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Full Length Research Paper

Comparative analysis of on-farm timber conversion systems in Kenya

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Exploitation of trees on private farms in Kenya is mainly by chain, bench and pit sawing systems, whose efficiency has not been well established. The sawing systems were evaluated for their performance using three species: *Eucalyptus saligna*, *Grevillea robusta* and *Prosopis juliflora*. Data was subjected to analysis of variance and mean comparisons. Results showed significant differences (*P<0.05*) among the sawing systems. Chainsaw system recovered more logs from the trees with a log recovery rate of 76%, which was significantly higher than those of 65 and 63% for bench and pit saws respectively. Timber recovery rates of 39.8, 35.9 and 30.0% for pit, bench and chain saws respectively were observed. The chainsaw system produced the highest rate of timber output (0.23 m^3/man-hour), differing significantly from benchsaw (0.17) and pit saw (0.08). Chain and bench saws recorded significantly different fuel consumption rates of 8.41 and 14.86 m^3l^{-1} respectively. Timber sawn with the chain saw had the highest dimensional deviation (+/-5.53 mm), which was significantly higher than deviations for benchsaw (+/-3.55 mm) and pitsaw (+/-2.44 mm). The study shows that, although chainsaw recorded the highest timber production rate per man hour, it had the lowest timber recovery. Timber sawn with this system had the highest dimensional deviations. Bench saw was more economical for sawing large diameter logs, with chainsaw performing better for small diameter logs. The three systems recorded very low recovery of timber and are thus not suitable for processing timber, in this error of diminishing tree cover unless they are improved.

Key words: Efficiency, sawing systems, timber recovery, production rate, size, deviation.

INTRODUCTION

Forest cover in Kenya has been decreasing in the past 20 years and is estimated to be about 6% (FAO, 2010). Some of the major factors that contributed to this situation are illegal harvesting and conversion of forest land to other uses. Inefficient logging and processing to a lesser extent has also contributed to the same. This decrease led to partial ban on logging in state forests by Kenyan government in 1999 (FAO, 2005). The ban led to the closure of saw mills and a serious shortage of sawn timber in the country, contributing to high timber prices. Due to the timber shortage, farms have became a major source of timber, sawn using small-scale sawing systems that include chain, bench and pit saws (Holding et al., 2001; Holding-Anyonge and Roshetko, 2003).

Bench saws are used mainly in areas where saw logs are available in relatively large quantities and trees are easily accessible by a tractor. The initial cost of this system is high, thus limiting its affordability. Pit sawing is an old and cheap technology used in areas where trees grow in steep terrain. Pit saws are considered slow and uneconomical to operate (Muthike et al., 2010).

Chain saw, which initially was used for felling and cross cutting wood, has been adopted for sawing dimensional timber because it is portable, easy to operate relatively cheaper to acquire and less limited by terrain (Pasiecznik and Brewer, 2006; Popoola, 2010). While in some countries, chainsaw milling is a legal and important sub-sector of the forest industry, supporting rural livelihoods, in many others, it is associated with illegal forest activities. In such countries, different scenarios exist. Some of them are; the system is illegal, permitted under some regulations, restricted to domestic use only while in others it is only permitted for small-scale commercial production. Even when it is authorized, its activities are often difficult to monitor due to the large number of people involved and the small size and mobility of its operations (Wit et al., 2010).

Despite various studies (Holding et al., 2001; Holding-Anyonge and Roshetko, 2003; Marfo, 2010) showing that chainsaw milling system is inefficient, its use has continued to rise unabated, gradually replacing other timber milling systems (Pasiecznik, 2010). There have only been a handful of studies in Kenya reporting on the efficiency of timber milling systems and these have only reported timber recovery while ignoring efficiency and other critical aspects of timber sawing.

Conversion efficiencies of sawing systems are very important for the management of sustainable production of sawn timber resources in a contemporary world (Pasiecznik, 2010).

In order to efficiently utilize the limited timber resources in Kenya, there is need to establish the efficiencies for timber sawing systems used. Factors to investigate are log and sawn timber recovery, timber yield and fuel consumption rates, which are key elements in production of timber (Owusu et al., 2011). Similarly, there is a need to study the factors affecting recovery and introduce appropriate measures to improve them. This study was therefore conducted in order to address the information gaps on the relative efficiencies of different timber sawing systems.

MATERIALS AND METHODS

Selection of timber species, sawing systems, equipment and operators

Timber species used for this study included two species commonly grown and converted into sawn timber on the farms (*Eucalyptus saligna* and *Grevillea robusta*). A third species, *Prosopis juliflora*, was added to the list to represent some of the difficult to saw hard wood species currently being promoted for planting in the dry areas in Kenya. Mature trees of *Eucalyptus* and *Grevillea* species were sampled from farms, while Prosopis trees were obtained from a research plot in a dryland district. Due to scarcity of mature trees on farms as a result of high demand, the oldest available Grevillea and Eucalyptus trees with relatively good stem form and minimum defects were sampled and felled using a chainsaw.

A well maintained chainsaw, fitted with a new chain and sharpened appropriately was used in chain sawing. Similarly, for bench sawing, a locally fabricated saw bench, driven by a tractor was used (Table 1). A trained and experienced sawyer operated the chainsaw and also acted as the lead sawyer for the bench saw. Two operators with over 5 years experience in pit sawing were sourced from the field to operate the pit saw system during the study.

Timber sawing and data collection

After each tree was felled, total tree height was measured from the bottom to the tip of the crown using a measuring tape. The total merchantable bole length from the butt to the first or second forking point depending on the stem characteristics was taken to determine the length of the useful portion of the tree. The trees were then randomly sampled and three trees marked for each sawing system.

Each tree in the respective group was crosscut into logs of lengths that are acceptable in the timber market while minimizing on defects. Logs with the smallest diameter and length that a particular sawing system can economically convert were chosen and the rejected ones set aside. The volume of the logs obtained in each case and volume of the rejected ones were determined to evaluate the log recovery for each sawing system.

Diameter measurements were taken at the butt, top and at every 0.5 m along the length of the log using a diameter tape and used to compute the mean diameter for each log. Log lengths were measured to the nearest 0.1 of a meter using a measuring tape. Log volume was then computed using Smalian Formula (ISO, 1983); (Equation 1) where V_L is the merchantable log volume, L is the merchantable log length, D is the log mean diameter and π is a constant.

$$V_L = \pi D^2 L/4 \quad (1)$$

All timber sawing was done on the felling site in order to minimize cost. Monkey jacks were used in turning the logs to facilitate processing. A stop watch was used to time the operations. All timber sawing involved the through and through method and produced timber of nominal market dimensions. The volume of the resultant sawn timber was computed as shown in Equation 2, where b is timber breadth, d is timber depth, l is timber length (ISO, 1983). System timber recovery rate (*R%*) was computed by considering the relationship between log volume (V_L) and volume of the resultant sawn timber (V_T) as shown in Equations (3).

$$V_T = \Sigma\,(bdl) \quad (2)$$

$$R\% = 100 V_T / V_L \quad (3)$$

For both chainsaw and bench saw systems, the fuel tank capacities were recorded. At the beginning of each sawing operation, the machine fuel tank was filled to capacity. The machine was operated until all the fuel was used then refuelled and the records updated accordingly. After sawing, the tank was emptied and the balance re-measured to determine the volume of fuel used in litres to the first decimal place. Pit sawing did not involve measurement of fuel since the system is operated manually.

Three pieces of sawn timber from every log sawn using each system were randomly sampled. On each of these pieces, timber thickness was measured at the ends and at every 0.5 m along the length. This data was used to compute the mean size deviation from the pre-set dimension for the timber. Three other pieces were

Table 1. Specification for the sawing systems used.

Sawing system	Make/ model	Engine power (HP)	Fuel type	Saw type and Kerf (mm)
Chain saw	Husqvarna 365	4.6	Petrol/oil mix	9.5 (chain)
Bench saw	MF 135 Tractor (3 years old)	20	Diesel	7.5 (circular saw blade)
Pit saw	N/A	Manual	Manual	3 (flat blade)

randomly sampled from each of the species and tested for wood density at 12 to 15% moisture content.

Economic analysis

A simple economic analysis of the sawing systems was performed using the generated data, prices of production inputs like fuel and lubricants, labour and trees. Data generated based on different log diameters and shapes for the different sawing systems and timber species. Further still, analysis was focused on the specific effects of timber species and the size of sawn timber, owing to their effects on timber production, recovery rates and therefore to the cost of production.

Data analysis

The data were analyzed using Microsoft Excel and SPSS software. The effects of the experimental factors; wood species and sawing systems, both in isolation and in combination; on log recovery, sawn timber recoveries, fuel consumption rate, sawn timber production rate and timber size deviation were determined. Mean comparisons were performed for individual factors in isolation and in combination at 95% confidence level.

RESULTS AND DISCUSSION

Log conversion characteristics

Individual species log conversion rates were found to significantly vary with the sawing system used and had the chainsaw system recovering more logs than the other two systems (Table 3). The higher log conversion rate of the chainsaw system can be attributed to the ability of the chainsaw to process smaller log diameters (15 cm) where other systems could not.

High log conversion rate by chainsaw system could be attributed to the ability of the system to convert very small diameter and poorly (crooked) shaped logs than the other two systems (Samuel et al, 2007). In a study using different tropical hardwood species and various sawing systems in Ghana, Owusu et al. (2011), reported that chain sawing (as used in this study) recorded higher (mean 75%) log conversion rate than wood mizer system (68%). Similar results are reported in the same country by Marfo (2010). However, both studies reported that sawyers tended to leave out smaller diameter logs unprocessed due to abundance of wood in tropical forests unlike Kenya where trees are in short supply and sawyers aim at maximizing on the available materials.

The mean log conversion rate for all species sawn with pit saw was significantly lower than when sawn with the other two systems. This is attributed to the mode of operation for pit sawing. The log being sawn must be at least 2.4 m long to accommodate one of the operators to stand on one end while sawing the other end.

Low log conversion rate observed for *P. juliflora* and partly *G. robusta* was attributed to the species stem characteristics. The *P. juliflora* trees used for this study were sourced from a plantation that was planted in the 1980s for drought mitigation in the dry lands. These trees lacked management and grew into bushes with a few dominant trees towering above the rest. The stems were therefore small diameter, crooked and branchy, thus lowering the merchantable bole length and diameter. *G. robusta* trees from farms similarly lacked management attention due to farmers' limited knowledge on tree growing. This resulted into short merchantable bole length due to poor pruning and thin top logs compared to Eucalyptus, which is self pruning and develops straight and more or less cylindrical stems.

Sawn timber recovery

Timber recovery differed from system to system. Chainsaw system consistently recorded the lowest mean timber recovery for all the three species (Table 4).

Among the tree species, *E. saligna* recorded the highest mean sawn timber recovery for the respective sawing systems, while *P. juliflora* had the lowest timber recoveries. Similar trends were observed when the other sawing systems were used for the respective species. This could be attributed to the log characteristics (form and diameter size) of the respective species.

These results however differ from on-farm timber recovery results reported by Frimpong-Mensah (2004), which reported timber recovery rates ranging from 22 to 28% for a variety of hard wood species sawn using chainsaws. A related study (Gyamfi and Adu, 2009) reported on-farm recovery rates ranging from 28 to 45% for the same species sawn using small-scale circular saw mills, which is within the range reported for bench saw in this study. Such variations may be due to differences in sawyer skills and experience. In a study in Kenya, Samuel et al. (2007) pointed out that operators' level of skill and experience significantly contributed to both recovery and surface quality of sawn timber, although it is not clear whether the logs used in that study had similar diameter and form as those used in the current study.

Table 2. Characteristics of the tree species used in the study (Density is at 12-15% moisture content).

Scientific name	Mean tree Age (years)	Mean tree height (m)	Mean merchantable bore length (m)	Mean diameter (dbh) (m)	Mean density (kg/m^3)
Eucalyptus saligna	25	16.72	12.54	0.36	639.67
Grevillea robusta	20	11.70	7.35	0.29	529.99
Prosopis juliflora	27	6.67	2.66	0.21	864.67

Table 3. Log conversion rate for the sawing systems (p<0.05).

Sawing system/species	Percentage Log Conversion Rate			
	Eucalyptus saligna	***Grevillea robusta***	***Prosopis juliflora***	**Mean**
Chain saw	84.16	76.72	66.41	75.76
Bench saw	73.95	63.43	57.95	65.11
Pit saw	72.35	62.10	53.34	62.60

Table 4. Timber recovery for the three sawing systems (P<0.05).

Sawing system	Timber Recovery (%)			Mean
	E. saligna	***G. robusta***	***P. juliflora***	
Chainsaw	32.43	29.85	27.84	30.04
Bench saw	38.15	36.45	33.09	35.90
Pit saw	42.38	38.85	38.03	39.75

Timber production rate

The volume of sawn timber produced per unit time of system operation varied from system to system. Chain saw system consistently recorded the highest mean sawn timber production rates per operator for all the three species (Table 5). The bench saw system emerged the fastest among the three sawing systems and thus had the highest timber production rate. However, it should be noted that the system used at least six laborers unlike chain saw and pit saw systems which required two operators each. On conversion of the production rates per man-hour, chain saw system performed better except for *E. saligna* timber. Pit saw recorded the lowest sawn timber production rate for all the three species sawn. This was attributed to the manual operation of the system. High timber production rate achieved with *E. saligna* for all the sawing systems could be attributed to large diameter and good stem form as well as moderate density (640 kg/m^3), which makes it relatively easy to saw. Timber production rate for *G. robusta* was lower than *E. saligna* despite its lower density (527 kg/m^3). Small diameter logs with poorer stem form associated with *P. juliflora* wood as well as its high density (865 kg/m^3) may have been responsible for the low sawn timber production rate. An earlier study in Kenya reported similar trends for *E. saligna* and *G. robusta* wood sawn using chainsaw (Samuel et al., 2007). In Nigeria, Popoola (2010) reported that timber production rate and recovery increased with increase in log diameter and stem quality for a variety of species.

Fuel consumption

Fuel consumption by chain and bench saw systems differed for different wood species with bench saw recording higher mean fuel consumption (Table 6). Pit saw system was manually operated, therefore did not use fuel.

These differences in fuel consumption rate follow the same pattern shown by wood density for the respective species (Table 2). More fuel was consumed in sawing high density wood than when sawing lower density species. The rate of fuel consumption for sawing *P. juliflora* and *E. saligna* with chainsaw system however did not differ significantly although the species densities were significantly different. These results are similar to those reported by Owusu et al. (2011). High density wood poses higher resistance to sawing tools and therefore requires more fuel to drive the cutting tools through it (De Lasaux et al., 2004; Damnyag and Darko, 2009).

Size deviation

Timber size differed among wood species and among sawing systems (Table 7). On the overall, chainsaw recorded the highest mean timber size deviation.

Table 5. Timber Production rates for the three sawing systems as used to process different tree species (*P<0.05*).

Sawing system	Timber production rate (m^3/h)			
	E. saligna	***G. robusta***	***P. juliflora***	**Mean**
Chainsaw	0.21	0.24	0.16	0.20
Bench saw	0.26	0.18	0.12	0.19
Pit saw	0.09	0.08	0.07	0.08

Table 6. Fuel Consumption rates for the three sawing systems (*P<0.05*).

Sawing system	Timber recovery (%)			Mean
	E. saligna	***G. robusta***	***P. juliflora***	
Chainsaw	32.43	29.85	27.84	30.04
Bench saw	38.15	36.45	33.09	35.90
Pit saw	42.38	38.85	38.03	39.75

Table 7. Size deviation in timber sawn using different sawing systems (*P<0.05).*

Sawing system	Timber size deviation (mm)			Mean
	E. saligna	***G. robusta***	***P. juliflora***	
Chainsaw	5.26	5.33	5.99	5.53
Bench saw	3.54	3.20	3.90	3.55
Pit saw	2.42	2.20	2.70	2.44

This could be attributed to the mode of operation (freehand), machine vibration due to its engine characteristics (2-stroke), removed depth gauges and machine weight (8 kg). Timber size deviations for bench saw could be attributed to inconsistencies due to manual in-feeding of the logs during sawing. Low mean size deviation for pit saw system could be attributed to the mode of operation of the system.

Pit saw is operated by two operators, pushing and pulling the saw blade up and down, following lines drawn on the surface of the log being sawn. The operator standing on top of the log directs the saw blade to avoid wavering. Since the operation is manual, the cutting speed is slow and saw vibration is minimal. These reduce possibilities of the saw deviating from the pre-marked cutting line. This improves timber recovery and lowers size deviation.

Among the wood species, *P. juliflora* recorded the highest timber size deviation, while *G. robusta*. Although the mean size deviations did not differ significantly, there was a clear trend which showed that timber size deviation increased with wood density for all sawing systems. This could have been a factor of harder wood causing saws to deviate from the sawing line as a result of friction of the cutters as they bite into the wood. Other inherent differences in timber properties could also have contributed to variations in timber dimensions from the pre-set sizes. Timber defects like knots for example have been shown to interfere with smooth cutting of wood due to the change in density and grain direction around the knot area (Fehr and Pasiecznik, 2006).

Economic analysis

The cost of production per cubic meter of sawn timber differed among the sawing systems. Chainsaw system recorded the lowest mean production and the highest mean margin (Table 8). The profit margins obtained for each sawing system differed among timber species. Bench saw system performed well with large diameter and good form logs of *Eucalyptus saligna* wood. This provided more wood for bench saw to process within a shorter time and therefore more economical. The system however performed poorly with *P. juliflora*, a factor of both small diameter and high density. Chain saw system recorded higher profit margins when used to saw *G. robusta* and *P. juliflora* than bench saw. This was as a result of the system ability to process both low quality and high density logs better than bench saw. Pit sawing recorded the lowest profit margins. This was due to the long time engagement of labour to process logs manually.

With such returns, bench saw system can be more

Table 8. Mean Production cost, income and margins for *Grevillea robusta* timber sawn with the different sawing systems.

System	Production cost (m^3 US$)			Income (m^3)			Profit margin (m^3)		
	G. robusta	***E. saligna***	***P. juliflora***	***G. robusta***	***E. saligna***	***P. juliflora***	***G. robusta***	***E. saligna***	***P. juliflora***
Chain saw	65.23	74.02	116.12	103.20	120.35	153.18	37.97	46.33	37.06
Bench saw	76.55	67.59	132.67	103.20	120.35	153.18	26.65	52.76	20.51
Pit saw	81.24	86.15	141.24	103.20	120.35	153.18	21.96	34.2	11.94

*1US$ = Ksh 81.00.

profitable with large diameter logs of good form, which provide more wood for processing within a shorter time. Chainsaw system would be more preferred for smaller diameter logs of poorer quality. The system can also be good for the hard-to-saw tree species, particularly those dry land species with high densities.

Conclusions

The higher timber production rate for large diameter logs and low size deviation obtained with the bench saw suggests that this system would be appropriate for timber producers on farms. However, due to the high fuel consumption and labour requirement, the bench saw system becomes less economical than chainsaw, and particularly for small diameter logs and in situations where trees are few and scattered as in the case on farms today.

Chain sawing system shows higher profit margins when used to process smaller diameter logs. This makes chainsaw system a better choice for timber processors on farms. However, the low timber recovery and non-uniform timber sizes, associated with this sawing system make it a poor performer, especially when timber is desired for specialized uses. Unless a better sawing system is developed to replace chainsaws, there is need to improve timber recovery and timber size uniformity to make chainsaw more acceptable, since the system is the most commonly used for processing timber on farms despite its shortfalls.

Despite a relatively higher timber recovery rate compared to other systems, pit sawing was the most uneconomical amongst the three timber sawing systems. The pit sawing system is also not suitable for processing short and small diameter logs because of the potential risk of injury to the saw operators. It is therefore no a surprise that pit saw system is being replaced by chainsaw system in recent years, possibly due to the combined effects of poor economic performance and decreasing size of logs.

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