

## Modelling conversion efficiency for conventional, portable and artisanal sawmills in South-western Nigeria

<sup>1</sup>Kolapo, M.A.\* , <sup>2</sup>Kolapo, S.R. and <sup>2</sup>Omole, A.O.

<sup>1</sup>Department of Forestry, Wildlife and Fisheries, College of Agricultural Sciences, Olabisi Onabanjo University, Ogun State, Nigeria.

E-mail: abosedekolapo@oouaguiwoye.edu.ng

<sup>2</sup> Department of Forest Production and Products, University of Ibadan, Ibadan, Nigeria. E-mail: sr.kolapo@mail.ui.edu.ng, ao.omole@mail.ui.edu.ng

\*Corresponding author (E-mail: abosedekolapo@oouaguiwoye.edu.ng)

### ABSTRACT

Inefficiency of conventional sawmill in Nigeria has resulted in lower productivity, while in-situ primary processing of timber has not been well established to remedy this situation. This study was initiated to develop equations to model conversion efficiency for conventional, portable and artisanal sawmills in two selected locations within South-western Nigeria using a purposive site selection method. Log volumes each of 11.34 m<sup>3</sup> was randomly selected for each sawmill. A total of 34.02m<sup>3</sup> log volumes, made up of seventy eight (78) logs of different species, sizes and shapes were used for this study. Data was collected on each log before, during and after conversion to compute: log volume; log diameter; form factor; waste volume and required sawing time. Computed factors were used to model conversion efficiency using Multiple Linear Regressions to determine predictability of lumber recovery efficiency.

Prediction equations used for efficiency in conventional and artisanal were significant ( $P < 0.05$ ) while that of portable was not. Efficiency was highest in portable (0.997%), followed by conventional (0.935%) but least in artisanal (0.888%). The eight models developed (two for conventional, three for portable and artisanal respectively) were significant ( $P < 0.05$ ). Best fitting models were R-Square 0.924% in conventional and R-Square 0.981% and 0.880 in both portable and artisanal. Portable sawmill was the most appropriate for use and is therefore recommended that, mechanical modifications be carried out on it to improve its feed-work and set-work mechanisms (table height and head rig size) since it is highly efficient.

**Keywords:** Conversion efficiency, model, conventional, portable and artisanal sawmills.

### INTRODUCTION

The exponential growth of Nigeria's population has mounted a serious pressure on the Nigerian wood based industries, especially the round wood milling sector (RMRDC, 1991). Owonubi and Badejo (2000) succinctly put it that, sawmill is the most dominant and active within the wood based industry, as it accounts for about 95% of the total wood input into the industry. Record shows that about 50-55% of the original wood brought to sawmill are

marketable, while as much as 45-50% ends up as waste (Badejo, 2001). This situation is unacceptable both from the efficient and sustainable utilization of resources' point of view.

The observed downfall trend in the operational performance efficiency of wood based industries in Nigeria, particularly the sawmills, is attributed to the high volume of wood wastes like piles of slabs and off-cuts, half processed materials, rejects and

sawdust generated during the log conversion process. This makes it difficult to meet the growing demand for sawn timber (RMRDC, 1991; Ogunwusi, 2012; FAO, 2003).

The downward trend, coupled with the ever increasing demand for sawn wood, have paved way for illegal activities such as *in-situ* conversion, so called artisanal sawmilling 'chainsaw mill', to cushion the effect of inefficiencies in the saw milling industry (Ogunsanwoet *al.*, 2011). However, planks produced by "fitchers" are usually with rough surfaces and of low quality. This was not farfetched from the fact that sawing is hurriedly done as well as the crude method of sawing employed, occasioned by large and thick saw kerfs (Ogunsanwoet *al.*, 2005).

The use of obsolete machines as well as energy inefficiency affecting the optimum production of conventional sawmills, coupled with the illegal and low quality output of artisanal sawing affects to a large extent the conversion efficiency of round woods, and consequently more wastes are generated with low output. Therefore, there is a need for to make available of more sophisticated machines or technology, which can subjugate the effects observed in the aforementioned wood milling systems in Nigeria.

In the process of Nigeria trying to improve her wood processing industry, the Wood-Mizer, a portable sawmill, was introduced, though not yet on a large scale, to meet the need for accuracy and quality (Wood-Mizer Planet, 2016). Portable sawmills are mills which can be trailered and set up on site, next to the trees being cut. It can also be used to harvest urban timber where moving the logs to the milling site may be impractical (Portable Sawmills Wikipedia, 2016). There are various successes in Asia, Europe and other parts of the world on the efficiency level of this new technology. This includes the fact that it yields eight one inch boards, that is one extra board for every

seven produced on circular sawmills and two for those converted on chain sawmills (Dave, 2013). It increases profits, minimizes waste generated during log conversion; increases the time and energy efficiency of sawmills as well as improving operator's safety (Wikipedia, 2017). Thus, there is a need to investigate the efficiency of the portable sawmill technology in Nigeria, to ascertain its possibility of improving the efficiency of the sawmilling industry by developing equations to model conversion efficiency for the portable sawmill, as well as developing new conversion efficiency models for the other two milling systems already in existence in the country. Comparisons of these models will help to identify the most efficient of these mills in the country and ways of improving their efficiencies.

This study was therefore initiated to model conversion efficiency for conventional, portable and artisanal sawmills in two selected locations within south-western Nigeria, with a view to determining suitable models for enhancing efficiency in the Nigerian sawmill technology.

## **MATERIALS AND METHODS**

South-Western Nigeria lies between longitude 2° 311'E and 6°001'E and Latitude 6°211'N and 8°371'N with a total land area of 77,818 km<sup>2</sup> and an estimated population of 178.5 million people in 2016 (Agboola, 1979; World Population Review, 2019). The predominant vegetation in South-western Nigeria ranges from Coastal belt of mangrove swamp forest especially Ogun water-side area, Igbokoda, Ilaje and Ijaw in Ondo State and Epe area in Lagos State through tropical rainforest that spread across southern part of Ogun, Oyo, Ondo and Ekiti states and covered by savanna in the northern parts of Oyo, Osun and Ekiti States. The areas, which has a combined total of 85 constituted Forest Reserves, with a forest area cover of 842,499 hectares, is endowed with natural forest resources and mineral

deposits with extensive fertile soils (FORMECU, 1998).

### Experimental design

Oyo and Ogun states in South-west Nigeria were purposely selected based on the accessibility and availability of the three saw milling types desired for this research work, as the types are preponderant in these locations.

The selection of timber species for the study was based on (a) commercially available timber species in the selected sites (b) most harvested timber species found in the experimental site (c) species being worked on currently in the selected site. The timber species selected from both experimental site and types under which they were converted are shown in Table 1.

The study site selection was based on the availability, accessibility and functionality of the three milling types chosen for this study. In the case of conventional and portable mills the University of Ibadan, Oyo State was selected, while, Ayetoro, Ogun State was selected for Artisanal millingmaking use of purposive site selection method.

The sawing equipment selected was based on those that were available and whose adoption for use was under study. These included the CD6 Band Saw Machine, Wood- Mizer (LT 50) and Stihl 070 (chainsaw type mostly used for chainsaw milling in Nigeria).

The three sawmilling types were fed with 78 logs of different species, sizes and shapes which amounted to 34.02 cubicmeter used for this research work. The 34.02 cubicmeters were fed at 11.34 cubic metres to each conversion type.

The logs were converted with the use of chainsaw or Wood-Mizer or band saw machine using through and through technique, while the numbers of the lumber

pieces obtained for each sawmilling type were then recorded. The duration of conversion of each logs was also noted with a stop watch (Egbewole *et al.*, 2011). The procedure was repeated for all the sampled logs. Personal interview with the operators in each sawmill was carried out to ascertain the efficiency of workers.

At each sawmill, data was collected on the following variables:  $D_b$  = diameter at the base of the log,  $D_m$  = diameter at midpoint of log,  $D_t$  = diameter at the top of the log,  $W$  = Width of the lumber,  $T$  = Thickness of the Lumber,  $L$  = Length of the lumber,  $H$  = Log length (m),  $K$  = saw kerf thickness,  $NSP$  = Number of saw passes,  $NPY$  = Number of planks yielded,  $T_t$  = Total working Time and  $DT$  = Down time. The standard length of log being processed in these sawmills was 12ft (3.6m).

The collected data was used to compute the following variables to develop equations for predicting efficiency in the selected milling systems:

#### i. Determination of Log Volume:

Before each primary conversion, the top, middle and base diameters of the logs, as well as log length were measured using 50 meters measuring tape. The input log volume was then computed for each log using Newton's formula (Adesoye, 2004; Ogunsanwo *et al.*, 2005).

$$V = \frac{\pi h}{24} (D_b^2 + 4D_m^2 + D_t^2) \dots \dots \text{Eqn. 1}$$

Where,

$V$  = volume of log ( $m^3$ );  $D_b$  = diameter at the base of the log;  $D_m$  = diameter at midpoint of log;  $D_t$  = diameter at the top of the log;  $h$  = Log length (m);  $\pi = 3.142$  or  $22/7$

#### ii. Determination of Form Factor:

Real form factor for every tree is equal to ratio of tree volume to cylinder volume such that its height is equal to height of tree and its basal area is equal to tree basal area using Eq. 2 (Namiranian, 2007; Kalantari *et al.*, 2012).

$$fr = \frac{v}{g_{1.3}^2 X_{24}^{\pi} Xh} = \frac{v}{g_{1.3} Xh} \dots \dots \dots \text{Eqn. 2}$$

Where,  $f_r$  is real form factor of trees,  $V$  is real volume for every tree,  $g_{1.3}$  is basal area for every tree and  $h$  is tree height.

### iii. Determination of Lumber Recovered:

At the end of every log processing, the number of planks produced from each log were enumerated and parameters such as length, breadth and thickness of the planks were obtained to determine the lumber recovered using the method adopted by Ogunsanwo *et al.*, (2005).

$$V = W \times T \times L \dots \dots \dots \text{Eqn. 3}$$

Where,

$V$  = Volume of lumber recovered;  $W$  = Width of the lumber;  $T$  = Thickness of the Lumber

$L$  = Length of the lumber. The width of the plank was taken at different points along the plank to cater for irregularities along the plank and the average was calculated.

### iv. Determination of Lumber Recovery Factor (%):

The Lumber Recovery Factor is the proportion of the volume of acceptable lumber produced (output) to the log input volume.

Lumber Recovery Factor =

$$\frac{\text{Volume of timber recovered (output) (m}^3\text{)}}{\text{Volume of log (input) (m}^3\text{)}} \times 100 \dots \dots \dots \text{Eqn. 4}$$

### v. Determination of Wood waste in the selected sawmills:

This is the volume of waste produced at every conversion. The wood waste generated was in the form of sawdust and slabs (Egbewole *et al.*, 2005).

**Volume of Waste** = Volume of input – Volume of output  $\dots \dots \dots \text{Eqn. 5}$

### vi. Determination of required sawing time:

In selected sawmills, this was done by measuring and finding the difference between the total time taken in conversion of each logs and the down time using a stop watch (Egbewole *et al.*, 2011).

Required Sawing Time =

$$\text{Total Time (hr)} - \text{Idle Time (hr)} \dots \dots \dots \text{Eqn. 6}$$

Where;

Required sawing time = effective time utilized during conversion of each log

Total time = time taken in converting each of the logs both idle time and required time inclusive

Idle time = down time, the time that the machine was not in effective production and reasons for idle working time were noted

Variables included in the models for predicting the lumber recovery efficiency for the conventional, portable and artisanal sawmills were density, waste volume, log diameter, log volume, time and form factor.

Multiple Linear Regression was used in developing the models from selected variables according to the methods of Adesoye (2004) and Egbewole *et al* (2005).

The model is given as  $Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_n X_n \dots \dots \dots \text{Eqn. 7}$

Where:

$Y$  = Performance efficiency of the milling system (lumber recovery factor (LR)) (%)

$X_1$  = Density (D) (kg/m<sup>3</sup>);  $X_2$  = waste volume (WV) (m<sup>3</sup>);  $X_3$  = Log volume (LV) (m<sup>3</sup>)

$X_4$  = time; duration of log conversion operation of chosen sawmills (0-9hr);  $X_5$  = log diameter (m);  $X_6$  = form factor;  $a, b_1 \dots b_n$  = Regression Coefficient (k), 0hrs = zero efficiency, 9hrs = 100% time efficiency.

### Data Analysis

#### Analysis of lumber recovery and waste generated

The data generated were analyzed using analysis of variance (ANOVA) and Duncan post hoc test.

$$Y_{ij} = \mu + B_i + T_j + e_{ij} \dots \dots \dots \text{Eqn. 8}$$

#### Analysis of time efficiency

The data generated were then subjected to analysis of variance (ANOVA) and Duncan post hoc test.

$$Y_{ij} = \mu + B_i + T_j + e_{ij} \dots \dots \dots \text{Eqn. 9}$$

## RESULTS

The University of Ibadan Teaching and Research Sawmill was used for conventional sawmilling type (Table 1). The major tree species converted here were *Albizia saman*, *Terminalia catappa*, *Tabebuia rosea*; all of which fall within a density range of 460 – 540 kg/m<sup>3</sup>. These species were used because they were harvested at the time of this study and so readily available.

The Wood Mizer used for the portable sawmilling type was located at the Department of Forest Production and Products within the University of Ibadan campus. Species such as *Gmelina arborea*,

*Triplochiton scleroxylon* and *Tectona grandis* used for this study were obtained from the Zoological Gardens, University of Ibadan campus. The densities of these wood species varied between 440 kg/m<sup>3</sup> and 500 kg/m<sup>3</sup>.

However, the artisanal sawmilling type as shown on Table 1 was carried out at Ayetoro, Yewa North of Ogun State where *Anthocleista vogelii*, *Funtumia elastica* as well as *Antiaris toxicaria* were converted in a natural forest. These species ranged from 380 kg/m<sup>3</sup> to 510 kg/m<sup>3</sup>. Moreover, all the species used for the three milling types fell between low and medium densities.

**Table 1:** Timber species used for study in the selected sawmill types

Sawmills	Scientific name	Common name	Density kg/m <sup>3</sup>	Density class
<b>Conventional</b> (University of Ibadan)	<i>Albizia saman</i>	Rain tree	460	Low
	<i>Terminalia catappa</i>	Tropical almond tree	520	Medium
	<i>Tabebuia rosea</i>	Pink trumpet tree	540	Medium
<b>Portable</b> (University of Ibadan)	<i>Gmelina arborea</i>	Gmelina	450	Low
	<i>Triplochiton scleroxylon</i>	Obeche/African	440	Low
	<i>Tectona grandis</i>	Teak	500	Medium
<b>Artisanal</b> (Ayetoro, Ogun State)	<i>Anthocleista vogelii</i>	Cabbage tree	500	Medium
	<i>Funtumia elastic</i>	African Rubber Tree /Silkrubber	510	Medium
	<i>Antiaris toxicaria</i>	False iroko	380	Low

Source: Field Study (2017)

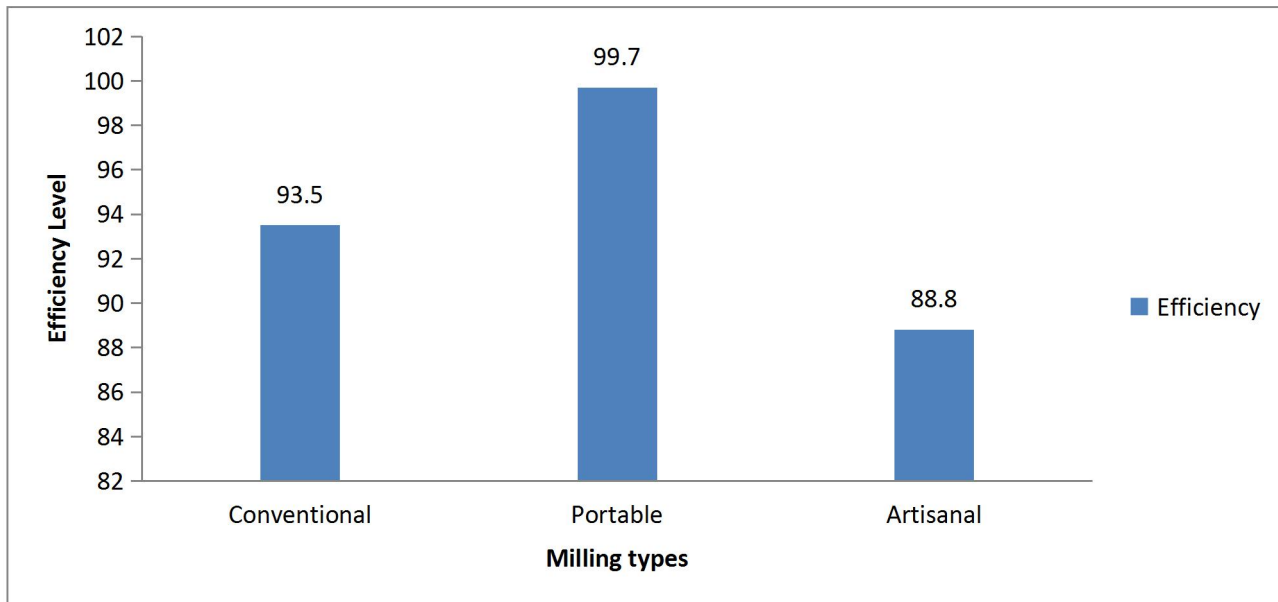
### Conversion Efficiency of the Sawmills

Table 2 shows the regression of processed variables on conversion efficiency stratified by sawmilling types. For conventional sawmill, it was only the waste volume that significantly influenced conversion efficiency ( $P < 0.05$ ), while the effect of density, log volume, time, log diameter and form factor on conversion efficiency were insignificant. In the case of the portable sawmill, all the variables used; density, waste volume, log volume, time, log diameter and form factor do not

significantly influenced conversion efficiency ( $P > 0.05$ ). Meanwhile the log volume, time and log diameter showed significant effect on conversion efficiency in the artisanal milling ( $p < 0.05$ ), but the effects of density, waste volume and form factor on conversion efficiency was not significant ( $P > 0.05$ ). The prediction equation used for conversion efficiency for conventional and artisanal sawmills were significant at ( $P < 0.05$ ), while the portable sawmill was not significant. The portable sawmill had the highest conversion efficiency R-Square

0.997, followed by conventional sawmill 0.935 while the artisanal sawmill recorded the least 0.888.

Figure 1 below showed that the portable milling types converts best at 99.7%. This is followed by the conventional milling type (93.5%) and artisanal sawmilling had the lowest (88.8%) conversion efficiency.



**Fig. 1.** Efficiency level of the milling types

**Table 2:** Regression of Process Variables on Conversion Efficiency Stratified by Sawmills

Sawmills	Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Remark	ANOVA		R-Square
		B	Std. Error	Beta			Lower Bound	Upper Bound		F	P-Value	
<b>Conventional</b> (University of Ibadan)	(Constant)	52.952	25.5876		2.070	0.065	-4.058	109.963	ns	23.924	0.000	0.935
	Density	-0.032	0.042	-0.072	-0.770	0.459	-0.125	0.061	ns			
	Waste Vol.	-122.357	12.197	-1.260	-10.032	0.000	-149.533	-95.181	**			
	Log Vol.	50.907	27.570	0.751	1.846	0.095	-10.523	112.337	ns			
	Time	-0.132	0.237	-0.072	-0.556	0.590	-0.660	0.396	ns			
	Log Diam.	19.578	25.681	0.251	0.762	0.463	-37.642	76.798	ns			
	Form Fact	0.627	5.182	0.012	0.121	0.906	-10.920	12.173	ns			
<b>Portable</b> (University of Ibadan)	(Constant)	319.688	163.577		1.954	0.301	-1758.757	2398.132	ns	58.379	0.100	0.997
	Density	-0.620	0.409	-0.491	-1.515	0.371	-5.822	4.582	ns			
	Waste Vol.	-57.891	6.367	-0.570	-9.093	0.070	-138.785	23.004	ns			
	Log Vol.	55.596	24.613	1.981	2.259	0.265	-257.145	368.337	ns			
	Time	-0.615	0.269	-1.408	-2.283	0.263	-4.039	2.808	ns			
	Log Diam.	7.215	23.032	0.166	0.313	0.807	-285.436	299.865	ns			
	Form Fact.	0.028	0.270	0.052	0.105	0.933	-3.403	3.460	ns			

<b>Artisanal</b> (Ayetoro, Ogun State)	Constant)	79.963	10.335		7.737	0.000	59.147	100.778	**			
	Density	0.019	015	0.069	1.243	0.220	-0.012	0.050	ns			
	Waste Vol.	-304.305	22.072	-1.008	-13.787	0.000	-348.760	-259.850	**			
	Log Vol.	218.273	26.439	1.555	8.256	0.000	165.023	271.523	**	59.596	0.000	0.888
	Time	-0.096	0.153	0-.041	-0.627	0.534	0-.405	0.213	ns			
	Log Diam.	-81.291	21.855	-0.790	-3.720	0.001	-125.309	-37.273	**			
	Form Fact	0.279	.172	0.097	1.625	0.111	-0.067	0.624	ns			

**The prediction equations used for conversion efficiency for the three milling types are therefore stated thus:**

Conventional =  $CE = 52.952 - 0.032(D) - 122.357(WV) + 50.907(LV) - 0.132(T) + 19.578(LD) + 0.627(FF)$

Portable =  $CE = 319.688 - 0.620(D) - 57.891(WV) + 55.596(LV) - 0.615(T) + 7.215(LD) + 0.028(FF)$

Artisanal =  $CE = 79.963 + 0.019(D) - 304.305(WV) + 218.273(LV) - 0.096(T) - 81.291(LD) + 0.279(FF)$

As shown in Table 3, a total of eight models were developed for conversion efficiency in the study areas, the eight models (two for conventional, three each for portable and artisanal sawmills) were all significant ( $P < 0.05$ ). Out of the two models developed for conversion efficiency for conventional sawmill, the second model had the highest R-Square (0.924%), though with a higher Standard Error (4.615). In the case of the portable sawmill, the third model had the highest R-Square (0.981%) and the least standard error (4.75). The third model

had the highest R-Square (0.880) and the least standard error (5.26) in the artisanal milling system as well.

On the other hand, Figure 2 gives a brief summary of the fitness models. From the figure the best model for conventional sawmilling was obtained at 92.4%; for portable sawmilling (98.1%) while the least fitting model was found in artisanal sawmilling type (88.0%).



**Table 3:** Models for Conversion Efficiency Stratified by Sawmills

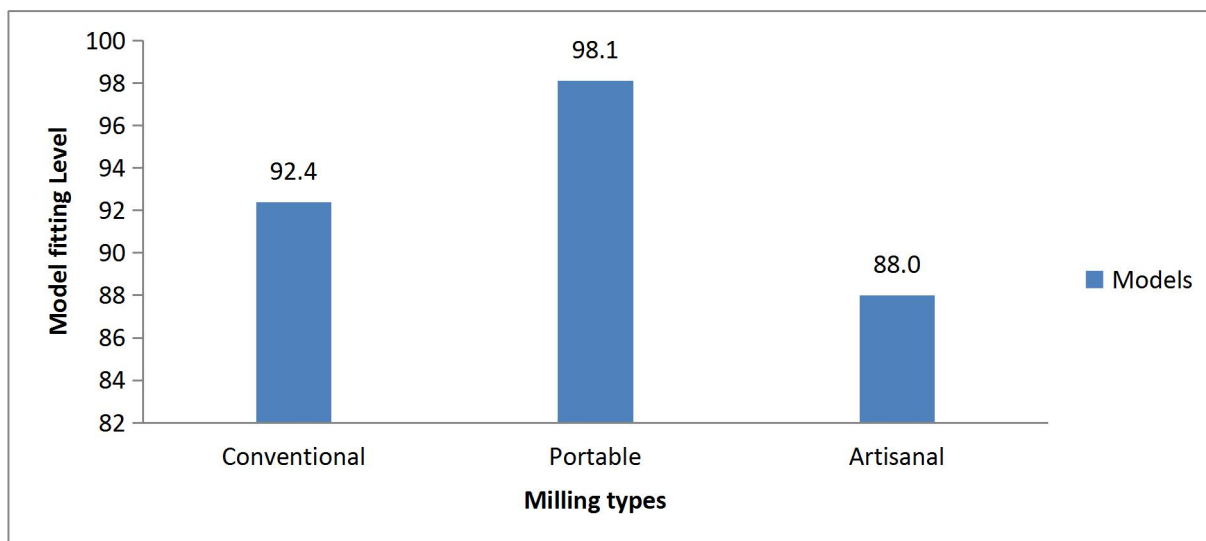
Sawmills	S/N	Models	R Square	Std. Error	ANOVA		Remark
					F	P-Value	
<b>Conventional</b> (University of Ibadan)	1	CE = 71.824+-60.399(WV)+-e---	0.387	2.645303	9.470	0.008	**
	2	CE = 46.946+-122.924(WV)+66.092(LV)+ -e---	0.924	4.614996	84.859	0.000	**
<b>Portable</b> (University of Ibadan)	1	CE = 73.630+-.472(FF) + -e---	0.742	14.358071	17.242	0.006	**
	2	CE = 94.766-.549(FF)--41.853(WV) + -e---	0.892	10.177083	20.631	0.004	**
	3	CE = 46.659-0.266(FF)-55.230(WV)+28.245 (LD)+ -e---	0.981	4.753866	69.340	0.001	**
<b>Artisanal</b> (Ayetoro, Ogun State)	1	CE = 76.721-192.683(WV) + -e---	0.408	11.438054	34.404	0.000	**
	2	CE = 64.536-347.604(WV)+116.031(LV) + -e---	0.827	6.239585	117.317	0.000	**
	3	CE = 93.236-307.459(WV)+215.204(LV)-85.174(LD)+ -e---	0.880	5.262413	116.916	0.000	**
		-					

The following are the best fitting model selected on the basis of coefficient of determination ( $R^2$ ) and results of ANOVA:

Conventional = CE = 46.946-122.924(WV)+66.092(LV)+ -e---

Portable = CE = 46.659-0.266(FF)-55.230(WV)+28.245 (LD)+ -e---

Artisanal = CE = 93.236-307.459(WV)+215.204(LV)-85.174(LD)+ -e---



**Fig. 2.** Best fitting models for the milling types

## DISCUSSION

The prediction equations used to determine conversion efficiency in conventional and portable mills showed that, there was a significant positive correlation between lumber recovery and log volume; log diameter and form factor; while the correlation between sawn wood recovery and density; waste volume and time were negative. The equation used for artisanal milling system indicated a significant positive correlation between lumber recovery and density; log volume and form factor but a negative correlation between lumber recovery and waste volume as well as time and log diameter.

The high coefficient of determination ( $R^2$ ) value in the second model for conventional and third models for both portable and artisanal sawmills, coupled with the statistical significance of the model indicated that conversion efficiency of each of the three sawmills considered can be modelled as a linear function of sawmill and log characteristics. This agrees with the findings of Egbewoleet *al.*, (2011) that at any given log diameter class of known log shape and log length, the average lumber recovery can be estimated.

The models demonstrated the decrease in volume of timber recovered from a log when sawing with the portable sawmill available as the machine was not built for large diameter logs obtainable in the tropical West Africa relative to artisanal sawmills. The model further predicted that portable sawmills can achieve the same level of efficiency as conventional sawmills. The results revealed that large-diameter logs yield more timber than small diameter logs. This agrees with the report by Ayarkwa (1999) that there were significant differences between timber yield from log diameter classes 10-20, 21-30 and 31-40 cm, with the larger log diameters generating higher timber yields.

The models also showed that lumber recovery, regardless of any sawmill conversion method, depend on the volume of the log, density as well as form factor. When all these are put into consideration, then there can be higher lumber recovery efficiency. This is in agreement with Fuwape (1985), Lucas (1983), Sonigitu, (2011), Egbewoleet *al.* (2006), and Egbewoleet *al.* (2011). The negatively correlated factors like wastes and time can be removed when the experience of the operator is put into consideration as he can choose the best opening face (BOF) as well as select the proper blade and kerf that will minimize wastes.

## CONCLUSION AND RECOMMENDATION

Portable sawmill was the most efficient sawmilling technology for converting the large diameter logs into sawn timber while artisanal sawmills was the least efficient as they dealt more in small logs as represented by r-square. The linear models 2 and 3 have shown that the conversion efficiency of both portable and conventional sawmills were a function of sawmill and log characteristics (log diameter, density and form factor). Also, lumber recovery will increase by 7.6% in the conventional sawmill as predicted by Model 2 provided that small diameter logs (70cm – 100cm) with good forms were supplied to the mill. Model 3 predicted that recovery of sawn wood would increase by almost 2% if the table level and headrig can be adjusted to accommodate larger logs characteristic of our tropical region.

Since portable sawmills are highly efficient and faster, It is recommended that mechanical modifications should be carried out on the Wood Mizer to improve their feed-work and set-work mechanisms (table height and head rig size).

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