Small Tree Harvesting with a Farm Tractor and Crane Attached to the Front

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ABSTRACT

A farm tractor was modified to become a single-grip harvester. A forest crane was attached to the front. Time studies on 695 trees in a clear cut stand and 793 in a thinned stand indicated that productivity was similar that of Nordic specialized harvesters and of farm tractors with a rear-mounted crane. The ability to operate was good where terrain was easy and ground surface was first class. Rough terrain slowed down moving speeds considerably because of the rigid frame.

Ergonomic assessment according to a 13-point checklist appeared to be not at the same level as that of specialized Nordic forest machines, but some of the ergonomic factors could be improved rather easily and at low cost. This machine can also be used for other types of work such as cleaning verges from bushes and in conventional farming operations, which have different ergonomic demands.

The relatively low investment cost compared with that of specialized Nordic machines should contribute to reduced ownership costs.

Keywords: *attachments, base machine, farm tractor, forest crane, harvesting.*

INTRODUCTION

Farm tractors are often used in forest operations, particularly in small scale forestry. Some possible advantages when compared to specialized Nordic forest machines include:

- increased flexibility (they can also be used for other types of work).
- lower capital investment.

This increased flexibility and relatively low capital input can reduce the need to maintain high productivity and annual utilisation.

Time studies of farm-tractor-based single-grip harvesters have indicated a relatively good productivity in comparison with specialized Nordic single-grip harvesters [11]. The forest cranes in those studies were attached to the rear of the tractors.

The ergonomics of farm-tractors with a rear-mounted forest crane, or with the crane on the trailer, are often not acceptable. Often the operator has to work in a twisted and exhausting position as the operator's seat is mostly not turnable. On machines where the seat can be turned backwards, the room for the feet, legs, and knees is usually too narrow.

Attaching the forest crane to the front could allow the owners of such tractors to use them in the forest for part of the year. Tractors that can then be used are, first of all, those with seats that cannot be turned and those with too little room for feet, legs, and knees when the seats are turned in backwards position.

OBJECTIVES

Time studies and ergonomic evaluation were conducted with the aim of determining the possibility of using a farm-tractor-based single-grip harvester, with the crane attached to the front, in forest harvesting operations. The study evaluated:

- suitability for use in forest harvesting operations.
- productivity in small tree harvesting.
- possibility to obtain good ergonomics.

MATERIALS AND METHODS

Standard definitions of elements used in Swedish time studies often differ from those used in other countries. One commonly used term is *effective time* which is defined as productive time with no delays [4]. The unit used is hundred(s) of a minute *(cmin)*.

Other terms used are defined as follows:

Thinning area -area with a large number of trees (stand). Some of the trees are to be harvested (thinned).

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Strip road - the road on the thinning area along which the machine is moved. The thinning area contains mostly a net of strip roads.

Crane zone - that part of the thinning area where the trees can be felled by crane from the strip roads.

Middle zone - that part of the thinning area that cannot be reached by the crane from the strip roads. The trees in the middle zone are felled manually towards the strip roads from where they are then processed.

Work station - the position from which the machine processes/harvests trees within reach of the crane.

Work cycle - the whole work for harvesting one tree. All elements included in work cycle are (in order): extending crane/positioning, felling/processing, and release top/moving slash.

Volume in this report refers to solid volume including bark. Diameter is quoted outside bark, according to the mean of each size-class. The width of each size-class was 1 cm. The machine was evaluated by studying the damage to remaining trees [5], in order to see when the machine caused damage and how serious the damage was. Damage was measured in the following six size-classes: 0–10, 11–50, 51–100, 101–200, 201–300, and larger than 300 cm^2. Location of damage was measured in three classes, namely:

1. stump (1% of tree height) and roots within horizontal distance of 70 cm from the stem surface at stump height.
2. from stump up to 1.5 m over stump.
3. the rest of the stem.

The machine

The machine studied was a Case 5120 farm tractor with a single-grip harvester attached (Figure 1). The tractor had been operated for 550 hours before being used in forest harvesting. A forest crane was attached to the front of the machine. The harvester head was second-hand but totally renovated. Specifications appear in Table 1. The investment for tractor, crane, harvester, extra pump, etc. was approximately US $ 93 000. The labour cost for modifying and making the concept complete was estimated to be approximately US $ 15 000. The market price

Figure 1. Case 5120/Mowi EGS 460/GM 728.

(including sales cost, profit, etc.) should be approximately US $ 130 000, less than half the price of a specialized small Nordic single-grip harvester.

Modifications included:

- an extra pump installed for increased hydraulic capacity,
- an extra window istalled in the front of the roof,
- front window and door glass replaced with safety glass,
- front axle stabilized by adding hydraulic cylinders,
- salt water added to rear tires,
- measuring equipment, levers, and arm rests fitted,
- bonnet volume in front decreased,
- holders for the crane attached to the frame.

Fuel consumption was also measured throughout the entire study.

The stands

Harvesting with the machine was studied in two stands, a 30-year old spruce (*Picea abies*) stand to be thinned and a 90-year old mixed stand (pine/*Pinus silvestris*, spruce/*Picea abies*, birch/*Betula pubescens*, and aspen/*Populus tremula*) to be clear cut (Table 2). In the stand to be clear cut the small trees were to be harvested with the machine studied, and the large trees were to be harvested with a large specialized

Table 1. Specifications of the base machine and attachments.

Base machine:	**Case 5120**
Engine	66 kW (1800 rpm)
Gear box	Manual, 4 pos. + group gear 4 pos. Forwards and reverse, electric lever
Brakes	Hydraulic, wet brake discs placed on the differential
Steering	Hydrostatic with steering wheel
Electric system	12 V, generator 95 A
Hydraulic system	Load sensing and constant pressure Flow: 140 litres x min^{-1} Pressure: max. 21 Mpa Tank volume: 255 litres
Tires	Front: 14.9 R 24 Rear: 16.9 R 38
Forest crane:	**Mowi EGS 460**
Type	Parallelogram
Reach	5.9 m
Turning angle	220°
Mass	750 kg
Harvester head:	**Grangärde GM 728**
Maximum cutting diameter	350 mm
Maximum delimbing diameter	280 mm
Feeding speed	0 - 3 m x sec^{-1}
Oil tank	4.5 litres
Delimbing tools	4 movable knives
Mass incl. rotator	335 kg
Mass of machine, incl. attachments	7750 kg
Mean ground pressure	
- front axle	88.5 kPa
- rear axle	52 kPa
- total	66.5 kPa

Table 2. Stand data (including terrain conditions [3]) in the studied stands.

	Thinning	Clear cut
Basal area, $m^2 \times ha^{-1}$	23.25	24.3
Species mix (pine, spruce, deciduous), in tenths	0,10,0	3,6,1
Number of trees per hectare	2120	940
Mean diameter of harvested trees, cm	12.9 ± 3.8 (SD)	16.4 ± 5.4 (SD)
Mean volume of harvested trees, m^3	0.096	0.194
Ground conditions	Very good	Very good
Surface structure	Very even	Medium class (some portions of the stand were worse than medium class).
Slope	Less than 7 degrees	Less than 7 degrees

Nordic single-grip harvester. Diameters and heights of trees varied widely. The stand to be thinned was first the generation on an afforested pasture, where the stems were heavily branched. Diameters and heights of the trees varied less than in the stand to be clear cut. The stands were located in the south of Sweden and the study was carried out in September with no snow on the ground. Terrain conditions were assessed according to a scale of five levels, from very good (very good ground condition, very even ground surface, slope less than 7 degrees) to very poor (very poor ground condition, very uneven ground surface, slope more than 26 degrees) [3].

Harvesting methods

The cut-to-length method was used in both stands. Logs were to be cut to lengths within the interval 2.5–5.5 m. In the clear cut the machine harvested the smallest trees from a work station within crane reach before moving to a new work station. There were no strip roads. Large trees were left to be harvested by another method, and operation was not studied. By taking only the smallest trees it was not a traditional clear cut operation, but as the rest of the trees were intended to be harvested shortly afterwards the operation is called "clear cut" in the following. In the stand to be clear cut 695 trees were studied.

In the initial phase of the thinning, the machine moved from work station to work station along strip roads, harvesting selected trees within the crane zone. Middle zone trees were then felled manually with tops towards the strip roads. These trees were repositioned and processed from the butt by the machine as it worked along the strip roads a second time. In the stand to be thinned 793 trees were studied (574 trees in the crane zone, 219 trees in the middle zone). Mean distance between strip roads was 19.2 m, and mean strip road width was 3.4 m.

The one operator who was used in the study had only one month experience with this machine, but had operated forwarders for six years, a Logma processor for three years, and an FMG Eva single-grip harvester for one year. The operator decided which trees were to be harvested.

Time study

The diameters of all trees in the stands were measured and marked on the trees. Heights of sample trees in each stand were measured to get tree volume. The time study was carried out during the harvesting operation, in normal production, using Husky Hunter time study equipment. All elements were recorded. However, down time for breaks, repairs, maintenance, etc. was not analyzed. Time for repairs and maintenance should be the subject of a follow-up study during a longer period. The distance to the strip road and the distance of crane extension for each tree was ocularly estimated.

Assessment of ergonomics

Ergonomics were assessed using a Standard Swedish checklist of 13 characteristics [2]. Assessments were made by measuring and/or categorising the machine and interviewing the operator. Each characteristic can be measured/categorised according to a scale of five levels, from very poor to very good. If a characteristic was measured as very poor, it complied with given criteria to a very low degree. If it was measured as very good, it complied with given criteria to a very high degree. Some of the factors had to be categorised subjectively since the checklist criteria are not precise. The scale was coded from 1 to 5, where 1 is very poor and 5 is very good.

Vibrations were measured with a Brüel & Kjær 2231/S vibration unit 2522 (module BZ) and a Brüel & Kjær 4322 tri-axial accelerometer. Whole body vibrations were measured for three directions [1]: x (forwards/backwards), y (sidewards), and z (up/down). Noise level was measured with a Brüel & Kjær 2221 sound level meter. Visibility was analyzed using a Nickometer G6 by measuring the position of head and neck, respectively. Lighting was not measured.

Analysis

The time study data was analysed by regression analysis. Time consumption is shown by a model and by means. Effective time was used to measure time. Productivity was used as per effective time.

Tested variables for a regression model were tree species, diameter at breast height, diameter squared, tree length, tree volume, number of logs per tree, distance of tree to strip road, and reach distance of the crane. The variables were tested individually or combined. Tree volume was the only variable which explained a large proportion of the original variation in time consumption. Contribution from other variables was limited. As variation in time consumption is large and there were variables that could not be controlled, there is no reason to use a more sophisticated model than is shown below.

RESULTS

Time per work cycle

Time is described according to the following model, and does not include moving forward:

$T = a + b \times Vol$

T = time per work cycle, cmin per tree
a = intercept in regression
b = regression coefficient
Vol = volume per tree, m^3

The model is presented in Figure 2. Mean time is presented in Table 3.

Productivity in the clearcut for the farm-tractor-based single-grip harvester was 52 trees (10.0 m^3) per effective hour (Table 4). Productivity in the thinning was 57 trees (5.4 m^3) per effective hour. Productivity for three medium-sized single-grip harvesters in the thinning varied in one study, in the same stand, from approximately 85 to 115 trees per effective hour [10] (Table 4). Mean diameter was smaller in that study, but ground conditions were worse, surface structure was more uneven, and slope was within the interval 6–11 degrees. In a study of three farm-tractor-based single-grip harvesters with attachments on the rear, productivity varied from 68 to 106 trees per effective hour [11] (Table 4). Terrain conditions were about the same as for the Case 5120.

Ergonomics

The ergonomic checklist results are summarized in Table 5. Some factors that need special mentioning are as follows:

Visibility: The angle between a horizontal line from the operator's eyes and a line from the operator's eyes to the upper edge of the front window was 35°, and was measured on a 180 cm tall person. On specialised forest machines this angle can be much larger [7, 8]. When analyzing visibility it was found that the operator was looking upwards much more in the thinning than in the clear-cut (Figure 3). However, to achieve an acceptable upwards view, the operator had to stretch his neck forward as the roof-window was too small (Figure 4). Work position then became less acceptable.

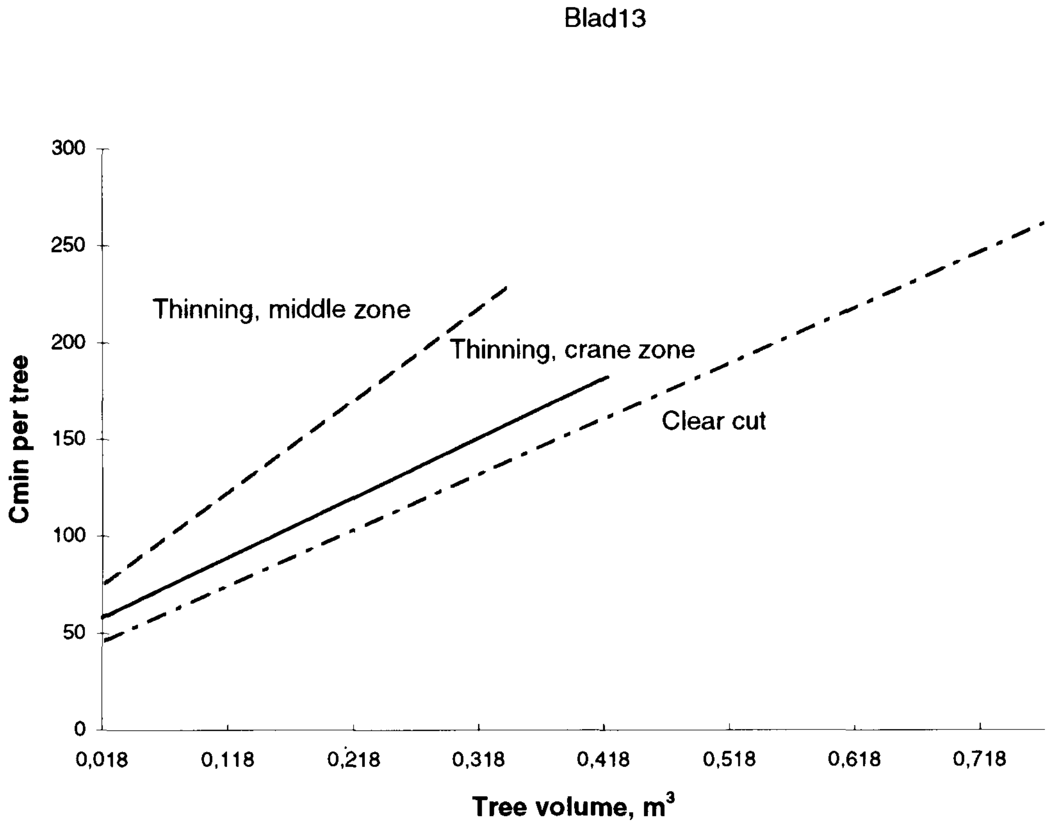

Figure 2. Time per tree (cmin) by tree volume in clear cut and thinning.

Table 3. Mean time per tree (effective), cmin, in clear cut and thinning.

Stand	**Time per tree by element, cmin**				**No. of trees per work station**
	Extending crane	**Processing/ harvesting**	**Release top/ moving slash**	**Moving time**	
Clear cut	19.8 ± 8.8 (SD)	75.9 ± 49.0 (SD)	0.3 ± 3.0 (SD)	20.8	3.0
Thinning					
- crane zone	22.2 ± 10.6 (SD)	60.3 ± 28.1 (SD)	-	15.3	3.0
- middle zone	19.6 ± 9.6 (SD)	90.8 ± 52.3 (SD)	0.6 ± 4.2 (SD)	16.4	2.6

Table 4. Productivity in thinning of the farm-tractor-based single-grip harvester compared with three Nordic single-grip harvesters [10] and three farm-tractor-based single-grip harvesters with rear mounted crane [11].

Machine	Reach, m	No. of trees per hectare	Mean diam., cm	Productivity, trees (m^3) per effective hour
Case 5120/GM 728	5.9			
- clear cut (smallest trees)		940	16.4	52 (10.0)
- thinning (crane zone)		2120	12.9	62 (6.0)
- thinning (middle zone)		2120	12.7	48 (4.4)
Valmet 901 [10]	9.5	2700		
- crane zone and middle zone[1]			10.1	105 (4.6)
- no middle zone			10.1	115 (5.1)
Rottne Rapid [10]	10	2700		
- crane zone and middle zone[1]			10.1	85 (3.7)
Bruun Two [10]	5.1	2700		
- also working off strip road			10.1	110 (4.8)
MB Trac 1000/Tapio 250 [11]	6.7	2007		
- crane zone			10.5	106 (4.6)
- middle zone			10.3	93 (3.9)
Ford 276 Versatile/Tufab GS 302 [11]	5.3	1580		
- crane zone			13.8	89 (12.4)
- middle zone			14.8	78 (13.3)
Ford 276 Versatile/Tufab GS 301 [11]	5.5	1540		
- crane zone			14.2	86 (13.9)
- middle zone			17.0	68 (16.0)

[1]"Crane zone and middle zone" is a total average for both zones where middle zone trees are felled manually.

Table 5. Ergonomic checklist results assessed and coded (by the author) according to a scale of five levels, from very poor (=1) to very good (=5) [2].

Ergonomic factor	Assessed level	Remarks
1. Entering/exiting	2	The ladders on both sides were demolished. Construction was not good enough for forestry conditions.
2. Work position	3	Obstructive pedals on the floor. Elbow-rests (Frameco) were not sufficiently adjustable. Levers obstructive for elbow-rest to the right. Poor view upwards.
3. Cabin	3	Cabin ceiling too low. Rear end of cabin difficult to clean. Hydraulic hoses and valving inside cabin.
4. Operator's seat	2	Back of the seat too low. Stability for the seat not acceptable . Ventilation for seat cover not acceptable. Elbow-rests were not sufficiently adjustable.
5. Levers	4	Mechanical gear box.
6. Instruments	4	Larger figures on data display desired.
7. Climate in cabin	2	Cabin temperature too high during summer (heat from engine and hydraulic tank). The temperature during winter was better.
8. Visibility	3	Visibility upwards (especially in thinning) not acceptable.
9. Lighting	–	Not measured.
10. Noise	3	79 dB(A) with fan switched on and one side window opened. 76.2 dB(A) with the fan switched off and the side window closed. Ear protectors should be used.
11. Exhaust gas and dust	–	Not measured
12. Vibrations	4	The rigid frame (front wheel steering) could cause relatively bumpy driving when the ground surface is not flat.
13. Maintenance	4	The fuel tank was made of plastic material, and was partially unprotected.

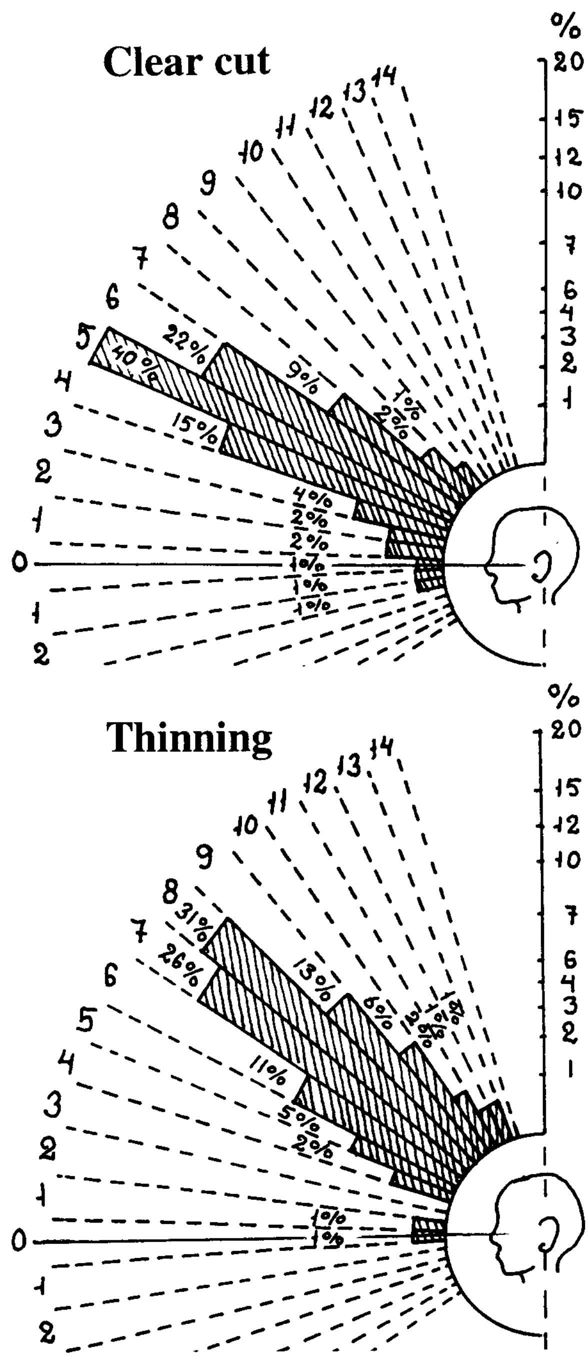

Figure 3. Time during which the operator is holding his head in different positions, up/down, (area in shade) when looking at trees, in percent of operating time. The sector numbers range between ø (looking forward) to 14 (looking upward). The angle for each sector is 5 °.

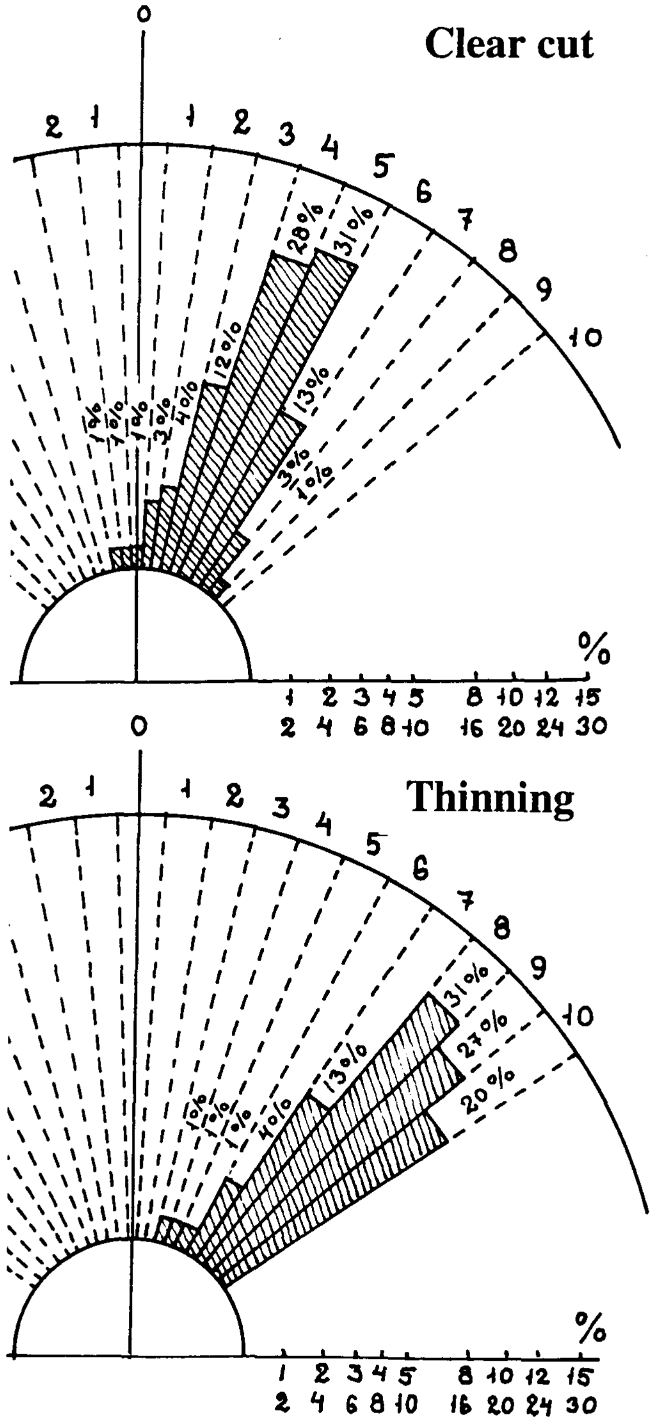

Figure 4. Time during which the operator is stretching his neck forwards (area in shade), when looking at trees, in percent of operating time. The sector numbers range between ø (operator's neck is parallel to a vertical line) and 10 (neck is stretched forward). The angle for each sector is 5 °.

Noise: Hearing impairment may occur if the equivalent level of noise at the operator's ear during a typical day of work exceeds 85 dB(A). The maximum level recommended in the checklist is 75 dB(A). The levels in the study show that ear protectors should be used.

Vibrations: Measured vibration level indicate that the operators can be exposed to vibrations for at least one eight-hour shift without exceeding the limit for fatigue and lowering work capacity because of vibrations [1].

Damage

Of the remaining trees, 6.3% were damaged during thinning [5]. The location and size of damage is presented in Table 6. Just over 70% of damage was caused when processing, 17.6% was caused by moving the crane, 6.8% was caused by moving the machine, and for 5.4% the cause was not identified.

Fröding [6] found, when trees were thinned with single-grip harvesters, that damage to remaining trees was mainly situated between the stump and 1.5 m height on the stems. Of remaining trees, 5.9% were damaged when harvesting with a single-grip harvester (including trees damaged when forwarding). Of the remaining trees, 0.2% were damaged when loading, and 2.2% were damaged when driving with the harvester and the forwarder. Cause of damage was not identified for 0.2% of the remaining trees.

Fuel consumption

Fuel consumption was 5.66 litres per effective hour (0.57 litres per m^3) in clear cut and 6.57 litres per effective hour (1.22 litres per m^3) in thinning. In another study, fuel consumption was 9.06 litres per hour [PMH] when harvesting a black spruce/balsam fir stand (0.102 m^3 per stem) with a Ford farm-tractor-based single-grip harvester [13]. Engine power for the Ford carrier was 87 kW.

DISCUSSION

The number of studied trees is rather small, especially in thinning, but they give an indication of productivity. Productivity in the time study was at about the same level as that of Nordic specialized harvesters. However, nothing is known so far about productivity in the long term. When comparing different machines and methods one must take into account that manual felling of middle zone trees accounts for extra cost.

Ergonomic characteristics for the Case 5120 machine were judged to be less favourable than those of the two Nordic machines FMG 250 E and Skogsjan/LL 487 [7, 8]. However, some factors can be improved easily and probably at low cost. Whether this can be justified will depend on the number of hours the machine is used for forestry work each year.

Table 6. Trees damaged during thinning [5]. Percent distribution of damage by location and size class.

Location of damage		
Root or stump	**From stump to 1.5 m over stump**	**Rest of stem**
7	85%	8%

Area of damage, cm^2					
0–10	11–50	51–100	101–200	201–300	>301
22%	45%	16%	12%	1%	4%

Ground pressure on the rear axle was a little higher than total mean ground pressure for the two Nordic custom-built machines FMG 0470 [12] and Ponsse HS 15e [9]. Ground pressure was much higher on the front axle, but that could be lowered by using wider front tires.

A real ground pressure of 60 to 70 kPa may result in an acceptable level of soil disturbance, which could be achieved with a 5 to10 tonnes machine with good tires and rather low inflation pressure [14]. However, mean ground pressures are calculated for ideal conditions, with the machines standing still and all wheels contact with the ground. In practice ground pressure will vary due to dynamic effects when the machine is working.

Mobility was good where the ground surface was of the best class. As might be expected with this type of chassis, rough terrain slowed moving speed considerably. The weakness for rough terrain for rigid chassis is one of the main reasons why their use in forestry has evolved towards frame-steered kinds in both Scandinavia and North America.

Transportation to the next logging site is not more costly than for specialized Nordic machines, whether transported by truck or driven on the road. A tractor that can function as a carrier for attachments for different types of work could increase machine utilization and lead to reduced cost. Machine flexibility also increases. One disadvantage is the increased demands for operators to be skilled in the different types of work, such as forest harvesting and operations in agriculture.

CONCLUSION

It is concluded that the machine studied had good productivity. Production could probably be higher with more operator training. The machine ergonomics remain to be improved for long term production. Some of the factors can easily be improved, however, as their use in other types of work may have other ergonomic demands. Greater utlisation of the tractor should reduce ownership costs.

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