Fuel, Hydraulic Oil and Lubricant Consumption in Swedish Mechanized Harvesting Operations, 1996

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ABSTRACT

When subjecting forest products to certification the total environmental load of wood harvesting machinery should also be assessed. In this study fuel, hydraulic oil and lubricant consumption in harvesting operations in Sweden has been examined by using machine data acquired through a questionnaire. The objectives of the study were to assess the contractor and forest company owned harvesters' and forwarders' average oil consumption in practical harvesting operations in Sweden, ascertain if the ownership and size of the machines give different consumption figures and estimate the use of environmentally acceptable hydraulic oils as well as the amount of oil spilled outdoors. Diesel consumption was found to be 935 l/1000 m^3 ub for forwarders and 1 167 l/1000 m^3 ub for single-grip harvesters. Hydraulic, transmission and chainsaw oil consumption was significantly higher in forest company owned harvesters while no significant differences were observed among forwarders. Hydraulic oil spillage was estimated for both harvesters and forwarders at 20 l/1000 m^3 ub. For felling and crosscutting trees a further 35 l/1000 m^3 ub of chainsaw oil is spilled. Ninety percent of the utilized hydraulic oil was environmentally compatible.

Keywords: *Forestry machinery, fuel, hydraulic oil, lubricants, spill.*

INTRODUCTION

All mechanized forestry related operations are associated with oil consumption, and material usage and, as a consequence of that, releases to the environment. In the process of subjecting forest industry products to certification the total environmental load of wood harvesting operations, transport and supporting activities should be assessed. Environmental impact from mechanized harvesting operations is primarily due to fuel, hydraulic oil and lubricant consumed by the forestry machinery. A pilot study to assess the consumption of fossil fuels was done by Berg (6,7). The study, however, lacks reliable data on lubricant consumption and oil spillage.

In Sweden wood volume harvested annually is estimated to be 55 Mm^3 ub (4). The shortwood method, where the stems are bucked to assortments at the stump, is the dominant timber harvesting method. A harvester and a forwarder are usually employed. The harvester (single-grip or two-grip) fells and processes the trees and the forwarder transports the logs to the roadside. According to our calculations based on the official statistics (4) almost ninety percent of the cut wood volume is cut by harvesters and transported by forwarders (large scale forest operations). The rest is cut motor-manually and transported by means of small off-road vehicles equipped with a forwarding attachment (small scale forest operations). Large scale forestry operations in Sweden are either conducted by contractors or forest company machine teams. Löfgren and Myrhman (14) estimate that there are 1 730 harvesters and 2 310 forwarders working in harvesting operations in Sweden.

Involvement of contractors in harvesting operations was rather low some time ago and earlier studies on forest machine oil consumption (8,19) concentrated on forest company-owned machines, leaving outside machines owned by contractors. Recent statistics (3) show that there are 1968 contractor companies possessing 3071 harvesters and forwarders. It is necessary to include contractor forest machines in studies which consider forest machine and mechanization aspects.

Environmental regulations in Sweden prohibit spillage of oil in the forest. Oil gathered up after oil changes is handled as an environmentally dangerous fluid, collected and disposed of by professionals specialized in this work. Chainsaw and spilled hydraulic oil are discharged to the environment. Chainsaw oil consumed is released on the forest floor over large areas while a part of it is captured by the logs and the sawdust produced during felling and bucking of the trees (19). Hydraulic oil is released during breakdowns (hose breakage) and concentrates in small areas (11).

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OBJECTIVES

The purpose of the study is to:

- Quantify fuel, hydraulic oil, motor oil, transmission oil, grease, and chainsaw oil consumption of forest machines (harvesters and forwarders) in Sweden,
- Examine if the ownership (contractor-forest company) and sizes of the machines give different consumption figures,
- Estimate the use of environmentally acceptable hydraulic oils as well as the amount spilled outdoors.

MATERIALS AND METHODS

Data were collected by means of a mail questionnaire sent to a large number of machine owners (contractors and forest companies) distributed all over the country. The "Business Register" (CFAR) database provided by Statistics Sweden was used as the selection frame (3). CFAR contains all juridical or physical persons, by nourishment code, conducting businesslike activities in Sweden. The selection code forestry as a nourishment code and a tax code resulted in a recovery of 4007 physical or juridical persons. A three step manual selection was done to improve the target population:

1) Physical or juridical persons not having harvesting activities as their main economic activity (nourishment code 1 or 2) were excluded.

2) Physical persons only conducting small scale harvesting operations in their own forest were excluded.

3) The five largest forest companies were removed from the contractor selection frame in order to make up a second population to which a total inventory was made.

Finally 2535 contractor companies were left to provide the selection frame by which a random sample of 300 could be drawn. The selection was made by using the SPSS random sample generation procedure (16). Before the questionnaire was sent to the selected group of contractors, it was tested on two contractors situated in the vicinity of the University and three experts from outside the University. The questionnaire, a cover letter and a postage-paid return envelope were sent in April 1997. A second mailing was made one month later to non-respondents. At a third stage a personal telephone call was made. Respondents were promised anonymity in all cases. The same questionnaire was also sent to the management districts of the five largest forest companies. In the questionnaire the respondents were asked to provide reliable data concerning:

1) the size and age (expressed in year of construction) of their machine park,

2) the harvested and transported wood volume in m^3 ub in 1996,

3) an estimation of the percentage of productive machine time dedicated to different operations (i.e. final felling, thinning etc.),

4) the market name and quantity of fuel, hydraulic oil, motor oil, transmission oil, chainsaw oil and grease consumed in 1996,

5) an estimation of the hydraulic oil quantity that was spilled during work in the forest.

In total, 170 responses were received from contractors, representing a return of 56.7% (Table 1). Four out of five forest companies responded to the questionnaire and contributed with data for 189 machines for which they had readily available data. Due to the fact that several respondents reported aggregated consumption for a group of machines finally 191 machines belonging both to contractors and forest companies were used to calculate oil consumption. The geographical distribution of the machines is illustrated in Figure 1. Here, Sweden is divided into four regions according to standing volume per hectare of forest land (13).

To distinguish between environmentally compatible (vegetable oils, synthetic esters and poly-alpha-olefines) and mineral hydraulic oils the list of environmentally compatible hydraulic oils compiled by the city of Gothenburg (2) was used as a guide. In this list the oil product classification is based on data on biodegradability and acute aquatic toxicity of the main and minor product components. In addition, the product should contain no components classified as dangerous to health or irritants.

Incoming data were checked for consistency. All variables were tested for normality by using the one sample Kolmogorov-Smirnov test procedure. Subsequently, independent-samples t tests were employed to examine possible statistically significant

Table 1. Received answers from contractors on the questionnaire

	Answers		Machine number
	No	(%)	
Non-respondents	130	43.3	-
No activity/closed down	20	6.6	-
No own forest machine	67	22.3	-
1 forest machine	44	14.6	44
2 forest machines	30	10	60
3 forest machines	7	2.4	21
4 forest machines	2	0.6	8
Sum	300	100	133

differences in fuel and lubricant consumption between contractors and forest companies (16). The Tukey's honestly significant difference test (16) was used to make all pair wise comparisons.

Some terms used are defined as follows:

Contractors: Contract companies which conduct forest work on another property.

Forest companies: The five largest forest land owners in Sweden.

Other fellings: Includes seed tree fellings, shelterwood fellings and harvesting of wind thrown trees.

m^3ub: Cubic meter solid volume excluding bark.

m^3sk: Cubic meter standing volume (stem volume over bark from stump to tip).

Class I machines: Small-sized forwarders with load capacity up to 10 tons and small-sized harvesters with motor output up to 80 kW.

Class II machines: Medium-sized forwarders with load capacity from 10 to 12 tons and medium-sized harvesters with motor output from 80 to 120 kW.

Class III machines: Large-sized forwarders with load capacity more than 12 tons and large-sized harvesters with motor output more than 120 kW.

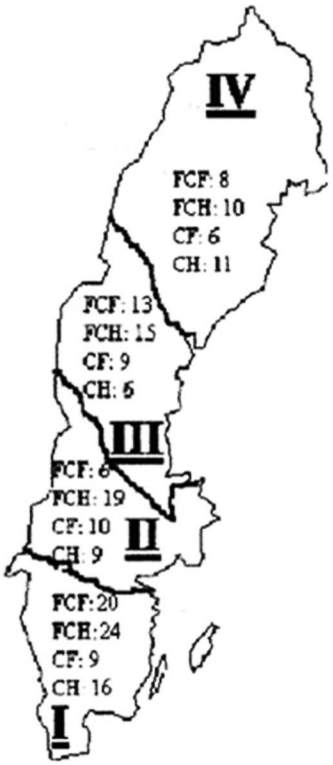

Figure 1. Regional distribution of the machines included in the study to country region and ownership; FCH: Forest company harvester; FCF: Forest Company forwarder; CH: Contractor Harvester; FC: Contractor forwarder; (Region I: 158 m^3 sk/ha; Region II: 128 m^3 sk/ha; Region III: 119 m^3 sk/ha and Region IV; 75 m3 sk/ha.

RESULTS

The material in this study represents approximately 5% (2 747 000 m^3ub) of the total volume cut in Sweden in 1996, and 3% (1 767 700 m^3ub) of the volume extracted. The work was achieved by using 3 million litres of diesel for harvesters and 1.65 million litres of diesel for forwarders. The machine category that consumed most diesel, hydraulic oils and lubricants per m^3ub was the single-grip harvester (Table 2). Differentiating the answers on owner category, it was found that forest company owned machines consumed about twice as much hydraulic oil, transmission oil and chainsaw oil as the con-

Table 2. Average calculated consumption (l/1000 m³ ub) at harvesting and forwarding based on the questionnaire answers (N).

	Forwarders			Single-grip harvesters			Two grip harvesters		
	Consum.	Std. Error	N	Consum.	Std. Error	N	Consum.	Std. Error	N
Diesel oil	935	36	81	1167	54	89	1010	65	21
Hydraulic oil	17	2	74	34.6	3	71	32	4	19
Motor oil	8	0.6	62	8.5	0.8	61	6	0.5	19
Transmission oil	6	0.7	55	3.5	0.5	54	5	1	19
*Greases**	1.5	0.2	35	1.8	0.3	37	1	0.2	9
Chainsaw oil				35	5	63	21	2.5	20

* kg/1 000 m³ ub

tractor owned machines (Table 3). The average age of the machines was six years except for the forwarders belonging to contractors which were much older (nine years).

The machines were distributed over owner category and size (Table 4). Medium size machines constituted 50% of the machines studied. When grouping the information on machine size, it was observed that generally bigger machines have less consumption of diesel, oils and grease per m³ ub than the smaller ones (Table 5). Contractor owned machines were more frequently used in final fellings compared to forest company owned machines. On the other hand, the company owned machines were more used in other type of felling work (Table 6).

Table 3. Statistically significant differences in average consumption (l/1000 m³ ub) between contractors and forest companies.

	Contractors			Forest companies		
Harvesters	Consumption	Std. Error	N	Consumption	Std. Error	N
Hydraulic oil	28	4	41	40	3	49
Transmission oil	2	0.8	34	5.7	0.8	39
Chainsaw oil	20	2.3	40	42	7	43

Table 4. Distribution of machines in different size and owner classes.

	Forest companies		Contractors	
	Forwarders	Harvesters	Forwarders	Harvesters
Class I	7	4	3	3
Class II	31	35	17	11
Class III	9	15	14	19
Two-grip		13		8
Unknown		1		1

Table 5. Differences in fuel and lubricant consumption (l/1000m³ ub) between machines in different size classes.

	Fuel	Hydraulic Oil	Transmission Oil	Motor Oil	Grease*	Chainsaw Oil
Forwarders						
Class I	1220[a]	27[a]	10[a]	11[a]	1,5[a]	-
Class II	902[b]	16[a]	5,2[a]	8[ab]	1,1[a]	-
Class III	878[b]	15[a]	5,1[a]	6,2[b]	1,1[a]	-
Harvesters						
Class I	1853[a]	74[a]	6,5[ab]	20[a]	6,2[a]	33[a]
Class II	1224[b]	38[b]	5[a]	9[b]	1,5[b]	45[a]
Class III	960[c]	27[b]	1,9[b]	6,3[b]	1,4[b]	23[a]
Two-grip	1010[c]	32[b]	5,3[a]	6,4[b]	1,3[b]	21[a]

[abc] Values with the same letter show no significant difference ($p<0.05$) between machine classes for each column respectively.
*kg/1 000 m³ ub.

Table 6. Proportion of time spent in conducting different types of operations.

	Harvesters		Forwarders	
	Contractors	Forest Companies	Contractors	Forest Companies
Final felling	80	66	84	52
Thinning	17	22	12	24
Other fellings*	3	11	3	24
Soil preparation	0	0	1	0

*Other fellings include seed-tree fellings, shelterwood fellings and harvesting of wind thrown trees.

The question concerning what type of hydraulic oil they used, was answered for 72% of the contractor owned machines and for 55% of the forest company owned machines. Ninety percent of the reported consumption was environmentally compatible oils. Hydraulic oil spillage data were acquired on 99 contractor machines and 82 forest company machines. The inquiry indicated that 42% of the hydraulic oil used by contractors and 36% of the hydraulic oil used by forest companies was released in the forest mainly due to hydraulic hose breakage during work. On average this would mean that almost 20 litres of hydraulic oil per 1000 m^3 ub is spilt unintentionally in the forest.

DISCUSSION

In Sweden two records exist of forest contractors; one from the Forest Machine Owners Association and one from Statistics Sweden (CFAR). The former one does not include non-organized contractors while CFAR includes contractors as well as forest owners with a forest related income. The CFAR register was used since the aim was to obtain a complete initial population to avoid systematic errors.

Harvesting operations in Sweden are performed by machines of various brand names and models. Machine productivity and hence fuel, hydraulic oil and lubricant consumption per m^3 ub depends upon the harvesting system, operational phase, ambient temperature, outcome product, stand factors, operator factors and machine factors (5,9). Terrain and climatic conditions as well as standing volume per hectare differ between different country regions. To secure a good representation of the results of this study and allow generalization for the whole machine population a satisfactory country coverage was strived for by closely examining a randomly selected sample of contractor companies. The use of a questionnaire for data collection was preferred since

questionnaires are a well tested method in the forestry context. Studies based on questionnaires have been used in Sweden (10,12,15) and abroad (17,18) to describe the state of art in the use of machinery and to forecast the situation for the future.

Since fuel and lubricant consumption, together with repair and maintenance, constitutes a large expense component, contractors and forest companies were expected to have an accurate record of the consumption of each individual machine. However, both among forest companies and among contractors different routines are maintained for recording consumption. Some record consumption separately for each machine while others record aggregate consumption for a group of machines belonging to the same work team. The same observation was made by Sundberg (20) when calculating the cost of the use of the machines on the basis of their fuel consumption. This causes difficulties in deciding the fuel, hydraulic oil and lubricant consumption of each individual machine. To tackle this problem only machines for which oil consumption was reported individually were used to calculate average consumption while machine data from machine teams were used for the calculation of oil spillage and the amount of environmentally compatible hydraulic oil consumed.

Despite the fact that contractor owned forwarders were on average three years older than forest company owned forwarders, no statistically significant differences were detected in fuel, hydraulic oil or lubricant consumption even though consumption was somewhat higher in the latter owner group. Study results on forwarder fuel consumption are in agreement with Löfgren and Myrhman (14) who estimated the fuel consumption for forwarders operating in Swedish forests to be 0,93 l/m^3 ub.

Statistically significant differences between forest company and contractor harvesters in hydraulic, transmission and chainsaw oil consumption can be accounted for by the observed differences in machine size as well as by the proportion of time spent conducting different harvests. The contractor harvesters under study were mainly large size harvesters operating 80% of their time in final felling operations while forest company owned medium size harvesters operated 66% of their time in final fellings and 34% in other fellings. Large size harvesters in final felling operations tend to consume less fuel and oils per m^3 ub than middle size harvesters in other fellings due to larger tree dimensions and shorter distances between the trees.

Harvester average hydraulic oil consumption per m^3 ub in the present study was above the consumption stated by harvester manufacturers. Hydraulic oil spillage due to breakdowns and leaking connections in the hydraulic system is probably responsible for the high hydraulic oil consumption reported. The estimated amount of hydraulic oil spilled in the forest reached almost 1150 m^3 in 1996. Hultman (11) estimated the total amount of hydraulic oil spilled in the forest due to failures of the hydraulic system of forest machines at 1500-3000 m^3 in 1969. His study involved 100 processors and 5000-6000 forwarders. Harvesters consume twice as much hydraulic oil as forwarders not only due to the complexity and the higher oil demand of their hydraulic system but also due to the fact that hose breakages are more frequent.

Löfgren and Myrhman (14) estimated in 1994 that 25% of the hydraulic oil consumed in mechanized forest operations in Sweden was environmentally compatible. In our study the percentage seems to have increased dramatically and reached ninety percent. Unfortunately the small number of responses received, does not allow a generalization but a trend is clear. In recent years forest companies have demanded the use of environmentally compatible hydraulic oils - less toxic than mineral oils and biodegrading more rapidly - in the machines operating on their property. That has most likely contributed to the increased rate of consumption of these oils. Unfortunately no identification criteria were set on chainsaw oils in the questionnaire. Lubricating systems that reduce chainsaw oil consumption have been introduced in Swedish forestry (1). Official data on chainsaw oil are lacking to provide comparisons.

Berg (6) estimates the total amount of hydraulic oil and lubricants used annually in harvesting operations in Sweden to be 4 200 m^3 for 53 Mm^3 ub harvested and transported wood volume. Löfgren and Myrhman (14) estimate the total quantity of hydraulic oil consumed annually in forestry operations in Sweden to be 6 000 m^3 while for diesel they report an annual consumption of 106 000 m^3. According to our calculations, consumption of hydraulic oil and lubricants is 50% more than that estimated by Berg, while fuel consumption reaches 111 500 m^3.

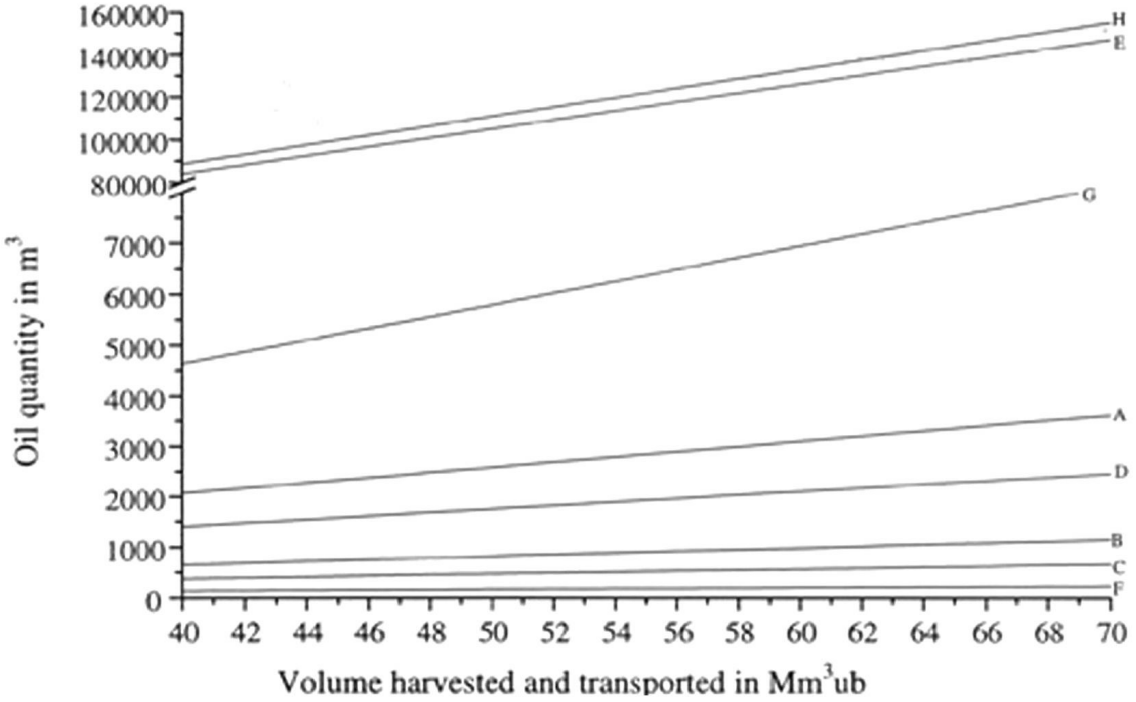

Figure 2. Estimation of fuel, hydraulic oil and lubricant consumption in harvesting and forwarding operations in Sweden under different harvested volumes A: Total hydraulic oil consumption, B: Total motor oil consumption, C: Total transmission oil consumption, D: Total chainsaw oil consumption, E: Total diesel consumption, F: Total grease consumption, G: Total lucricant consumption, H: Total fuel and lubricant consumption.

CONCLUSION

At a harvested volume of 55 Mm^3 ub the total amount of diesel oil consumed reaches 115 610 m^3 while the total amount of hydraulic oil and lubricants consumed reaches 6 300 m^3. Hydraulic oil spillage by both harvesters and forwarders for felling the trees and transporting the logs to the roadside was found to be 1 150 m^3. Spillage is even higher if we take into consideration that 1 920 m^3 of chainsaw oil were released during the operations. The outcomes of the present study will be used for a life cycle assessment of forest machinery.

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