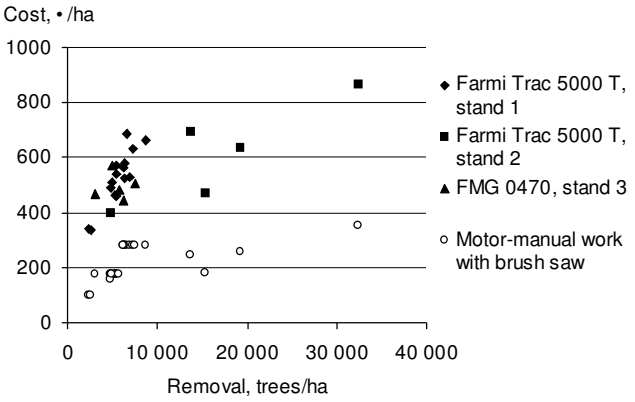

Figure 6. Costs of mechanized and motor-manual PCT in time-study plots

Discussion and conclusions

Studied machines were prototypes and thus the results of this study must be looked at carefully. Technical changes may change the productivity levels greatly. It is noteworthy that in spite of technology used, cleaning devices are basically very effective in cutting the trees. The problem is that precise control of cleaning device and tree selection is difficult. This problem should be given more attention in machine development.

Data of the study were small consisting 20 sample plots and total treated area of about 1.1 ha. Studied stands were however stands where PCT is typically done in Finland. Additional information gained from larger data would probably have been quite insignificant.

In cost calculations coefficient of 1.393 was used for changing effective time consumption to operating time consumption. The coefficient is determined for mechanised cutting in thinnings. However, the structure of cleaning device is simpler than the structure of harvester head thus resulting in somewhat lower amount of delays. Since follow-up studies of mechanised PCT have not been done lately above-mentioned coefficient was used in this study although a coefficient of 1.2–1.3 could be more usable.

Time consumption of mechanised method should be decreased almost with 60 % to make the work cost competitive with motor-manual work. This may be possible with serious method and machine development. However, with current technology it is really difficult to decrease costs of PCT with mechanisation. Concentrating on method development can give better results and even quite rapidly. Costs can be reduced by for example optimizing timing of PCT (Kiljunen *et al*. 2003). PCT should also be seen as a part of regeneration process. Scarification and regeneration method affect greatly the costs of PCT.

Hypothesis of this study was that mechanized PCT is cost competitive in stands with high cutting diameter and density. However, moving the cleaning device between the remaining trees becomes difficult in stands with the height over 3–4 m. Also visibility from machine's cabin can be poor when trees are big. In lower stands the crane can be moved above the remaining trees and if the height of main stems is less than 1.5 m strip roads are not necessary. This may be a reason why earlier studies particularly in Sweden (e.g. Freij 1991) gave lower time consumption of mechanised PCT (even only 3–6 E_0 hours/ha). Choosing lower stands for mechanized PCT could give better results than in this study.

Motor-manual work is still very cost-competitive and its work quality is good. Therefore everything possible should be done to maintain the current self-employment level of forest owners and also to give full-time job opportunities to forest workers. However also mechanising is desirable but precommercial thinning may be one of the most challenging works for forest machines and therefore innovative technological and methodological solutions must be developed.

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ЗАТРАТЫ ВРЕМЕНИ, КАЧЕСТВО РАБОТ И РАСХОДЫ ПО УХОДУ ЗА МОЛОДНЯКОМ

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Резюме

Развитие эффективных технологий ухода за молодняком вызвано постоянным ростом расходов на этот вид работ в Финляндии. Хотя возможности для развития технологий с применением бензопил себя полностью не исчерпали, считается, что именно внедрение машин в процесс ухода за молодняком позволит минимизировать расходы.

Технология ухода за молодняком с применением машин ещё не получила распространения. Главной причиной этому является низкая производительность машин и, как следствие, высокие эксплуатационные затраты. Если механизация ухода за молодняком вызовет деятельный интерес у машиностроителей и в сфере обслуживания, необходимо будет решить все технические проблемы.

В этом исследовании рассматриваются два прототипа устройства для прочистки. Они являются изобретением частных предпринимателей. В исследовании даны оценки производительности, качества работ и стоимости эксплуатации этих машин. Затраты времени для обоих машин составляют в среднем 7,5 эффективных рабочих часов/га для сосняков, где густота древостоя в целом составляет 7 000 стволов/га и средний диаметр спила ствола около 5 см. Затраты на механизированный уход за молодняком, по результатам данного исследования, более чем в два раза выше затрат при мануальном способе.

Ключевые слова: механизированный уход за молодняком, прочистка, устройство для расчистки, хронометраж