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Lumber Recovery and Production Rates of Small-Scale Mobile Sawmilling Industries in Northern Tanzania

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ABSTRACT

This study was carried out to quantify technical efficiency of mobile sawmills by determining the lumber recovery rates and production rates of two mobile sawmills namely as Wood-Mizer (band saw machine) and Ding-dong (circular saw machine). The study was conducted in Lushoto district, located in the Northern part of Tanzania. The results indicated that Wood-Mizer had lumber recovery of 51.3% and production rate of $0.64m^3$/hr., while Ding-dong had lumber recovery rate of 35.2%, and production rate 0.86m3/hr. Generally, results have shown that both sawmills have reasonable lumber recovery rates and production rates irrespective of the differences between the two, however Wood-Mizer had great conversion efficiency compared to the Ding-dong machine. Considering the reduced supply of saw logs for sustainable forest management, a machine with high conversion efficiency is highly encouraged than machine with high speed of production, thus Wood-Mizer stands to have more chances of applications as compared to Ding-dong machine which had relatively higher production rates. However, we encourage further studies to be conducted with diverse sets of factors associated with economic aspects as well as tree species to have more baseline information on the performance of these two mobile sawmilling machineries.

Key words: fixed-based - mobile sawmill – Wood Mizer - Ding-dong - Lumber recovery - productivity

BACKGROUND

Wood industries play major roles in the conversion of forest products into various end uses such as timber, plywood, and poles. Of all the industries, sawmilling has been dominating the wood industry to a larger extent (Ngaga 2011). Like elsewhere in the world, Tanzania has witnessed the largest transformation in sawmill technologies in the recent decade (URT 2017). Up to the early 1970s, fixed-site (stationary) sawmills had been the dominant technology since the colonial era. However, following the increase in annual allowable cuts in 1983 and inadequate industrially capacity to cope with excess wood supply, re-thinking of introducing mobile (portable) sawmills as a supplement but not replacement to fixed-site sawmill was considered the best option to sustain utilization of forest products (Kowero *et al.* 1985). This is attributed to a number of their technical advantages (Smorfitt *et al.* 2001) such as; flexibility in operations, high recovery rates (Smorfitt *et al.* 2003), low investment costs and less technical demands (Blackwell and Stewart 2003).

With the growing demand for wood-based products (Borz *et al.* 2021) and the scarcity of technologies for sawing small scale logs in recent years, sawmilling industries are constantly looking for ways to increase the value and quantity of their products i.e., conversion efficiency. Sawmill conversion efficiency affects both the profitability of the forest sector and the rate at which forest trees are harvested, to meet the demand for timber

(Kambugu *et al.* 2005). Lumber recovery rate (RR) and sawmilling productivity of sawmill machines are among the most important measures of sawmill conversion efficiency. Despite that, lack of information on appropriate technologies in most areas of Tanzania, makes a lot of sawmills rely on obsolete equipment and machines (Borz *et al.* 2021). Some entrepreneurs still import a wide range of mobile sawmill machinery which uses thick saw blades that cut with a wide kerf, producing large quantities of sawdust (Kambugu 2005) and thus low recovery rates.

Lumber recovery rate and productivity vary across different sawmills because the factors affecting individual sawmills are rarely the same (Steele 1984). They may be highly dependent on certain variables such as; log diameter, length and volume (Steele 1984, De Lasaux *et al.* 2009). Several studies have reported high RR of Wood-mizer machines (WMM) being around 50 (Olufemi *et al.* 2012) to 70% (Thulasidas and Bhat 2009) and above, while that of Ding-dong machines (DDM) lies between 20 to 35% (Ngaga 2011, Held *et al.* 2017). Meanwhile, their productivities are reported to vary due to difference in feeding speeds of the machine and total sawing time (De Lasaux *et al.* 2009, Milledge *et al.* 2018). Thus, it is necessary to understand which of these mobile sawmill technologies is better for use when making decisions.

It is however difficult to obtain accurate data on the sawmilling activities because timber millers are nervous to report details of their resource use (Wiedenbeck *et al.* 2016). While some research on recovery rates and productivity of mobile sawmilling has been undertaken in other countries (Smorfitt and Herbohn 2003, Kambugu *et al.* 2005, Antobre 2010, Owusu *et al.* 2011, Cedamon *et al.* 2013, Gligoraş and Borz 2015, Wiedenbeck *et al.* 2016, Regional and Millen 2020), little research has been undertaken in Tanzania, an exception being that of Kowero *et al.* (1985). Thus, this study was carried out to determine the lumber recovery rate and productivity (m^3/day) of the mobile sawmills operating around Western Usambara Mountainous forests. The information is required in order to make rational choices of sawmilling equipment, ensure efficient processing of the wood, and a reduction in deforestation.

MATERIALS AND METHODS

Study site

This study was conducted in Mavumo village, Lushoto district in Tanga region in Eastern coast of Tanzania. Lushoto District is in Western Usambara Mountains which lie between 300 - 2,100 meters above sea level. The main physical features are highlands covering about 75% (1,725 km^2) of the total District area, with altitudes of 1,000 - 2,100m.a.s.l. The area is characterized by cool weather throughout the year. The highest temperatures are reached from October-February and lowest during June-August. The district generally receives rainfall on a bi-modal pattern, with short rains from October-December and long rains from March-June. The highlands get an average of 800 - 2,000 mm rainfall per annum and the lowlands get about 500 - 800 mm per year (Lushoto District Council 2016).

The area is remarkable for its many small reserves, production and private forests. Some of these are owned by either the government or villagers. Such forests are Shagayu (7,754ha), Shume Magamba (11,567ha), Balangai West (1,074ha), Mkusu (3,670ha), Ndelemai (3,554ha) and Bombo West (3,565 ha). The mountainous part of West Usambara is composed of indigenous species such as *Ocotea usambarensis*, *Juniperus procera*, *Podocarpus usambarensis*, *Podocarpus pensiculy* and dense undergrowth of *Lansthus cirumilee* and other shrubs. The fact that the forests are in highlands, makes it special for use of mobile sawmills to ease production activities.

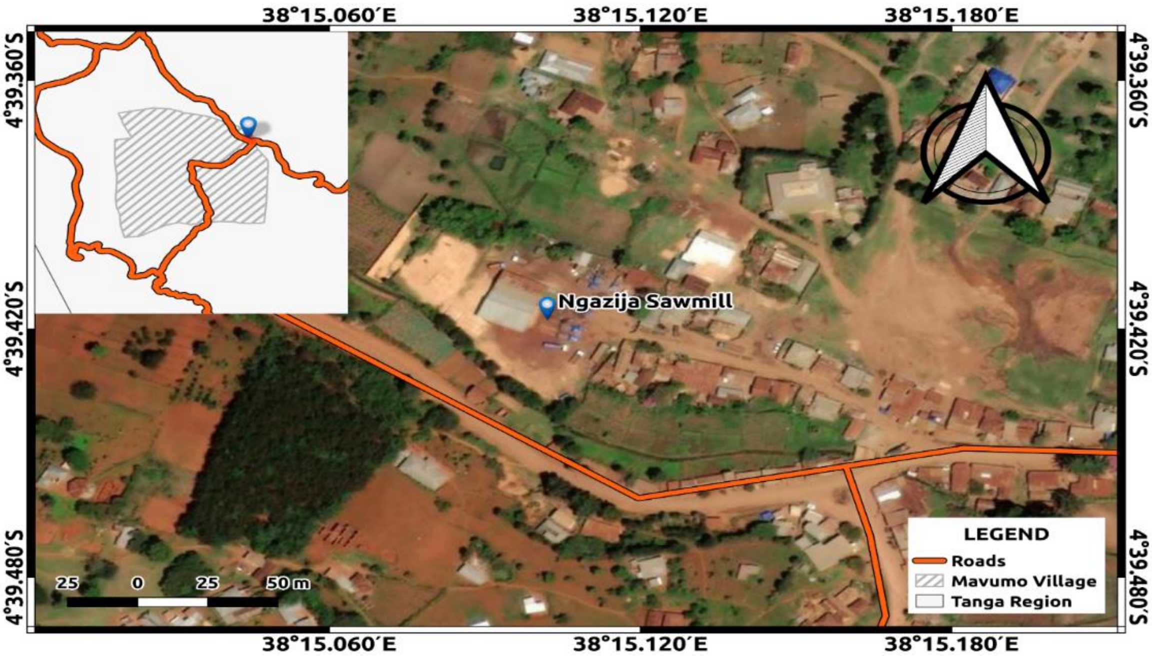

Figure 1: Map of Mavumo village showing location of the sawmill

Sampling design

Purposive sampling was used in the selection of the study sample, as only sawmills with mobile sawmill machinery were selected. Two different sawmill machines (Ding-dong and Wood-mizer machine) were selected in the study area for the purpose of comparison since they use different blades (i.e., circular for Ding-dong and bandsaw for Wood-mizer machines). Considering the season of data collection (rainy) and resources, a total of 50 relatively straight logs of Pinus patula species were randomly selected for sawing into lumber by cant sawing technique, 25 by Ding-dong and 25 by Wood-mizer machine (Plate 1).

Data collection

Before sawing, each log was measured for length by the tape measure and diameter over bark on both ends by the caliper. After the logs were sawn and converted to lumber, dimensions of each lumber piece were measured for width (W) and thickness (T). The length (L) of lumber was considered equal to that of the log.

Plate 1: Sawing of logs into lumber using a Ding-dong machine (left) and a Wood-Mizer machine (right)

The entire sawing operation was divided into basic work elements which included loading to the machine, breakdown, sawing and re-sawing. During the sawmilling operations, a time study technique was used to collect data for the measurement of productivity from both sawmills. Time consumption was measured in seconds and cumulative timing methods involving zero reset timing method was used to collect elemental time. The time used for each operation was recorded by a stopwatch in seconds. Total sawing time was obtained as the summation of the elemental time. Delay time (necessary and unnecessary delays) was also recorded.

Data analysis

Statistical analysis consisted of several steps and procedures that were taken to accommodate the type of data used in the analysis. Data on recovery rate and work element time were checked for normality using a Shapiro–Wilk test that was applied to all the variables taken into study, then a correlation analysis was done the independent variables (average log diameter, log volume and number of lumber pieces) to check the opportunity of building multiple linear regression models needed to predict the total and efficient sawing time related to productivity. A threshold set at 0.5 for the correlation coefficient was considered to exclude the independent variables, based on a pair-by-pair analysis. Simple regression modelling techniques were used to check the dependence between the time consumption and independent variables. Significance of the developed models and of the independent variables were tested and evaluated for a threshold set at $\alpha = 0.05$ using the p-values as a criterion ($p \leq 0.05$). The predictive capacity of the developed models was evaluated by the magnitude of the coefficient of determination (R^2).

Recovery rate computation

Conversion efficiency of each sawmill type was determined as the ratio of timber volume to log volume. The overall recovery for each sawmill category was obtained as the simple average recovery for individual sawmills in that category.

Descriptive statistics was used to determine the mean and the standard deviation (SD) of the Recovery Rate (RR) of different logs and time conjunctions of different work elements for the operations of the two sawmill machines. Also, inferential statistics including a paired t-test was used to compare the significant differences in Recovery Rate and the total work time of DDM and WMM.

Productivity rate computation

The consumed time (in seconds) for effectively sawmilling each log into lumber (T) was obtained as a sum of times recorded for each work element in each cutting repetition. Following a detailed time study, empirical relations between the feeding times of the log saw capacity and independent variables such as the top and bottom diameter of the log, log length and the volume of the log were developed mathematically by regression analysis. Then, the proportion measuring productivity(P) in m^3/hr., was estimated as shown in (equation 1).

$$P = \frac{Tvol \times F \times 60}{T} \qquad (1)$$

- Tvol = total volume of all logs/trees for a given logging operation m^3
- 60 = number of minutes per a workplace hour
- F = proportion measuring productive minutes per workplace hour
- T = total productive time in minutes (min)

RESULTS

Recovery rate

The overall mean recovery rate (RR) of the WMM was found to be generally higher than that of the DDM (Tables 1). RR also varied between the logs processed across both machine types, showing maximums of 48.5 and 74%, and minimums of 14 and 33% for DDM and WMM respectively (Figure 2). The results from the t-test indicated a statistically significant difference in the means of RR between machines (Figure 3).

Table 1: Descriptive statistics of recovery rates by sawmill machine.

Statistic	Machine type	
	Ding-dong	Wood-Mizer
Sample size (n)	25.0	25.0
Mean	35.2	51.3
Standard deviation	8.01	11.7
Standard error	1.60	2.34
Lower confidence limit	31.9	46.5
Upper confidence limit	38.5	56.1
Minimum	14.3	33.0
Maximum	48.5	74.0

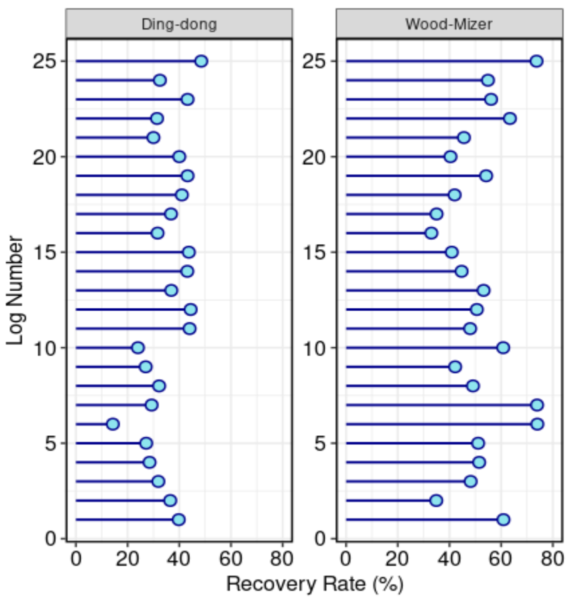

Figure 2: Recovery rate of individual logs per sawmill machine.

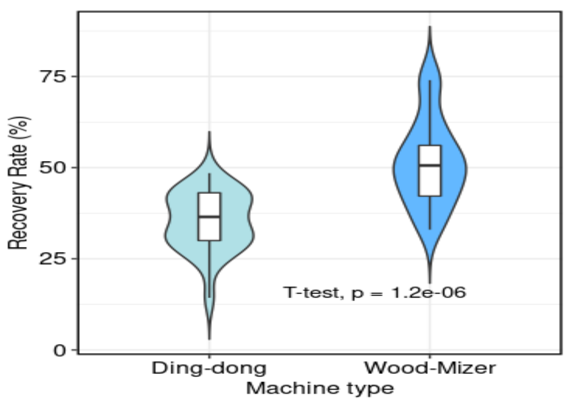

Figure 3: Violin plots showing mean RR by sawmill machine.

Productivity

Overall, the mean productivity was 0.86 m^3/hr. and 0.64 m^3/hr. for DDM and WMM respectively. The mean efficient sawing time, which was the time involved in sawing the logs only, between machines was also found to be significantly different statistically (Figure 4). Table 2 shows the descriptive statistics of all work elements for each machine. The total study time was approximately 9 hours for WMM and 3hours for DDM. For the DDM, 79% of the total time was effectively used for productive activities, 11% for supportive activities, and 10% was used on activities that did not contribute to the production process (Figure 5a). The WMM on the other hand used 89% of the total time for effective production, 8% for supportive activities and only 3% for unnecessary delays (Figure 5b).

The simple regression modelling was done for two dependent variables, total time (TT) and effective sawing time (EST) in minutes. These variables were regressed with single independent variables: average log diameter (cm), log volume (m^3) and number of lumber pieces produced. No attempt to develop multiple linear models was made due to high correlation among independent variables.

TT models performed relatively poorer than the EST models (Figure 6a-c; 7a-c) for both machine types. For DDM, log volume was found to be the best predictor while for WMM, average diameter explained more variation in both model categories (Figure 6b and 6e; 7a and 7d). Across all model categories for both machines, those that used a number of lumber pieces performed the poorest in terms of R^2.

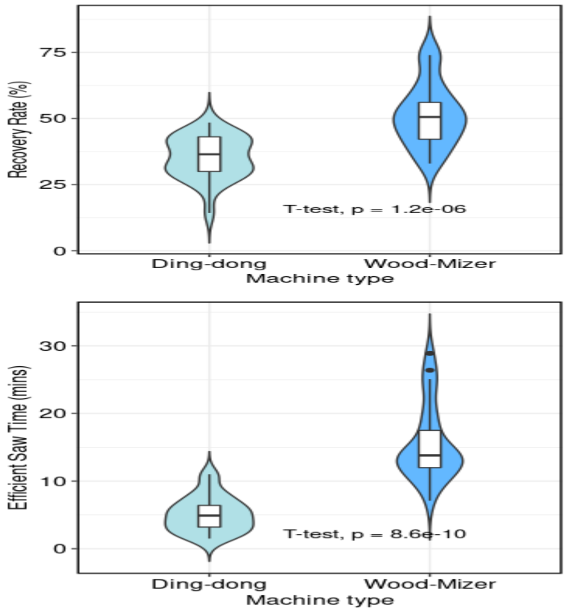

Figure 4: Violin plots showing mean efficient sawing time by sawmill machine

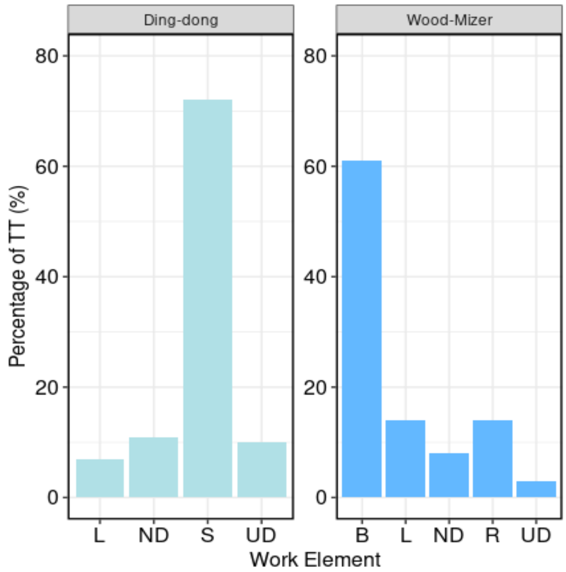

Figure 5: Bar plots showing loading (L), breakdown (B), sawing (S) resawing (R), necessary (ND) & unnecessary delays (UD).

Table 2: Descriptive statistics of work time elements of the machines in minutes

Machine type	Work element	Mean	Standard error	Standard deviation
Wood-Mizer	Loading	2.82	0.17	0.85
	Breakdown	12.5	1.02	5.11
	Resaw	2.93	0.20	0.99
	Necessary delays	1.70	0.94	4.71
	Unnecessary delays	0.65	0.57	2.85
Ding-dong	Loading	0.49	0.05	0.27
	Sawing	5.09	0.52	2.61
	Necessary delays	0.78	0.63	3.16
	Unnecessary delays	0.74	0.54	2.71

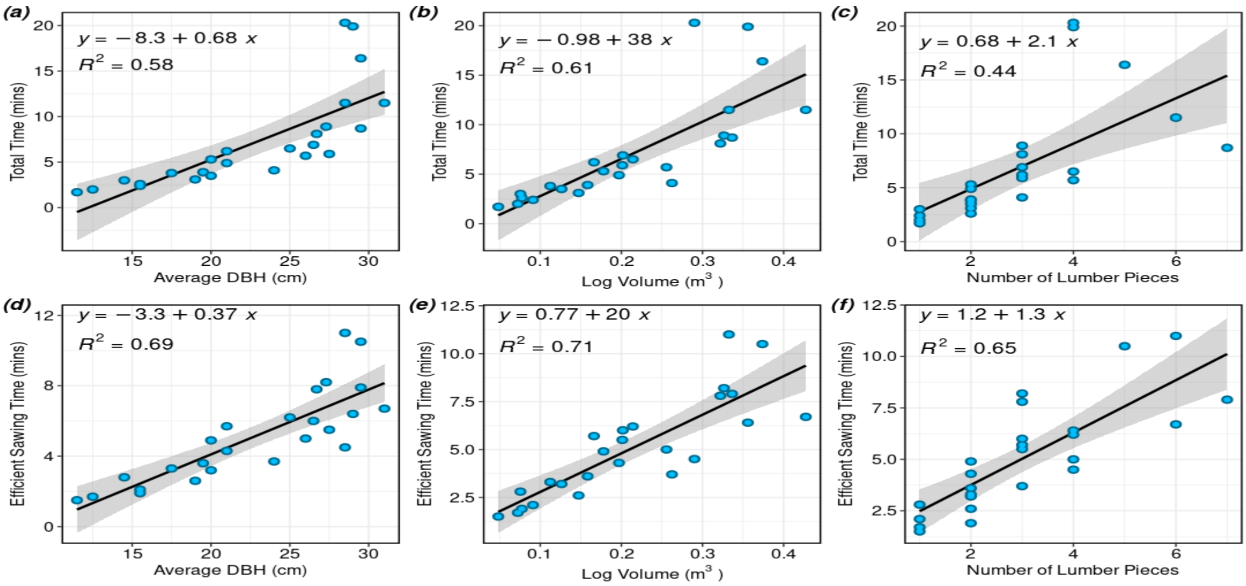

Figure 6: Total time and efficient sawing time models for DDM.

Legend: total time against (a) average diameter, (b) log volume, (c) number of lumber pieces; efficient sawing time against (d) average diameter, (e) log volume, (f) number of lumber pieces.

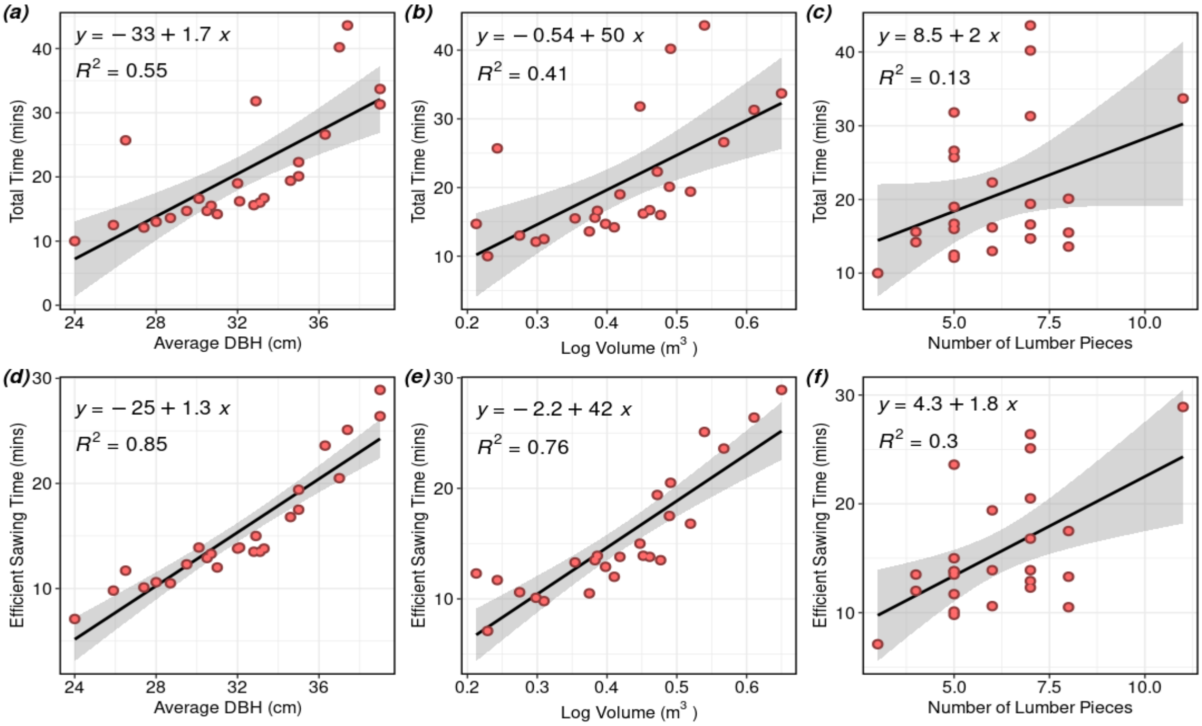

Figure 7: Total time and efficient sawing time models for WMM.

Legend: total time against (a) average diameter, (b) log volume, (c) number of lumber pieces; efficient sawing time against (d) average diameter, (e) log volume, (f) number of lumber pieces

Table 3: Comparison of Recovery Rated in various studies.

Machine type	Current study results	Other study results	References
Ding-dong	35.2%	20% - 35%	Ngaga (2011) & Held *et al* (2017)
Bandsaws	51.3%	>40%	Kambugu *et al.* (2005)
		56.08%	Olufemi *et al.* (2012)
		52%	Cedamon *et al.* (2013)
		66.8 - 78.8%	Thulasidas & Bhat (2009)
		70.6%	Owusu *et al.* (2011)
		67%	De Lasaux *et al.* (2009)
		66%	Gligoraş &Borz (2015)

DISCUSSION

For efficient utilization of wood, high recovery rate is highly considered when processing wood (Gligoraş and Borz 2015). The study shows that WMM was more efficient with RR (51.3%) than Ding-dong Machine (35.2%). Several other studies reported similar results of RR and higher (Table 3)

De Lasaux *et al.* (2009), claimed that the recovery rate may be as high as 67% with proper working pattern of the operator, the use of cant sawing method and minimum size of kerf. However, the current study shows that each sawmill had an overall conversion loss of 48.7% (WMM) and 64.8% (DDM). It is evident that lumber recovery increases when a shift in the sawing pattern due to kerf reduction allows wider and longer lumber to be cut from the same log (Cedamon *et al.* 2013, Steele 1984). Hence, the difference in RR between DDM and WMM ($p < 1.2E-6$), from this study may be a result of different blade sizes used. DDM had a large blade size (60 mm) while that of WMM was 25 mm. Also, almost all of the operators for both machines had no qualified sawmill skills. Thus, the lower RR from both sawmills may also be a result of lack of skills by operators, which may have jeopardized their decisions during sawing (Ngaga 2011).

Efficiency of a sawmill can also be determined by the productivity of the sawmill. The WMM had lower productivity of 0.64 m^3/hr than DDM which was 0.86 m^3/hr. Productivity of sawmills is highly dependent on certain independent variables such as log diameter, length and volume. These factors strongly affect the feeding speed of the machine and total sawing time (De Lasaux *et al.* 2009, Milledge *et al.* 2018). While there are also other work elements which influence the overall time consumption, the effective sawing time accounted for the highest share in both machines of the total operational time. From the models described by Figure (6b, 6e, 7a and 7d), average log diameter better explained the variation in both model categories while, the number of pieces of lumber was the worst predictor of effective sawing time.

Large diameter logs yield more lumber per volume than small diameter logs input (Steele 1984, Wiedenbeck *et al.* 2017). Obtaining good productivity with a small log is still problematic, because the time required to handle one small log outweighs the quantity of timber that can be produced from a large diameter log (De Lasaux *et al.* 2009, Gligoraş and Borz 2015).

There was also a statistically significant difference in the mean productivities between WMM and DDM ($p < 8.6E-10$), with WMM being lower. The low productivity of WMM is accounted for by more delays times, in the form of several down times due from manually turning logs, and from blade movement, several blade failures and breakdowns requiring time to fix, reducing the total productive time. Meanwhile, working with the DDM was easier due to longer blade life i.e., no noticeable blade breakdown, easy sharpening with less maintenance costs and faster operating speeds.

Circular blades last longer than bandsaw blades and can be sharpened in-situ without separating blades from the machine. Mobile circular sawmills are capable of cutting more boards per day than a chainsaw or band sawmill while taking into account log size, species and products being cut (Milledge *et al.* 2018).

CONCLUSION AND RECOMMENDATIONS

Conclusion

WMM has proven to be the appropriate technology to be adopted for sustainable forest management and environmental protection in the timber processing industry. This study revealed that there is an additional loss of 16% more from the logs in DDM than WMM in the form of sawdust and slabs. Considering the annual allowable cut of 42.8 million m^3/yr in 2013, the use of DDM will result in a loss of 68.5 million m^3/yr, leading to low timber supply and low annual profitability. The study suggests that the use of WMM will reduce wood residue generated in operation by 25% compared to DDM. Despite their lower production speed, WMM is still a good choice of sawmill machine as it has higher RR (i.e., produces less wood wastes) and thus a lesser rate of deforestation.

Recommendations

Thus, in order to improve sawmill production and technical efficiency of the sawn timber, the use of Wood-Mizer technology should be promoted. However, considering the other volume of wood waste generated during sawing (49% of wood not recovered), more research and discoveries should be done to develop more innovative machines that will have high recovery efficiency compared to the current ones. Additionally, the invention of safe automatic loading/unloading and self-turning machine parts will help to increase feeding speed and reduce manpower for lifting and turning logs. However, we encourage further studies to be conducted with diverse sets of factors associated with economic aspects as well as tree species to have more baseline information on the performance of these two mobile sawmilling machineries.

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