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Relative efficiency of sawmill types operating in Uganda's softwood plantations

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Abstract

The overall aim of this study was to determine the appropriate sawmilling technologies that should be promoted for use in Uganda's softwood plantation. Conversion efficiency, sawing accuracy, and sawing capability of four sawmill categories were evaluated. Data were collected from sawing of 604 good-quality logs using eleven Rolling-Table Sawmills, Dimensional Swivel Sawmills, Band Sawmills, and Locally-fabricated Sawmills. Sawing accuracy data were collected from 165 boards in three timber sizes (75 mm x 50 mm, 100 mm x 50 mm, 150 mm x 50 mm). Sawing capability was assessed from saw blade parameters, merchantable timber size, and size of available logs. ANOVA was used to show differences in recovery and sawing accuracy between and within sawmills. Band sawmills exhibited the most efficient sawmill technology for converting logs into sawn timber while rolling-table sawmills were more efficient than dimensional swivel and locally manufactured sawmills. Baud sawmills were more accurate than sawmills in the other categories. Therefore, band sawmills should be promoted in Uganda and mechanical modifications carried out on the swivel and locally-manufactured sawmills operating in softwood plantations to improve their feed-work and set-work mechanisms.

Key words: *sawmill, conversion, efficiency, softwood, plantation, recovery*

Introduction

The long-term sustainability of Uganda's forest resources depends on sound conservation practices. These include environmentally friendly harvesting methods, use of efficient processing technologies and appropriate use of wood resources. The sawn wood industry in Uganda is characterised by poor harvesting and processing methods, limited value addition and high wastage. Sawn wood recovery seldom exceeds 40% for large diameter hardwood logs and 25% for small diameter plantation logs (Jacovelli and Carvalho, 1999). There are a number of underlying reasons for the inefficiency and waste in the saw milling industry. These include the use of inappropriate processing technologies, poor maintenance of sawmill machinery, poor management and lack of technical skills by the sawmill operators

The lack of investments in training and purchase of wood-efficient harvesting and processing technologies is often attributed to the low prices charged for saw logs from both government forest reserves and private forests (MLWE 2002). In addition, the sawn wood industry, like many other industries in Uganda, has not recovered from the economic decline that occurred in the 1970s. Thus pit sawyers who use inappropriate hand sawing technologies that lead to wasteful production still dominate the industry.

Rigid market requirements that accept only timbers longer than 4.2 m also increase waste and decrease efficiency of harvesting and processing operations. Research has shown that there is a reduction in sawn timber recovery with increasing log length (Aryakwa, 1999). Research carried out at Nyabyeya training sawmill showed that cutting plantation logs into 4.2 m logs gave a recovery of 25% compared to 41% when a variable length system was used for bucking logs (Balikudembe, 1997).

Sawmill conversion efficiency affects both, the profitability of the forest sector and the rate at which forest trees are harvested in order to meet the demand for timber. Often, low conversion efficiency results in increased rate of deforestation. In order to conserve the environment and to ensure profitability, the manufacturing of timber needs to be done in the most efficient manner (Wade *et al.*, 1992;

FAO, 1994). Accordingly, the Forest Policy (2002) and the National Forest Plan (2002) advocate for a modern, competitive, efficient and well-regulated wood processing industry.

With natural hardwood forest reserves nearly depleted of merchantable timber, softwood plantations have become the main focus of the saw milling industry. Many of the plantations were planted in the 1960s and 70s. Due to the economic decline in the 1970s, these plantations were not well managed. Weeding, thinning and pruning were not carried out (MacCaughan and Carvalho, 2003). The logs harvested from these plantations are small in diameter and have poor form. Even with good saw milling technologies, recovery of timber from such poor logs is low.

During the late 1980s, private entrepreneurs were encouraged to invest in the saw milling industry to salvage the softwood plantations that were deteriorating due to old age. Production of timber from the softwood plantations was also intended to reduce the pressure on the tropical high forests. Emphasis in natural forests has been attached to biodiversity conservation and tourism. This has resulted into the present plantation-based sawmilling industry (MacCaughan and Carvalho, 2003).

Due to lack of information on appropriate equipment required to process the small, poor quality plantation logs, entrepreneurs imported a wide range of mobile sawmill machinery. These included rolling-table sawmills, band sawmills, and dimensional swivel sawmills. Many of the sawmills use thick saw blades that cut with a wide kerf thereby producing large quantities of sawdust. Most of the sawmill machinery imported is suitable for processing large hardwood logs as opposed to the small softwood plantation logs (Carvalho and Pickles, 1994, Uganda Forest Sector Co-ordination Secretariat, 2001; Jacovelli and Carvalho, 1999). In addition, there are several types of small mobile sawmills that have been fabricated locally. The sawing efficiency of these locally made sawmill machinery is not known.

The question being asked by policy-makers, regulatory bodies and entrepreneurs is: which of the above saw milling technologies should be promoted for use in Uganda's softwood plantation? In order to answer the above question, a study was carried out to determine the relative efficiency of the different sawmill types operating in the softwood plantations of Uganda including those locally fabricated. The information is required in order to make rational choice for saw milling equipment, ensure efficient processing of the wood, and a reduction in deforestation. Government is committed to reducing wastage and inefficiency in the wood processing industry and to improve the environment as spelt out in the Uganda Forest Policy of 2002.

Materials and Methods

Characterisation of the sawmill machinery operating in softwood plantations

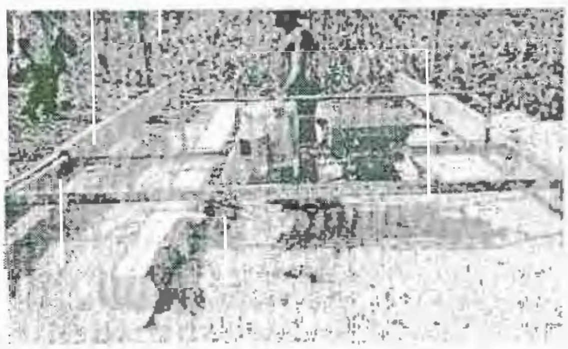
Sawmills operating in Uganda's softwood plantations were categorised as rolling table sawmills, dimensional swivel sawmills, band sawmills and locally manufactured sawmills.

Table 1 and Fig. 1 show the general characteristics of the sawmill types:

Table 1: Selected characteristics of sawmill categories operating in softwood plantations in Uganda.

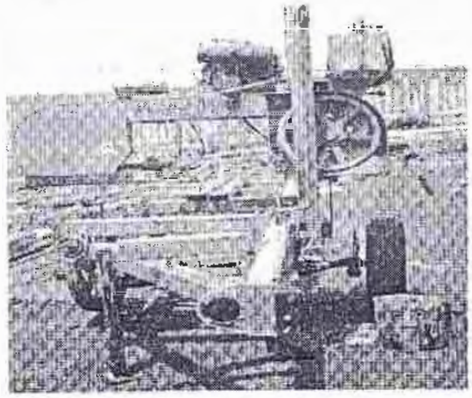
	Rolling-table sawmill	Dimensional sawmill	Band sawmills sawmill	Locally- fabricated saw mill
No of sawmills studied	3	4	2	2
Rated production capacity (m^3/year of round wood)	3,000	4,000	2,500	Not available in records
Saw blade thickness (mm)	4.30	3.30	1.25	4.40
Teeth setting /width (mm)	0.70	5.30	0.75	1.76
Collar diameter (cm)	200	100	-	200
Blade diameter /width (cm)	1000	420	-	1000

(a)



(b)

(c) ***Figure 1*** *. Sawmill structured: (a) Lucas Sawmil Swivel (b) Kaara Sawmill (rolling-table) (c) Bench Sawmill (Locally Fabricated)*



(d) *(D) Wood-Mizer sawmill (Band).*

Determination of the conversion efficiency of each sawmill type

Eleven sawmills operating in Nyabyeya, Katugo, Oruha and Swam softwood plantations were studied. A total of 604 defect free logs of *Pinus patula* and *Pinus caribea* were sawn using rolling-table sawmills, dimensional swivel sawmills, band sawmill and locally manufactured sawmills. The logs studied were grouped into four-diameter classes; small (10-19 cm), medium (20-29 cm), large (30-39 cm) and very large (40 cm and above). The volume of each log was determined using the log-volume table based on top log diameter. The logs were sawn into timber using the through and through method. Timber volume was ascertained using the nominal timber dimensions. 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.

Determination of sawing variation of each sawmill type

At each sawmill, 15 boards were randomly selected and their width and thickness measured at four random locations along the length of the board. Sawing variation was computed as the standard deviation of the thickness of the timber sampled.

Data analysis

One-way ANOVA was used to ascertain whether there was a difference in recovery between mills in each category while the difference in recovery between sawmill categories was analysed by two-way ANOVA. The sawing variation within sawmill categories was analysed using one-way ANOVA while the variation in sawing accuracy between mill categories was analysed by two-way ANOVA.

Development of a model to predict sawmill recovery

The following linear regression model was proposed;
$R = a_o + a_1D + a_2L + a_3K + a_4SA + a_5T + a + b$, where, R is the conversion efficiency (%), a_o is the intercept and a_1 to a_5 are regression coefficients, D is the top log diameter (m), L is the log length (m), K is the average saw kerf width (mm), SA is the total sawing variation (mm), T is the log taper (cm/m), a and b are dummy variables to take account of the sawmill category and log diameter class respectively. Bi-variate plots were carried out to establish the relationship between sawmill recovery (R) the dependant variable and each of the independent variables (top log diameter, log length, saw kerf width and log taper). Regression analysis was carried out to obtain the model parameters. The best fitting model was selected on the basis of coefficient of determination (R^2) and results of ANOVA.

Results

Efficiency of sawmills operating in Uganda

Analysis of variance showed that there was no significant difference in conversion efficiency within individual sawmill categories ($P>0.05$). However, differences in conversion efficiency between sawmill categories were significant (Table 2). Band sawmills and rolling table sawmills were the most efficient. On average, band saws and rolling table sawmills had a conversion efficiency of 40% and 37% respectively while the locally manufactured sawmills and dimensional swivel sawmills were less efficient and had a timber recovery of only 31% and 33% respectively.

A paired t-test showed that there was no significant difference ($P= 0.379$) between the conversion efficiency of band and rolling table sawmills. Similarly, there was no significant difference ($P= 0.423$) between the conversion efficiency of locally manufactured and dimensional swivel sawmills.

Log diameter significantly affected conversion efficiency regardless of the sawmill type used (Table 2). Large-diameter logs yielded significantly more timber than small diameter logs ($P>0.05$). Table 1 shows that locally manufactured sawmills were not suitable for processing large logs. The large diameter logs yielded significantly more timber when sawn using band and rolling table sawmills than when sawn using dimensional swivel and locally manufactured sawmills. Band sawmills were significantly more efficient in processing small logs than any other category of sawmills operating in Uganda's soft wood plantations. On average, band sawmills had conversion efficiency of 34% when sawing small diameter logs compared to 27% obtained when small logs were sawn using locally manufactured and dimensional swivel sawmill

Table 2: Effect of log diameter and sawmill category on conversion efficiency

Sawmill Category	Log Diameter Class				Weighted Average
	10-19 cm	20-29 cm	30-39 cm	< 40 cm	
Rolling Table sawmill	28.6	38.1	39.0	48.7	36.7
Dimensional swivel sawmill	26.5	32.8	39.0	43.7	32.5
Band sawmill	34.0	41.6	40.5	46.0	39.5
Locally manufactured	27.0	32.0	32.0	35.1	31.6
Average	**29.0**	**36.1**	**38.4**	**42.8**	**35.0**

Sawing variation of sawmills operating in Uganda

Analysis of variance showed that there is a significant difference in sawing variation between sawmill categories (Table 3). A Standard deviation of 0.5 mm from the target size was observed in band sawmills compared to 7.6 mm for locally manufactured and dimensional swivel sawmill. The size of the timber sawn significantly affected sawing variation regardless of the sawmill type used. All sawmill categories sawed small dimension timbers (those less than 100 mm wide) more accurately than the large dimension timbers (those larger than 100 mm wide).

Table 3: Analysis of variation in sawing accuracy between sawmill categories

Source	df	ss	ms	F	P
Mill Category	3	2.0401	0.6800	11.85	0.06
Timber Size	2	1.8314	0.9157	15.96	0.004
Error	6	0.3443	0.0574		
Total	**11**	**4.2158**			

Conversion efficiency model

According to the model, there was a significant positive correlation between recovery and log diameter while the correlation between sawn wood recovery and both log taper and saw kerf were negative (Table 3). The following is the best fitting model selected on the basis of coefficient of determination (R^2) and results of ANOVA:

$$R = 35.6 + 0.31D - \frac{4.03}{T} + a + b$$

Where; a is numerically equal to -4.18 for small-diameter logs and zero for the other diameter classes while b is -4.41 for dimensional swivel sawmills, -7.51 for locally manufactured sawmills and zero for both band and rolling table sawmills.

The interaction between log diameter and log taper was significant. Often log taper tend to increase with increasing log size. Similarly, the interaction between sawmill category and saw kerf width were also significant. Band saws use

Table 4: Correlation between conversion efficiency and independent variables

Variable	Correlation Coefficient	P
Diameter	0.703	0.000
Taper	-0.704	0.000
Kerf	-0.264	0.105

thin saw blades and consequently cut with a narrow saw kerf while circular saws use thick saw blades that produce a large kerf. The presence of multicollinearity implies that coefficients and statistical significance of these two variables may be depressed. The adjusted valne for the coefficient of determination was 79% and was statistically significant. The model could explain 79% of the variation in recovery. Using the model, the performance of the different sawmills while sawing various log sizes were calculated (Fig.2). RTS= rolling table sawmills, DSS= dimensional swivel sawmills, BS= band sawmills, OS= Other sawmills

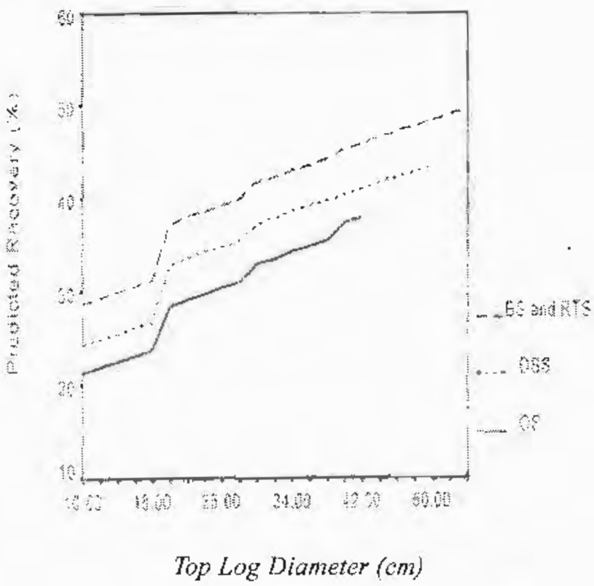


Figure 2: Predicted efficiency of various categories of sawmills operating in Uganda's softwood plantations

Discussion

Among the various categories of sawmills operating in Uganda's softwood plantations, the band sawmills were found to be most efficient. This may be attributed to the thin saw blades these sawmills use. The average kerf width for the band saws studied was 2.75 mm compared to 8.2 mm for the circular saws used by locally manufactured and dimensional swivel sawmills. Consequently, the locally manufactured and dimensional swivel sawmills generate three times more sawdust than the band sawmills and significantly less timber.

According to the yield model developed from this study, a loss of 8% and 4% is expected when locally manufactured and dimensional swivel sawmills respectively are used instead of band sawmills or rolling-table sawmills. The loss would increase to 12% and 9% respectively if these sawmills were used to process small diameter logs.

The average annual allowable cut for dimensional swivel sawmills is 1400 m^3 of round wood per annum (McCaughan and Carvalho, 2003). Thus a firm using a dimensional swivel sawmill instead of a band sawmill would lose an average 168 m^3 of timber in form of slabs and sawdust. A cubic meter of *Pinus patula* timber costs an average Ug. Sh 150,000/= implying that the firm would lose on average a total of Ug. Sh 25,200,000/= annually. The profitability of the saw milling industry in Uganda is consequently poor since 66% of the sawmills operating in softwood plantations in Uganda are dimensional swivel sawmills. In addition to decrease in profitability, the use of inefficient saw milling machinery leads to unsustainable utilisation of the forest resource as more logs are harvested to prodnce a given volume of timber.

Logs sampled in this study show that only 2% from the plantations have a diameter above 40 cm. The majority of logs (79%) processed in softwood plantations are small to medium size with a top diameter ranging between 10 cm and 30 cm. The results revealed that large-diameter logs yield more timber than small diameter logs. This agrees with a report by Ayarkwa (1999). He found out 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. This may partly explain the low recovery of sawmills operating in Uganda's softwood plantations.

According to Jacovelli and Carvalho (1999), the small size of the log resource and the need to sustain log supply are the two major factors to be considered when assessing the type of saw milling technology suitable for processing logs. The results from the study revealed that band sawmills were more efficient at sawing small diameter logs than the dimensional swivel and locally manufactured sawmill and should be recommended to potential investors. On this basis, therefore, dimensional swivel sawmills and locally manufactured sawmills are inappropriate for use in Uganda's softwood plantations and investors should be discouraged from buying this type of machinery. On the other hand, these sawmills are cheap to buy and maintain and are therefore more affordable to the local entrepreneurs. They are also better than other alternatives such as pit sawing or power saws commonly used in Uganda.

Band saws sawed timber more accurately (closest to the intended target size) and produced smoother surfaces than all other types of sawmills. This may be attributed to the fact that the saw blades of locally manufactured and dimensional swivel sawmills are not stable when the saw is running. In dimensional swivel sawmills, the saw blade is supported on the same movable frame as the engine and is therefore likely to wobble due to vibration. This would lead to a relatively wide kerf and deviation from the intended line of cut. The mechanism for size adjustment in locally manufactured and dimensional swivel sawmills is also poor and often leads to inaccurate size adjustment. For categories of mills, feeding was partly or exclusively manual while the setworks for size adjustment at one mill consisted of pieces of timber and at another it was manually done for each piece being sawn.

A linear model to predict conversion efficiency based on sawmill and log resource characteristics was developed. The high value for the coefficient of determination and the statistical significance of the model indicates that conversion efficiency of the sawmills operating in softwood plantations can be modelled as a linear function of sawmill and log characteristics. The model demonstrates the decrease in volume of timber recovered from a log when sawing with dimensional swivel and locally manufactured saws relative to band sawmills or rolling-table sawmills. The model further predicts that rolling-table sawmills can achieve the same level of efficiency as band sawmills.

Conclusions and recommendations

The majority of the logs harvested from the softwood plantations in Uganda are small. Often, they are less than 40 cm in diameter. Band sawmills were the most efficient sawmill technology for converting small diameter saw logs into sawn timber while rolling-table sawmills were more efficient than dimensional swivel and locally manufactured sawmills. The linear model has shown that the conversion efficiency of sawmills operating in softwood plantations in Uganda was a function of both sawmill and log characteristics. The model predicts that recovery of sawn wood would increase by 12% if small diameter logs (10-19 cm) were sawn using band saws instead of dimensional swivel and locally manufactured sawmills.

Band saw mills are the most appropriate for use in Uganda's soft wood plantations and should be recommended to potential investors. Since locally manufactured sawmills are cheap and affordable by the local entrepreneurs, we recommend that mechanical modifications should be carried out on these sawmills to improve their feed-work and set-work mechanisms.

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References

Ayarkwa J. 1999. Processing of small diameter logs: the effect of log diameter, sawing pattern and some bole variables on lumber recovery. *Ghana Journal of Forestry* 8: 43-51

Balikuddembe L. S. M. 1997. A training guide for plantation sawmillers of Uganda. MSc. Dissertation, University of Wales, Bangor.

Brown T. D. 2000. *Lumber Size Control. Part 2: Size Analysis Considerations.*

Extension Service, Oregon State University

Carvalho J. and Pickles 1994. *Forest Industries Rehabilitation and Development Plan.* Report for the Forestry Rehabilitation Project

FAO 1994. *Putting United Nation's Conference on Environment and Desertification (UNCED) to Work in Forestry.* FAO, Rome

Jacovelli P. and Carvalho J. 1999. *The Private Forest Sector in Uganda - Opportunities for Greater Involvement.* A Report for the UFSCS, Kampala

Kilborn K. 2001. *Lumber Recovery Studies Of Alaska Sawmills Conducted from 1997 to 1999.* USDA Forest Service, Gen. Tech. Rep.544.

Lunstrum Stanford J. 1993. *Circular Sawmills and their Efficient Operation*

USDA Forest Service, Wisconsin

Maness C. T., Staudhammer C. and Kozak A. R. 2002. Statistical Considerations for real-time Size control Systems in Wood Products Manufacturing. Wood and Fibre Science **34**(3): 476-484

McCaughan R. and Carvalho J. 2003. Plantation harvesting and sawmilling. Report for the FRMCP, MWLE, Republic of Uganda, Kampala

MWLE 2002. *The National Forest Plan.* Government Printer, Entebe

MWLE 2000. *The Uganda Forestry Policy.* Government Printer, Entebe

Plumptre R. A. and Carvalho J. 1994. *Marketing of Uganda's Softwoods* Forestry Rehabilitation Project, Ministry of Environmental Protection

Steele P. H., Wade M. W., Bullard S. H., and Araman P. A. 1992. *Relative Kerfand Sawing Variation Values for Some Hardwood Sawing Machines.* ForestProducts Journal **42**(2): 33-39

Steele P. H., Wagner F. G., and Skog K. E. 1992. *Regional Softwood Sawmill Processing Variables as influenced by Productive Capacity.* Forest Products Laboratory, Madison, Wisconsin

Steele P. H., Wagner F. G., Kumar L., and Araman P. A. 1993. *The Value versusVolume Yield Problem for Live-Sawn Hardwood Sawlogs.* Forest Products Journal **43** (9) : 35-40

Todoroki C. and Ronnqvist M. 2002. Dynamic control of timber production at a sawmill with log sawing optimisation. Scandinavian Journal of Forest Research 17 (1): 79-89

Todoroki C. and Ronnqvist M. 2001. Log sawing optimisation directed by marketdemands. New Zealand Journal of Forestry 45(4): 29-33

Tugumizirise O. 2001. *Report on Monagement Planning Exercise in ConiferousPlantations.* FD, MWLE, Kampala

UFSCS (2001). *Voices from the Field. A Review of Forestry Initiatives in Uganda.* Asynthesis Report organised by staff of the UFSCS, Kampala

Uganda Forest Department 1999. *Baseline Information on the Status of Operations in Government Owned Forests.* Report to the Commissioner ofForestry.