COMPARATIVE ANALYSIS OF RECOVERY EFFICIENCIES OF SOME MILLING TECHNIQUES IN GHANA

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ABSTRACT

Inefficient primary processing of timber in the Ghanaian sawmills has resulted in lower lumber recoveries/yields hence generating too much residues. But in situ primary processing of timber with appropriate technologies has not been well established to remedy the situation. This study considered freehand with two different chainsaw bland (Stihl 070 and Husqvarna 395XP), chainsaws with frame attachments (Husqvarna 395XP with Alaskan frame & Stihl MS880 with logosol frame/rail) and Wood-Mizer milling technologies. Forty-four (44) trees from six timber species were extracted from two ecological zones in Ghana. The conversion efficiency ratios, which include lumber recovery/yield, production rate and fuel consumption rate, have been determined for four milling technologies that were used based on the number of timber species and trees felled. Comparison of the efficiency ratios of the freehand (Stihl 070 and Husqvarna 395XP), attachments (Alaskan and logosol frames) and Wood-Mizer milling technologies (using the same species for all of them) indicate that the percentage mean average lumber recovery/yield was highest with Wood-Mizer milling technology (70.6%) than the attachment technologies (49.6%) and that of the freehand (43.5%). In terms of lumber production rate, Wood-Mizer recorded a mean rate of 1.52 m^3/hr as against 0.519 m^3/hr and 0.435 m^3/hr for freehand and attachment technologies. The mean average fuel consumption rates were also estimated to be 6.31 lit/m^3, 8.4 lit/m^3 and 10.8 lit/m^3 for Wood-Mizer, freehand and frame attachment technologies respectively. The quality of lumber generated with the Wood-Mizer, Alaskan and logosol frame attachments were observed to be comparable to that of sawmill lumber while those from freehand milling were rough and thick & thin..

Keywords: Efficiency, milling techniques, lumber recovery, production rate, consumption rate

INTRODUCTION

The depletion of the tropical high forest of Ghana has been estimated to be 80% in the past 100 years. Among the factors that have contributed to this unfortunate situation are illegal harvesting, inefficient logging and primary processing and chain saw milling. The conversion of trees into lumber and or beams with chainsaws started when sawmills in Ghana began collapsing in the 1980's. At this period chainsaws had been in the system for over fifteen (15) years since its introduction. It has become a major source of lumber supply onto the Ghanaian timber market and beyond because the lumber produced are available, can easily be accessed, prices are comparatively lower and acts as a source of employment. The chain saw milling enterprise in Ghana has engaged over 50,000 people (Otoo, 2004). This is an indication of the potential of the enterprise to reduce poverty and contribute to the global millennium development goals.

Notwithstanding this remarkable contribution, its activities are said to have serious environmental and economic effects among others. It has been indicated that out of 3.72 million cubic meters of the total annual timber that was harvested in 1999, illegal harvesting and chain saw milling contributed 1.0 million cubic meters and about 1.7 million cubic meters respectively (Birikorang, 2001). Chain saw milling has been described to be a wasteful activity and environmentally unfriendly, hence needed to be banned. Despite some drastic measures that the government of Ghana continues to put in place in curbing the situation since it was outlawed in 1998, no better results have been achieved but continue to flourish in the timber industry.

Conversion efficiencies of sawing or milling technologies are very important for the management, maintenance, optimum and sustained yield of production of timber resources in this contemporary world. The selection of milling machines could be considered under efficiency and productivity, mills availability, capital and products accessibility. Some factors that are known to affect conversion efficiency of the various sawing technologies include log shape/defects, log size, saw kerf, sawing patterns, opening face (first saw line), dimensions of lumber, allowance for shrinkage, operators' skills, machine settings, obsolete machine, maintenance and market demands.

The chainsaw milling sector is said to operate under very low efficiency in terms of lumber recovery even though in Ghana there is scanty statistical information on chainsaw milling, especially on the negative impact of the operation. For example, Frimpong-Mensah (2004), established that the lumber conversion efficiencies for eleven Ghanaian timber species, using Sthil 070 chainsaw machine, ranged from 22% to 60% with a mean of 40%. Gyimah and Adu (2009) after a pilot study on sawnwood conversion efficiency in selected sawmills in Ghana indicate that the mean recovery for small to large scale enterprises ranges from 28% to 64%. The above figures suggest that there is huge waste generation associated with both chainsaw and sawmill milling operations in Ghana, especially if compared. For example, in Malaysia, the lumber of commercial dimensions that were recovered in some sawmill is reported as 54.5% while that of Venezuela ranged between 60% and 70% (Gyimah and Adu-Gyamfi, 2009).

To efficiently utilize the limited timber resources in Ghana, there is the urgency to establish the actual recovery estimates for Ghana within the chainsaw and sawmill sectors, hence, the lumber yield, production and consumption rates for both chainsaw and other improved milling technologies, the factors affecting recovery inefficiencies in the chainsaw sector and introduce appropriate milling technologies to improve upon the freehand chain sawing.

The specific objective of this study was to establish the efficiencies of chain saw milling and other available small scale milling technologies in relation to resource utilization. The scope of the study involved the processing of both forest and plantation trees using:

a) Freehand with Stihl 070 and Husqvarna 395XP
b) Husqvarna 395XP with Alaskan frame attachment
c) Stihl MS 880 with Logosol attachment
d) Wood-Mizer with a horizontal narrow bandsaw to determine the lumber recoveries, lumber production and fuel consumption rates and review of the conversion efficiencies of the sawmilling sector in Ghana.

MATERIALS AND METHODS

Selection of Timber Species and Site

The selection of timber species for the study was based on a) commercially available timber species from both the forest and plantation b) most patronized timber species c) species being worked on currently with logosol milling machine under an ITTO/CSIR-FORIG Project PD 431/06. The timber species selected from the natural forest (NF) & plantation (P) resources and their densities at 12-15% moisture content are shown in Table 1. The site selection was based on the availability of the species at the forest area. In this case CSIR-FORIG research plot located within Pra-Anum and Asenanyo Forest Reserves were selected. A total of 44 trees of the selected species were felled for the study.

To compare the freehand chainsaw milling with other milling technologies, some preliminary results from ITTO/FORIG project PD 431/06 "Processing and utilization of trees on farmlands and logging residues through collaboration with local communities" using logosol attachment was adopted. The results of the following species were considered.

Selection of Sawing Equipment

The sawing equipment selected was based on those that were available to the project team and whose adoption for use was under study. These included Stihl chainsaw (MS 880) with logosol (Big mill Basic) frame attachment, Husqvarna 395XP with Alaskan frame attachment, Wood-Mizer (LT 30) and Stihl 070 (chainsaw type mostly used for chainsaw milling in Ghana).

Table 1: Timber species selected for the milling study

S/no.	Scientific name	Local name	Density kg/m^3
1	*Piptadeniastrum africanum*	Dahoma	700
2	*Nesogordonia papaverifera*	Danta	750
3	*Mammea africana*	Bompagya	800
4	*Terminalia ivorensis* (NF)	Emire	550
5	*Terminalia ivorensis* (P)	Emire	550
6	*Tectona grandis*	Teak	650

Density is at 12-15% moisture content; NF = Natural Forest, P = Plantation
Source: TIDD, 1994

Timber Processing and Data Collection

At least one tree per timber species was processed using chainsaws with attachment, Wood-Mizer and freehand technologies: a) freehand with Stihl 070 and Husqvarna 395XP (plates 1 and 2) b) Husqvarna 395XP with Alaskan frame attachment (plate 4) c) Stihl MS880 with Logosol attachment (plate 3) d) Wood-Mizer with narrow horizontal bandsaw (plate 5). In situ processing was undertaken to minimize the destruction of the forest ecosystem and costs. Field measurements were undertaken. After each tree was felled, its butt and top diameters (two perpendicular measurements at each end) and the total length (from the butt through the merchantable bole to the first or second forking point depending upon its characteristics) were taken to determine the volume of the useable portions. The timber was then cross-cut into lengths of 2.5m ($8^1/_6$ feet), 3.66m (12 feet), 4.27m (14 feet), 4.57m (15 feet) or 4.88m (16 feet) depending upon the use and grade (quality) required. Monkey jack was used in turning the logs to any required side to facilitate processing. Other items used for the study included saw chains, starter plugs, files for sharpening saw chains, measuring tapes and brass screws (used to fix a face-plate on the face of logs).

Petrol and engine oil were used to run the engines of the machines. A stop watch was used to time the operational activities (from the beginning to the end of every cut that was made). Lumber pieces were cut to dimensions (thicknesses and widths) that were recognized at the local timber market. One-face cutting technique was used by the operators. In this case, an initial cut was made to give an open face for the log to be turned or rotated at an angle of 90 degrees. This made each log stable for further cuttings to be undertaken to remove slabs at the opposite sides of the log. During processing the following parameters were noted and recorded for each log and hence a tree: quantity of fuel (in terms of volumes) used and actual machine time. In addition, the thicknesses and widths (at the two ends) and length of each lumber were measured and recorded, as shown in plate 6, to compute for the volumes of lumber pieces generated. Plates 1-6 are photographs of the various milling techniques used for the study and the collection of data.

Plate 1: Freehand milling with Stihl

Plate 2: Freehand milling with Husqvarna

Plate 3: Milling with logosol attachment

Plate 4: Milling with a frame attachment

Plate 5: Milling with wood-mizer

Plate 6: Measurements being taken by field staff

Data Analysis

The data collected was analyzed using Microsoft Excel for; a) the volumes of the mechantable boles, logs and lumber generated, b) mean, standard deviation and minimum and maximum values, c) the percentage log and lumber recoveries, d) fuel consumption rate, and e) lumber production rate.

RESULTS AND DISCUSSION

Freehand with Stihl 070 Chainsaw Milling

Eight trees were felled for this study of which diameters ranged from 0.363 m (for Teak) to 0.803 m (for Dahoma) while that of the lengths varied from 14.46 m (for Teak) to 25.7 m (for Emire from the natural forest). Apart from the plantation species (Teak and Emire), the rest of the species, Dahoma, Danta and Emire from the natural forest had their diameters bigger than the minimum felling diameter of the respective species (Ghanaian timber tree species at exploitable sizes are above 50 cm diameter at breast height (dbh) or above buttress).

Table 2 shows the average percentage log and lumber recoveries for each of the selected species. The percentage logs recovery for the trees of the various species felled ranged from 50% to 86%. Emire (*Terminalia ivorensis*) from plantation (Emire P) had the highest logs recovery while Teak had the lowest. This low value was due to the form/shape of the trees, which might be attributed to lack of pruning and hence reduced the merchantable bole length as compared to that of Emire. Lumber recovery also varied from 36% to 54%. The mean percentage lumber recovery was estimated to be 47%. This lumber recovery values are comparable to those established by Frimpong-Mensah (2004) as 40% (22-60%) on freehand milling and Gyimah and Adu-Gyamfi (2009) on small to large scale enterprises 53.9% (28-64%)

Table 2: Log and lumber yields of some timber milling technologies

Milling technologies	Yield %	Timber species: Dahoma	Danta	Emire N	Emire P	Teak	Bompagya
	Log	75.1	66.1	70.7	85.7	50.2	-
Freehand with stihl 070	Lumber	46.2	47.8	51.3	53.9	36.2	-
	Log	70.1	65.96	81.99	86.8	94.4	-
Freehand with Husqvarna 395X	Lumber	32	42.7	56.7	43.6	36.7	-
	Log	76.7	92.3	73.7	-	82.5	-
Husqvarna with Attachment	Lumber	46.3	47.8	41.4	-	49.9	-
	Log	70.6	-	-	-	74.8	55.4
Logosol Attachment	Lumber	61.1	-	-	-	48.4	61.9
	Log	75	80.8	83.2	83.2	-	-
Wood-Mizer	Lumber	68.1	71.5	70.6	70.6	-	-

Dahoma (*Piptadenia africana*), Danta (*Nesogordonia papaverifera*), Emire, N (*Terminalia ivorensis from natural forest*), Emire, P (*Terminalia ivorensis from plantations*), Teak (*Tectona grandis*) and Bompagya (*Mammea africana*)

The volume of lumber generated per hour for the five species ranged from 0.33 m^3/hr to 0.66 m^3/hr as shown in Table 3. Emire from plantation was the highest followed by Emire from the forest and then Dahoma and Danta. Therefore with the minimum rate of 0.33 m^3/hr, the volume of teak that can be produced in a day by two operators, two assistants and using one machine (working for 8hrs) will be 2.64 m^3. The mean average of the lumber production rate was 0.52 m^3/hr, which translates into a production of 4.2 m^3 per day. Thus the range of the production rate with freehand chainsaw milling is between 2.6 to 5.3 m^3 per day or an average of 4.2 m^3 per day.

Fuel consumption rate, on the other hand, was highest for Danta (9.63 lit/m^3) and the lowest (5.67 lit/m^3) was for Emire from the forest (Table 3). Dahoma, had the second highest fuel consumption rate of 9.24 lit/m^3. Since the densities of Dahoma and Danta are 700 kg/m^3 and 750 kg/m^3, their high fuel consumption rate is realistic.

The two plantation species (Emire and Teak) recorded 7.82 lit/m^3 and 7.58 lit/m^3 respectively. The second lowest consumption rate of 7.58 lit/m^3 was for Emire from the forest while that of Emire from plantation was 7.82 lit/m^3.

With this technology the mean average fuel consumption rate was estimated as 7.985 lit/m^3 meaning that about 8 litres of fuel could be used to mill a cubic meter of any of the above mentioned timber species.

Freehand with Husqvarna 395XP

A total of nine trees were used for the Husqvarna machine when it was operated with freehand. The mean log diameter, length and volume ranged between 0.329 – 0.755m, 2.46 - 4.8 m, 0.215 - 2.225m^3 respectively.

The percentage log and lumber recoveries for the five species are shown in Table 2. For the log recovery, Teak, Emire (from plantation) and Emire (from the forest) scored 94.41%, 86.76%, and 81.99% respectively which was followed by Dahoma (70.13%) and Danta (65.96%). With respect to the lumber recovery the minimum and maximum values recorded were 32.01% (for Dahoma) and 56.68% (Emire from the forest) respectively. The comparatively low recoveries of Dahoma and Danta were due to heart rot defect that was observed. For this technology even though the maximum value of 57% is lower than those that have been established by Frimpong-Mensah (2004) and Gyimah and Adu-Gyamfi (2009), its minimum value of 32% is quite higher than theirs (22% and 28%). The mean percentage lumber recovery for the Husqvarna machine when operated at freehand was 42.3% whilst those of Frimpong-Mensah (2004) and Gyimah and Adu-Gyamfi (2009) were 40% and 53.9% respectively. Meanwhile the percentage lumber recovery range for small-scale sawmill enterprise (SSE) in Ghana is 28% - 45% with a mean of 39.7% (Gyimah and Adu-Gyamfi, 2009). This means that the freehand milling has a higher recovery than SSE.

The production rates for the technology under discussion varied from 0.384 m^3/hr (for Dahoma) to 0.756 m^3/hr (for Emire from the forest) with a mean average rate of 0.534 m^3/hr (see Table 3). This means that working for 8 hours in a day, two operators and two assistants with one Husqvarna chainsaw machine will produce a lumber volume of 4.27 m^3 of any of the five species being discussed and possibly others with equivalent densities.

Fuel consumption on the other hand ranged from 6.78 lit/m^3 to 13.45 lit/m^3 for Emire from natural forest and Emire from plantation as indicated in Table 3. The difference might be due to the conicity and dead knots of some of the stems of the species. The fuel used in milling one cubic meter each of Dahoma and Danta were recorded as 9.58 lit/m^3 and 9.28 lit/m^3 respectively. The mean average fuel consumption rate for the five species was 9.56 lit/m^3. Therefore with the freehand milling 10 litres of fuel could be used to mill one cubic meter of any one of the five species mentioned.

Husqvarna 395XP with Frame Attachment

The range of the mean diameters of the four species was from 0.333 m to 0.654 m. With the exception of teak, all the others exceeded the national felling limit of diameter at breast height (dbh). The mean length and volumes of the logs varied from 2.67 m (for Teak) – 3.72 m (for Dahoma) and 0.229 m^3 (for Teak) – 0.991 m^3 (for Danta).

The recoveries of logs and lumber from the four species range from 73.65% to 92.35 and 41.38% to 49.85% respectively (Table 2). The mean lumber recovery is 46.31%, which is above the 40% determined by Frimpong-Mensah (2004). On the other hand, it is lower than 53.9% as estimated by Gyimah and Adu-Gyamfi (2009) for sawmill recovery (mean of Small-Scale Enterprise - SSE, Medium-Scale Enterprise - MSE and Large-Scale Enterprise - LSE). The estimated 46.31% recovery for the Husqvarna 393X with frame attachment is higher than the mean lumber recovery for small-scale sawmills (in Ghana) of 39.7% as reported by Gyimah and Adu-Gyamfi (2009). Even though operators were only trained on the handling of this new machine alongside the study it is an improvement over the traditional freehand chainsaw milling and the small-scale sawmill enterprise in Ghana.

The rate at which lumber was generated from the four timber species varied from 0.348 m^3/hr (Teak) to 0.481 m^3/hr (Danta) with a mean rate of 0.434 m^3/hr. From Table 3 the production rates for the species were very close except Teak. Again, with two operators, two assistants and one Husqvarna machine with a frame attachment, 2.78 m3 of teak and 3.85 m3 of Danta could be produced in 8 hours (one working day).

Table 3: Production and fuel consumption rates of some timber milling technologies

		Timber species					
Milling technologies	Rates	Dahoma	Danta	Emire N	Emire P	Teak	Bompagya
Freehand with stihl 070	Production, m^3/hr	0.539	0.429	0.625	0.662	0.33	-
	Fuel, lit/m3	9.24	9.63	5.67	7.82	7.58	-
Freehand with Husqvarna 395X	Production, m^3/hr	0.384	0.526	0.756	0.507	4.96	-
	Fuel, lit/m3	9.58	9.28	6.8	13.5	8.7	-
Husqvarna with Attachment	Production, m^3/hr	0.443	0.481	0.463	-	0.48	-
	Fuel, lit/m3	14.51	10.99	12.04	-	8.77	-
Logosol Attachment	Production, m^3/hr	0.565	-	0.401	-	0.26	0.697
	Fuel, lit/m3	6.65	-	9.32	-	14.26	7.8
Wood-Mizer	Production, m^3/hr	1.49	1.25	1.83	1.66	-	-
	Fuel, lit/m3	6.58	7.1	5.25	5.97	-	-

Dahoma (*Piptadenia africana*), Danta (*Nesogordonia papaverifera*), Emire, N (*Terminalia ivorensis from natural forest*), Emire, P (*Terminalia ivorensis from plantations*), Teak (*Tectona grandis*) and Bompagya (*Mammea africana*)

Table 3 shows the fuel consumption rates for four commercial timber species. The fuel consumption rate for Dahoma (14.51 lit/m^3) was the highest followed by Emire (from the forest) and Danta with rates 12.04 lit/m^3 and 10.99 lit/m^3 respectively whilst Teak trailed with 8.77 lit/m^3. These indicate that less quantity of mixed fuel was used to generate a cubic meter of teak lumber than the rest of the species, especially Dahoma indicating that fuel used was dependent on the characteristics of the species and the tree.

From the above discussion it can be deduced that freehand milling of Emire species is comparatively more efficient than the rest but chainsaw lumbering of teak is the least. Generally the quality of lumber produced was assessed to be better as compared to those that are produced by those who undertake the activity illegally. This was based on direct expert observation of smoothness of cut.

Milling using Stihl MS 880 with Logosol Attachment

Logosol attachment was used to mill nine trees, which was made up of four species that were felled for this study. The diameters were within the range of 0.295m (for teak) and 1.058m (for Bompagya) while the lengths ranged from 7.56 to 29m for the same species.

The percentage lumber recovery varied from 48.2% to 61.91%. In this case Bompagya and Dahoma had 61.91% and 61.08% lumber recoveries while Teak and Emire (from the forest) recorded 48.2% and 52.11% respectively (Table 2). The mean average lumber recovery was 55.8%, which is higher than those established with freehand milling with Stihl 070 (40% estimated by Frimpong-Mensah, 2004) and from sawmills (SSE – LSE) (53.9% as reported by Gyimah and Adu-Gyamfi, 2009). Meanwhile, as indicated in Table 2, log recoveries were higher with Teak (74.83%) and Emire from the forest (70.92%) than Dahoma (70.56%) and Bompagya (55.37%).

The trend is the same with lumber production rate whereby Bompagya and Dahoma recorded 0.697 m^3/hr and 0.565 m^3/hr respectively while Emire and Teak had 0.401 m^3/hr and 0.26 m^3/hr in that order (Table 3). The rate at which fuel was used in generating a cubic meter of lumber was higher for Teak (14.25 lit/m^3) and lower for Dahoma (6.649 lit/m^3) as shown in Table 3. From the results, more fuel was used in milling Teak and Emire than it was used for Dahoma and Bompagya.

Comparison of the two Freehand-Milling Machines

Stihl 070 and Husqvarna 395X machines used for freehand milling of some timber species were compared as shown in Tables 4 and 5. The Stihl machine recorded higher lumber recovery values for three of the five species (Dahoma, Danta and Emire (from plantation)) than Husqvarna machine while Emire (from the forest) and Teak were higher with Husqvarna 395XP (Table 4). This means that freehand milling of Dahoma, Danta and Emire (from the forest) using Stihl generated more lumber than Husqvarna machine. Again, with the mean average lumber recovery values for the five species, Stihl machine recorded 47.1% as against 42.32% for the Husqvarna machine. In comparison with small-scale sawmill enterprise, lumber yielded from Stihl (36.2-53.9%) and Husqvarna (32-56.7%) machines with freehand milling were higher. In terms of the lumber production rate, there is no consistent trend as seen in Table 5.

The mean averages of lumber production rates for Stihl and Husqvarna were 0.517 m^3/hr and 0.534 m^3/hr respectively. These show that the rate of producing lumber from the five species is higher with Husqvarna than with the Stihl.

With the fuel consumption rate, the values for the Stihl were lower with four of the species while Husqvarna was better with only Danta (Figure 15). Still the trend is not clear but the mean averages indicate that the fuel consumption rate for the Husqvarna 395XP was higher (9.56 lit/m^3) than with Stihl 070 (7.99 lit/m^3). Therefore Stihl machine used less fuel in producing one cubic meter of lumber than the Husqvarna machine.

Comparison of the two Attachment-Milling Machines

The means of the percentage lumber recovery, production rate and fuel consumption rate for three timber species milled using Stihl MS880 chainsaw with logosol rail attachment (Logosol) and Husqvarna 395XP chainsaw with Alaskan Frame Attachment (HFA) are shown in Tables 4 and 5. From Table 4, the recoveries for Dahoma and Emire from the natural forest are higher with logosol frame attachment than with the Alaskan frame attachment. The mean averages for logosol and Alaskan frame attachments are 54% and 46% respectively, hence logosol having an edge over the Alaskan frame attachment.

Values for the lumber production rate indicate that the Alaskan frame attachment recorded higher values for Emire (from the forest) and Teak than with the Logosol but vice versa with Dahoma (Table 5). Mean averages of 0.418 m^3/hr and 0.409 m^3/hr were obtained for the Alaskan frame attachment and Logosol respectively. This means that the rate of producing lumber was higher with the Alaskan frame attachment than with the Logosol.

Table 4: Comparison of lumber yields (%) of some timber milling technologies

Milling technologies		Timber species				
		Dahoma	Danta	Emire N	Emire P	Teak
Freedhand machines 070 & 395X	70	46.17	47.77	51.29	53.89	36.17
	395X	32.01	42.65	56.68	43.6	36.67
Milling attachments	Alaskan	46.26	-	41.38	-	48.4
	Logosol	61.1	-	54.71	-	49.85
Freehand and attachment milling	Freehand	36.86	45.81	54.71	-	36.53
	Attachment	57.84	47.84	43.95	-	48.59

Dahoma (*Piptadenia africana*), Danta (*Nesogordonia papaverifera*), Emire, N (*Terminalia ivorensis from natural forest*), Emire, P (*Terminalia ivorensis from plantations*) and Teak (*Tectona grandis*)

The fuel consumption rates were higher in milling Dahoma and Emire (from the forest) with the Alaskan frame attachment while Logosol was higher for milling Teak (Table 5). In milling any of the species in question, mean average fuel consumption rates of 10.07 lit/m^3 and 11.77 lit/m^3 for Logosol and Alaskan frame attachments respectively were estimated, implying that Logosol consumed lesser fuel in milling one cubic meter of lumber of any of the species than the Alaskan frame attachment.

Comparison of Freehand and Frame Attachment milling machines

Tables 4 and 5 also show the means of the percentage lumber recovery, production rate and fuel consumption rate for four timber species that were milled with freehand (Stihl 070 and Husqvarna 395XP) and frame attachments (Stihl MS880 chainsaw with Logosol frame attachment and Husqvarna 395XP chainsaw with Alaskan frame attachment). The lumber recoveries were better with the frame attachment machines than with the freehand milling machines. The range of values for the frame attachment machines was 43.95% (for Emire from the forest) to 57.84% (for Dahoma) and 36.53% (for Teak) to 54.71% (for Emire from the forest) for freehand machines (Table 4). From the mean averages, the frame attachment milling machines had a higher percentage lumber recovery of 49.6% as against 43.5% for the freehand milling machines. There is a clear indication that milling of timber with frame attachment will increase the quantity of lumber in terms volume by 6.1%. The range of percentage recoveries and the mean percentages of both the freehand and attachment milling machines are higher than that of small-scale sawmill enterprise (28% - 45%)

Milling with a frame attachment generated higher lumber production rates for Dahoma and Danta while the freehand machines recorded better rates for Emire and Teak as shown in Table 5. The established lumber production rates for the species varied from 0.433 m^3/hr to 0.705 m^3/hr for freehand milling machines while that for frame attachment milling machines were from 0.273 m^3/hr to 0.539 m^3/hr. On the mean averages, freehand milling recorded 0.519 m^3/hr while frame attachment machines registered 0.435 m^3/hr. This means that generally more lumber were produced from the four species with freehand milling per given time than with the frame attachment machines.

For the fuel consumption rates, the quantity of fuel used in milling Danta and Emire with freehand was comparatively less than it was used with the frame attachment machines as shown in Table 5. The minimum and maximum consumption rates for both freehand and frame attachment milling were 6.4 lit/m^3 & 9.4 lit/m^3 and 8.0 lit/m^3 & 13.2 lit/m^3 respectively. On the whole the fuel consumption rate from the mean averages was lower with the freehand machines (8.4 lit/m^3) than with the frame attachment machines (10.84 lit/m^3). However, the result does not conform to any trend.

Milling of some Species with Wood-Mizer

The average diameter range for the ten trees that were felled for this study was from 0.4 m (for Emire from plantation) to 0.787 m (for Dahoma) while that of the lengths varied from 10.0 m (Emire from the natural forest) to 23.6 m (Danta).

The percentage log recovery for the trees of the various species felled ranged from 75% (for Dahoma) to 83% (for Emire from plantation). These recoveries are higher than those reported by Ofosu-Asiedu *et al* (1996) that after logging 50% of the tree stem is left on the forest floor.

Emire from plantation having the highest percentage log recovery indicates that some good management practice was adhered to in managing the plantation at Pra-Anum research plots as compared to the rest of the species that were from the natural forest. Dahoma on the other hand had so many branches at short distances from each other and therefore reduced its log recovery. Again, Emire from both sources generated a percentage log recovery of 81.9% indicating that only 17.1% of the stem of the trees were left in the forest. The percentage lumber recoveries (Table 4) vary from 68.1% (Dahoma) to 72.2% (Emire from natural forest). This is an indication that the quality of Emire from the natural forest was better than Emire from plantation and Danta whose log recoveries were higher. The lumber recovery for each of the species was quite higher than those from the sawmills in Ghana (28-64%). The quality of the lumber generated was better as saw marks and thick and thin machining defects were absent in comparable with chainsaw milling technology.

Table 5 shows the volume of lumber produced in an hour for each of the species. The rate of producing lumber from the species ranged from 1.25 m^3/hr (for Danta) to 1.83 m^3/hr (for Emire from the natural forest). From the timber species, Danta is knotty and has the highest density (750 kg/m^3 at 12% moisture content), hence its lower production rate. This was followed by Dahoma of density 700 kg/m^3. An average production rate of 1.73 m^3/hr for Emire from the two sources was recorded. Its density at 12% moisture content has been recorded to be 550 kg/ m^3. The results indicate that lumber production increases with decreasing density of the timber species. The rate of fuel consumption of the wood-Mizer during milling of the species as shown in Table 5 increased with increasing density.

Table 5: Comparison of production and fuel consumption rates of some timber milling technologies

		Milling technologies					
		Freehand milling		Milling Attachments		Freehand and attachment	
Timber species	Rates	70	395X	Alaskan	Logosol	Freehand	Attachments
	Production, m^3/hr	0.539	0.384	0.443	0.565	0.461	0.539
Dahoma	Fuel,	9.24	9.58	14.51	6.65	9.38	8.02
	Production, m^3/hr	0.429	0.526	0.481		0.478	0.482
Danta	Fuel	9.63	9.28	10.99		9.45	10.97
	Production, m^3/hr	0.625	0.756	0.463	0.401	0.705	0.445
Emire, Natural	Fuel	5.67	6.8	12.04	9.32	6.4	11.17
	Production, m^3/hr	0.33	0.496	0.348	0.26	0.433	0.273
Teak	Fuel	7.58	8.7	8.77	14.26	8.37	13.2

Dahoma (*Piptadenia africana*), Danta (*Nesogordonia papaverifera*), Emire, N (*Terminalia ivorensis from natural forest*), Emire, P (*Terminalia ivorensis from plantations*), Teak (*Tectona grandis*) and Bompagya (*Mammea africana*)

Therefore Danta with the highest density recorded a rate of 7.1 lit/m^3 and was followed by Dahoma (6.58 lit/m^3) while Emire from plantation and the natural forest registered 5.97 lit/m^3 and 5.25 lit/m^3 respectively. These show that more fuel was used in milling Emire from plantation than Emire from the natural forest, which might be due to some inherent properties of the species. Again, the quantity of fuel used in milling any of the four species increased with increasing density.

CONCLUSION

The conversion efficiency ratios (lumber recovery/ yield, production rate and fuel consumption rate) have been established for four milling technologies that were used based on the number of timber species and trees felled. The average diameters of the trees felled from the natural forest were all above the felling limit 50 cm dbh. Comparison of the efficiency ratios of the freehand (Stihl 070 and Husqvarna 395XP) and attachments (frame and rail (logosol) milling technologies(using the same species for all of them) reveals that the percentage mean average lumber recovered was higher with the attachment technology (49.6%) than that of the freehand (43.5%) while the wood-mizer (LT30) recorded 70.6% in a range of 68.1% and 72.2%. The average lumber recovery rates for the chainsaw and improved chainsaw milling technologies ranged between 32% and 61.9%. The mean average lumber recovery from sawmills (small-scale, medium-scale and large-scale enterprises) study also recorded 53.9% with the minimum and maximum values of 28% and 64% respectively. In terms of the lumber produced per hour, freehand technology recorded a rate of 0.519 m^3/hr as against 0.435 m^3/hr and 1.52 m^3/hr for the attachments and wood-mizer milling. The quantities of mixed-fuel used in producing a cubic meter of lumber (fuel consumption rates) were obtained to be 8.4 lit/m^3, 10.8 lit/m^3 and 6.31 lit/m^3 for the freehand, attachments and wood-mizer technologies respectively.

With the freehand chainsaw and improved chainsaw milling technologies, the lumber production rate varied from 0.26 m^3/hr to 0.76 m^3/hr while the fuel consumption rates were estimated to be between 5.67 lit/m^3 and 14.51 lit/m^3. Also the lumber production and fuel consumption rates for the wood-mizer technology ranged between 1.25 m^3/hr & 1.83 m^3/hr and 5.25 lit/m^3 and 7.1 lit/m^3 respectively.

The main conclusion from these findings is that the Wood-Mizer milling technology has a higher efficiency than the freehand chainsaw and improved chainsaw milling technologies. This is followed by logosol technology.

ACKNOWLEDGEMENT

This research activity was funded by the European Union under the project entitled “Chainsaw milling project: Developing alternatives for illegal chainsaw lumbering through multi-stakeholder dialogue in Ghana and Guyana”. We are grateful to the European Union and Management of Tropenbos International for making it possible for us to undertake this study. We are also thankful to ITTO/CSIR-FORIG for the logosol equipment for their project entitled “PD 431/06: Processing and utilization of trees on farmlands and logging residues through collaboration with local communities” that was used for the study. The authors are grateful to the field technicians and operators who were involved in the work.

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