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REDOGÖRELSE: Utförlig redovisning av genomfört forskningsarbete.
HANDLEDNINGAR: Anvisningar för hur olika arbeten lämpligen utförs.

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Contents

Economic and silvicultural performance of different thinning machinery

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Summary

Thinnings have an essential role in Nordic wood production. High harvesting costs compared to the value of harvested raw material are the main problem in thinnings. Optimal number and spacing of remaining trees, low number of tree and soil damage are the demands of good silvicultural thinning result. The thinning machinery used must fulfill both high economic and silvicultural standards.

The high capacity of expensive one-grip harvesters designed for final fellings and later thinnings cannot be totally utilized in first thinnings, where machines with lower capital costs can be one solution in solving the harvesting costs problem. The long-term productivity of thinning harvesters and harvester-forwarders was investigated with the follow-up study. Three harvester-forwarders and five thinning harvesters were studied. The work of harvester-forwarders includes both cutting and forwarding. The total harvested volume was almost 30 000 m^3. Also the silvicultural result of machinery was studied.

The average productivity of a harvester-forwarder varied from 3.81 m^3/E_{15} in first thinnings to 7.87 m^3/E_{15} in regeneration cuttings. The productivity was calculated for a 250 metre forest haulage distance. Average stem size of the stand, removal per hectare, and number of timber assortments were the factors affecting productivity when the forest haulage distance was standardized. The productivity of thinning harvesters varied from an average of 6.92 m^3/E_{15} in first thinnings to 16.18 m^3/E_{15} in clear cuttings. Some of the harvesters were well capable in small dimensioned clear cuttings, the smallest machines being solely designed for thinnings.

Harvesting costs were compared at the harvesting system level. The costs of a medium-sized forwarder were added to the costs of harvesters. Costs data of the widely used medium-sized harvester system were added to the comparisons made for the forest haulage distance of 250 metres. The thinning-harvester system had the lowest costs for both two and five timber assortments. In the case of five assortments, which is the typical number in thinnings in Finland, the medium-sized harvester system had lower costs than the harvester-forwarder above a stem size of 60 dm^3. At an average stem size of 200 dm^3 the difference between the harvester systems was minimal. In the case of two assortments, the competitiveness of the harvester-forwarder was better, and below a stem size of 100 dm^3 its costs were lower and between 100–200 dm^3 at the same level as for the medium-sized harvester system. The thinning harvester system was still the cheapest alternative.

The silvicultural harvesting result was acceptable with all studied harvesting machinery. The average damage percentage with harvester-forwarders was 2.5% in autumn experiments and 0.8% in winter. The corresponding numbers with thinning harvester were 2.3% and 2.8%. With thinning harvesters the use of cutting strip method allowing a longer strip road distance is possible. With cutting strip method and 30 m forwarding strip distance the distribution of remaining trees was steadier than with 20 metres strip road distance. However, the risk for tree damage increases with cutting strip method. The cutting strip method allowing a longer forwarding strip road distance can be recommended in pine stands with varying tree quality.

***Keywords**: Thinnings, harvester, harvester-forwarder, productivity, harvesting costs, damage*

Introduction

High harvesting costs and marketing problems, partly caused by technical properties related to first thinning wood, are the main problems in first thinnings. Small stem size, low removal/hectare, high number of remaining trees, and often also dense non-marketable undergrowth, mean low machine productivity and high costs. In 1998 the average cost of mechanized harvesting in first thinnings was 11.8 – 15.1 € and 5.0 – 5.9 € in final fellings (Hakkila *et al.* 1998). The costs of manual cutting with forwarding in first thinnings is even higher, on the average 18.0 € in the year 2000 (Örn 2001).

Near 90% of the thinnings carried out by the Finnish forest industry and Forest and Park Service is mechanized. Most of the thinnings are cut with medium-sized, one-grip harvesters with a mass of 13–15 tonnes, and forwarded with 11–13 tonne forwarders. Machines with lower operating costs can be one solution for cost-efficient first thinnings (Högnäs 1997). However, cost efficiency is not the only demand for thinning machinery. Also a good silvicultural thinning result is needed to optimize the productivity and value of forests.

Materials and methods

The long-term productivity of thinning harvesters and harvester-forwarders was investigated in a follow-up study in 1999–2000 (Sirén & Aaltio 2003). The productivity data were based on Kienzle data collection clocks and information collected by machine operators. The cost comparisons were made between harvester systems and the harvester-forwarder on harvesting stand level. For these calculations the productivity of the harvester-forwarder was converted to a 250 m hauling distance using the time study data results of Rieppo & Pekkola (2001).

The study material was collected from five thinning harvesters (one Nokka Profi, two Sampo 1046X, and two Prosilva Ässä 810 machines) and three harvester-forwarders (Pika 828).

Study material of harvester-forwarders consisted 11 859 m^3 and 53 harvesting sites. In first thinnings (15 sites) the average stem size was 86.8 dm^3 and removal per hectare 42.9 m^3. With thinning harvesters total of 17 002 m^3 from 77 sites was harvested. Harvested volume from first thinnings was 4 420 m^3, the average stem size 103.6 dm^3 and removal per hectare 50.3 m^3. More than half of the harvested volume was Scots pine (*Pinus sylvestris*), some 30% Norway spruce (*Picea abies*) and 20% leaf trees. Pulpwood was cut to 3–5 metre lengths.

The machine prices excluding taxes and the calculated operating costs € per E_{15} hours used in cost comparisons are presented in Table 1. The operating costs were calculated with machine calculation program of Metsäteho. The calculation procedure is presented in Kärhä (2001).

Table 1.The machine prices (€ excluding taxes) and the calculated operating costs (€ per E_{15} hours) used in cost comparisons. Operating costs include both time dependent and variable operating expenses.

Machine	Machine price, € excluding taxes	Operating costs, € per E_{15} hours excluding taxes
Medium-sized harvester	274 012	65.8
Sampo 1046X	140 496	54.0
Nokka Profi	223 784	61.5
Ässä 810	168 259	56.9
Pika 828 harvester-forwarder	269 215	62.1
Forwarder	172 465	51.2

Silvicultural thinning results were measured in connection with time studies of thinning harvesters and harvester forwarders carried out by Metsäteho and Work Efficiency Association (Kärhä 2001). Following results are originally presented by Sirén (2001). Silvicultural harvesting result was measured with the method presented by Sirén (1998). In the method post-harvesting sample plots of 240 m^2 consist four 10 m x 3 m measuring zones on both sides of strip road. When cutting strip method was used with thinning harvesters, post-harvesting sample plot consisted of ten measuring zones.

Silvicultural results of harvester-forwarders were studied both in winter- and summertime at the same area. The machines studied were Pika 828, Nisula/Valmet prototype and Moipu. Pika 828 and Nisula/Valmet are machines with rotating cabin. The base machine of Moipu is a medium-sized forwarder. Harvester-forwarders were studied both in first thinning stands (Scots pine) and second thinning stands (Scots pine and Norway spruce). Total of 90 experimental plots with 720 measuring zones were inventoried.

Nokka Profi, Sampo Rosenlew 1046X, Timberjack 770, Valtra Forest 120 thinning harvesters were studied both in summer- and wintertime. Summer experiments were made at the same area with harvester-forwarders. All study stands of thinning harvesters were dominated by Scots pine. Total of 169 experimental plots with 1515 measuring zones were inventoried.

Results

Productivity of harvester-forwarders

Time elements were calculated according to the joint Nordic (NSR) recommendations (Nordisk avtale... 1978). The average proportion of gross effective time (E_{15} hours) out of work place time (W_0) with harvester-forwarders was 84.6% and with thinning harvesters 81.6%. The average technical availability of harvester-forwarders was 79.1% and of thinning harvesters 84.5%.

The productivity of harvester-forwarders was calculated for a forwarding distance of 250 metres. The average productivity per operating hour (E_{15} hours, includes interruptions shorter than 15 minutes) (Nordisk avtale... 1978), its variation between machines, average stem size (dm^3) and removal (m^3/hectare) in different harvesting conditions are presented in Table 2.

Table 2. Productivity (m^3/E_{15} hours) of harvester-forwarders in different types of cutting.

	Productivity, m^3/E_{15} hours	Average stem size, dm^3	Average removal, m^3/hectare
First thinning	3.81 (2.68 – 4.22)	89.4	41.5
Later thinning	4.41 (4.09 – 4.98)	137.0	45.6
Clear cutting	7.48 (5.11 – 9.65)	264.6	159.5
Regeneration cutting	7.87 (7.85 – 7.87)	276.3	152.8

In regression analysis average stem size, removal and number of timber assortments were factors affecting productivity in both thinnings and clear cuttings. Each extra assortment lowered the productivity of the harvester-forwarders by 0.147 m^3 during one operating hour in thinnings.

The work of harvester-forwarder includes both cutting and forwarding. Thus the productivity does not rise as rapidly as with harvester, when the stem size rises. Figure 1 presents the productivity of harvester-forwarders as a function of the average stem size, when the removal (m^3/ha) increases from 40 to 80 as the average stem size (dm^3) rises from 40 to 200. The number of timber assortments is five.

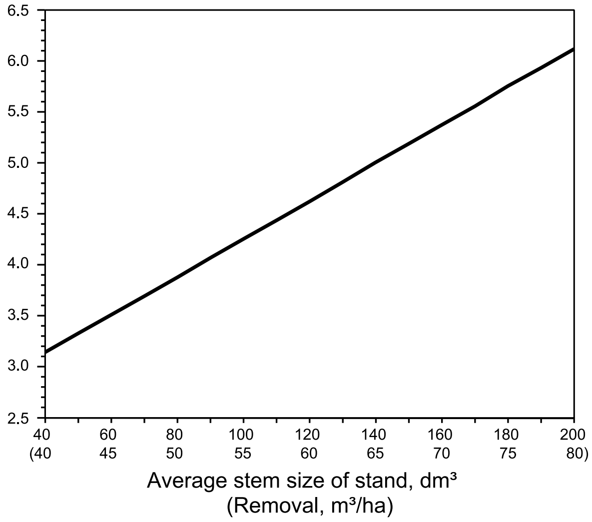

Figure 1. Productivity of harvester-forwarders in thinnings.

Productivity of thinning harvesters

Table 3 presents the productivity of harvesters in different harvesting conditions. The data for Sampo 1046X in clear cuttings consist of only one stand.

Table 3. Productivity (m^3/E_{15} hours) of thinning harvesters in different types of cutting. Average stem size (dm^3) is given in parentheses.

Machine	First thinning	Later thinning	Clear cutting	Regeneration cutting
	Productivity, m^3/E_{15} hours			
Nokka Profi	8.81 (131.1)	10.28 (129.5)	12.07 (168.4)	11.82 (362.5)
Sampo 1046X	6.26 (94.6)	7.76 (121.7)	12.97 (302.6)	7.08 (82.01)
Ässä 810	7.65 (112.0)	10.43 (177.5)	19.47 (465.3)	16.53 (380.8)
Total	6.92 (103.6)	9.20 (140.3)	16.18 (336.8)	14.02 (311.5)

Figure 2 shows the productivity of thinning harvesters as a function of the average stem size of the stand. When costs/m^3 in thinnings were compared, Prosilva Ässä 810 had the lowest costs due to its high productivity and low operating costs.

Economic comparison of harvesting systems

Cost comparisons of the harvesting systems were made for thinnings with a forwarding distance of 250 metres and five timber assortments (Figure 3). Nokka Profi was the thinning harvester used in the comparisons. The cost of harvesting was calculated as a function of the average stem size of the stand, which varied from 40 dm^3 to 200 dm^3. Removal, m^3/ha, varied within the same range from 40 to 80 m^3/ha.

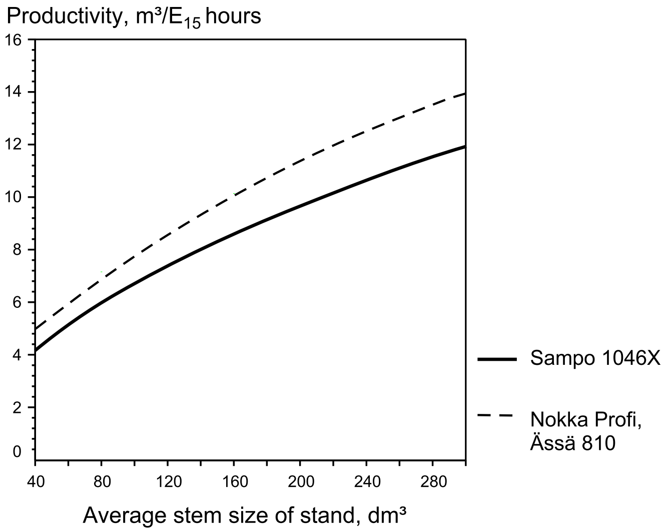

Figure 2. Productivity (m^3/E_{15} hours) of harvesters as a function of the average stem size of the stand in thinnings.

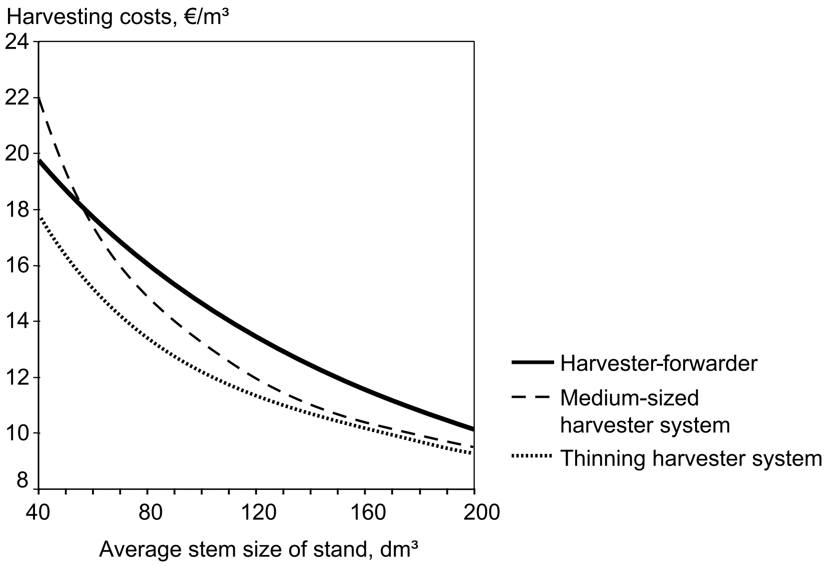

Figure 3. Harvesting costs of a harvester-forwarder and harvester systems including a harvester and a forwarder in thinnings.

Silvicultural results

The average damage percentage with harvester-forwarders in first thinnings was 3.6% in summer and 1.2% in winter experiment. Cutting caused 80% and forwarding 20% of damage, and 80% of damage was superficial. The distance between strip roads was 20 metres. Strip road width was measured with SLU-method (Björheden & Fröding 1986). Strip road width varied between 3.8 – 4.2 metres.

Table 4 presents the damage percentages and number of damage with thinning harvesters. The different working methods are also compared.

Table 4. Damage percentage and number of damage with thinning harvesters. Damage of forwarding included.

Condition/working method	Damaged trees, %		Damaged trees/ha	
	Summer	Winter	Summer	Winter
First thinning				
Strip road method	1.2	1.8	10	15
Cutting strip method/1 cutting strip	4.7	2.3	39	18
Cutting strip method/2 cutting strips	0.8	6.1	8	58
Second thinning				
Strip road method	3.7	4.3	30	22
Cutting strip method/1 cutting strip	0.4	1.7	4	9
Whole material	2.3	2.8	20	17

All damage was stem damage, and 77% of damage was superficial. Over 90% of damage was caused in cutting, and tree under felling or processing caused most damage. Strip road width varied between 3.8 – 4.1 metres. The distance between forwarding strip roads was 20–24 metres with strip road method and 25–36 metres with cutting strip methods.

In Finland the number of remaining trees is determined by recommendations (Metsänhoitosuositukset 1989). The amount of remaining and removed trees with harvester-forwarders and with different cutting methods of thinning harvesters is presented in Figure 4.

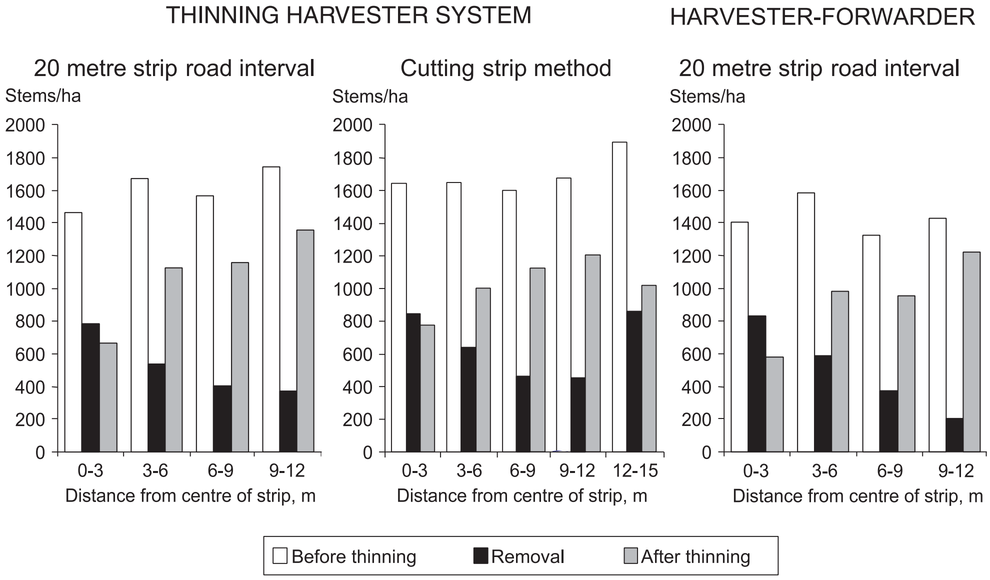

Figure 4. The initial growing stock, the remaining stand and the number of felled trees with harvester-forwarders and with different cutting methods of thinning harvesters.

Discussion

The machine operator has a considerable influence on productivity (Rajamäki 1997, Sirén 1998) Thus, the differences in productivity between thinning harvesters can be caused by both machines and operators. For harvester-forwarders the average stem size of the stand, removal per hectare and number of timber assortments explained the productivity. The hauling distance also affects the productivity (Rieppo & Pekkola 2001).

The productivity of harvester-forwarders and thinning harvesters in the follow-up study was lower than that reported in time studies (Lilleberg 1998, Rieppo & Pekkola 2001, Ryynänen & Rönkkö 2001) even though the productivity obtained in the time studies was converted to correspond to the long-time productivity using a coefficient of 1.36. There are some possible explanations for the differences. When several machines participate in comparative time studies, all machines must have same conditions. For this reason time studies are often carried out in high volume stands with minimum undergrowth in relatively easy terrain. A comparative study can also lead to competition between the makes of machine.

The number of timber assortments clearly affected the productivity of the harvester-forwarder. The change from two assortments to five, which is the typical number in Finnish thinnings, lowered the productivity by 0.44 m^3/E_{15} hours. The harvester-forwarder head is a compromise, and sorting especially during unloading is not as effective as with the grapple of a forwarder (Rieppo & Pekkola 2001). The number of timber assortments was also found to affect productivity in recent Swedish studies on the harvester systems (Brunberg & Arlinger 2001). In harvester work, one extra assortment lowered the productivity by only 1%, but in forwarding one extra assortment increased the time consumption by almost 3%.

When harvesting systems were compared, the thinning-harvester system had the lowest costs with both two and five timber assortments. In the case of five assortments, the medium-sized harvester had lower costs than the harvester-forwarder at a stem size above 60 dm^3. At 200 dm^3 the difference in average stem size of the harvester systems was minimal. In the case of two assortments, the competitiveness of the harvester-forwarder was better, and its costs below a stem size of 100 dm^3 were lower, and between 100–200 dm^3 at the same level, as for the medium-sized harvester system. The thinning harvester system was still the cheapest alternative. In the costs comparison the costs of moving the timber were not included. However, the influence of moving the machine is rather reasonable, 0.25 €/m^3 (Rieppo & Pekkola 2001).

The study material also included some clear cuttings. Of the thinning harvesters studied, Nokka Profi and Ässä 810 can be used effectively in clear cuttings with a reasonable stem size. Sampo 1046X is clearly designed for thinnings. Pika 828 harvester-forwarder is technically well suited for clear cuttings. The harvester-forwarder is an overall machine for small-sized stands ranging from thinnings to clear cuttings. The same conclusion concerning the application areas of harvester-forwarders has also been drawn in time studies (Rieppo & Pekkola 2001).

Harvester-forwarders are currently undergoing an intensive development process. The harvester-forwarder is most competitive in small stands with a short forwarding distance. Harvester-forwarder also has some clear advantages. Operator´s work is less monotonous than in harvester or forwarder operation. Poor capacity balance of harvester systems in thinnings is also avoided (Rieppo & Pekkola 2001). The low number of passes on sensitive soils can be one advantage of the harvester-forwarder. The number of passes and degree of rutting are highly correlated (Sirén *et al.* 1997). The total travel of a harvester system is 4.5– to 5.0-fold and with a harvester-forwarder 2.5– to 3.0-fold the total length of the strip roads (Björheden 1999).

Silvicultural harvesting results of both harvester-forwarders and thinning harvesters were acceptable. The damage percentages with studied machinery were a little lower than corresponding numbers in large scale annual inventories carried out by The Forestry Development Center Tapio (Ranta 2001). In these routine inventories more than 200 stands per year are inventoried. Between the years 1998–2000 the average damage percentages resulting from mechanized cutting varied from 2.2 to 3.0%.

Sirén & Tanttu (2001) studied harvester-forwarder and thinning harvesters in first thinning of pine bog. The mean damage percentage with harvester-forwarder was 2.2 and with thinning harvester including forwarding 3.6. Using the cutting strip method with thinning harvesters, the amount of tree damage was more than double that of method using a strip road distance of 20 metres. Damaged trees were concentrated near to cutting strips. These results are near to the results presented in this paper.

The number of remaining trees has followed the instructions both with harvester-forwarders and with thinning harvesters. With thinning harvesters the use of cutting strip method allowing a longer strip road distance is possible. With cutting strip method and 30 m forwarding strip distance the distribution of remaining trees was steadier than with 20 metres strip road distance. The number of remaining trees on the cutting strip area did not differ from density outside the forwarding strip road area. Thus the cutting strips were actual "ghost" strips, as they were earlier called. Similar results were presented by Sirén & Tanttu (2001).

Sirén & Tanttu (2001) compared the total economy of cutting strip method and the method using normal 20 metre strip road distance with thinning harvesters. The total costs of the methods compared, including harvesting costs and costs caused by damage, were very similar. Use of the cutting strip method can be recommended in pine stands with large tree-quality variations. Fewer high quality trees are lost under strip roads. In spruce stands, the risk for tree damage and problems with visibility may hinder the use of cutting strips. The cutting strip method also sets demands on both the machine and the operator. The machine must be narrow and the operator must be skilled.

Both thinning harvesters and harvester-forwarders are interesting harvesting alternatives. In thinnings, where the high capacity of medium-sized harvesters cannot be fully exploited, the thinning harvester system is very competitive. Harvester-forwarder is an interesting alternative for small sized stands. For first thinnings harvester-forwarders with rotating cabin are quite tall machines. Anyhow, when cutting and forwarding are combined, sufficient load capacity is needed. This and need for good machine balance make the harvester-forwarder relatively heavy. Anyhow, harvester-forwarder and it´s working methods are under strong development process, which sets interesting challenges for machine manufacturers, forest enterprises and research institutions.

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A mechanized harvesting system for large-sized wood in permanent stands

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Summary

Main influences for harvesting operations in Germany are strategies of silviculture, development of forest technology and the demand on the timber market.

Usually there were motor-manual tree-length systems for harvesting large-sized wood. More and more modified demands of timber market and new developments of technology offer new possibilities. The conditions for harvesting are changing.

This paper refers on a combined harvesting method with forwarding studied in three different permanent stands of the Southern Black Forest. The stands differed with regard to distribution of tree species and size of timber. Results for technical potentials of harvester, productivity, costs, damages to residual stand are shown and discussed.

The described mechanized harvesting system presents an economical and ecological alternative to motormanual harvesting systems in permanent stands.

***Keywords**: Combined harvesting method; permanent stands; productivity; costs; damages to residual stand*

Introduction

The concept of natural forest management in Germany demands a multi-use forestry, natural production and stable forests, the ecological conversion of even-aged pure conifer in uneven-aged mixed stands, a variety of ecological and environmental aspects and above all ecologically compatible harvesting methods (MLR, 1994). The economical goal is to produce valuable large-sized timber. The modified stands effect higher demands to harvesting and timber marketing. In the last 15 years the part of deciduous trees and the large-sized wood have essentially increased (von Teuffel et al., 2000).

With regard to the management of permanent stands there is no separation of final felling, thinning, tending of growing stock, improvement felling, shelterwood cutting, felling of exploitable size and promotion of regeneration. These types of stand tending are made on the same area at the same time.

For this reason permanent stands cause other demands for harvesting operations and timber marketing than even-aged pure stands. The conversion of forest leads to modified spatial and temporal conditions which effect the following (Bacher, 2001a):

- Selective or grouping thinning replaces systematic one.
- There is a variety of assortments because of the utilization of small-sized until large-sized wood of different species at the same time.
- There is an irregular intensity of utilization and more felling per 10 years than in even-aged pure stands. For this reason a permanent forest opening is absolutely necessary.
- The stand structure complicates the clearness and creates high demands to work safety.
- A high work quality is required.

Stand and site conditions, demands of timber market, structure of forest owners, code of forest law and demands on mechanization represent further important influences on harvesting operations. Large-sized wood has been only harvested in tree-length and commercialised as long logs. More and more the customers demands large-sized short-wood.

The development of harvesting technology has orientated above all on silvicultural strategies and the obligation for efficient harvesting methods. Large-sized, more powerful and stable harvesting and skidding machines with higher boom reaches and higher lifting capacity of booms. One example is the development of tracked harvester in Central Europe (Mahler et al., 1999; Schöttle et al., 1997/1998; Weixler et al., 1998).

Harvesting methods and technology are necessary which promote an intensive silviculture, are fulfil customer wishes and meet economic, ecological and social aspects at the same time.

Since three years the Forest Research Institute of Baden-Württemberg in Germany has been effecting a project which is dealing with the ecological conversion of even-aged pure stands (Norway spruce) to uneven-aged, structured and mixed stands (Norway spruce, Fir, Beech) in the Southern Black Forest. The project is financially promoted by the Federal Ministry of Germany for Education, Science, Research Work and Technology. It is dealing with the consequences and effects of the ecological conversion of forests for harvesting operations and timber marketing. One main objective was studying the realization of mechanized harvesting methods. Within this project economical and ecological mechanized harvesting systems have been developed for permanent stands. In the following one mechanized harvesting system is discussed which was studied under different stand conditions.

Materials and Methods

With regard to permanent stands there are selective thinning and less thinning grades in pieces, in according to Schütz (1989) 40–50 trees per ha with an average volume per tree of 1 – 1,5m³. Further restrictions for harvester are tree dimensions, harvesting of valuable timber, knottiness of wood, the possibility of clearness in structured stands and steep slopes (Bacher, 2001a).

Because of these restrictions typical wheeled and tracked harvester can only used in combination with motormanual harvesting methods. Only with the large-sized tracked harvester (IMPEX HANNIBAL) a full-mechanized method is possible but only on flat terrain until 15% (Schöttle et al.,1998; Weixler, 1998). Several studies present that such combined harvesting methods using large-sized wheeled or middle-sized tracked harvester with forwarding are economical and ecological on flat terrain until slopes (<45%) in permanent stands (Bacher, 2001a/2001b/2002).

Objectives

The objectives of the studies were the following:

- realization of mechanized harvesting methods in permanent stands
- develop combined harvesting methods with forwarding
- evaluate influences of silvicultural stategies and determine some limits
- investigate the harvesting system and its components with regard to productivity, costs, damages to residual stand

Stand and Site Description

The studies were made in three different permanent stands locating in the Southern Black Forest. There were uneven-aged, mixed and structured stands of Norway spruce (*Picea abies*), Fir (*Abies alba*), Beech (*Fagus silvatica*) and Maple (*Acer pseudoplatanus*) with natural regeneration on the whole cut-bloc. Tab. 1 describes the harvested stands and sites.

Table 1. Description of harvested stand and site.

Characteristics	Study 1	Study 2	Study 3
Thinning grade [m³/ha] / [N/ha]	61 / 66	43 / 24	88 / 50
Number of harvested trees	375	232	347
% of hardwood	39	3	34
Averaged DBH [cm]	33	49	43
Maximum DBH [cm]	61	84	87
Minimum DBH [cm]	12	16	9
Terrain	Flat terrain (<20%)	Flat terrain (<20%)	Slope (36; 8–58%)

Study 1 and 2 were conducted on flat terrain. There were selective thinning. The thinning grades varied from 43 until 88 m³/ha. Study 3 had a higher thinning grade because of setting of new skid trails. The harvested stands differed with regard to tree species and size of timber. They consisted above all in softwood (Norway spruce, Fir). For Study 1 and 3 there was a third part of hardwood (Beech). Small-sized until large-sized stems had to be harvested but there were different distributions of size of timber (Fig.1).

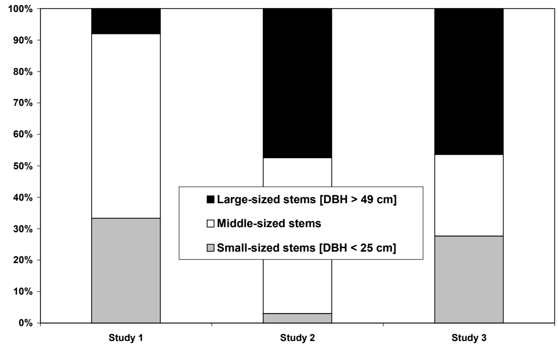

Figure 1. Distribution of size of timber for the harvested stands .

System and Equipment Description

The studied harvesting system was a cut-to-length system. With regard to the forest opening there were permanent skid trails with averaged distances of 40 m. Smaller distances possess high influences to the stand structure. For this reason not only restrictions for the harvester have demanded motormanual felling but also cutting the middle zone. The used tracked harvester 'IMPEX KÖNIGSTIGER' possessing a boom reach of maximal 15 m was not able to operate the whole area.

WORKING SEQUENCE	WORKING PLACE			
	Stand		Skid trails	Forest road
	Middle zone	Boom zone		
Felling		Motormanual felling of the trees with the DBH > 55 cm		
Delimbing Pre-Bunching Cutting Scaling Bucking				
Skidding Piling				

Figure 2. Description of the studied harvesting system.

Figure 3. Operating forest worker.

The studied harvesting system (Fig. 2) consists in three temporal separated phases:

Felling and Processing Method

Phase 1:

Trees of the middle-zone and with a DBH > 55 cm in the boom zone were felled by two forest workers (Fig. 3) in direction to the skid trails. With regard to Study 1 beeches were pre-bunched by a standard cable skidder to the boom reach of the tracked harvester. For Study 2 and 3 the forest workers had partly to delimb because of too much knottiness. Moreover they had to cut 1–2 assortments of the most overlarge-sized stems.

Phase 2:

For all studies the same tracked harvester 'IMPEX KÖNIGSTIGER' (Fig. 4) felled the rest of the marked trees, processed them and the motormanual felled trees during one crossing at the same time. It cut the stems into 4–7 assortments of short-wood and piled them up for the forwarder.

The tracked harvester 'IMPEX KÖNIGSTIGER' possess a weight of about 30.000 kg, an engine power of 125 kW, a harvester head LAKO 63 and the management system MOTOMIT 4.0. Special features are the possibility of endlessly slewing and tilt equipment for cabin and boom. Moreover there is a potential climbing power up to 60%.

Skidding Method

Phase 3:

The logs were brought out with forwarders (TIMBERJACK 810, VALMET 860, WELTE 210) for piling to the forest road.

The forwarder 'WELTE 210' (Fig. 5) is a combined machine which is also equipped with two cable winches and one of the largest existing boom 'LOGLIFT 1010' with a high lifting capacity and reach of 8,70 m.

Figure 4. Operating tracked harvester IMPEX KÖNIGSTIGER'

Figure 5. Operating forwarder 'Welte 210.'

Data Collection

Before the cutting the complete harvested stands were assessed. During the total harvesting period productivity was measured by time studies for the system and its components.

After the selective thinning sample surveys with regard to damages to the residual trees with DBH more than 7 cm were conducted according to Meng (1978). He defined a damage when it is larger than 10 cm² and the bare wood can be seen.

Results and Discussion

Productivity

Tab. 2, Fig. 6 and 7 show important results with regard to productivity.

Table 2. Results for productivity.

Characteristics	Study 1	Study 2	Study 3
Total volume [m³ under bark]	384	440	616
Averaged time cost for motormanual felling [Min/Tree]	16	21	24
Standard Deviation	4,14	9,60	5,95
% of the standing trees for the tracked harvester	74	54	55
Averaged DBH [cm]	331	49	45
Averaged productivity for the tracked harvester [m³/TMH]	27	22	26
Standard Deviation	14,02	9,41	17,01
Middle Skidding Distance [m]	131	154	109
Averaged productivity for skidding [m³/TMH]	12	27	25
Standard Deviation	7,44	6,34	12,10

As you can see in Fig. 6 there is an increasing total time cost for motormanual felling by DBH. For Study 2 26% of the felled trees had to been partly delimbed which causes together with the natural regeneration existing in different heights a higher dispersion and increase. Study 3 possess a higher time cost because of the slope influence.

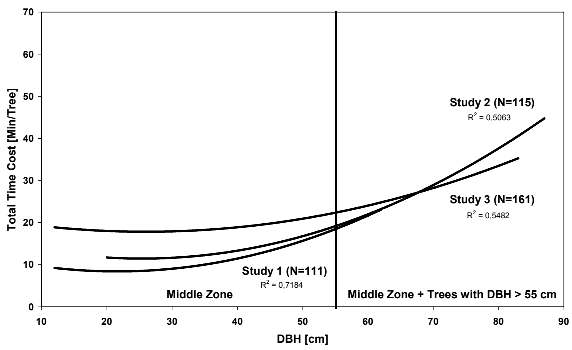

Figure 6. Distributions of time cost for motormanual felling by DBH under different conditions.

The tracked harvester had to fell the most marked trees itself (Tab. 2). There was a big variety of piece-volume per tree. For Study 1 and 3 there is a higher dispersion because of harvesting softwood as well as hardwood. Fig. 7 shows a less productivity with regard to Study 2 which caused by a less thinning grade per ha and difficult conditions because of natural regeneration.

Other studies show that large-sized wheeled harvester can also been used within combined harvesting methods in permanent stands. The productivity is comparable with the tracked harvester (Bacher, 2001c/2002).

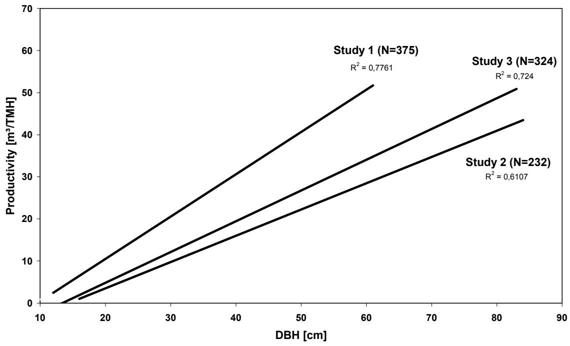

Figure 7. Distributions of productivity for the tracked harvester 'IMPEX KÖNIGSTIGER' by DBH under different conditions.

The productivities for skidding were similar besides for the forwarder TIMBERJACK 810 using for Study 1 (Tab. 2). Comparing with the other forwarders this machine is smaller and had a less load capacity. Further there was less large-sized timber (Fig. 1).

Costs

The costs were calculated by machine internal pricing rates of the State Forest Administration in Baden-Württemberg. The costs (all incl.) are presented in Tab. 3.

Table 3. Costs of the harvesting operations and the damages to residual stands.

STUDIES	Processing costs [€/m³]	Skidding costs [€/m³]	System costs [€/m³]	Damages to residual stand [%]
Study 1	9,66*	6,37	16,03	9
Study 2	11,48*	3,57	15,05	8
Study 3	11,02*	3,86	14,87	19

* including operations of the forest workers and the tracked harvester, for study 1 also pre-bunching by the cable skidder

The costs of conventional harvesting system – including motormanual felling and delimbing, skidding of the tree length to the roadside by a hydraulic bundler, motormanual cutting and bucking on logs and piling by a forwarder - are about 20–23 €/m³ (all incl.). Savings of about 25% can be realized because of less skidding costs concerning with the mechanized harvesting system. With the operating tracked harvester the productivity of skidding could be increased by the pre-concentrated loads on the skid trails.

Damages to Residual Stand

All studies have less damages to residual stands in comparison with motor-manual tree length systems for large-sized wood (BACHER, 1999). In the most cases there are no more than 1 damage per tree. In the structured stand with high natural regeneration (Study 2) the most damages were located up to 3 m at the stem in the opposite of the other both areas on which the locations were mostly around the root area of the trees. Tab. 3 presents that Study 1 and 2 have less damages to residual stands like full-mechanized harvesting systems in stands with small-/middle-sized wood (SCHÖTTLE et al., 1998; WEIXLER et al., 1998).

With regard to Study 3 the reasons for a higher percentage of damaged trees are the influence of slope and the higher thinning grade per ha which provoke more damages (BACHER, 1999).

Soil Disturbance

Operations with large, heavy harvesting machines cause long-term soil degradation on the trails. Therefore crossings should be restricted on less areas of stands as possible. In this way a systematic net of permanent skid trails is one contribution to soil preserving.

Conclusions

- ☞ The management of permanent stands needs flexible, stable harvesting methods which promote an intensive silviculture and satisfy social, economical and ecological interests at the same time. The described harvesting system including operating by forest worker and harvester together presents with forwarding a suitable possibility on flat terrain and slope until 40–45%. With such combinations advantages of harvester like delimbing, cutting, bucking can be used and its restrictions like tree dimensions and harvesting of valuable timber can be overcome.
- ☞ Comparing with conventional systems cost savings can be realized above all because of the reduced time cost for skidding.
- ☞ High demands for co-ordination are necessary using such combined harvesting methods.
- ☞ Because of work safety there must be a temporal separation of operating forest worker and operating harvester on the same area in structured stands.
- ☞ Such harvesting operations in permanent stands provoke satisfied damages to residual stand. It is very important because of conserving wood quality and silvicultural variety. The higher the thinning grade and the slope are there is an increasing percentage of damages to residual trees.
- ☞ Huge, heavy, powerful harvester and skidding machines are totally necessary for handling large-sized wood. Soil damages must be reduced by setting permanent skid trails.
- ☞ In Germany the demand for large-sized logs is more and more increasing. Harvesting of short-wood enables a sensible operation with harvester.

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Semi-autonomous logging systems

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Summary

Robotics and semiautonomous forestry machines were a strong talking point a few years ago. A systems analysis has now revealed that logging costs are not always reduced when elements of the logging work are automated. On the contrary, costs can increase as a result of the waiting time that occurs when logging and extraction are out of phase.

The system with the greatest potential would be a system with two autonomous shuttles. This system has its greatest potential for big trees and could be a complementary system to the harwarder system. With optimal choice between these two systems, the cost can be reduced for almost any combination of mean stem and transport distance compared with today's dominating harvester system.

The analysis also shows that multitree-handling and more effective unloading would reduce costs regardless of system.

Keywords: *Harwarder; harvester; systems analysis*

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Mechanized forest regeneration —is the planting pipe soon to be history?

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Summary

Mechanization of planting is not impossible to solve technically, the problem is to reach a biologically successful planting which is cost competitive compared to manual labour. The major dilemma with planting in general versus natural regeneration is the cost. High cost in the beginning of the rotation period affects the net at the time of cutting significantly because of interest rate. Lately, in some markets, more elements have had influence on the choice of regeneration method—e.g. shortage of manual labour and the demand for careful soil scarification.

After many years of different manufacturers trying to develop a competitive machine we are today of the opinion that the Valmet EcoPlanter is a machine system which fulfils biological and environmental demands and in most cases also the economical ones. The expression *"most cases"* means that some conditions lead to manual labour still being competitive. The differences are still so small that we feel the target is in sight. This is not only the case for the Nordic countries since the machine can be used for most hardwood and softwood plants as long as they are rooted plants. Wherever labour with low costs are used, it is however difficult to motivate mechanization at all.

The EcoPlanter is what we call a "purpose built machine", it is designed only for its specialized task. Combined with a rubber-wheeled harvester with a turnable cabin and telescopic crane, it has been highly appreciated among the operators and the concept has become more or less standard among Ecoplanter customers. 12 machines exist on the market today. During the conference, we intend to present data about the machine's capacity, both during field tests and according to the operators' experiences so far. We will also present the biological results so far.

There is a common responsibility between manufacturer, customers, the purchasers of planting services and the nurseries regarding further development. Just as for mechanization of cutting and forwarding, method evolution is crucial, in order to handle the machine in an optimal way. Established variations between different operators and EcoPlanter systems show that, disregarding the influence of reliability for each machine, there is an potential for improving method technique by analyses and training. The plant systems are today fully adapted for manual planting. By adapting the number of plants per container for the design of the plant magazine, establishing a standard regarding quality and size of plants and adapting the plants for automation of loading the magazine, capacity can be improved. Stricter regulations for the use of insecticides, e.g. Permethrine, means also that there is today no knowledge about what functions are required from a planting machine in a couple of years. A quick solution from a united forest industry would help to push the development.

Globally, problems of mechanized planting may vary a lot. In Germany, the use of bare-root plants dominate. This can on long term basis restrain the German forestry's possibility of rendering forest regeneration more cost efficient through mechanization. On Ireland, where the Sitka Spruce predominates, the vaste amount of forest residues obstructs any type of planting. In Italy, manual planting is subsidized and earmarked for unemployment activities.

Planting does not cover all needs required for regeneration at clear-fellings. Sowing is another method which has experienced development for a long time. The systems consist in most cases of conventional scarifiers with extra sowing machines. As a result of the good experiences from the EcoPlanter machine, it is now a natural thing to start looking at the possibilities of commercializing a sowing system, in the shape of a purpose built machine. Partek Forest has, as a major machine manufacturer, a distribution network which makes it possible to achieve large volumes and allocation of resources needed for making a sowing equipment long-term usable in the global forestry. We will tell about different systems which we study and develop and what we think about the potential for each of the systems to succeed on the market.

Keywords: *Mechanized planting, regeneration, Valmet Ecoplanter*

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Mechanized cleaning down and out and back again?

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Summary

Mechanized selective cleaning (precommercial thinning) was developed in the 1980s and 1990s in Sweden. On the whole, the concept of mounting the cleaning head (rotary cutter) on the tip of the boom has worked well. Although the biological result has been satisfactory, there is still room for improvement in the technology. The problem was, and still is, that the productivity achieved was simply too low in relation to the cost of the machines. Mechanized selective cleaning had difficulty in competing with motormanual (brush-saw) cleaning in young stands containing, initially, fewer than 10,000 trees per hectare—precisely the type of stand in which most cleaning is done. Another implication of this was that mechanized cleaning did not secure any significant reduction in the labour force.

To both reduce cleaning costs and the manpower requirement, methods must be developed that enable cleaning machines to handle several trees simultaneously, whilst moving forward continuously through the stand. This calls for some form of geometric cleaning, which is often met with resistance because of apprehensions that the quality of the tree-selection process will be reduced. Consequently, before we start work on a third generation of cleaning machine, we need to determine whether geometrical cleaning in strips is a practical and acceptable method of treatment, judged on the basis of the quality of the residual stand, its spacing and the future growth in it. If a biologically acceptable outcome can be achieved, it should be perfectly feasible to design a machine for geometric cleaning in stands up to 3 m in height that could do the job at half the cost of motormanual cleaning and also require a smaller team of forest workers.

The driving speed of the machine is an important economical factor in geometric cleaning. A machine for geometric cleaning must therefore be able to operate in dense cleaning stands without having to reduce its speed of advance too much. It is also worth investing in off-road mobility and comfort in the cab, so that, in low-density stands, the speed of the machine will be slightly faster than that of a scarifier.

Keywords: *Forest technology; mechanized cleaning; precommercial thinning; silviculture; stand treatment*

Thirty years of mechanized cleaning

The 1970s

According to Bäckström (1971), it was difficult to recruit people for silvicultural work and it would therefore be necessary to develop mechanized forms of cleaning that would involve a low manpower requirement. Back in the 1970s, people had a lot of faith in the benefits that could be derived from mechanization. Hägglund (1974) estimated the demand for cleaning machines and found that 20–25 geometric (strip) cleaning machines would be required up to 1979, followed by 10 units a year up to 1999. There would also be a demand for 200 geometric-selective cleaning machines up to 1979 and 100 per year thereafter up to 1999.

The 1980s

In 1981, Mellström & Thorsén found that the shortage of trained personnel, combined with an increasing area in need of cleaning and a ban on the use of chemical herbicides, had created problems in the form of a cleaning backlog (Mellström & Thorsén, 1981). Work on the mechanization of cleaning therefore got under way and by the mid-1980s three machines (all converted Bruunett Mini forwarders) were working on an operational scale (Lindman, 1985). However, the anticipated shortage of labour failed to materialize and the majority of industrial forest enterprises adopted a wait-and-see approach, given that there was no difficulty in recruiting labour for the silviculture season (Freij, 1989). At the end of the decade, 12–14 cleaning machines were in operational use (Freij, 1989).

The 1990s

Hellström (1991) also found that many of the forest enterprises had decided not to rush into mechanized cleaning yet, owing to an ample supply of labour for motormanual work. But despite this, the number of cleaning machines in use increased. In 1991, some 20 machines were operating in cleaning during at least part of the year (Hellström, 1991). Apart from a few exceptions, the forest enterprises showed only a lukewarm interest in mechanized cleaning. In the mid-1990s, about 15 cleaning machines were in use (Mattsson, 1995b). Mattsson (1995b) asserted that this was because rationalization in the forestry sector had given rise to large numbers of forestry contractors, and also because the cost of mechanized cleaning was no lower than that in motormanual cleaning. In the latter half of the 1990s, mechanized cleaning was marginalized, eventually to peter out altogether.

Early 21st century

Early in the 2000s, concern started to be expressed about a real, not imaginary, shortage in the labour market (Davner, 2002a). Tavener (2002b) refers to a crisis meeting arranged by employers seeking to solve the problem of the shortage of labour for silvicultural work in the north of the country by recruiting immigrant labour—a move that the government put the brakes on. The question that needs answering is whether recruiting workers from other countries will be a temporary or a permanent solution to the problem of silviculture work, and also whether this might give rise to a renewed interest in mechanized cleaning.

Base machines and cleaning heads

Bruunett Mini

The Bruunett was the mother of Swedish cleaning machines. It consisted of a forwarder with a loader mounted on the cab roof, which lent itself perfectly for conversion as a machine for selective cleaning (Fig. 1). The Bruunett Mini underwent a host of trials and studies, the findings of which showed, for instance, that time consumption was 4.5–5 productive hours per hectare, that the machine caused injury to 8–10% of the main stems, and that the cleaning cost was on a par with motormanual cleaning in leaf-free hardwood stands having an initial 10,000 stems/ha. The studies also revealed that the speed of advance did not impose a limit on productivity, but that the rear wheels of the machine should follow in the same tracks as the front wheels, to avoid seedlings being run over after they had been cleared by the front wheels (Mellström & Thorsén, 1981; Petré, 1983; Fries et al., 1985; Lindman, 1987).

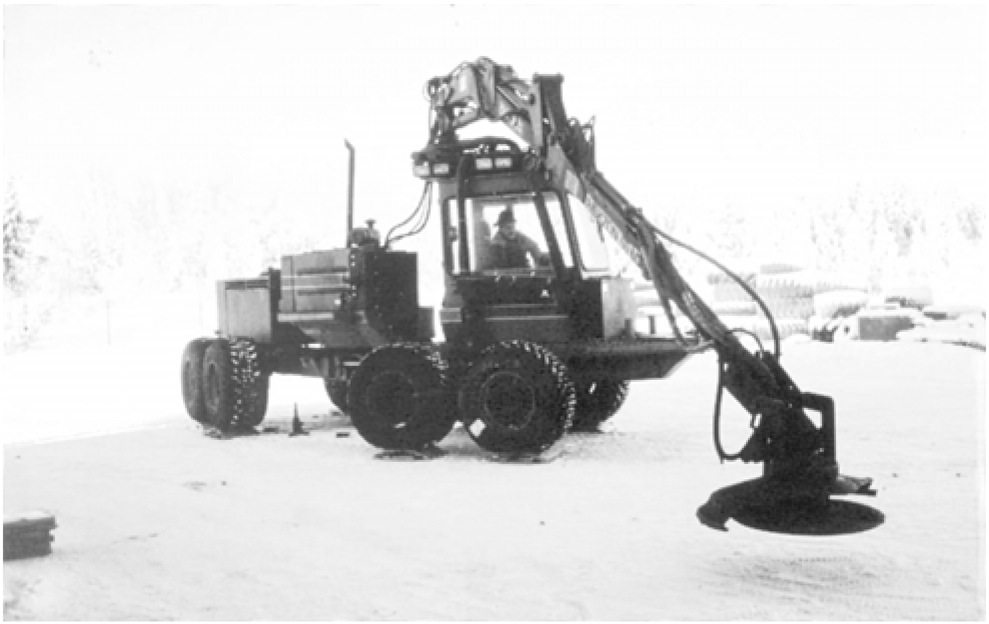

Fig. 1 The FMG Mini 678 cleaning machine, based on the original Bruunett Mini forwarder. The engine has been moved aft of the cab, and the knuckleboom loader has been mounted on the cab roof, making for excellent visibility. The machine has hydrostatic transmission, eight wheels, is 259-cm wide, has a ground clearance of 55 cm, weighs 11.4 tonnes and has a loader reach of 6.55 m.

Lillebror

The Lillebror base machine was converted into a cleaning machine designated the Lillebror 504R in a collaboration between Stora Skog and Bror Hult (Fig. 2). In its variety of guises, the Lillebror was the base machine used for most of the cleaning machines on the Swedish market. Studies of the machine revealed that it caused injury to 3–6% of the main stems and that it was competitive with motormanual cleaning in stands with an initial 13,000 stems/ha or more (Lindman, 1988; Lindman & Nilsson, 1989).

Fig. 2. The Lillebror 504 R cleaning machine. It weighs 5.5 tonnes, has a ground clearance of 90 cm and, as pictured here, is equipped with an MKR-80 cleaning head.

Other machines and prototypes

A variety of harvester types have been tested in mechanized cleaning over the years. The Valmet 901, which was studied at an early juncture by Eickhoff & Lindman (1987), had an average time consumption of 3.5 productive hours/ha and caused injury to approximately 8% of the main stems.

The Jumbo cleaning machine manufactured by Häglinge Industri was specially developed for cleaning in collaboration with Domänverket but failed to make an impact on the market (Nordberg & Rudén, 1988). Another prototype, the Hultdin, was developed in conjunction with SCA but failed to advance beyond the prototype stage (Myhrman, 1990).

The Skogsjan 487 Spindeln was studied, *inter alia,* by Freij & Tosterud (1991), who found that it could achieve a higher productivity than the FMG 0450 and was capable of straddling seedlings 3.0 m in height; in contrast, the Lillebror and Valmet 901 could only straddle seedlings 1.7 and 1.2 m tall, respectively.

The Valmet 701 and the Rottne 2000 were both single-grip harvesters that operated off the striproad. They were in the same size class as the Lillebror and first appeared in the 1990s. Some of these harvesters were equipped with an auxiliary head for the purpose of being used for both cleaning and thinning (see, *inter alia*, Andersson & Karlsson, 1991; Nordmark, 1993b).

Cleaning heads

The literature describes a host of cleaning heads, which include rotary cutters with 2–4 teeth, cutters with some form of saw teeth, units with flails and chains mounted on discs (2–4 flails) or drums (> 10 flails); rotating knives or rotating triangular discs that cut or shear through stems forced against an anvil; reciprocating shears of a type similar to those used on harvester heads, etc. At an early juncture in Sweden, the forestry enterprises decided to go for cleaning heads that consisted of two pivoting flails mounted on a disc. Examples of these are the Häglinge (Fig. 3) and the JM 77. These units were in urgent need of improvement as they proved to be a hazard—the flails could work loose, for instance (Magnusson, 1987).

Fig. 3. The Häglinge cleaning head, comprising a steel disc 80 cm in diameter and two pivot-mounted flails.

Adolfsson (1991) and Andersson et al. (1991) compared the MKR 80 flail head (similar to the one shown in Fig. 3) with the MKR 70 K rotary cutter (Fig. 4) and concluded that the rotary cutter, which was equipped with a fully enclosing guard, represented an enormous improvement in safety over the old flail heads. No differences in productivity were identified from any of the studies. Andersson & Mattsson (1992) made a comparative study of a large cleaning head (MKR 70) with a small one (MKR 50) but could not detect any difference in time consumption between the machines (Fig. 4).

Fig. 4. The MKR 70 and MKR 50 cleaning heads.

Factors affecting productivity

Brunberg (1991) looked at the factors that affect productivity in mechanized cleaning and identified the following: cleaning type (conventional v. simplified); removal of trees with or without leaves; number of stems removed; height of the trees cleaned; height of the main trees; ground roughness; slope and snow cover. Unlike Fries et al. (1985) and Eickhoff & Lindman (1986), Brunberg did not find that the number of main stems influenced productivity, even if there is covariance with the number of stems removed. The ratio of the height of the stems removed to that of the main stems also influences productivity, if only to a moderate degree.

The stand

Soil and root damage

According to Eickhoff (1986a), the resistance of the ground to machine passes is influenced by:

- Moisture content in the soil
- Thickness of the humus layer
- Soil type and texture
- Incidence of roots and stones

Similarly, according to the same study, the extent to which the ground is damaged is influenced by:

- The number of machine passes
- Surface pressure applied by the machine
- Wheel slip/spin
- Slash cover on the striproad

After several years of monitoring mechanized cleaning, Jansson & Wästerlund (1999) found that the driving of machines weighing 5–9 tonnes (eg, FMG 0450 & Häglinge Jumbo) over the site had no effect on growth in regenerations of Norway spruce.

Injury to regeneration crop caused by cleaning heads and straddling

After damage to soil and roots, the next most documented damage is that done by the cleaning head and by the machine straddling the seedlings. The incidence of injury to the residual trees is 6–9% of the total number of trees or main stems remaining (Magnusson, 1987; Wästerlund, 1986 & 1988). The incidence of injury is roughly the same (3–8%) if a lower machine that winds its way over the site is used (FMG 0470: width 1.8 m; ground clearance 0.5 m) (Andersson & Mattsson, 1993).

Freij (1990a) and Nordmark (1993a) investigated Scots pine seedlings that had been straddled by an FMG 0450 cleaning machine with a ground clearance of 88 cm. The variation in leading-shoot growth between seedlings that had been straddled or not diminished with time and apparently disappeared altogether after four years. The conclusion drawn was that mechanized cleaning in stands is fine if the average height of the stand is twice the ground clearance of the machine.

Methods and patterns

Geometric (mechanical) cleaning

Bäckström (1972) found that geometric cleaning, in which corridors or strips are opened up in the stand, was used in all mechanized-cleaning operations or trials. Hägglund (1973a) also determined that geometric cleaning is clearly advantageous for mechanized operations and that it had been used only on a limited scale in Sweden. He also established (1973a) that the effects of cleaning in strips are of benefit above all to edge trees and, consequently, that the ideal operating width should be within 2–2.5 m and should not exceed 3 m if production losses are to be avoided. In a comparative study with selective cleaning, Pettersson (1986) monitored growth in the stand after cleaning in strips of between 2 m and 2.8 m wide, supplemented by selective cleaning in intermediate zones 1.5 m in width. The outcome was that growth ten years after treatment was 6% and 17% lower for the respective methods in this mixed-method regime than in the conventional selective method. Pettersson (2001) believes that there is a good deal of evidence to suggest that the more uneven distribution of stems is a strong contributory factor to the inferior growth on the regeneration after geometric cleaning.

Most of the systems analyses performed in the 1970s point in the same direction, namely, that mechanized geometric cleaning returns higher productivity and a lower labour requirement than in motormanual cleaning, mechanized selective cleaning and geometric-selective cleaning (Bäckström, 1972; Hägglund, 1973 a & b; Friberg, 1974). Lindman found that changing from square spacing to line spacing could result in a 25% saving in time and costs. With the use of special cleaning machines for line spacing, it should be possible to reduce costs by 40% compared with today's methods, and to reduce time consumption by 75% as compared with conventional motormanual cleaning (Lindman, 1984).

Combining men and machines

Several studies have shown that cleaning costs could be substantially reduced by combining mechanized and motormanual operations; motormanual cleaning would take place round the main stems, at a distance of 0.3–0.5 m, before or after the mechanized cleaning, and stems less than half the average height of the main stems would be retained (Bjurulf & Nilsson, 1988; Freij & Nilsson, 1990 a & b; Freij & Tosterud, 1990).

Mattsson et al. (1991) and Freij et al. (1991) found that productivity was highest when the machine cleaned the stand first, and the brush-saw team then finished off by doing the precision work afterwards.

Accessible areas

From his analysis, Bjurulf (1991) deduced that mechanized cleaning should be accessible from a technical point of view on 61% of the area in need of cleaning in Sweden. The shortfall was because of the inability of cleaning machines to operate in terrain in which the indices for ground conditions, ground roughness and slope (GYL), as defined in Skogsarbeten's *Terrain Classification for Swedish Forestry*, exceed 3, 3 and 3, respectively. There are also restrictions on stand height (< 2.4 m), stand size (> 0.4 ha) and density (> 10,000 stems/ha). This is because most of the cleaning area has a relatively low stand density, with 78% of the area containing fewer than 10,000 trees/ha (Bjurulf, 1991).

Taken together, these restrictions leave just 22% of the area accessible for mechanized cleaning (Bjurulf, 1991), which corresponds to about 70,000 ha/year. Bjurulf also noted that dense stands are usually low in height, which is evidenced by the fact that the majority of the 22% of cleaning stands that have a tree population of more than 10,000/ha also have a stand height of # 2.4 m.

Discussion and analysis

What drives progress?

Samseth (1969), in his law of development leaps, describes how slow increases in the level of nominal operating costs, coupled with stagnant productivity in established machines and methods, drive forward new methods and machinery, so that productivity tends to increase in steps. Despite the earlier analyses of mechanized cleaning that highlighted the advantages of geometric cleaning (Bäckström, 1972; Hägglund, 1973 a & b; Friberg, 1974), the first cleaning machine to be put into operational use was the Bruunett Mini—a machine for selective cleaning.

Was it purely chance that drew investment to selective cleaning? Probably not. It could have been the depressed economy that inspired the notion to convert the first Mini Bruunett for use as a cleaning machine. But history has taught us that once a functional machine exists, it becomes difficult for people to see beyond it and look for a new concept—although some did try: Lindman (1984), for instance, produced an analysis that underlined the economic advantages of geometric cleaning.

That machines and methods for some form of geometric cleaning failed to find favour among the forest enterprises in Sweden might be explained by a resistance or unwillingness to adopt standard methods of stand treatment that were based more on cultural reasons than rational ones. But the fact remains that mechanized selective cleaning had difficulty in competing with motormanual methods on most of the area to be thinned, ie, stands containing fewer than 10,000 trees/ha. The question now is whether the time has come to try something new; or, as Samseth (1966) said, to take the next step up to higher productivity.

Geometric cleaning

Reduced selectivity

The question is just how great an effect does geometric cleaning, such as in strips 2–2.5 m wide, have on the quality of the residual stand? There are no studies here to help us. Pettersson (2001) has shown that the scope for choosing quality is limited even in selective cleaning. The best selective cleaning could only reduce the proportion of trees with quality defects by 5–6 percentage points, owing to the consideration that has to be given to the areal distribution of the trees.

Line planting

Creating stands by line planting, in addition to reducing the cost of stand establishment could conceivably also reduce the cleaning costs, particularly if some form of strip-operating cleaning machine could be used.

Davidsson (2002) has surveyed the five furthest-advanced experimental sites in a nationwide series of trials involving stands established with various forms of line spacing at the beginning of the 1980s (Bäcklund & Näslund, 1985). Davidsson concluded that the planting pattern had no influence on growth, survival, stem ovality or formation of compression wood up to the present stand height (approximately 10 m). Salminen & Varmola (1993) and Gerrand & Neilsen (1988) also concluded that the planting pattern had no effect on production. Bjurulf & Westerberg (1992) visited a number of Bäcklund & Näslund's (1985) experimental sites and discovered that, at times, it was difficult to find the planted rows, owing to self-seeded natural regeneration. What this means is that we cannot be sure that any clear planting rows will remain by the time the stand is ready for cleaning. To anticipate an eventual profit in cleaning and thinning on the basis of regenerations planted in rows therefore strikes us as being somewhat risky.

A step towards increased production and reduced costs?

The question is what potential does geometric cleaning have for increasing production and reducing costs? Let's perform a theoretical analysis in which we restrict the average height of the stand to 3 m, the number of residual stems after cleaning to 2000/ha, and we vary the number of stems before cleaning to between 5000 and 40,000 per hectare.

There are some well-documented and proven productivity levels for mechanized selective cleaning (Bergstrand, 1986; Eickhoff, 1987a; Freij & Tosterud, 1990; Brunberg, 1991; Mattsson et al., 1991).

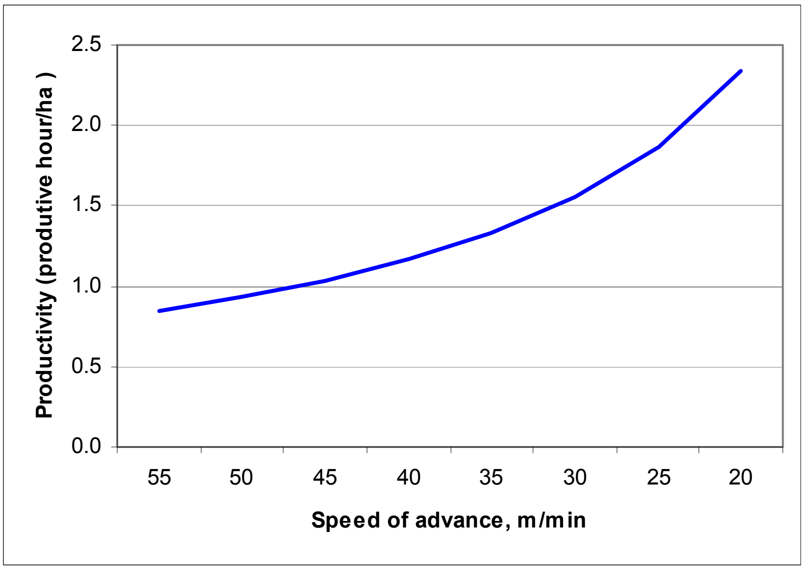

Fig. 5. Time consumption for various speeds of advance in an imaginary geometric cleaning consisting of strips 2-m wide and intermediate zones 1.5-m wide.

We have to make a number of assumptions for geometric cleaning. We assume that cleaning is done in strips roughly 2-m wide, separated by untouched intermediate zones 1.5-m wide. This gives a driving distance of about 2800 m/ha. To determine a reasonable speed of advance, we can compare the cleaning machine with other forestry machinery. A scarifier, for instance, has an average advance speed of some 30 m/min; a forwarder a speed of about 50 m/min. We assume that the speed varies from 20 m/min at 40,000 stems/ha to up to 55 m/min at 5000 stems/ha. This gives us a time-consumption figure ranging from 2.8 down to 0.8 productive hours per hectare (Fig. 5).

To obtain a true comparison of time consumption and costs between mechanized selective cleaning and motormanual cleaning, we need to add a motormanual cleaning operation in the intermediate zone between the strips for the geometric-cleaning method. For this we use the findings of Freij et al. (1991) to determine productivity in the motormanual cleaning of the 1.5-m wide zone between the strips for a stand of average height. The productivity curves from the studies, together with the figure of 56% for the proportion of the area of strips in which cleaning has already been done, give us a time-consumption figure ranging between 1.4 productive hours per hectare, with 5000 stems in the original stand, to 2.1 hours/ha with 40,000 stems.

Altogether, this gives the time consumption shown in Fig. 6, in which it is clearly apparent that geometric cleaning, followed by supplementary motormanual cleaning, is relatively unaffected by the number of stems and, when added together, give the lowest combined time-consumption figure down to 5000 stems/ha.

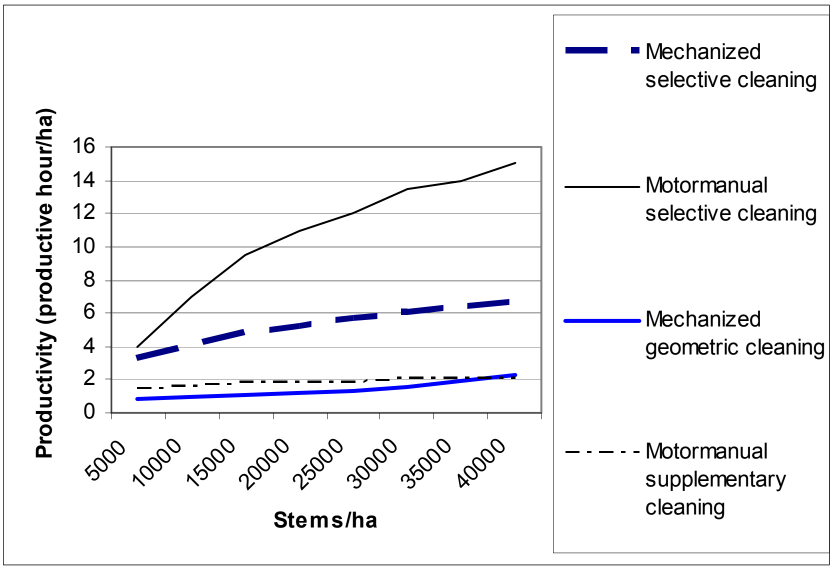

Fig. 6. Productivity for different numbers of stems in mechanized selective cleaning and motormanual cleaning, and with mechanized geometric cleaning in strips 2.5-m wide and supplementary motormanual cleaning in the 1.5-m wide intermediate zones.

Time consumption is a key factor in the decision process but for a complete picture we need to estimate the costs in cleaning. We have assumed a cost of Skr260/h (productive) for motormanual cleaning, and of Skr500/h for combined mechanized selective cleaning and the imaginary mechanized geometric cleaning. The costing shows that, for the conditions specified above, mechanized geometric cleaning is clearly the most cost-effective option, regardless of the initial number of stems (Fig. 7).

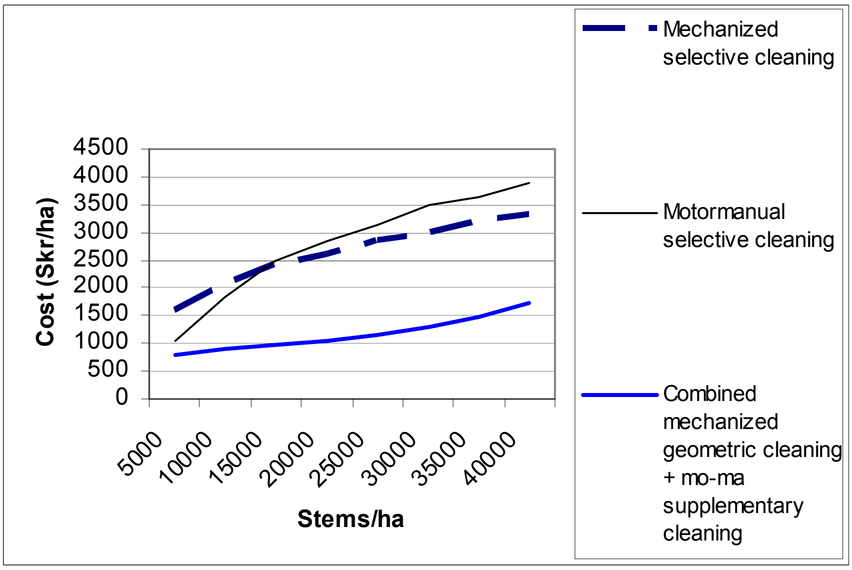

Fig. 7. Cost of cleaning, with different initial numbers of stems, for combined mechanized selective cleaning and motormanual supplementary cleaning, and for mechanized geometric cleaning in strips 2.5-m wide and supplementary motormanual cleaning in the 1.5-m wide intermediate zones.

The competitiveness of the combined geometric-motormanual cleaning option is largely unaffected by the machine costs. If the cost of the machine is increased to Skr700/h, the curve for the combined geometric-motormanual cleaning option in Fig. 7 will be displaced in parallel, so that the cost will be the same as for the mechanized-selective cleaning option for an initial 5000 stems/ha. On the other hand, the competitiveness of the combined geometric-motormanual cleaning option is relatively sensitive to the speed of advance of the machine. At a speed of 30 m/min instead of 55 m/min, the cost with 5000 initial stems/ha will increase to Skr1,140/ha—which is slightly higher than for the motormanual option. Since the cost does not change with an increase in the initial number of stems per hectare, the combined geometric-motormanual option will still be competitive when the number of initial stems in the stand is high, although such stands are fairly unusual.

At a speed of 20 m/min instead of 55 m/min, the cost with 5000 initial stems/ha will increase to Skr1,530/ha, and the combined geometric-motormanual cleaning option will not be able to compete with the motormanual-cleaning option until there are at least 10,000 stems/ha.

Conclusions

Mechanized selective cleaning (precommercial thinning) was developed in the 1980s and 1990s in Sweden. On the whole, the concept of mounting the cleaning head (rotary cutter) on the tip of the boom has worked well. Although the biological result has been satisfactory, there is still room for improvement in the technology. The problem was, and still is, that the productivity achieved was simply too low in relation to the cost of the machines. Mechanized selective cleaning had difficulty in competing with motormanual (brush-saw) cleaning in young stands containing, initially, fewer than 10,000 trees per hectare—precisely the type of stand in which most cleaning is done. Another implication of this was that mechanized cleaning did not secure any significant reduction in the labour force.

Mechanized selective cleaning was developed in the 1980s and 1990s. The concept of mounting the cleaning head (rotary cutter) on the end of the loader boom worked quite well. The biological outcome was satisfactory, but there is still scope for technological improvement. The problem then as now is that productivity is too low in relation to the cost of the machine. It was difficult for mechanized selective cleaning to compete with motormanual (brush-saw) cleaning in young stands containing, initially, fewer than 10,000 trees per hectare—precisely the type of stand in which most cleaning is done. Another implication of this was that mechanized cleaning did not secure any significant reduction in the labour force.

To both reduce cleaning costs and the manpower requirement, methods must be developed that enable cleaning machines to handle several trees simultaneously whilst moving forward continuously through the stand. This calls for some form of geometric cleaning, which is often met with resistance because of apprehensions that the quality of the tree-selection process will be reduced. Consequently, before we start work on a third generation of cleaning machine, we need to determine whether geometrical cleaning in strips is a practical and acceptable method of treatment, judged on the basis of the quality of the residual stand, its spacing and the future growth in it. If a biologically acceptable outcome can be achieved, it should be perfectly feasible to design a machine for geometric cleaning in stands up to 3 m in height that would be half the cost of motormanual cleaning and require a smaller team of forest workers.

The driving speed of the machine is an important economical factor in geometric cleaning. A cleaning machine for geometric cleaning must therefore be able to carry out geometric cleaning in dense cleaning stands without having to reduce its speed of advance too much. It is also worth investing in off-road mobility and comfort in the cab, so that the machine will be slightly faster than a scarifier in low-density stands.

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Conversion of Norway spruce

Site preparation and planting in a shelterwood

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Summary

Many heathland plantations in western Denmark are currently transformed by shelterwood regeneration from even-aged single-species stands of Norway spruce into mixed stands of species that can fit into a future close-to-nature silvicultural system. The aim of the present study was to (1) evaluate six site-preparation methods in a shelterwood, (2) study the planting, and (3) assess the mortality of the planted seedlings. Seedling mortality varied considerably between tree species. Beech had a high mortality, while oak had a very low mortality. All mechanical site-preparation treatments resulted in lower mortality compared to manual removal of humus. The high mortality after manual removal of humus seemed to be caused by a poor planting. The boom-mounted soil auger makes the best site preparation for planting, but the costs exceed tractor-drawn implements, especially in row-thinned stands. Site preparation by the inversion method (digging up a full bucket and inverting the profile with an excavator) led to greater windfall.

Keywords: mortality, regeneration, soil scarification, time consumption, work quality.

Introduction

The majority of the plantations on former heathland were originally established with mountain pine (*Pinus mugo* Turra) as the pioneer tree species by planting either directly in the heather or after site preparation. At the end of the first rotation of mountain pine, Norway spruce (*Picea abies* (L.) Karst.) became the most commonly used tree species. Presently 80% of the large conifer plantations that dominate the forests of the western part of Denmark are made up of Norway spruce.

The large even-aged Norway spruce plantations are susceptible to windthrow, and root rot caused by the fungus *Heterobasidion annosum* (Fr.) Bref. is a serious threat to Norway spruce, especially in second and later rotations. Therefore objectives have been set to transform these plantations into mixed forests composed mainly of species that is expected to fit into a close-to-nature silvicultural system. A method has been developed where the spruce plantations at a rather young stage (height < 15 m) are used as shelterwood stands under which several species are planted with or without site preparation. The advantages with this method are a low risk for frost together with a shelterwood stand less sensitive to windthrow.

Transformation of Norway spruce stands by shelterwood regeneration has also come into focus especially in central Europe (e.g. Kazda & Pickler 1998, Mossadl & Küssner 1999, Hasenauer & Sterba 2000, Schütz 2001), but most studies put little weight on the operational aspects. Some operational studies of shelterwood regeneration in the boreal forests have been identified, but they focus on natural regeneration, and the shelterwood has been established in mature stands.

The question is whether it is beneficial to do site preparation in shelterwoods, which are to be underplanted. Site preparation before planting is common on clearcuts especially on soils characterised by a thick raw humus layer and results in several advantages such as easy planting, removal of competing weed and reduced attacks from weevils. Site preparation might intuitively follow the establishment of a shelterwood. The goal should be to combine the silvicultural advantages of shelterwood and site preparation, but there are also disadvantages such as operational difficulties, injuries on the shelter trees and increased risk of windthrow.

The aim of this study was to study the productivity, intensity, and damage rates of six site-preparation methods in a shelterwood established either by row or selective thinning, to study the planting productivity following these methods, and examine the mortality of the planted seedlings (The planted species included silver fir (*Abies alba* Mill.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), beech (*Fagus sylvatica* L.), and oak (*Quercus robur* L.).

Materials and methods

Study area

The study area was a 50-year-old Norway spruce stand (8.6 ha) located in north-western Denmark (56°30'N, 8° 22'E). The soil was poor and sandy and covered by an approximately 10-cm thick layer of raw humus, and no hard pan was found in the soil. The stand was originally planted in rows with approximately 1.4 m between and within the rows. A striproad system was established in former thinnings dividing the stand into 108 plots (57×15 m) surrounded by striproads.

The site preparation was done in late October 1997, and the planting in March 1998. The summer of 1998 was cold with few sun-hours, many wet days, and few warm summer-days.

The stand was divided into two blocks. In each block, row thinning and selective thinning had been performed to establish the shelterwood. Row thinning was established by the removal of every second row (normally row no. 2, 4, 6 and 8 out of 9 tree rows) to give the best possible accessibility for site preparation implements. Selective thinning was established by leaving the most vigorous trees equally distributed over the area without taking site-preparation implement accessibility into consideration (stand data in Table 1).

Table 1. Stand data for the two blocks by row and selective thinning.

	Selective thinning	Row thinning
Block 1		
Area (ha)	2.0	2.1
D_{g3} (cm)	18.3	18.0
N_3 (trees ha^{-1})	536	569
G_3 (m^2 ha^{-1})	14.1	14.5
V_3 (m^3 ha^{-1})	106	110
Block 2		
Area (ha)	2.1	2.4
D_{g3} (cm)	18.0	17.1
N_3 (trees ha^{-1})	524	569
G_3 (m^2 ha^{-1})	13.4	13.1
V_3 (m^3 ha^{-1})	101	97

Site preparation and planting

Six site preparation methods were studied (Fig. 1):

(1) Manual site preparation (MANUAL). The humus layer was removed manually with a forest spade (type: Fiskars/Lysbro no. 176) in spots of 30×30 cm at planting.

(2) The Loft disc trencher (TRENCHER) produced a 40–60 cm wide furrow.

(3) The Kulla mill harrow (HARROW) has three tines that removed the raw humus layer and exposed the upper part of the mineral soil (0–5 cm). The patches were approximately 60 cm wide and 100 cm in length.

(4) The Polyteknik drum rotator (ROTATOR) has a hydraulically driven drum with two oblique ribs. The ribs pushed aside the humus layer, while the drum intermittently rotated backwards. The patches were approximately 60 cm wide and 100 cm in length.

(5) The soil auger (AUGER) was mounted on a harvester boom. It made circular spots with a diameter of 40 cm, where the soil was loosened to a 60-cm depth. The oblique rib on the auger's top-plate removed the humus layer.

(6) The Hanix n450 compact excavator (EXCAVATOR) was equipped with rubber tracks, a 4-meter long boom and a 100-litre bucket (50 cm wide). The excavator drove backwards through the shelterwood scarifying an approximately 6-meter wide area. Scarification involved digging up a full bucket and inverting the profile. This scarification method is known as the inversion method (Örlander et al. 1998). The patches were approximately 50 cm wide and 100 cm in length. The depth of the treatment was estimated at 50 cm at the deepest point.

Implements 2 to 4 were tractor-drawn and implements 5 and 6 were boom-mounted.

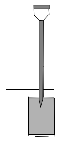
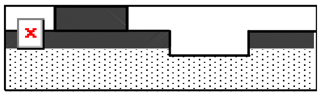
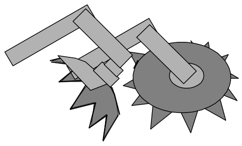
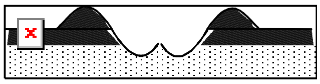
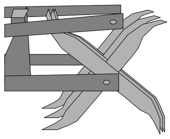
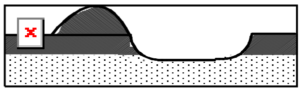
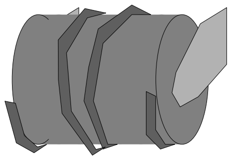
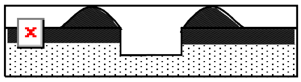
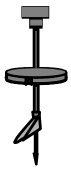
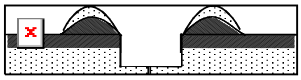
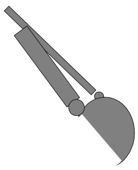
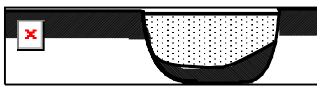
BASE MACHINE	IMPLEMENT	PRINCIPAL RESULT
MANUAL (Forest worker)		 Spots
TRENCHER Valmet 6400 farm tractor 70 kW Disc trencher, tractor drawn. Weight: 5.0 t Width: 2.32 m Length: 7.3 m		 Furrows
HARROW Fendt 308 farm tractor 57 kW Mill harrow, tractor drawn. Weight: 4.4 t Width: 2.19 m Length: 5.8 m		 Rows of patches
ROTATOR Systra 750 h farm tractor 53 kW Drum rotator, tractor drawn. Weight: 4.1 t Width: 1.95 m Length: 5.4 m		 Rows of patches
AUGER Silvatec 854F forwarder 114 kW Soil auger, Boom mounted. Weight: 9.5 t Width: 2.37 m Length: 7.4 m		 Spots
EXCAVATOR Hanix n450 33 kW Excavator, Boom mounted. Weight: 4.6 t Width: 1.85 m Length: 4.0 m		 Patches

Figure 1. Site preparation implements.

Planting of the bare-rooted seedlings was carried out manually with a forest spade. The seedlings were wedge-planted (the spade split the soil, the plant is put down in the wedge and the soil is trodden down) and the workers were instructed to plant 2500–3000 seedlings per ha. uniformly spaced. Planting should be done in exposed mineral soil if possible. The goal for species composition was 50% beech, 30% silver fir, 15% oak and 5% Douglas fir.

Measurements

The costs of site preparation and planting were estimated as current market prices per work-place hour supplied by the local forest district. Costs per work-place hour for TRENCHER, HARROW and EXCAVATOR was set to 50 Euro h^{-1}, ROTATOR to 56 Euro h^{-1}, AUGER to 75 Euro h^{-1}, and worker to 20 Euro h^{-1} (Paul Schmidt Andersen pers. comm. 1999). A lower price per hour was set for the AUGER because an unoccupied forwarder was used. Work place time for site preparation was calculated as the productive work time registered in time studies multiplied by 1.46, and work place time for planting was calculated as the productive work time registered in time studies multiplied by 1.52 (Samset 1995).

Seedling mortality and the number of windblown trees was registered as indicators of the quality of the site preparation. One and two years after planting, all seedlings were registered as dead or alive. All visible injuries on the above ground part of the shelter trees were registered after site preparation irrespective of their size. As an indication of root damage, the number of windblown trees was registered three years after the site preparation.

Results

Time consumption

The TRENCHER and the HARROW were the two most productive implements. They were both more productive in row thinning than in selective thinning. The ROTATOR was slower than the two other tractor-drawn implements, but faster than the boom-mounted implements. The ROTATOR was also more productive in row thinning than in selective thinning. The AUGER was more productive than the EXCAVATOR, and the two boom-mounted implements' productivity was not influenced by row or selective thinning (Figure. 2).

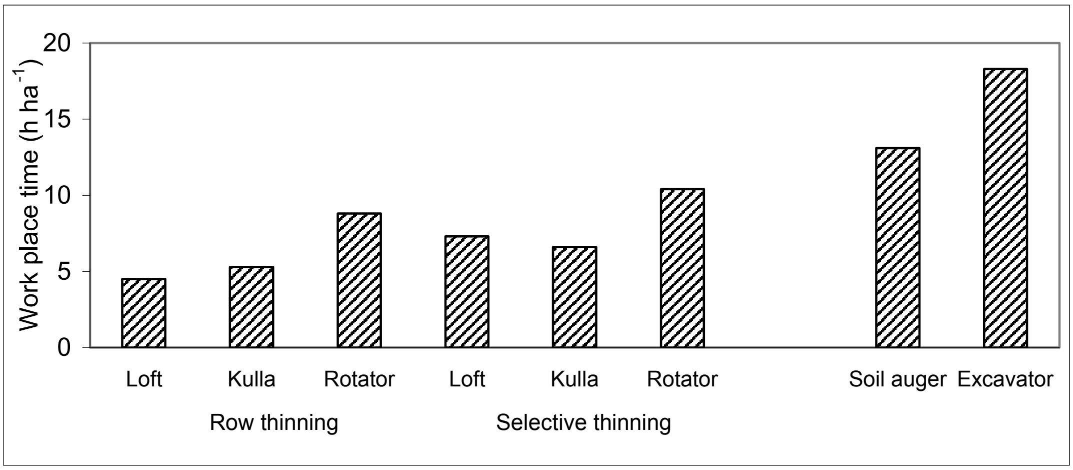


Figure 2. Time consumption for site preparation.

Time consumption for planting (PLANT) was more than twice as high in MANUAL than in the mechanically prepared plots, because MANUAL included removal of the raw humus in the planting operation. There was no significant difference in PLANT between the five mechanical site preparation methods. It did appear though, that it was somewhat quicker to plant in plots prepared by the AUGER.

Cost analysis

The economic analysis (Table 2) showed that the lower planting costs more than compensated the site preparation costs for the TRENCHER and for the HARROW and, conversely, site preparation with AUGER and EXCAVATOR was so expensive that the lower planting costs could not solely on justify site preparation costs.

Table 2. Productivity per work-place hour and costs for site preparation and planting.

	MANUAL	TRENCHER		HARROW		ROTATOR		AUGER	EXCAVATOR
	Row/Sel.	Row	Sel.	Row	Sel.	Row	Sel.	Row/Sel.	Row/Sel.
Productivity									
Site preparation (hour ha^{-1})		4.5	7.3	5.3	6.6	8.8	10.4	13.1	18.3
Planting(seedlings hour^{-1})	76	158	146	146	141	158	152	164	149
Costs									
Site preparation (Euro ha^{-1})		227	357	263	333	509	560	986	916
Planting (Euro ha^{-1})*	789	380	411	411	426	380	395	366	403
TOTAL (Euro ha^{-1})	789	607	768	674	758	889	955	1 352	1 319

*Based on 3000 seedlings per ha.

Plant mortality

Plant mortality was greatest for beech seedlings, followed by Douglas fir, silver fir, and oak (Figure. 3). For beech seedlings, mortality is greatest in MANUAL, and lowest where the AUGER and the EXCAVATOR had made a thorough site preparation. The other species showed a similar trend to beech, but mortality was too low to show significant differences.

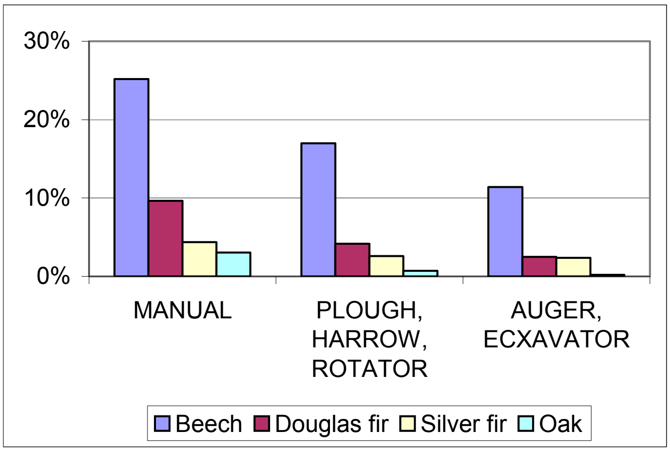


Figure 3. Plant mortality.

Causes to mortality was not registered, but mortality was assessed both after first and second growing season and it showed that almost all mortality happened in the first growing season.

Windthrow

Three years after thinning and site preparation only 45 of the 4758 shelter trees were wind-thrown. Forty percent (18 trees) toppled in plots prepared with the EXCAVATOR and only 7% (3 trees) toppled in plots with MANUAL, of which two trees were placed in the western margin of the stand. 11% (5 trees) toppled in plots prepared with the AUGER of which two were placed in the western margin of the stand. 13–16% (6–7 trees) toppled in plots where one of the tractor-drawn implements did the site preparation.

Discussion

This study shows that it is technically feasible to do site preparation with all the tested implements in shelterwoods having 500–600 trees per ha in both row and selective thinning.

Fjeld (1996) suggested that a circle (radius 1,5 meter) around each shelter tree should not be site prepared. This is not possible in shelterwoods with 500–600 trees per ha simply because of the number of shelter trees. Attack from root rot is a serious problem because it reduces the economic output from future thinnings, but if root rot is not present in the stand when the shelterwood is established, quite some years will pass before root rot growths into the stem. The physical stability of the stand might be reduced by attack of root rot, but Neckelmann (1995) showed that even stands attacked by root rot was quite stable if not too tall. If the stand is already attacked by root rot when the shelterwood is established, it must be expected that root rot will develop in the shelter trees even without site preparation. Therefore site preparation should not be excluded because of the risk of root rot.

Different types of site preparation damage the root system to differing extents. Root damages made by the EXCAVATOR seems to reduce the physical stability of the stand when producing 50 cm deep invertions. The other site preparation methods also reduce the physical stability to some extent and therefore site preparation in shelterwoods should be excluded on exposed sites. On the other hand it is probable that all shelterwoood regeneration should be avoided on such sites because the establishment of the shelterwood itself reduces the physical stability.

One reason for site preparation is to ensure faster planting. The planting speed is indeed affected by the site preparation method and increased planting efficiency alone can often justify site preparation (Table 2).

Some other studies have investigated the mortality of seedlings according to different site preparation methods under shelterwoods, and these studies show different results. Neckelmann (1976) found much lower mortality in silver fir after site preparation under shelterwood, while Gemmel et al. (1996) found no effect on mortality of beech and oak after site preparation under shelterwood. Löf (1999) found lower mortality, in beech and oak, but he concludes that acceptably low mortality can be achieved without site preparation. The mortality in the present study is mostly dependent on tree species, but site preparation is also a significant factor. Mortality below 5% is normally judged as insignificant, and this means that only beech and Douglas fir had significant mortality. Draught is believed to be the most important cause to mortality and the favourable growing conditions in 1998 should guarantee seedling growth if the seedlings were healthy, and good contact between the root system and the soil was achieved. Because of the good quality seedlings and the favourable growing conditions in the first season it is believed that mortality is related to an unproper planting giving inaquate contact between the roots and the soil. Under less favourable conditions, a higher mortality would have been expected, especially in seedlings planted in MANUAL. It is unknown whether a larger difference between the different mechanical site preparation methods would have shown up under less favourable conditions.

The higher mortality in plots with MANUAL can be attributed to the fact that the soil could not be adequately compacted around the seedling, as this is done by foot, in the relatively small holes in the organic layer. All site preparation methods seem to create the prerequisites for improved quality of manual planting and thereby obtain lower mortality (Berg 1991, Neckelmann 1976, Örlander & Gemmel 1989). Lower mortality in augered or excavated plots relative to the mortality in plots treated by tractor-drawn implements can be attributed to the deep subsoiling treatment, that blends the mineral soil and humus and severs the roots. This might improve humidity in the soil and reduce root-competition from the shelter trees. However, the most probable explanation of the lower mortality is that the method facilitated a better planting.

Conclusion

Seedling mortality is an important factor, because replanting is expensive and often inefficient. Therefore mortality must be given high weighting in the judgement of the site preparation methods. Although significant mortality was only achieved in beech and Douglas fir, the results might have general relevance in less favourable growing seasons. In order to minimise mortality the two thorough site-preparation methods, the AUGER and the EXCAVATOR, could be recommended, but in spite of the low mortality, the EXCAVATOR can not be recommended because of the destabilising effect upon the stand.

The TRENCHER can also be recommended because it was less expensive and achieved acceptable low mortality for silver fir and oak and made few damages on the shelter trees.

Planting without site preparation (MANUAL) has been used for many years and the method is attractive because the shelter is not destabilised by site preparation. In stands where stability concerns demand it, and if robust tree species are planted, this method can be recommended.

If accessibility in the stand is good the TRENCHER or the HARROW can be recommended. They are both cheap site preparation methods and the results seem satisfactory.

Acknowledgements

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Mechanised harvesting in cable operation

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Summary

The activity of cable crane operations in Norway is heavily reduced during the last years. At the same time we know that there is a large quantity of mature forest in steep and difficult terrain. In order to try to to stop this negative trend the Norwegian Forest Research Institute are carrying out a project to mechanise the harvesting in steep and difficult terrain. A Menzi Muck A 71 harvester is working together with a Owren 400 cable crane in steep terrain (30 – 70% steepness) The machine is felling, delimbing, bucking and piling in bundles at 1 – 1,3 m^3. The bundles are then transported to forest roads with the cable crane. Temporary results from the project look promising. Operational statistics shows an increase in production of Menzi Muck from 4 m^3 (ob)/ E_{15} hour at the beginning of the project to 8,5 m^3 (ob)/ E_{15} hour after six months.

***Keywords**: Steep terrain, mechanisation, harvesting, Menzi Muck, cable crane system*

Introduction

The activity of cable crane operations in Norway is heavily reduced during the last years. There may be different reasons for this:

- Low wood price.
- High logging cost.
- Relatively low technical development.
- Hard to recruit skilled workers.
- General scepticism to logging in steep terrain, due to environmental influences.

At the same time we know that there is a large quantity of mature forest in steep and difficult terrain. Nearly 20% of productive forest area in Norway is in steep terrain with more than 20% steepness and length more than 50 m. Statistics from Norwegian Institute of Land Inventory indicating that share of mature forest increase with increasing steepness.

The positive environmental effect by use of cable crane systems is not too well known, and is overshadowed by the negative publicity. Use of cable crane systems are among others contributing to reduce technical encroachment in the terrain like road building, wheeled terrain transport etc.

When the harvesting operation in steep terrain is mechanised the work safety will increase and the workload will be reduced. We hope this will have a positive effect on recruiting workers to this kind of operations.

The use of harvester inn logging operation will probably also increase the productivity of the cable crane system and give better economy for steep terrain harvesting.

Materials and Methods

A harvester (Menzi Muck A71) is developed in Switzerland for use in steep and difficult terrain. The harvester is based on a Menzi Muck excavator.

The machine is mainly build for operations in steep terrain up to 70%, but with an auxiliary winch it may operate in steepness up to 100%.

The wheels are mounted on four legs, and they can be moved independently in all directions. The engine and cabin is mounted in the centre of the four legs. This construction makes the machine very stabile in steep terrain. The machine has a Kyburz eight-ton winch for safety and improved terrain mobility. It is normally used when it is steeper than 70%.

Figure 1. Menzi Muck harvester.

Konrad Forsttechnich, Austria produces the harvester head. The head, Woody 50, has endless rotation and the feeder rollers are possible to tilt. When the feeder rollers are tilted the aggregate works as a grapple.

Figure 2. Woody 50 harvesting head

Table 1. Technical data.

Menzi Muck A71 Harvester	
Total weight	9 200 kg
Engine	Perkins 84 kW
Reach	8 059 mm
Winch	Kyburz 8 000 kg
Woody 50 Harvester Head	
Max cutting diameter	55 cm
Delimb feed rate	0–4 m/sec
Grapple diameter	105 cm
Features	Endless rotation, tiltable feeder rollers
Owren 400 Cable crane	
Total weight	24 000 kg
Engine	Deutz 134 kw
Tower height	13 m
Pulling capacity	6 000 kg
Reach	400 m
Cable system	Running skyline
Option	Standing skyline

The Norwegian Forest Research Institute has together with the Forest owner union and two counties started a developing project. The Menzi Muck harvester is now working together with an Owren 400 cable crane system in steep terrain (30 – 70% steepness).

When starting the project we investigated the type of machines in use throughout Europe. We found out that for Norwegians conditions a wheeled machine would be preferable, and of that principle, two machines were of interest. Kaiser S2 Bergbiber from Austria and Menzi Muck A71 from Switzerland. Both machines were built on the same principle with the wheels mounted on four moveable legs. Kaiser S2 Bergbiber is more complicated and more expensive than Menzi Muck, and it was more or less on a prototype stage at that time. In addition, in Norway there was an importer of Menzi Muck. This made the choice of machine simple. (Torgersen & Lisland. 2000).

The aim of the project is, during a mechanisation of the felling and yarding operation, to make better economical terms for operations in steep and difficult terrain in the future.

By mechanisation of the felling operation, the heavy manual felling and choker work, will be much easier. It is to be hoped that this will make it easier to recruit workers to this kind of terrain.

The Menzi Muck harvester has operated together with Owren 400 cable crane during a period of six months. When the logging area is planned and the skyline location is marked, the Menzi Muck harvester starts the logging operation. The machine is felling, delimbing, bucking and piling in bundles at 1 – 1,3 m^3. The bundles are placed closed to the cable strip as possible. When prechoking load of this size, the production of the yarding may increase from ca. 6 to 10 m3/E0 hour. When yarding logs there are fewer problems with the load getting stuck. When the load hits an obstacle it will turn around, and continue without getting stucked.

The Menzi Muck machine can operate in terrain up to ca. 70% steepness without auxiliary winch. If it is steeper, bad ground with obstacles or high water content, it is necessary to use the winch in order to move as well as for safety reasons. The machine in the project does not have a mooring system on the winch. A mooring system keeps a constant preloaded tension in the wire. Without this system the winch is rather complicate to operate. The machine also has hydraulic adjustable supporting legs. The legs are acting as parking brakes and help to stabilize the machine when processing.

During the six-month period, the Menzi Muck has operated both on bare ground and in winter season with snow. The steepness has varied from 20–80%, and stand volume has varied from 150–500 m^3 /ha.

Skogforsk has during the project period collected data for productivity of the cable crane in cooperation with Menzi Muck harvester, and compared the results with ordinary cable crane operation with manual felling.

This has been done by time study (E0) and operational statistics (E15).

Results

The operational statistics shows an increase in performance from the project started in July 2002 until January 2003 from 4 to 8,5 m^3 (ob)/ E_{15} hour

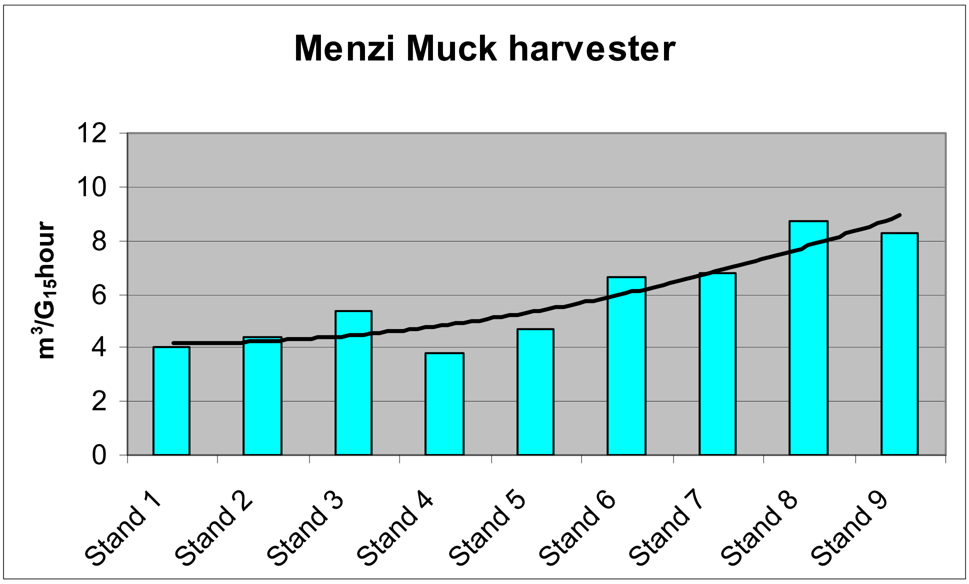

Figure 1. Performance in m^3ob / E_{15} hour.

Figure 1 shows the development in performance during the first six months of the project. The goal of the project is 10 m^3/ E_{15} hour

Lileng (2001) collected statistics from four different harvesters. The material included 144 shift, and the production varied from 10,6 m^3 /E_{15} hour to 17,6 m^3/ E_{15} hour. Average performance for the machines was 13,4 m^3/ E_{15} hour. The four machines in this investigation were standard harvesters and operating in flat terrain. Purchase prize of Menzi Muck is about 2/3 of ordinary harvesters, which means that the capital costs for the Menzi Muck will be less and a lower production is acceptable for Menzi Muck.

Smith, Nyeggen & Aarra (1992) studied FMT Tor harvester in the western part of Norway. The terrain was rather steep, varying from 0 –70% steepness with an average of 30%. Max steepness for the FMT Tor harvester was 55%, and area with steepness between 55 and 70% was felt manually. Average performance for FMT Tor in this study was 10,1 m^3/ E_{15} hour.

Together with the operational statistic we have carried out time studies (E_0) of both the harvester and the cable crane. The results from these studies are positive. Steepness of the studied stands varied from 30 to 70%, and the stand volume from 300 to 500 m^3/ha. The performance varied from 10 to 21 m^3 ob/ E_0 hour. Average performance was 16,6 m^3 ob/ E_0 hour.

Table 2. Results from time studies.

Stand						
Study nr.	1	2	3	4	5	
Height class	1,5	1,6	1,6	1,8	1,6	
Stand volume	420	397	397	511	308	m^3 /ha
Mean volume	0,480	0,496	0,496	0,659	0,332	m^3/tree
Production						
Volume	116,2	66,1	67,2	45,1	44,60	m^3
Effective time	6,30	4,10	4,40	2,12	4,74	hour (Eo)
Performance	18,45	16,12	15,27	21,27	9,41	m^3/hour (Eo)
Time consumption	1,60	1,85	2,32	2,32	1,71	min/tree
Volume / tree	0,492	0,505	0,589	0,819	0,267	m^3/tree

Discussion

The project is not finished, so it is difficult to give a final conclusion. But from experience and results so far, it seems that we shall reach the aim of the project which is an increase from 50 to 75 m^3 /day.

The Menzi Muck harvester works well on bare ground. But, we see that in winter season with heavy snowfall it is hard to find the bundles, and the choking is also difficult. In these periods it would probably be better to fell and delimb and then pile the stems in bundles. Bundles of stems is easier to recover and choke in the snow.

In these periods it is important that the cable crane is as close to the harvester operation so that the intermediate storage time is as short as possible.

We do believe in this concept, and feel that this is the right way to go for logging in steep and difficult terrain, but there is a lot of development work remaining. Experience so far tells us that the machine should have more power to the aggregate and to the driving wheels. Delay time due to repair of aggregate is too long. One reason is too close fit of the hydraulic hoses.

The conditions in the operator cabin are not good enough. The heater and defroster should be improved. The machine should have air conditioning for the summer season.

The cable logging operation also needs development on methods and equipment. We have to look at choking methods and develop better self-releasing chokers. The operation at the landing needs improvement in handling of logs and organisation of work.

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Mechanized harvesting system for hardwoods

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Summary

In France, 13 million cubic meters of hardwoods are harvested every year, but it has become more and more difficult to find skilled chainsaw operators (number is decreasing), especially for harvesting small size trees or for working in areas affected by windstorms. Naturally, the idea of trying to use harvesters originally built for softwood to harvest broadleaved stands has appeared. The first experiments took place in the mid-nineties, in chestnut coppices. Now, several contractors are working according to the CTL system with conventional rubber-tire harvesters or with combo tracked excavator – harvesting head to cut and process hardwoods for pulpmills and sawmills. Depending on the size of the trees to be harvested and on the type of operation (clear cutting, thinning…), strategies are different. In 2002, AFOCEL made a survey, analysed different systems and made several time studies on different logging operations. The paper presents the results of these investigations and draws up the situation: about 350 000 m^3 of hardwoods (pulpwood + saw logs) are harvested by the equivalent of 20 machines working full-time in broadleaved stands and another 20 machines working part-time in broadleaved and conifer stands. Most often, these are "normal" CTL harvesters, originally built for softwoods felling and bucking. The technical feasibility is then demonstrated for hardwoods until 0.300 m^3. But if loggers all agree about the fact that mechanization brings advantages in terms of organisation and security, a lot of them, even after 2 years of experience, remain doubtful about the profitability of this activity. To be developed in the future, hardwoods mechanization must be thought "globally": every player of the forest-wood chain has to make efforts (manufacturers, forest owners and managers, loggers, industry, schools).

***Keywords**: Hardwoods. Harvesting. Mechanization*

Introduction

In France, the classical system to harvest hardwoods is a two-stage system:
1. motor manual felling, delimbing and bucking at the stump,
2. extraction with forwarders or cable skidders, depending on the size of the logs, the slope…

According to this system, 13 million cubic meters of hardwoods are harvested every year: 8 millions for lumber and veneer, 5 millions for pulp and particle or fibreboards. There are four sources of pulpwood: coppices clear-cuts (chestnut, oak), poor value stand clear-cuts (mixed hardwoods species: beech, oak, birch, aspen…), thinnings in oak and beech high forests, and tops of large crop trees in final cuts.

In the last decade, the number of chainsaw operators has been considerably decreasing. Because of a lack of profitability, pulpwood and small size tree harvesting is becoming a real challenge. Naturally, the idea of trying to use harvesters originally purpose-built for softwood in broadleaved stands has appeared. Several initiatives have been undertaken since the early nineties but so far, hardwood mechanized harvesting was remaining at the experimental level.

Things have been changing since December 99, when two windstorms blew down in two days 140 million cubic meters (4 times the average annual harvest), including 60 million cubic meters of hardwoods. Because priority then has been given across the country to the recovery of largest and more valuable pieces of timber, both in conifer as in broadleaved stands, this event completely changed the situation concerning hardwood harvesting, especially pulpwood or small size trees, and lead to different strategies among contractors, wood suppliers and mills. In 2002, AFOCEL made an investigation to draw up the situation: how many cubic meters of hardwoods and what kinds of products are harvested by machines? What kind of machines can be used and in which conditions? What evolution can be expected for the near future?

Materials and methods

Survey

In mid 2002 we drew up a list of loggers using or intending to use harvesters in broadleaved stands. Basically this list was developed from the results of an exhaustive survey conducted by AFOCEL a few months before to characterize the French harvesting fleet. We have used and crossed different sources of information: regional lists, provided by the State offices, of loggers who applied for subsidies when investing in new machinery, phone books, books of professionals, but also verbal exchanges with loggers and foresters. We have mailed questionnaires but as the response rate was very low (< 10%), we had recourse to phone calls to get the basic information needed (type of machine, date of purchase, number of machine hours, type of products).

Interviews

In fall 2002, we visited 22 logging companies identified as harvesting hardwoods with machines or having the project to start such an activity:
8 contractors (working for wood-suppliers or sawmills), 10 suppliers (purchasing the wood stumpage, having the logging done by their own crews and machines, selling the products to sawmills and pulpmills) and 4 sawmills managing the logging (own crews + contractors) of the purchased standing timber. We interviewed harvester owners and harvester operators on several topics:

- The reasons that have driven them to decide to work in broadleaved stands with machines and the conditions in which they have developed, if so, this new activity
- The organisation and the performance of this activity
- Their feelings about the development of this activity in the future, both in their company and in forestry in general.

Time and productivity studies

In some cases we also carried out short time studies (3 to 10 hours) according the European harmonized protocol AIR3-CT94-2097 in order to get objective data on productivity of the process in different conditions, that we could confront to the annual, monthly or daily productivity that loggers had announced to us.

Results: a panorama of hardwood mechanized harvesting

Men

We have found 43 logging companies concerned, but more or less, by hardwood mechanized harvesting. Except a large pulpmill supplying company (100 people), all are small size companies (1 to 6 people). Among contractors, the main part of them was already loggers, carrying activities such as motor-manual harvesting, softwood fully mechanized harvesting or forwarding. A couple of them were also originally specialised in agricultural work. Concerning the suppliers, hardwood mechanized harvesting is mostly developed among those who were specialised in the hardwood trade than those who purchase and sell both softwoods and hardwoods.

The majority of these people have developed this activity by their own but we have also found a few examples of partnerships, of different types: supplier/contractor, mill (sawmill or pulpmill)/contractor, mill/supplier.

We have also found a dozen of professionals interested in developing an activity of hardwood mechanized harvesting but who have not taken any final decision yet: until then they have just experimented the technique on little patches or informed themselves on the subject (questioning machine sellers and operators).

Machines

Loggers use various types of machinery to cut and buck hardwoods. It seems that they have not found “the pearl” yet, but no machine is considered as totally inadequate either.

Concerning the harvesting heads, we can distinguish three categories.

- Conventional harvesting heads, built for softwoods, with no major mechanical modification, compose the more prevalent category. However, they require special adjustments, on rolls and knives pressure and speed in particular, to perform well in deciduous trees delimbing and bucking. These are, for example, KETO 100 and 150L, WOODY 50 and WOODY 60 (KONRAD), PATU 505, PONSSE H60, SILVATEC 445MD50, TIMBERJACK 742, 745, 746 and 762, SIFOR 350 and 500, WARATAH 762.
- Conventional harvesting heads with special mechanical modifications for a better adaptation to hardwood processing form a second category of machines. The special requirement is that they must perform well both in hardwoods and softwoods. Most often, they have been the fruit of a partnership between a machine dealer and a machine user, with sometimes the support of French government funds. Common modifications and adaptations concern the knives (number, position, profile) and their controlling mechanism. Sometimes a top saw is also mounted.
  KETO 150 HW, PONSSE H60W, SILVATEC 445MD50 and TIMBERJACK 762 are models of this category.
- Hardwood purpose-built harvesting heads are the third and last category. Until now, only two models have been specially designed for hardwood cutting and bucking: FORICOM H2564 and CHARLIER. They can also process softwoods.

All these heads are mounted either on wheeled carriers (60%) either on tracked carriers (40%). The latter are mainly excavators (different models from CASE, DAEWOO, KOMATSU, LIEBHERR…); there is just a few examples of forest carrier (TIMBCO 425). The rubber-tyre carriers are 4-wheeled (SIFOR 614 – TIMBERJACK 770 and 870 – VALMET 901), 6-wheeled (LOKOMO 990 – NOKKA, TIMBERJACK: 1070 et 1270 – VALMET 911) or 8-wheeled (PONSSE HS10, SILVATEC 856TH, 886TH and 896TH). We even found a specimen of a “4-wheeled walking” carrier (MENZI MUCK A71).

Generally, the 4-wheeled machines are preferred to the 6- or 8-wheeled ones because of their lower price but on the other hand, they are not so powerful and stable in steep terrain. Tracked excavators are also cheaper than conventional harvesters, and they can be easily resold if the harvesting activity is stopped. The problems are that it is harder to operate them in thinnings (because of the counterweight size and emplacement), they cannot be used to cross a road because of the tracks, and they have bad reputation among forest owners and managers.

Systems

At the end of 2002, we can consider that the equivalent of 40 machines are harvesting hardwoods in France but 20 of them are working full-time in broadleaved stands whereas the other 20 are working part-time in broadleaved—conifer stands.

Full-time or part-time working in broadleaved stands?

We met 8 machine-owners (mainly contractors) having their harvester cutting and processing hardwoods 80% to 100% of the time. Except one of them who is specialised in poplar, all have been working for at least one year in chestnut coppices, in private forest. As woodlots size is very often between 0.5 and 10 ha, loggers have to amalgamate several of them. By this way, they manage to move their machine by road in average 1 or 2 times per month. The most common products are sawlogs of varying length (from 2 m to 6 m) and 2 m or 4 m length pulplogs. Top end diameter is nearly always 8 cm. The proportion of pulpwood varies between 25% and 75% of the total volume. Some loggers are used to buck only 1 to 3 sorts of logs per site, others 5 to 7.

We also interviewed 8 loggers (mainly suppliers) who had invested in a harvester with the intention to use it both in conifer and broadleaved stands. So far, only 2 of them work significantly (at least 50% of the time) in hardwoods (beech, oak, aspen, birch…), in thinnings (100% pulpwood) or clear cuts (pulpwood proportion variable). The 6 other loggers, all working in the north-east part of France, where a lot of spruce, pine and fir stands were stormdamaged in December 99, preferred to give the priority to softwood recovering, instead doing thinnings in deciduous stands. So they have finally worked in broadleaved stands very scarcely.

With or without chainsaw operator?

Three systems have been developed, none of them prevailing on the others.

- Some loggers have a chainsaw operator (a salary or a contractor) working systematically in tandem with the machine. In most cases, he is in charge with felling the non-merchantable stems before the harvester, and the too large trees (generally, machines find their limits with trees having a diameter of 40–45cm). Sometimes, if necessary, he also re-cuts the stumps and check/correct the quality and the grading of logs that the machine has bucked. This generates an extra-cost but the aim is to improve the quality and the productivity of the machine work, while preventing also mechanical incidents.
- Other loggers have their machine working by itself the main part of the time and have recourse to a manual feller only in specific conditions (understorey too much developed for example), considering that a full-time manual worker would not be profitable.
- Other loggers have developed an original system: noting that the forwarder is able to extract the wood quicker than the harvester is able to process it, the forwarder operator works with a chainsaw ½ day to 1 day per week, to clean up the tricky zones or to put the finishing touches to the forest site.

Productivity and Costs

As seen above, systems used for hardwood mechanized harvesting are very different:

- Some loggers are specialised in very small size trees (DBH 8–15 cm) whereas others harvest rather medium sized trees (DBH of 20–30 cm),
- Some loggers are specialist in optimising tree value (they buck 5 to 7 different grade logs) whereas others harvest only pulpwood,
- Some machines are operated by an employee and work hardly 1500 hours per year whereas others are operated by the machine-owner himself for more than 1800 hours per year,
- Some machines work in tandem with a chainsaw operator, others not.
- Etc.

As a result, harvest productivity and costs are very variable. About costs, it seems that a 2 year experience is not long enough to evaluate them with accuracy but what is already sure is that they will be higher than in softwood harvesting due to lower utilisation rates, higher maintenance and repair costs, and lower productivities.

Concerning productivity, Figure 1 shows a few examples of productivity measured on different situations, but with operators more or less experienced (a few months to 2 years): this is the reason why we have preferred not to fit any model yet. These data are not conflicting with productivities announced by interviewed loggers: 6 to 8 apparent cubic meter per machine hour, 50 to 300 apparent cubic meter per day, 12 000 to 30 000 apparent cubic meter per year.

Discussion: positive and negative aspects for the development of hardwoods mechanization

About people motivation

Loggers come to hardwood mechanized harvesting by force of circumstances.

Interviewed on their motivation to start an activity of hardwood mechanized harvesting, loggers generally point out:

- The difficulties to find skilled manual workers to perform the job
- The intention to reduce the management cost (managing people take more time than managing a machine)
- The willing to improve work-planning and to be more reactive (tandem working with a forwarder is easier, machine production is less dependant on weather than manual crews…)
- The desire of diversification and modernisation.

Nevertheless, looking closer to the circumstances in which loggers have started this new activity, we have identified the factors that have really launched the method: these are the shortage of manual workers, work or wood, resulting in most cases from the December 99 windstorms.

Just after the windstorms, manual workers have widely deserted the too dangerous and non-profitable damaged stands (poor-value stands and chestnut coppices). This means a lack of work for loggers who were specialised in hardwood pulp logs and chestnut saw logs forwarding or trading but also a risk of interruption in the wood supply for the industry using these kinds of products. Even if in some cases, loggers managed to convince manual crews to work in windfall, harvest costs expanded then so considerably (sometimes twice) compared to usual conditions (higher wages and lower productivity) that a machine based system appeared finally to them as a more profitable and safer solution.

In a second phase, in regions less affected by windstorms, when local softwood recovering was completed, some loggers started to run out of work in conifer stands. They decided to transfer their harvester in broadleaved stands instead of moving to further areas.

In such contexts, the support of the principle client (financial support or pluri-annual contract) played also a key-role for contractors or suppliers.

Mentalities and fears are without any doubt a real obstacle

The widely expressed feelings among loggers who have not started yet an activity of hardwood mechanized harvesting are:

- the fear of non-profitability,
- the fear to have their logs refused by the mills,
- the fear of the mechanization non-acceptance from forest owners and managers,
- the uncertainty about the total and annual volume of wood-resources (in the local area) that could be harvested with machines,
- the questions about market evolution (prices, types of products…).

A lot of these questions are also recurrent among loggers having at least one year of experience in hardwoods mechanization. Three types of behaviour can be distinguished, none of them prevailing or typical of a given situation:

- Optimistic loggers, who want to keep on working in hardwoods with machines and intend replacing their machine by a new one after 5 years,
- Hesitating loggers, who still do not know what they will do in the near future (1 or even 2 years seem a too short period to know if the system is profitable): "*we will do whatever we can so that it works and we will do it until the machine is paid then we'll see*".
- Pessimistic loggers, ready to stop the activity: *"if in a couple of months it is still non profitable, I'll stop the machine"*.

About the method itself

Hardwood mechanized harvesting: not an easy job, but an interesting one

Machine availability and capacity is naturally a very important issue but technical matters are not the real obstacles to hardwood mechanized harvesting. Indeed all hardwood loggers agree: "*globally, it works*" (in certain conditions of course, but the job is technically feasible and meets the forest owners/managers requirements, when the products characteristics also comply wood users specifications), but is also true that breakdowns are very frequent, far more frequent than with softwood harvesting: *"there is always something wrong with mechanics"*. To limit the negative impacts of breakdowns on productivity and costs, loggers point out the *solution "you must be able to carry out repairs by yourself and as quick as possible: that means being able to anticipate and identify problems, keeping a stock of spare parts in your truck or pick-up, etc."*. As this ability comes with time and experience, loggers who had already operated CTL-harvesters in conifer stands were better prepared than novices. The quality of after-sale services from machine sellers is of course also crucial.

In hardwood mechanized harvesting, operator skills are perhaps even more important than machine capacities. In conifer harvesting, characterised by rather homogenous trees, the bucking has been automated because log grading is principally based on dimensional criteria (diameter and length). For hardwood logs, grading takes into account qualitative criteria as well, that the machine is unable to identify. As a result, operators can use the automated bucking process only for pulp logs. The rest of the time they have to be very concentrated to choose the right quality class bucking alternative before every cross-cutting: that implies that operators have to know exactly all product specifications (quality and dimensions). This is perhaps the reason why the major part of the operators we have found driving harvesters in broadleaved stands were people with a former experience in hardwood logging (they used to work as a chainsaw or forwarder operator). Several operators have also told us that this made the job more interesting.

A method procuring real advantages

According to loggers for who hardwood mechanized harvesting is a daily work, this method has two major and undeniable advantages.

First, the whole organization of the logging is easier, especially the coordination with the extraction and transport stages. The just in time production is now possible, working on large scale operations far from the office is also possible (only 1 or 2 operators to lodge, and who are able to manage their job by themselves, instead of large crews that require a supervisor), *etc*. Therefore, if time spent on management and time lost in bad coordination decrease, that means lower costs.

Concerning security and ergonomic point of view, no doubt mechanization is a significant progress. Hardwood harvesting could transform in a more attractive job to young people.

Conclusion

Since December 99 windstorms, hardwood mechanized harvesting is no longer at an experimental stage in France: at the end of 2002, 20 machines work full-time in broadleaved stands (mainly in chestnut coppices) and other 20 machines part-time in broadleaved and conifer stands. Hardwood mechanized harvesting accounts for 2–3% of the average total annual hardwoods harvest (250 000 m^3 on 13 million m^3).

In France, there is now a general acceptance among loggers (not yet among forest owners and managers) that mechanization is the only way for pulpwood and small size deciduous trees harvesting in the future to face the lack of manual workers, and the question of profitability is considered as the most important problem. This situation looks very much like the one at the end of the eighties, when French loggers started to use CTL harvesters to do the thinnings in conifer plantations; nevertheless, nowadays, less than 15 years later, 450 to 500 harvesters harvest about 8.5 millions m^3 of softwood, that is to say 40% of the total annual softwood harvest.

It would probably be dangerous to think that the lack of manual workers will be a driving force strong enough to launch and sustain the development of mechanization in hardwoods. For softwoods, the real driving force was the development of dynamic sylviculture schemes, planning regular thinnings in plantations to produce quickly high value timber. As this kind of sylviculture does not exist (yet) for broadleaved stands, another driving force must be found. The wood industry (pulp, board, lumber, veneer…) must be aware that his supplying strategy will have a strong influence on the future of hardwood mechanization. But hardwood mechanization must also be thought "globally" to be developed: every player of the forest-wood chain has to make efforts:

- Manufacturers, to improve machinery,
- Forest owners and managers, to fit sylviculture methods to mechanization,
- Loggers, to improve the efficiency and the quality of the whole chain (harvesting + extraction + transport),
- Industry, to develop log specifications without extra-quality,
- Schools, to train operators with adequate skills.

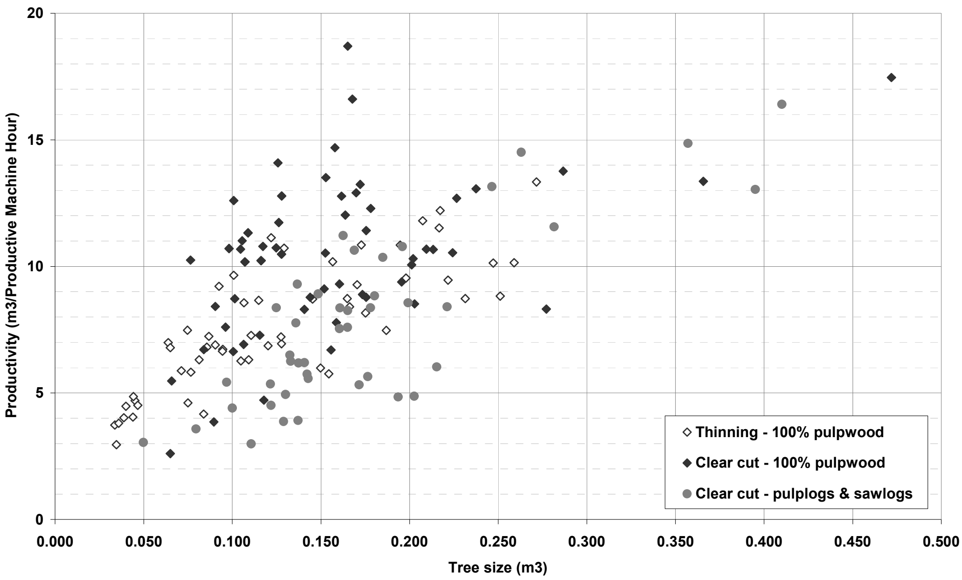

Figure 1. A few examples of harvester productivity measured in different hardwoods logging operations, with operators more or less experienced (1 point = 1 hour observation; 3 to 10 points per logging site).

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Bundling of forest fuel – profitability and potential for development

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Summary

The world is about to convert its production of energy from using fossil fuels to using renewable sources of energy. In Europe, the conversion has already begun, mostly with the use of governmental economical instruments and investment fundings. The Kyoto agreement stipulates that from year 1990 to the period 2008–2012, the European Communities have to reduce their common CO_2 emissions by 8%.

Biofuels have a large importance in this conversion and the growth of the wood fuel industry (thermal power stations, combined power and heating plants, pellets and briquet producers) has caused a state of shortage for by-products from the forest industry. At times, a spot market has appeared for forest fuels coming directly from the forest. Despite that, a comparison between price trends shows a somewhat discouraging result. The Swedish price for district heating increased about 23% between years 1995 and 2001. The price for chips is down a few percentage during the same period. The low profitability, combined with the irregular prices for energy and that development of technology for harvesting has more or less stopped, have caused many contractors to lose interest in working with forest fuels.

In a report from 1998, the Swedish National Board of Forestry recommends cautiousness when removing residues from the forest. Returning of ashes, fertilizing and excluding large areas from harvesting forest fuels were listed as necessary measures. However, by the year 2001, recommendations from the same authorities were published saying that one (1) removal of residues can be made during a rotation **without** any need for compensation by fertilizing, as long as the majority of the needles are left in the forest. This can be interpreted in a way that the authorities look upon the business in a more positive way, as long as it takes the environmental aspects into consideration, with the right methods and at appropriate sites.

If we assume that environmental demands are secured when harvesting forest fuel and that there is a demand from industry and society to increase the volume of forest fuel on the market, then how can the forestry make the business profitable? Partek Forest promotes a machine, the Valmet WoodPac, which bundles forest residues and forward the bundles to the landing, using the same machine. The bundles can either be chipped at roadside using a mobile crusher or they can be transported with a conventional timber truck to the power plant for crushing in a stationary crusher. The machine system can be used both for hardwood and softwood and is suitable for all markets where there is an industry using forest fuel. Partek Forest have participated in a research project together with the Swedish University of Agricultural Sciences, where the capacity of the machine system has been studied under different conditions. The project stretches over the winter period, which has made it possible to store and dry the bundles outside, in natural conditions, whereafter the energy contents are analyzed.

By using the data we have received during this research project, we will during the conference present calculations regarding the profitability for the concept of bundling forest fuels during various conditions. We will show information about energy prices in all links, from the consumer and backwards, via the power plant, the transport costs and to the contractor. The main focus will be on the contractor's profitability and working situation, since the operating profits in the forest fuel business is so low for this part of the chain.

Keywords: *Forest fuel, biofuel, Valmet Wood Pac, bundle*

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The effect of a new load suspension system on forwarding

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Summary

For most vehicles, transport capacity is determined by load size and travel speed. In forwarding, these limitations may be reduced by adjustable load width, load weight sensors and load dampening. These improvements are the basis of the Hydroflex feature available through a number of forwarder manufacturers. The system consists of mounting the load frames on hydraulic cylinders with adjustable height and dampening. The total weight of the load is registered via hydraulic pressure and a warning function alerts the operator when the allowable level is exceeded. The load frame may be widened by 65 cm per side, making it possible to increase the total width by up to 130 cm.

The goal of this study was to quantify changes in load size, driving speed and vibration levels resulting from use of the Hydroflex system. The results show that the average increase in load size (t) was 7% for sawlogs and 23% for pulpwood. The average driving speed (with load) increased by 5–10% depending on terrain type. The greatest difference in chassis vibration was found for higher frequencies (> 100 Hz) in the vertical axis.

***Keywords**: forwarding, load dampening, load size, driving speed*

Introduction

For most vehicles, transport capacity is determined by load size and travel speed. For forwarders operating in terrain transport, load size is limited by the maximum width, length and height allowed by the load compartment. The maximum dimensions of the load compartment are based on the average load weight and density. As a result it can be difficult to fully utilize the maximum forwarding capacity when transporting assortments with low bulk density such as pulpwood. On the other hand, the peak forces created when transporting assortments with high bulk density may exceed the machines tolerance, even though the machines engineered load weight is not exceeded.

These limitations may be removed by three improvements:

- adjustable load width
- load suspension
- load weight sensors

These improvements are the basis of a load system for shortwood forwarders called Hydroflex. The system consists of mounting both load frames on hydraulic cylinders with adjustable height and dampening. The total weight of the load is registered via hydraulic pressure and a warning function alerts the operator when the allowable level is exceeded. The load frame may be widened by 65 cm per side, making it possible to increase the total width by up to 130 cm.

The goal of this study was to quantify changes in load size, driving speed and vibration levels resulting from use of the Hydroflex system.

Methods

The experiment was divided into two parts. The first experiment examined load sizes before and after the installation of the new load configuration. The second part examined the changes in driving speed and vibration levels. In both cases the system was mounted on a medium-large eight-wheeled forwarder (Ponsse S-14 Buffalo).

Load size experiment

Changes in load size were measured in terms of load weight before and after installation of the Hydroflex system. This was done during normal operations in final harvesting. Machine weight was measured using four mobile ground scales. The front and rear parts of the forwarder were measured and summed to get the total machine weight. The total machine weight with and without load was then measured for 20 loads before and after installation. During the test period pulpwood and sawlogs were not mixed in the same load.

Driving speed and vibration experiment

After the load size experiment was complete the forwarder was transported to a circular test track for measurement of driving speed and vibration levels. The test track was divided into segments with similar terrain conditions. These conditions were classified in terms of bearing capacity, surface structure and inclination according to the Swedish terrain classification system (anon 1991). In this terrain classification the conditions are rated on a scale of 1 to 5 where 5 is the most difficult. The forwarder was equipped with a tri-axial accelerometer on the rear frame for the measurement of vibrations. The vibration level was measured in the three orthogonal directions; X (fore and aft), Y (lateral or right to left) and Z (vertical). For each segment of the test track the driving speed (m/min) and vibration levels (m/s^2) were recorded. The vibration data was afterwards analysed in the 1/3-octave band within the frequency range of 0.1 to 400 Hz.

The experimental design consisted of a direct comparison of loaded driving with and without the Hydroflex system in operation. This was done over the same terrain segments with the same operator and the same load weight (15 t). The operator was instructed to drive at the speed, which was acceptable in terms of the limitations of both man and machine. Each comparison consisted of three round trips of the test track (table 1). Three replications were made of the comparison. For driving without Hydroflex system in operation the load frame was reduced to its original width and bolted directly to the machine chassis. Each replication was separated by a control treatment of two round trips with no load.

Table 1. The experimental design for comparing driving speed and vibration levels with the Hydroflex system (Hyf) and without (Std). The number of rounds of the test track per treatment is shown in parentheses.

	Treatment		
Replication 1	Hyf (3)		Std (3)
		No load (2)	
Replication 2	Hyf (3)		Std (3)
		No load (2)	
Replication 3	Hyf (3)		Std (3)

Results

The first study showed that the increase in load weight after installation of the Hydroflex system was largest for pulpwood (table 2). The average increase in load weight was 7% for sawlogs and 23% for pulpwood. The coefficient of variation for load weight decreased from 7.4 and 12.1% for sawlogs and pulpwood before installation to 4.8 and 4.6% for sawlogs and pulpwood after installation.

Table 3. Average load weight before (std) and after (Hyf) installation of the Hydroflex system.

	Load weight (t)	
	Std	Hyf
Pulpwood	10.6	13.6
Sawlogs	13.7	14.6

The second study (driving speed) also showed changes with the new load system. Driving speed increased most on the easiest terrain (table 4). The relative increase in loaded driving speed was between 5 and 10% on all terrain types.

Table 4. Average driving speed with and without the Hydroflex system (Hyf=with Hydroflex, Std=without Hydroflex). Terrain difficulty is indicated by the surface structure class (1=very even, 3=moderately uneven).

	Driving speed (m/min)		
	Surface structure 1	Surface structure 2	Surface structure 3
Std	59	40	32
Hyf	64	45	34
No load	83	56	45

The vertical vibration levels (Z-direction) for the chassis show an increase in the average acceleration levels with the higher speeds achieved with the Hydroflex system (Table 5).

Table 5. Average vertical vibration levels (Z-direction) on the machine chassis during transport (Hyf=with Hydroflex, Std=without Hydroflex). Terrain difficulty is indicated by the surface structure class (1=very even, 3=moderately uneven).

	Acceleration (m/s^2)		
	Surface structure 1	Surface structure 2	Surface structure 3
Std	0.52	0.54	0.65
Hyf	0.60	0.66	0.85
No load	1.57	1.31	1.29

An analysis of the distribution of the vertical acceleration levels (Figure 1) show that the greatest differences in chassis acceleration occurred at frequencies higher then 100 Hz.

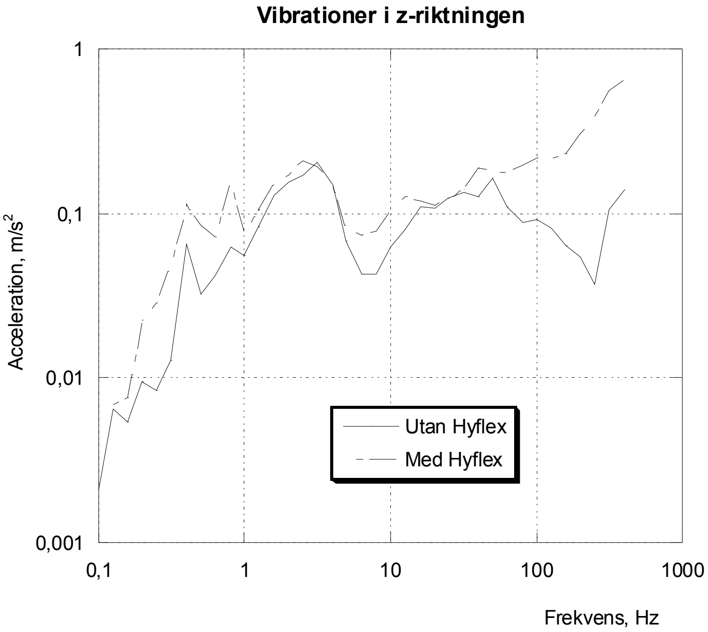

Figure 1. The distribution of acceleration levels for the vertical vibrations (m/s^2 on y-axis) as function of the frequency (Hz on x-axis) during loaded transport with (med Hyflex) and without (utan Hyflex) theHydroflex system.

Discussion

The study shows two basic trends with direct consequences for production. First, that the problem with low load weight when transporting pulpwood can be satisfactorily solved with the widened load cage. Second, that the load dampening makes it possible for the operator to drive at slightly higher speeds without perceiving the higher speed as adversely effecting either himself or the forwarder.

The effect of the dampening on the machine should be discussed in more detail. The location of dampening between the chassis and load enables the entire rear chassis to more freely follow the terrain surface structure without requiring the corresponding movement of the entire load. The hydraulic load suspension takes over the shock absorbing function previously forced on the wheels and tires, resulting in the observed increase in vibration levels transmitted to the chassis through the wheels and axles.

Another aspect of importance for the technical lifetime of forwarders, are the forces exerted on the machine chassis. These forces may be indirectly measured by the hydraulic pressure in the dampening system. Preliminary measurements have been done by the manufacturer in a study of driving at varying speeds over varying obstacle sizes (Table 6). These measurements indicate that the forces in the load chassis interface are 30–75% lower with hydraulic dampening. In the manufacturers study, the reduction of pressure is slightly greater for smaller obstacles, presumably because they are closer in size to the systems available amplitude.

Table 6. The influence of the Hydroflex system (std=no dampening, hyf=dampening) on relative hydraulic pressure in the suspension system for varying driving speed (0, 50, 62.5 m/min) and hinder heights (1 and 2 dm). After Karlsson (unpubl).

	relative hydraulic pressure (in %)					
	0 m/min		50 m/min		62.5 m/min	
	Std	Hyf	Std	Hyf	Std	Hyf
1 dm	100	100	160	125	200	125
2 dm	100	100	180	150	230	170

Examining the values in table 6 for driving over 1 dm obstacles with load suspension, we see that the increase in driving speed has limited effect on the hydraulic pressure. This would indicate that the acceleration of the chassis components while passing over the obstacle was within the normal limits of the suspension systems amplitude. In this particular situation, one would logically expect greater forces acting on the chassis/load interface for the non-suspended load. This is shown to be true in table 6. One would also expect greater acceleration levels of the chassis components for the suspended load. This is shown to be true in table 5. Further increases in speed will be correlated with increased chassis forces for non-suspended loads, and increased chassis acceleration for suspended loads.

Conclusions

The use of the Hydroflex load frame and suspension system allows both increased load size and higher travel speeds for forwarders. Given the same load size, the system also results in reduced forces for rear chassis components and correspondingly higher acceleration levels.

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The suitability of multi-stem harvester heads in thinning and final felling applications in eastern Canada

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Summary

Using single-grip harvesters often results in high wood costs when harvesting small stems, as is often the case in the boreal forest and in commercial thinning. Recently introduced harvester heads such as the Waratah HTH-470 HD provide multi-stem felling and processing options. Multi-tree handling (MTH) during the harvesting of small trees can increase harvester productivity. This paper describes the potential of multi-stem heads based on results from FERIC studies of the Waratah HTH-470HD multi-stem harvester head operating in eastern Canada. The key elements that let this head efficiently process several stems at a time are the accumulator arms, which keep the cut stems vertical after felling; the four hydraulically or mechanically linked feed rollers, which prevent the bundle of stems from slipping during processing; and the extra-wide measuring wheel, which ensures constant contact with the tree bundles.

The ability to handle more than one stem at a time increased machine productivity by an average of 21 to 33% compared with handling stems one at a time. On average, multi-stem work cycles were longer than single-stem cycles, but the ability to process more than one stem at a time in 30 to 40% of the cycles lowered the mean harvesting time per stem. The delimbing quality and the length-measurement accuracy for sawlogs were comparable to those of conventional heads currently on the market.

This technology is thus well suited to final felling of small trees and to partial-cutting treatments such as commercial thinning because its productivity is less affected than with conventional heads by the small tree volumes. The accumulator that keeps felled stems vertical also provides benefits, since it lets the operator control the fall of the felled stems and thus may reduce the risk of damaging residual stems.

Keywords: *Multi-stem harvester head, Waratah HTH-470HD single-grip head, Operational study, Cut-to-length system, Productivity*

Introduction

Using single-grip harvesters often results in high wood costs when harvesting small stems, as is often the case in the boreal forest and in commercial thinning. Processing more than one stem per cycle, also known as multi-tree handling (MTH), offers potential productivity increases under such conditions, and thus, reduced costs. Gingras (1999) described the first trials in Canada of a dedicated multi-stem single-grip head, the Timberjack 745. After these trials, the head was modified and improved, and is now being sold in Canada by Waratah Forestry Attachments as their HTH-470HD model (Gingras 2002).

This paper describes the potential of multi-stem heads based on the results of FERIC's studies of the HTH-470HD head in 2001 and 2002. The key elements that let this head efficiently process several stems at a time are the accumulator arms, which keep the cut stems vertical during felling (Figure 1); the four hydraulically or mechanically linked feed rollers, which prevent the stems from slipping during processing; and the extra-wide measuring wheel, which ensures constant contact with the tree bundles (Figure 2).

Figure 1. The accumulator arms that hold stems vertical after cutting.

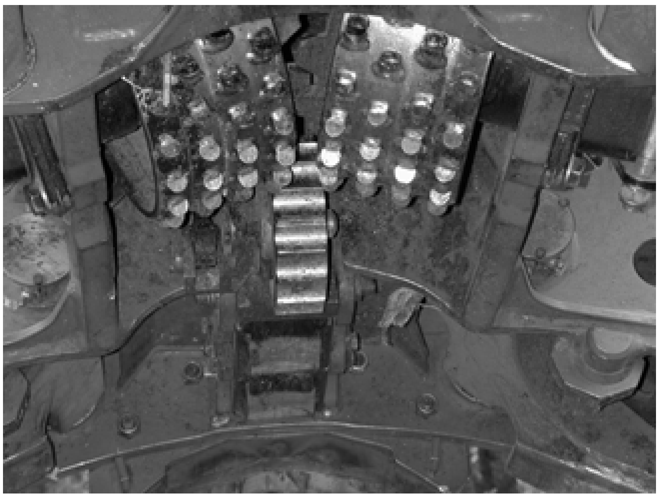

Figure 2. The wide measuring wheel that remains in contact with stem bundles.

Study methodology

FERIC conducted three different field studies of this technology in eastern Canada (two in 2001 and one in 2002). In two studies, the head was mounted on a tracked carrier such as the Timberjack 608L (Figure 3); in the third, it was installed on a wheeled Timberjack 1270B carrier (Figure 4). Large tracked carriers are well suited to final felling of mature stands on soft or hilly ground, whereas wheeled carriers are best suited to rocky sites and thinning applications. For the field studies, FERIC conducted short-term productivity evaluations using hand-held field computers and an in-house time study program called TS-1000. Complete work cycles were recorded, including time elements, the number of logs produced per assortment type, and the number of trees per cycle. The harvested stands were cruised prior to harvesting, and a sample of logs from each assortment type was scaled. Where possible, log pairs or triplets produced during multi-stem cycles were marked with paint so their lengths could be measured separately and compared with the average length of all sampled logs in the same assortment. The delimbing quality for these and other logs was assessed visually.

Figure 3. The multi-stem head on a tracked carrier.

Figure 4. The MULTI-stem head on a wheeled carrier.

Study results

Table 1 describes the results of FERIC's productivity studies in three different clearcutting operations. The productivity without multi-stem processing was estimated by using the mean positioning and cutting times for single-stem cycles to replace the recorded positioning and cutting times in cycles that combined felling and multi-stem processing, and by reducing the number of stems per cycle to one. The average processing time was also reduced by 10% to account for occasional difficulties encountered when processing multiple stems. All other work-cycle time elements such as moving, brushing, and miscellaneous delays were spread uniformly among all cycles.

Table 1. Productivity and quality results from the three field studies of the Waratah HTH-470HD: MTH = multi-tree handling, STH = single-tree handling.

	Site 1 (Spring 2001)	Site 2 (Summer 2001)	Site 3 (Fall 2002)
Stand and terrain conditions			
Stand	Fir – spruce	Spruce – jack pine	Spruce – jack pine
Density (stems/ha)	600	1 300	1 300
Volume/stem (m³)	0.10	0.10	0.10
Volume/ha (m³)	160	130	130
Terrain	Rough and hilly	Flat and soft	Flat and firm
Productivity			
Proportion of multi-stem cycles (%)	40	31	40
Stems/PMH[a]	157	154	155
Volume/PMH (m³)	16.0	15.1	15.4
Calculated productivity STH (m³/PMH)	12.0	12.5	12.4
Effect of MTH (% productivity increase)	+33	+21	+24
Length-measurement accuracy			
Proportion of logs within ±5 cm of target length (%)	80	88	92

[a] PMH: productive machine-hours (productive time minus non-operational delays and operational delays exceeding 15 minutes).

The ability to handle more than one stem at a time increased productivity by an average of 21 to 33% compared with harvesting similar stems one at a time. On average, multi-stem work cycles were longer than single-stem cycles, but the ability to process more than one stem at a time in 30 to 40% of the cycles lowered the mean harvesting time per stem. Obviously, such productivity gains cannot always be guaranteed, since they depend on several factors, including the operator's skill, the spatial distribution of the stems within the stand, and the mean stem volume. The smaller and more clustered the trees, the more opportunities exist for multi-stem felling and processing.

Figure 5 illustrates the effect of DBH on the productivity with and without multi-stem processing over the observed range of study conditions. It's clear that as mean diameter increases, the advantage offered by multi-stem processing decreases. At a DBH of around 20 cm, the two lines meet, since it becomes difficult to process more than one stem at a time with larger trees.

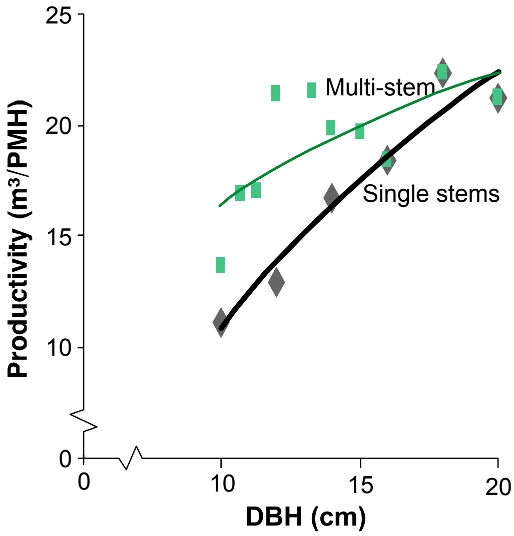

Figure 5. The effect of stem diameter on productivity with single stems and with multi-stem handling.

The usual concern with multi-stem processing relates to the quality of the logs produced, and particularly to the delimbing quality and length-measurement accuracy. In the field, we observed no difference in delimbing quality between logs produced by processing one stem at a time or with multi-stem processing. The five knives and four feed rollers of the HTH-470HD head seem to provide excellent contact with the stem surface during processing.

Table 1 shows that the proportions of logs whose length was within 5 cm of the target length were low in our initial studies (at 80%), but results steadily improved as the manufacturer modified the measuring wheel system to provide better contact with the stems during multi-tree cycles. A larger measuring wheel typically increases measurement accuracy since it is less affected by stem movements within the head during processing (Makkonen 2001). The last study provided very good results, with 92% of the logs within 5 cm of the target length and 95% of the logs within a 13-cm spread. The length accuracy for logs produced during multi-tree handling cycles was not less than those produced in single-tree handling cycles (Figure 6). It should be noted that these values are comparable to those obtained in other operations studied by FERIC that used conventional heads (Plamondon 1999).

Figure 6. 5-m logs produced during MTH cycles (marked) and STH cycles (unmarked).

Discussion & conclusions

Our studies clearly demonstrated the benefits of the Waratah HTH-470HD head's multi-stem technology, particularly the increased harvesting productivity with small trees. Because the head doesn't cost significantly more than other heads in its class, it represents an attractive option when purchasing a new or replacement head. Its relatively low weight (1285 kg) also makes it suitable for installation on most 16- to 20-tonne tracked carriers.

It's not essential to handle stems of the same dimensions (DBH or length) during multi-stem processing cycles. However, large differences in DBH (more than 4 cm) can create problems during processing of the top-end logs, since the point at which the minimum utilization diameter arises may not occur at the same position on the stem. Being able to produce pulpwood in a random-length environment definitely enhances fiber recovery with multi-stem processing.

Despite the head's good design, multi-stem processing does present a higher risk of quality losses compared with conventional heads, particularly in terms of length measurement; thus, operators should remain vigilant and conduct frequent quality checks of the logs produced especially if multi-stem cycles are common.

The performance of the head in single-tree handling is as good as or better than other heads on the market, which means that the multi-stem capabilities are simply a bonus feature to be used where feasible and advantageous, *but not necessarily to be used systematically in all cases*. Since the head suffers no penalties when it handles a single stem at a time, operators should avoid "forcing" multi-stem cycles under unfavorable conditions such as in difficult delimbing situations. As well, little time is saved by trying to harvest widely scattered stems within the same work cycle.

The greater productivity of the HTH-470HD head with small stems compared with conventional heads makes it an attractive tool in commercial thinning or other partial cuts because its productivity is less affected than other heads on the market by small stem sizes. The accumulator that keeps felled stems vertical also provides benefits, since it lets the operator control the fall of the felled stems and possibly reduce the risk of damaging residual stems.

The Waratah HTH470HD head has only been on the eastern Canadian market for a couple of years but it has already done well from a commercial perspective. At the time of writing this paper, more than 25 heads were in operation, mainly in clearcutting applications.

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Butt damage associated with feller-bunchers in winter operations

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Summary

To examine the issue of butt damage from feller-bunchers with high-speed circular saws, FERIC examined 1200 stems felled on 12 different cutblocks near Mackenzie, British Columbia and Manning, Alberta.

Overall, 19.7% of the stems had damaged butts. This resulted in an average loss in sawlog volume for lumber manufacturing of 0.2% of the merchantable stem volume. The frequency and extent of the butt damage were found to vary with stem diameter, felling technique, and condition of the cutting teeth. In general, butt damage was more extensive among small-diameter stems than among larger-diameter stems; among multiple-felled stems than among single-felled stems; and among stems felled with dull cutting teeth than among stems felled with sharp cutting teeth.

Differences in stem size, tooth sharpness, and multiple-tree felling did not explain all the variations in the recorded butt damage. Logging contractors attributed differences between the studies to conditions that made trees on some sites more susceptible to felling damage. However, this theory could be neither substantiated nor discarded. It also appeared that changes in the wood quality program of one of the cooperating companies, with emphasis on reducing butt damage, influenced the results, as a considerable reduction in butt damage had been observed since these changes were made.

***Keywords**: Feller-bunchers, butt damage, stem size, tooth sharpness, multiple-tree felling*

Introduction

Feller-bunchers are the most common machine for felling trees in western Canada. They are used in the traditional feller-buncher/grapple-skidder/ roadside delimber-processor systems, and also in combination with cut-to-length processors operating at the stump-area or at roadside. Consequently, more than 75% of the timber volume harvested in the interior of British Columbia, Alberta and Saskatchewan is estimated to be done by feller-bunchers equipped with high-speed circular saws.

Butt damage from feller-bunchers was a concern to operators of sawmills when the feller-bunchers were equipped with tree shears. Studies by FERIC in the early 1980s showed volume losses from butt damage of between 3.5 and 4.5% for felling machines with tree shears, compared to 0.1 to 1.9% for non-shear machines (McMorland and Guimier 1984). As various types of saw heads were developed and improved, they replaced tree shears. With this change, butt damage was reduced considerably and generally stopped being an issue. However in recent years, sawmill operators have reported end-splits on sawn lumber typically associated with butt damage from felling operations. In response to these reports, FERIC initiated a study in 2001 to examine butt damage from felling with high-speed circular saws in winter operations.

Description of studies

The overall objective of the study was to evaluate the butt damage associated with feller-bunchers equipped with high-speed circular saws. The specific objectives were to:

- Record butt damage from feller-bunchers in winter operations.
- Determine the impact of tree size, multiple-tree felling[1], and tooth sharpness on butt damage.
- Recommend strategies for reducing butt damage.

The field data were collected in January 2001 and January 2002 on regular harvesting operations near Mackenzie, British Columbia and Manning, Alberta (Figure 1). All feller-bunchers were equipped with high-speed circular saws but included carriers, felling heads, and saws from different manufacturers. No changes were made to normal felling patterns or operators' work habits, except when data for evaluating multiple-tree felling were collected (Figure 2).

Figure 1. Location of study sites in British Columbia and Alberta.

[1] Trees are cut one by one, but two or more trees are accumulated in the felling head before being bunched.

Figure 2. Feller-buncher at single-tree study site near Manning, Alberta.

The operating conditions on the study sites ranged from flat or gently rolling terrain to 30% slopes with the occasional steeper grade, and snow depths from 0.3 to 1 m. Stand composition varied from mature to overmature conifer stands of white spruce (*Picea glauca* (Moench) Voss), lodgepole pine (*Pinus contorta* Dougl.), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) to mature aspen (*Populus tremuloides* Michx.)/spruce mixtures. Average tree size per site ranged from 0.2 – 0.5 m^3, and the ambient temperature during data collection varied from –20° to 0°C.

A total of 1200 conifer stems were examined on 12 felling sites prior to skidding. The stems were randomly selected from sound stems located on top of the bunches and accessible for measuring. The diameters at the butt, and at 1.0 and at 5.0 m from the butt were recorded for each stem. A 5-cm thick cookie, assumed to represent the normal end-trimming of logs in sawmilling, was cut from the butt of each selected stem. The butt surface was then examined for visual damage. If there was no visual damage, a second cookie was cut and examined to ensure that the butt surface was free from hairline cracks. If butt damage was present, the type (split or torn piece) and the location of the butt damage were recorded (Figure 3). Additional cookies were cut from stems with end splits and each new butt surface was examined for damage until it was clear that the remaining stem was free from butt damage. The length of the damage was measured by totalling the thickness of the cut-off cookies and adding 0.75 cm kerf for each chainsaw cut made.

FERIC assumed that all butt logs were 5.0 m long, and uniformly tapered based on the diameter measurements at 1.0 and 5.0 m. The log's net butt diameter[2] was determined using the log's taper, and the volume was calculated with Smalian's formula. The total merchantable stem volume was calculated from data obtained in prior studies on the relationship between the total volume of a stem and the volume in its 5-m long butt log.

Only damage that occurred within the net butt diameter was assumed to affect lumber recovery from the log. The loss of sawlog volume available for lumber

[2] Actual butt diameter reduced to account for butt flare.

manufacturing was calculated using the same method as used in recent FERIC studies to quantify wood damage in illiard handling operations (Andersson et al. 2002). This calculated volume loss does not necessarily correspond to an equal percentage reduction in lumber recovery. It should therefore be seen as a 'wood loss index' for comparing the wood damage associated with different harvesting practices.

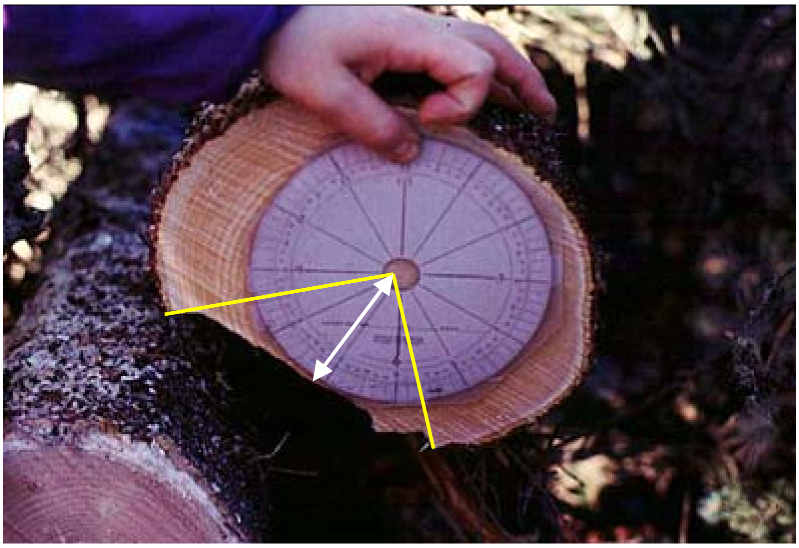

Figure 3. Measuring extent (sector) and location of butt damage.

Results

In the initial analysis to determine common factors and trends, FERIC found that the butt damage varied with stem diameter, felling technique (single-tree versus multiple-tree), and condition of the cutting teeth (old versus new). While these factors did not explain all the variations in butt damage, no other measurable factors (e.g., number of teeth per saw, or operator experience in years) could be correlated to the recorded butt damage. Thus, the data from some sites were combined and analyzed for six particular treatments.

The butt damage consisted typically of a single split or a piece torn from the side of the butt. The majority of the damage was located in the outer quarter section[3] of the net butt surface. The length of the damage on individual stems ranged from 4 to 280 cm, but most of the damage (69%) was confined to within the first 30 cm of the stem length. Less than 2% of the stems had damage that extended more than 60 cm from the butt.

The frequency of stems with damaged butts ranged in the different treatments from 9 to 53%. However, some of the stems were only damaged outside the net butt diameter. Excluding this damage, the frequency of damaged butts with loss of sawlog volume ranged from 8 to 33% (Figure 4). The projected loss of sawlog volume from the butt damage ranged from 0.04 to 0.5% of the total merchantable stem volume.

The butt damage was generally more extensive among small-diameter stems than among larger-diameter stems. For example, the damage frequency for

[3] Measured from the centre of the butt surface.

stems with dbh ≤20 cm was double compared to stems with dbh >30 cm, and the projected loss of sawlog volume was nearly five times higher (Figure 5). Similar trends were also recorded in the other treatments, although the differences varied in magnitude (Figure 6).

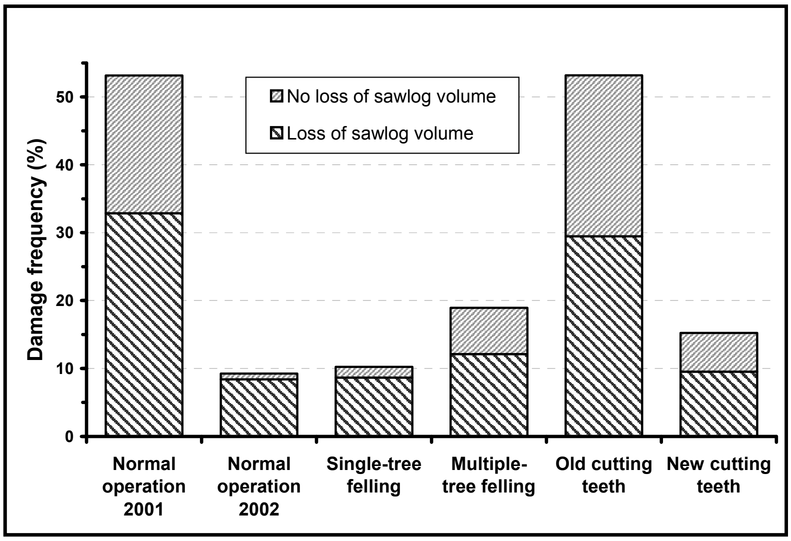

Figure 4. Butt damage frequency by treatment.

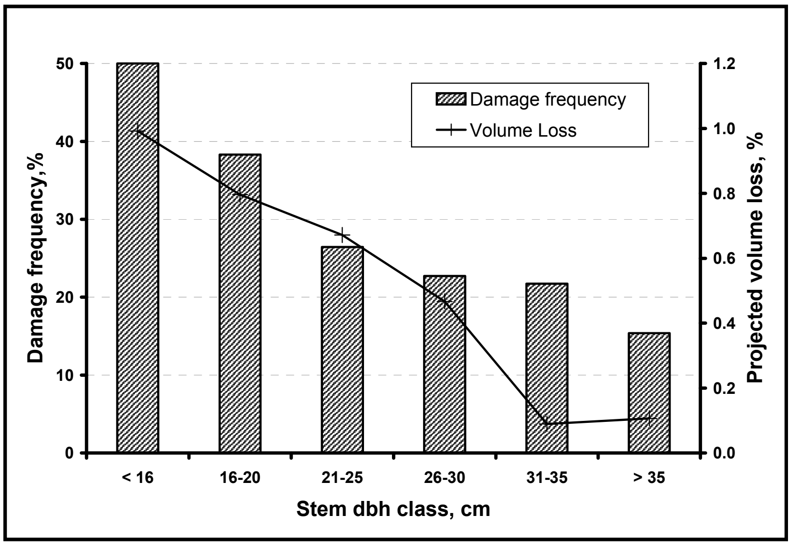

Figure 5. Butt damage by diameter class in Normal Operation 2001.

The volume loss among multiple-felled stems was four times that of the single-felled ones. Part of this was from higher damage frequency (12% compared to 9%), but mainly because the damage was more severe (closer to the centre of the butt and extended further up the stem) among the multiple-felled group.

The sharpness of the cutting teeth also influenced the severity of butt damage. Cutting teeth that had been in use for between 150 – 200 hours caused more butt damage in terms of frequency and loss of sawlog volume than teeth that been in use for about 20 hours. Overall, 30% of stems felled with old teeth were damaged compared with 10% of the stems felled with new teeth. The volume loss among the stems felled with old teeth was nearly six times that of stems felled with new teeth (Figure 7).

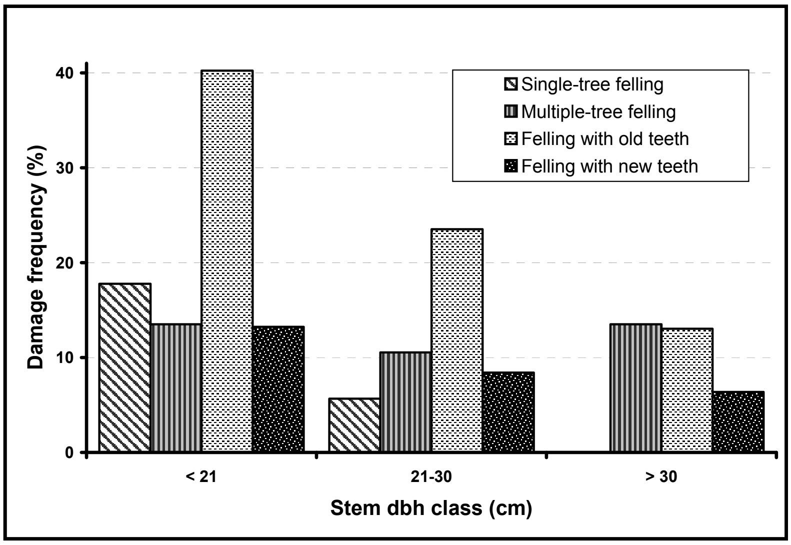

Figure 6. Damage frequency by treatment and stem dbh class.

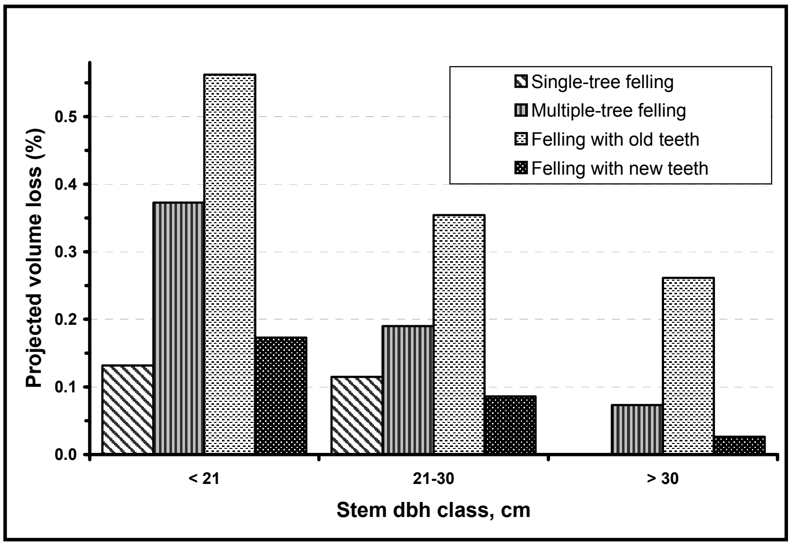

Figure 7. Loss of sawlog volume by diameter class and treatment.

FERIC found a considerable difference in butt damage between stems examined in the same general operating area and with the same group of logging contractors, but one year apart (Normal operation 2001 versus Normal operation 2002). The butt damage frequency had been reduced from 33 to 8% and loss of sawlog volume was reduced from 0.5 to 0.1% of merchantable stem volume. This difference had also been noticed at the cooperating company's sawmill. Some of the logging contractors believed that this reduction was associated with trees on some sites being more susceptible to felling damage. Unfortunately, this theory could be neither substantiated nor discarded. On the other hand, the company had, prior to the start of the 2002 logging season, strengthened its wood quality program in an attempt to reduce the butt damage experienced during the 2001 harvesting season. The impact of human factors coupled with regular quality checks and feedback to operators (now part of the wood quality program) has been shown in other studies to greatly influence wood quality issues. Thus, some of the reduction in butt damage from 2001 to 2002 can likely be attributed to the changes in the wood quality program.

Discussion

As one of the underlying causes of butt damage is the bending force applied to the tree at the time of felling (McMorland 1985), a key to preventing butt damage is the ability of the operator to position the felling head and sever the tree completely without subjecting it to bending forces (Figure 8). A program aimed at reducing butt damage should therefore include educating operators on the impact of butt damage on sawmill revenue, and assisting operators to develop felling techniques that would minimize the bending forces exerted on trees during felling.

However, trees are sometimes subjected to natural bending forces (e.g., wind or snow) or are leaning in a direction that makes it difficult to position the felling head squarely against the stem. Feller-bunchers equipped with head rotate and tilt will make it easier for operators to position the felling head at the stem with minimum or no bending forces. The cut must also be done quickly to minimize the risk of end splitting (Helgesson 1997). Therefore the cutting teeth must be kept as sharp as possible and the felling head in good operating condition.

Figure 8. Bending forces applied to tree during felling.

Although multiple-tree felling increases the risk of subjecting some trees to bending forces and thereby increases the risk of butt damage, it also increases machine productivity compared to single-tree felling. This increased productivity results in a lower felling cost that will likely more than offset the loss in revenue from more butt damage associated with multiple-tree felling, if kept at a reasonable level. However, at some point additional accumulation of trees in the felling head will likely cause more revenue losses from butt damage than is gained in reduced harvesting cost. That issue could not be addressed in this study.

The studies comparing the influence of tooth sharpness were done under normal operating conditions involving different machines, operators, and site conditions. Thus, factors other than the condition of the teeth could have influenced the results. The condition of the teeth may also have varied, as "hours-in-use" are not necessarily good indicators of sharpness. However, the large difference in the butt damage between stems cut with old and new saw teeth shows that the sharpness of teeth had a considerable impact on butt damage. Operators also reported improved productivity with sharp teeth.

While it is easy to accurately measure the occurrence and physical extent of butt damage in the studies, its actual impact on lumber recovery is more difficult to assess without a mill study. The actual impact on lumber recovery would depend on factors such as the type of sawmill equipment, products sawn, position of the log during the breakdown process, and the presence of other log defects. Thus, the results in this report should be seen as indices for comparing the butt damage associated with different felling practices.

Butt damage was also recorded and analyzed with the Bicycle-Wheel Method developed by FERIC in the 1980s for comparing butt damage between different felling alternatives (Guimier and McMorland 1981). This method can also be used to predict the effect of butt damage when different lumber dimensions are manufactured. Compared to the method used in this study, the Bicycle-Wheel Method projected a higher wood loss (Figure 7). The difference in predicted wood loss between the two methods was most pronounced for butt damage that had occurred in the outer two-thirds of the butt surface.

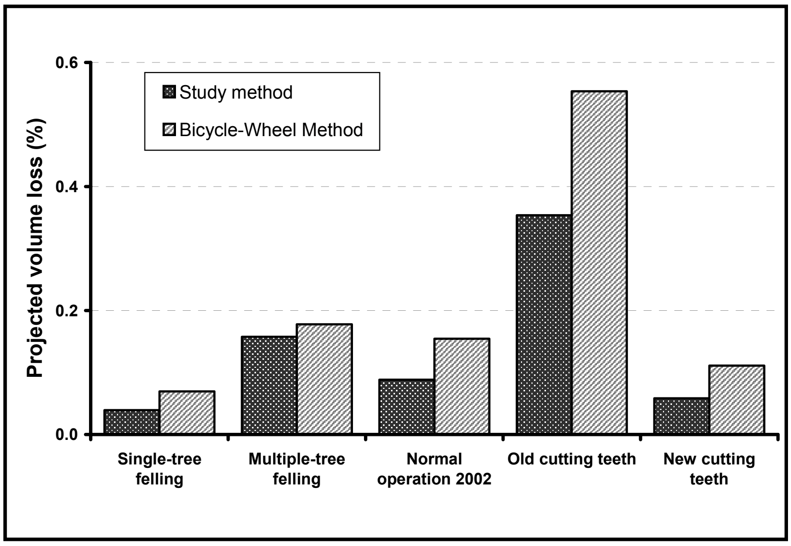

Figure 9. Comparing projected loss of sawlog volume between assessment methods.

Conclusion

The frequency of butt damage and the loss of sawlog volume associated with butt damage were found to decrease with increasing stem diameter. Multiple-tree felling was also found to cause more butt damage than single-tree felling, although the difference was less noticeable for butt damage frequency than for loss of sawlog volume. Overall, 9% of the single-felled trees were damaged compared to 12% for the multiple-felled trees, and the loss of sawlog volume among the multiple-felled trees was four times that of the single-felled ones. The difference in volume loss between the two groups decreased with an increase in tree size.

Cutting teeth that had been in use for 150–200 hours caused more butt damage both in terms of frequency and loss of sawlog volume, than teeth that had been in use for about 20 hours. Overall, 30% of stems felled with old teeth were damaged compared with 10% of the stems felled with new teeth, resulting in a loss of sawlog volume that was nearly six times that recorded for sharp teeth. The difference in damage frequency was somewhat higher for small-diameter stems than for larger-diameter stems.

Differences in stem size, tooth sharpness, and multiple-tree felling did not explain all the variations in butt damage recorded in the studies. Logging contractors attributed differences in the butt damage between the studies conducted to the conditions that made trees on some sites more susceptible to felling damage. However, this theory could be neither substantiated nor discarded. On the other hand, changes in the company's wood quality program may have influenced the results, as more emphasis is now being placed on reducing butt damage.

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