Effect of Log Taper and Length on Lumber Volume Recovery of *Cupressus Lusitanica* in Injibara Sawmill, Awi Zone, Ethiopia: *A Research Article*

Sisay Worku[1], *Beyene Belay*[2] *and Yohannis G/Mariam*[3]

[1]Department of General Forestry, Debre Markos University Burie Campus, Burie, P.O. Box 18, Ethiopia. Email: sisayworku87@gmail.com,;

[2]Forestry Research Directorate, Amhara Regional Agricultural Research Institute, Bahir dar, Ethiopia. Email: beyene.belay@gmail.com;

[3]Department of General Forestry, College of Agriculture and Environmental Sciences, University of Gondar, Gondar, Ethiopia. Email: yohanisgirma@gmail.com

Abstract

Log conversion efficiency in the sawmilling industry is commonly expressed as the yield or recovery of sawn wood from a given log. The aim of this study was to estimate the lumber recovery of Cupressus lusitanica logs under different log length, log taper and sawing techniques at Injibara wood sawmill, run by Amhara Forest Enterprise. A total of 240 sample logs were selected from Injibara sawmill log desk. From the total sample, 180 sample logs were used to compare the lumber volume recover of three log length levels (3m, 3.5m and 4m). Two sawing techniques (live and cant sawing) were also evaluated for their lumber volume recovery efficiency using 120 sample logs (60 logs for each sawing technique). The collected log volume, lumber volume and recovery percentage of all logs were analyzed by using Microsoft excel and R-software. The results revealed that there were significant (P<0.05) differences between log taper on lumber recovery percentage with small taper having higher recovery percentage (48.31%) than medium (46.40%) and large taper (44.61%) logs. This result also revealed that there were not statistically significant variations between two sawing methods (P>0.05). Logs having shorter length produced highest lumber volume recovery (47.68%) than logs having a longer length (45.46%). The significant interaction indicates that different degrees of log taper and length can generate different average lumber volume recovery with different sawing methods. Based on these findings, it is advisable to use logs with a shorter length and smaller taper size under live sawing and cant sawing patterns to have better recovery of wood volume.

Key words: *Cupressus lusitanica, Live sawing, Lumber, Cant sawing, Sawmill, Taper.*

1. Introduction

Over the past few years, wood-based industries have grown in Ethiopia. According to the Ministry of Environment, Forestry and Climate Change MEFCC (2018), small and micro-wood processors dominate in number and production compared to large and medium-sized industries. Many of these wood-based industries commonly produce wood which can be used to produce solid wood panels and manufactured panels (wood composed of different sized wood elements).

Sawing pattern or cutting as defined by Cooper (1994) a predetermined pattern for converting logs into lumber. According to the work done by How *et al*., (2007) live sawing is a method of sawing which results in all lines parallel and minimizes sawing time. It is suitable when only boards are being sawn. During cant sawing method, the sawyer has cut all faces around the log, turning it when needed to remove each board from the face promising the highest grade.

Cupressus lusitanica is under the family of Cupressaceae. The genus Cupressus is native to warm temperate climate in the northern hemisphere. It is found around the Mediterranean, in North America, and Asia. At least 25 taxa were identified and described as species. These taxa were considered to be species, related species, subspecies or simple varieties (Cros *et al.* 1999).Among many indigenous and exotic tree species, *Cupressus lusitanica*is one of the major exotic species used as inputs to wood products in various small wood processing industries in Ethiopia.(Web *et al*., 1984). *C. lusitanica* existed in Ethiopia before 1950 and was widely planted as hedgerows, road edges and hillside woodlots. According to Pukkala (1993), the first industrial plantation of *C. lusitanica* was established in 1950 in the Munessa forest surrounding the first sawmills. Gradually, it expanded to several regions of Ethiopia through reforestation programs (Negash*et al*., 1995). The Arsi woodland venture was among the areas where *C. lusitanica* has been planted widely as a timber tree.

In the production of lumber from softwood logs, maximizing benefits is the primary concern of wood-based companies. In particular, the volume of wood produced from a given log input and the quality of the recovered product determines the profitability of sawmill (*Kayode OA., 2005)*. On the other hand, sawmills are confronting numerous challenges including declining log estimate and quality, restricted asset accessibility, diminished benefit marginsbetween log costs and lumber costs, and pressure from competitors (Milauskas*et al*., 2005). Hence, to withstand these ever-increasing log costs and limited access to the logs, wood-based industries are always designing ways to improve their lumber recovery percentage (Occena*et al*., 2001) which can reduce waste.

The efficiency of timber recovery in thesawmill industry is commonly expressedas the efficiency or recovery of sawn wood processed from a given log (Adams, 2007). The yield of sawn timber is mostly expressed as a percentage of the volume of logs. Of course, the size, quality or quality and length of logs are also important factors to be considered in estimating and reporting the efficiency of wood recovery.Log taper, sawing strategy and the interaction between sawing methods together influences the volume of lumber recovery (*Hindle M., 2009)*. The lumber recovery efficiency diminishes with an increment in log taper (Edward and Felix, 2015).

According to the information obtained from unpublished documents and interview from experts In the Injibara sawmill, there was a problem with a minimum lumber volume recovery (40%) as compared with sawmills studied in other countries (Gyimah and Adu, 2009; Wilson *et al.*,2009; Egbewole *et al.*, 2011). Though there were very scanty studies (Edward and Felix, 2015; Adams 2007;Kayode, 2005 and Kilborn 2002) done at national level, no studies found in Amhara region concerning factors affecting sawmill wood processing efficiency. Generally, lumber recovery factor vary with log diameter and taper (Wenger 1984).

The major factors which affect the lumber recovery or yield as mentioned by White (1974) are , end-use requirement, the quality of personnel, log diameter, log length, sawing methods, and sawmill machinery and sawing accuracy. Therefore, this study aimed to estimate the lumber recovery potential of *Cupressus lusitanica* logs of different log lengths, log taper and sawing techniques (live and cant sawing).

2. Materials and methods

Study Area Description

The study was carried out in Injibara Town at a wood-processing mill in the Amhara Regional State, Ethiopia. Geographically, Injibara lies between 10^{0}57'N and 36^{0}55'E longitude and the altituderanges from 2540–3000 meter above sea level (Zewditu, 2017) (Figure 1).Currently, input logs for the sawmill were harvested from beterya and tsarikan nearby plantation forests, of which *C. lusitanica* plantation accounted for about 60% of the log source and the remaining 40% was obtained from Gravilia robusta and Eucalyptus specie (AFI, 2018). According to previous years’ unpublished documents of injibara Sawmill showed that, it obtained about 110m^3– 130$m^3$of lumber per month from *C. lusitanica* species.

According to 2018 year meteorological data from National Metrological Agency

(NMS, 2018), the mean annual rainfall ranged from 38 mm to 1813mm.The minimum and maximum temperature was 2.6^{0}C (on December) and 29.9^{0}C (April). The agro ecology of Injibara is categorized as Dega. Injibara sawmill was first established in 2015 by Amhara Forest Enterprise (AFE). The saw mill has 55 horse power engine and working with electric power. The sawmill has a total of 29 employees (8 permanent and 21 temporary).

C. lusitanica is an evergreen conifer tree with a conic to ovoid-conic crown, growing to 40 m tall. The foliage grows in dense sprays, dark green to somewhat yellow-green in color. The leaves are scale-like, 2–5 mm long, and produced on rounded shoots. *C. lusitanica* can be used as raw material for various applications such as construction material and furniture materials including panel products such as face veneer, core-stock and cross bands in plywood, and chips for wafer board and pulpwood (Web *et al.*, 1984). It was a widely planted species in the soil conservation and community forestry program in the Ethiopian highlands.

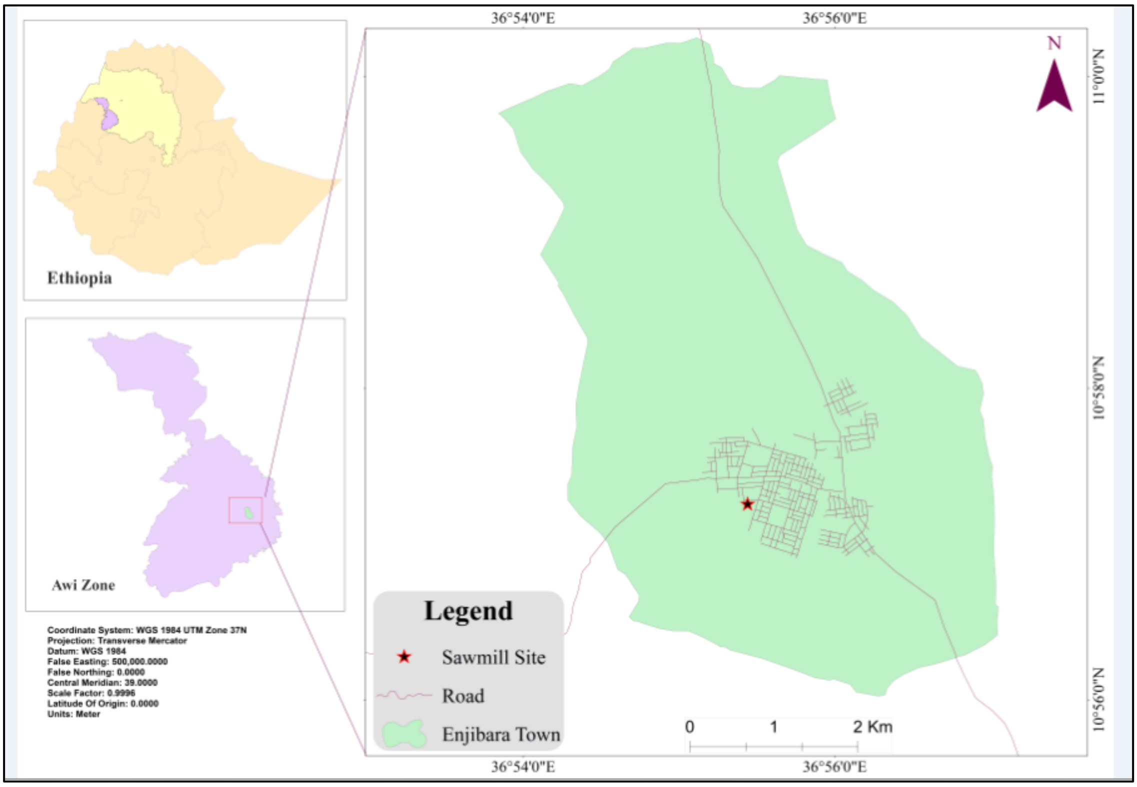

Figure 1: Study area Map.

Sample size and data collection

Although several variables influence the lumber recovery percentage, for this study, two log parameters under two sawing patterns totally three variables were investigated. This study were analyzed two log parameters under two sawing patterns because of the study area sawmill frequently used those two techniques. In addition it is impossible to address all factors which affect lumber volume recovery with this research due to limitation of time and budget. Three different log length classes (3 m, 3.5 m and 4 m), three log taper sizes (≤0.35, 0.35-0.75 and >0.75) (Edward and Felix, 2015) hereafter referred to as small, medium and high taper size, respectively) and two sawing patterns (live and cant sawing) were investigated.

For this study, a total of 240 sample logs of *C. lusitanica* species were used from the log deck of the Injibara sawmill, and sample logs were selected based on pre-defined log length and taper size. The samples under each length classareequally assigned for the three taper sizes i.e. each taper size has 20 log samples. From the total sample logs, 120 log samples which have 4m length were used to investigate the effect of two different sawing methods (60 logs for each sawing method) on lumber volume recovery (Table 1).

Table 1: Log length, taper size classes, sawing techniques and sample sizes assigned under each parameter.

Log length (m)	Sawing techniques	Sample No.	Taper classes (cm/m)		
			≤0.35	0.35-0.75	>0.75
3	Live sawing	60	20	20	20
3.5	Live sawing	60	20	20	20
4	Live sawing	60	20	20	20
	Cant sawing	60	20	20	20
Total		240	80	80	80

The length of each log in meter was first measured using a tape meter and the diameter in cm of each log at three places (base, middle and top) was measured using a caliper. Based on the measured data, the volume of each log was calculated following Newton's formula Akindenis *et al.* (2012).

$$V = \pi L\left(\frac{d_b^2 + 4d_m^2 + d_t^2}{24}\right) \ldots\ldots\ldots\ldots \text{Equation (1)}$$

Where; V= volume of each log (m^3), L= length of each log (m), db = diameter over bark at the base of log (m), dm =diameter over bark at the middle of the log (m), dt= diameter over bark at the top of the log (m).

The tapered size of each log was calculated as the difference between base diameter and top diameter divided by the given log length (Ese-Etame, 2006) as described in Equation (2). The log taper calculation was continued until the required sample numbers have been obtained for each taper class under each log length class.

$T_r = \frac{d_b - d_t}{L}$……………………………………………………………...……Equation (2)

Where; Tr = Taper size of each log (cm/m), L= Length of each log (m), d_b = Base diameter of log (cm), d_t= Top diameter of log (cm)

Lumber volume and recovery efficiency estimation

Once the required sample logs were set for each parameter, each log was given a clear identification code. Each coded log wasprocessed into lumber and the final lumber products from a given input log were re-measured for their length, width and thickness. Based on the square-edged lumber measured parameters the volume of each lumber was obtained by multiplying the factors length, width and thickness of lumber in m.

The total lumber volume produced from a given log was calculated as the sum of the volume of each piece of lumber. Then, the volume recovery efficiency of the lumber was calculated as the total volume of all lumbers produced from one given log divided by the log volume estimated before sawing following the formula of Edward and Felix (2015), Equation (3).

$$\text{Lumber recovery efficiency (\%)} = \frac{Total\ volume\ of\ all\ lumbers\ produced\ from\ a\ single\ \log(m^3)}{Volume\ of\ the\ given\ single\ \log(m^3)} * 100 \ldots \text{(Equation 3)}$$

Data Analysis

The collected data were analyzed using R-Software version 3.6.1 and Excel 2010 to compute the mean, minimum, maximum and standard deviation values. Scatter graphs were used to determine the relationship between lumber recovery efficiency and the diameter of logs using Microsoft excel. Data was subjected to two way Analysis of Variance Test (ANOVA). Differences between treatment means were separated using least significant difference (LSD) at 0.05 significant level and Results were presented with Tables and Graphs.

3. Result and Discussion

Input log and recovered lumber volume

The details of input log size and corresponding lumber volumes were presented in Table 2. From the total input log volume which is 52.13 m^3 used for this study, only (24.46 m^3) amount has been found as final lumber yield which was 45.85% of average lumber recovery efficiency generated from the input log which implied the average lumber recovery efficiency was less than half. This means that, the remaining (27.67 m^3) or 54.15% was lost as wood residues including solid wastes, off-cuts and sawdust. Of course, those residues produced during lumber production still can be sold for fuel wood or for other purposes which could help as means of income source of the wood processing company. Compared to the average input log volume ($0.217m^3$) the overall average lumber volume produced was very low ($0.102\ m^3$) which is less than half of the input log volume in all log length classes.

Wilson *et al.* (2009) noted that, among the characteristics that might affect recovery could be: the difference in the expertise of personnel used, wood density, heart rot, tapering of logs, sweep logs and the width of sapwood. Rappold *et al.,* (2007) also reported that the lumber recovery for circular sawmills was very low (40.0 ± 10%). Generally, many factors might affect the conversion efficiency of sawmills which include inherent defects in the timber, severity of taper, sharpness of saw. Also, knots, woodborer galleries, gum veins and rot are common defects seen on sawn timber. However, the reason for the low recovery percentage for this study might be due to circular sawmills which have larger kerf width and tapering of sampled logs which resulted in more waste wood as wobbling (Rappold *et al.,* 2007).

Log taper and lumber recovery

The result of input log volume showed no significant difference between different taper classes of ($p > 0.05$) (Table 2). However, the corresponding lumber volume (final products) showed a statistically significant difference between different taper classes ($P < 0.05$). The result in table 2 showed that, logs with higher tape size resulted in lower lumber volume whereas logs with lower taper size resulted in higher lumber volume. Similarly, lumber recovery percentage showed a statistically significant difference ($p<0.05$) between the taper classes (Table 2) i.e. lumber recovery showed a decreasing trend with the increase of log tapering size.

Table 2: The volume (mean ± standard error) of input log (LV) and the corresponding recovered lumber volume (LuV) and Lumber recovery percentage (LRP) under two sawing methods and three taper classes (Small:≤ 0.035, Medium, 0.35-0.75, High:> 0.75). Note: this result accounted for only 4 m log length data for both sawing methods.

Taper class (cm/m)	Sample No.	Recovery % for different methods of sawing					
		Live sawing			Cant sawing		
		Log volume (m^3)	Lumber volume (m^3)	Lumber recovery efficiency (%)	Log volume (m^3)	Lumber volume (m^3)	Lumber recovery efficiency (%)
Small (≤0.35)	20	0.25± 0.02	0.12± 0.01	47.21 ± 0.93[a]	0.22± 0.01	0.10± 0.01	45.35 ± 0.86[a]
Medium (0.35-.75)	20	0.25± 0.02	0.11± 0.01	45.77± 0.81[ab]	0.23± 0.02	0.11± 0.01	44.30± 1.05[ab]
High (>	20	0.21±	0.09±	43.40±	0.201 ±	0.09 ±	42.58 ±

0.75)		0.02	0.01	1.58^{b}	0.02	0.01	1.03^{b}

The result implies that, the size of the log taper used as input has a great impact on the lumber recovery potential. This finding was in line with Ackah (2004), which reported that the systematic reduction in size along the length of a log from the bottom end to the top end has a significant effect on lumber yield and it results in lower recovery per cubic meter of log volume. He also stated that, if tapering exceeded 1cm/m the effect of tapering on lumber volume recovery becomes very high. Hence, if the log taper is (e.g., more than 1cm/m), cutting the logs shorter than the average length of logs 4.0m can help to improve lumber volume recovery.

As shown in Table 2, logs with the lowest taper class (≤ 0.35cm/m) showed the highest lumber recovery percentage compared with logs with the highest taper size(> 0.75cm/m) but the lowest lumber recovery percentage. This result revealed that lumber volume recovery percentage decreases as the log taper increases. Likewise, Edward and Felix (2015) stated that, there were significant differences between log taper on lumber recovery percentage with small taper having a higher recovery percentage than medium and large tapers. The more tapered the log, the shorter the rectangular solids that can be removed from the outside of a given log (Kilborn, 2002; Kayode, 2005). This also agreed with the results of Kukogho *et al* (2011), who stated that a high percentage of lumber recovery with a small taper was due to the large size of log girth and straight forms.

There were significant differences between sawing method and log taper on the lumber volume recovery as presented in Table 2. The comparison between live sawing method and small taper (≤ 0.35) produced the highest (47.21%) lumber recovery percentage. On the other hand, the interaction between the cant sawing method and small taper (≤ 0.35) produced smaller lumber recovery percentage than the live sawing method (45.35 %) lumber recovery efficiency. Besides, the live sawing method with any log taper category produced higher lumber recovery percentage than the cant sawing method with any log taper presented in Table 2. So, different degrees of log taper can generate different average lumber volume recovery with different sawing methods which are consistent with the result of Ese-Etame (2006).

Log length and lumber recovery

The length of the input log and the corresponding lumber volume and lumber recovery percentage is shown in Table 3 and Figure 2. The result showed that, log length used as input for lumber production did not show a statistically significant difference on lumber volume. However, lumber recovery efficiency showed a statistically significant difference among the three-length classes. As log length increases, the lumber recovery percentage decreases (Table 3). This finding was in line with Steele (1984), who stated that as log length increases tapering size also increases.

Table 3: The volume (mean ± standard error) of input log (LV) and the corresponding recovered lumber volume (LuV) and Lumber recovery percentage (LRP) under three log length classes. Note: this result considered only the live sawing method, not cant sawing.

Log Length (m)	Sample No.	Log volume (m^3)	Lumber volume (m^3)	Lumber recovery efficiency (%)
3	60	0.201 ± 0.009	0.097 ± 0.005[a]	47.67 ±0.49[a]
3.5	60	0.219 ± 0.01	0.103 ± 0.006[a]	46.18 ± 0.49[ab]
4	60	0.233 ± 0.013	0.108 ± 0.007[a]	45.46 ± 0.69[b]

The percentage of lumber volume recovery for the logs of the various length classes under different tape sizes was presented in Figure 2. The result showed that, a log with a shorter length (3m) resulted in higher lumber products than 3.5m and 4m length logs on all the three taper size classes. The lowest long length with the lowest taper size resulted in the highest lumber recovery percentage (49.90 %) while the longest logs with the highest taper size resulted in the lowest recovery percentage (43.40 %).

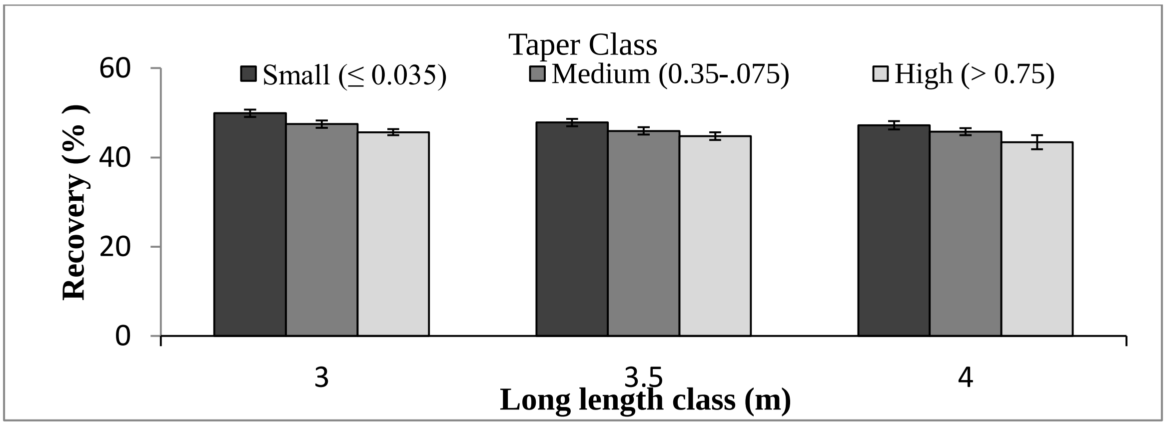

Figure 2: The Effect of log length on lumber recovery percentage under different taper class sawn by live sawing**.**

Other similar studies reported that the interaction of different log length classes resulted in different average lumber recovery with different degrees of log taper (Ese-Etame 2006). Hence, log length is a determinant factor in lumber production especially if the tapering sizes of the input logs are very high.

Sawmills are recommended to use a shorter log length class to maximize lumber yield though the objectives of the factory, species type, grade and sawing method determine the input log length. In addition, sawmills can enhance their wood utilization efficiency by re-using wastes after sawmilling processes through the development of new production lines, whereby waste in the form of slab and sawdust can be re-processed into products such as wood parquets, tools handle, production of panel doors and briquettes for energy production (Edward M. and Felix M., 2015).

Sawing methods and lumber recovery efficiency

The result in Table 4 showed that, the two different sawing methods have no significant difference ($p>0.05$) on recovered lumber volume. However, the calculated lumber recovery efficiency showed a significant difference between the two sawing methods. In comparing the two sawing methods, the live sawing method resulted in higher lumber volume than cant sawing, which implies that live sawing is more efficient in final lumber production than cant sawing. This is in line with those reported by Wang (1998) asserted that, the live sawing method produced a higher lumber volume recovery because in live sawing all the taper is thrown to one sawing face rather than two opposite faces.

Table 4: The volume (mean ± standard error) of input log (LV) and the corresponding recovered lumber volume (LuV) and Lumber recovery percentage (LRP) under two sawing methods in four meter length.

Sawing methods	log length (m)	Sample No.	LV (m^3)	LuV (m^3)	LRP (%)
Live sawing	4	60	0.233 ±0.013[a]	0.108 ± 0.007 [a]	45.46 ± 0.69[a]
Cant sawing	4	60	0.217 ±0.012[a]	0.098 ± 0.006 [a]	44.08± 0.58[b]

In contrast to our result, Ese-Etame (2006) reported that, the cant sawing method is best because it produces less radically tapered side lumber and cants with a more balanced form. These conflicting results among different kinds of literature show that, lumber recovery efficiency not only depends on sawing methods but also, in the skill of sawmill operators, the grade of the sawn log, taper class, and length. Additionally, problems with adequate study control in the production sawmills might be another factor to be considered for efficient lumber production (Olatunji, 2006, Hindle, 2009).

According to Ginoga (1999), a live sawing pattern is the simplest sawing method, the easiest to apply and obtains higher green-off-saw recovery rates as well as faster sawing time than alternative and more complex patterns which involve more handling time, for example turning the log (cant sawing method). However, Rachman and Malik (2011) stated that, the live sawing pattern generally produces sawn timber with low quality due to flat sawn timber which is susceptible to change its dimension (crook) and damage (crack) during the drying process.

Effect of log diameter on lumber recovery

The result showed that, log diameter had a positive correlation with lumber recovery percentage (Figure 3 and 4). Lumber recovery efficiency increased with an increase in log diameter under all length classes and sawing methods. This is an indication that, log diameter could be used as a parameter for predicting lumber recovery percentage in circular sawmills present at injibara sawmill. The result of this study was consistent with Kewilaa (2008) findings, which showed that, log diameter have a significant effect on the recovery. This may be due to the reduction of juvenile sapwood and an increase of the heartwood proportion in trees as they increase in diameter (Zobel and Talbert, 1991).

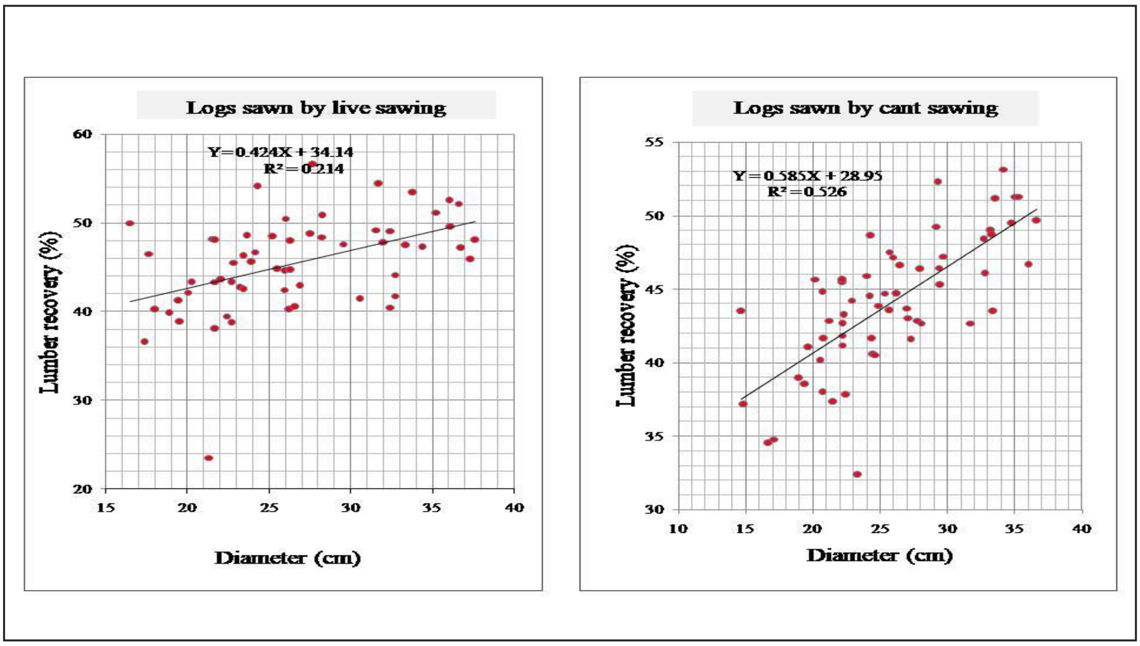

Figure 3: Relationship between diameter and lumber volume recovery of 4m length logs sawn by live sawing and cant sawing.

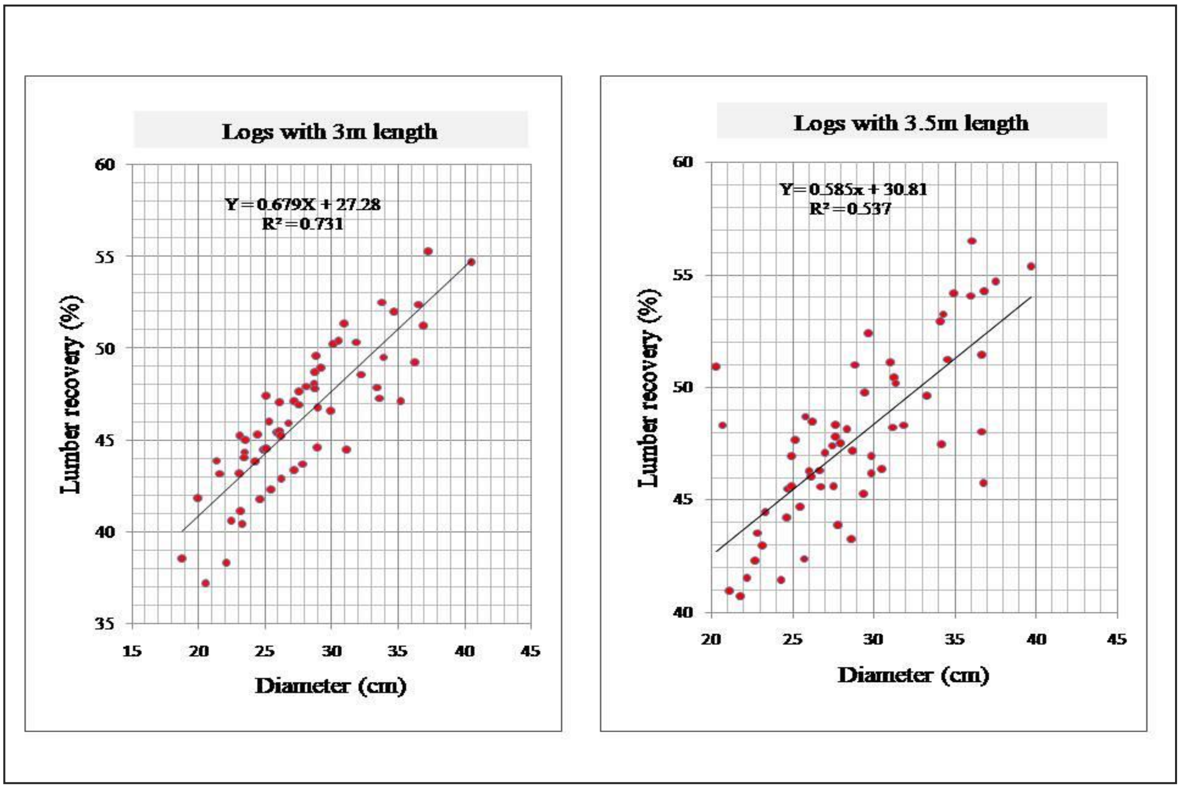

Figure 4: Relationship between diameter and lumber recovery of 3m and 3.5m length logs sawn by live sawing.

Generally, higher lumber recoveries were associated with bigger diameter logs. Kewilaa (2008) noted that, log diameter has a linear relationship with lumber recovery. However, if the heartwood is defective (holes in heart, heart rot) this could affect the amount of wood that can be obtained from the log. In this study, some relationships which were established between log diameter and recovery were not very strong as indicated by the low R^2values (Figure3). This may be due to the strong effect of defects which were very common in the logs.

4. Conclusion and Recommendations

Conclusion

The study result showed that the total average lumber volume recovery potential of the Injibara sawmill has dropped less than half (about 45.85%) which implies the rest 54.15% of log volume has been considering as waste wood residue. Among the studied input log characters/parameters, taper size was found to be the major influential factor on lumber volume recovery and lumber recovery efficiency that is as input log taper increases the lumber volume recovery and lumber recovery efficiency decreases.

The length of log used for lumber production has also shown an impact on final lumber recovery efficiency though the effect was not highly visible as log taper. In considering the comparison of taper size and log length, those with smaller tapered logs with shorter lengths generated higher lumber volume recovery. In comparing the two sawing techniques, the lumber volume recovery and recovery efficiency of the live sawing method was relatively better than the cant sawing method.Therefore, it is advisable to use logs with a shorter length and smaller taper size under live sawing and cant sawing patterns to have better recovery of wood volume.

Recommendation

Lumber recovery improvement is related to harvesting practices and quality of some performance, it is possible to observe from the piled log that the contract loggers tend to crosscut logs containing heavy buttresses, bumps, twists, knots, rots, flutes, crooks, and other defects. Therefore, close supervision must be done during harvesting operation on contract loggers in order to get sound logs as much as possible. In addition, Logs should be crosscut to a convenient length that avoids serious defects and maximizes lumber recovery rather than insisting on 4 m length that is well known in the country it reduce tapering effect.

During log preparation, storage, and before conversion logs should be clean and free from embedded dirt to avoid dulling of saw quickly and to make sawing of logs more accurately and efficiently. Providing training for the sawmill operators and other workers helps to gain more experience and make decisions correctly which can increase lumber recovery. There should be conduct further studies about other factors which affect lumber volume recovery such as log quality, kerf width, rough green-lumber size, product mix, decision making by sawmill personnel, condition and maintenance of mill equipment. Appropriate assortment, grading and proper measurement of wood residues, slabs and off-cuts and sawdust should be done. In addition, the recovery volume of each product should be determined separately.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The study was financed by the Ethiopia Ministry of Education.

5. References

Ackah, J. R. (2004). Recovery of lumber from some plantation grown timber species – *Tectonagrandis* and *Gmelinaarborea*.Graduate Thesis, Kwame Nkrumah University of Science and Technology.Pp. 42- 43.

Adams, M. J. (2007). Improving Utilization Efficiency and attracting Investment in the Wood Industries in the Pacific Region. Strategy and

Policy Options, pp. 54-76.

Akindenis, J.O., Olaniran, S.O. and Olufemi, B. (2012). Lumber recovery efficiency among selected sawmills in Akure, Nigeria. 63(1): pp 15-16.

Cooper, R.J. (1994). Sawmilling Notes. MSc. Forest Industries Technology School of Agriculture and Forest Science, University of Whales, Bangor, UK, Unpublished pp. 78.

Edward M. and Felix M. , (2015). Impact of Taper and Sawing Methods on Lumber Volume Recovery for Pinuskesiya and Pinus patula Logs in Circular Sawmills, Journal of Forest Products & Industries 4(1): pp. 12-16.

Egbewole , Z. T., Ogunsanwo , O. Y. and Omole , A. O. (2011). Technical Efficiency of Lumber Recovery from High Forest Tree Species in Selected Sawmills of Southwestern Nigeria. *Nigerian Journal of Agriculture,* Food and Environment. 7(1):34-41.

Ese-Etame R. (2006). Impact of Ellipticality on Lumber Grade and Volume Recovery for Red Oak Logs. MSc thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Ginoga, B. O. Rachman and J. Malik, (1999). Technical Guideline for Sawing on Small Log Diamater. Centre for Forest Products and Forestry Socio-economical Research and Development.

Gligoraş D, Borz SA. (2015). Factors Affecting The Effective Time Consumption , Wood Recovery And Feeding Speed When Manufacturing Lumber Using A Fbo-02 Cut Mobile Bandsaw. 60(2):329–338.

Gyimah, R. and Adu-Gyamfi, A. (2009). A pilot study on sawn wood conversion efficiency in selected sawmills in Ghana. A draft report presented at a National workshop in Kumasi, pp. 52.

Hindle M. (2009). Assessment of wood conversion efficiency in sawmilling; University of Wales, A monograph, School of Agriculture and Fired Veneer Science publication Number 32, Bonger, Wales: University of Wales.

How, S.S., Sik, S.H., Ahmad, I. (2007). Review on six types of log cutting methods in various applications, Timber technology bulletin. Forest Research Institute of Malaysia, 164 Part 1, pp. 1-8.

Kayode OA. (2005). The Effect of Log Form in Timber Recovery in Selected Sawmills, a case study of Oko-Baba sawmills, Ebute Meta Lagos. Federal College of Forestry, Jericho, Ibadan.

Kewilaa, B. (2008). Effects of wood species and log diameter on veneer recovery J. Ilmu&TeknologiKayuTropis Vol.5 (2): pp 49-56.

Kilborn KA. (2002). Lumber recovery studies of Alaska sawmills, 1997 to 1999. General Technical Report PNW-GTR-544. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Kukogho J, Aghimien EV, Ojo MO, Adams BA and Akinbosoye BS. (2011). Assessment of wood waste generated in some selected sawmills in Kajola Local Government Area of Oyo state. *Continental Journal of Agricultural Economics*.5: pp. 8 – 16.

Milauskas SJ, Anderson RB and McNeel J. (2005). Hardwood industry research priorities in WestVirginia.*Forest Products Journal*.55: pp. 28 – 32.

NegashMamo, BerehaneHabte, DawitBeyan. (1995). Growth and Form Factor of Some Indiginous and Exotic Tree Species in Ethiopia. Forestry research Center, Addis Ababa, pp. 42.

Occena L, Rayner GTJ, Schmoldt DL and Abbott AL., (2001). Cooperative use of advanced scanning technology for low-volume hardwood processors. In: Proceedings of the First International Precision Forestry Cooperative Symposium, June 17-20, 2001, Seattle, Washington; University of Washington College of Forest Resources, University of Washington College of Engineering, USDA Forest Service, pp. 83-91.

Olatunji MP. (2006). Assessment & utilization of wood residues in selected sawmills in Ibadan metropolis. ND project 2006 No. 46.

Rachman, O. and J. Malik, (2011). Wood Sawing and Machining for Indonesian Wood Industries.FORDA, Jakarta (in Indonesian Language).

Rappold PM, Bond BH, Wiedenbeck JK and Ese- Etame R. (2007). Impact of elliptical shaped red oaklogs on lumber grade and volume recovery. *Forest Products Journal*.59: 29 – 34.

Steele, Philip H. (1984). Factors determining lumber recovery in sawmilling. Gen. Tech. Rep. FPL-39.Madison U.S. Department of Agriculture, Forest service, Forest Products Laboratory, p 8.

TimoPukkala VP. (1993). Yield of Cupressus Lusitanica in Ethiopia. Silva Fenn. 27(3):195–207.

Tsoumis, G. (1991). Science and technology of wood structure, properties, utilization. New York:

Van Nostrant Reinhold publishers. pp. 240-260.

Wang SJ. (1998). A New Dimension Sawmill Performance Measure. *Forest Products Journal*.38:64 – 68.

Web, D., P. Wood J. Smith, G. (1984). A guide to species selection for tropical and sub tropical plantations. Tropical Forestry Papers, No. 15, second revised ed. Unit of Tropical Silvicultural, Commonwealth Forestry Institute, University of Oxford, pp. 256.

Wilson, F. O., L. Damnyag and B. Dominic (2009). Processing Efficiency of Milling Techniques: A Comparative Analysis.

Marfo, K. A. Adam and B. Darko-Obiri (eds). (2009). Developing Alternative to illegal chainsaw milling through multi-stakeholder dialogue in Ghana and Guyana project: A case study of illegal chainsaw milling. pp.111 – 136.

Zewditu, M. (2017). Assessment of the Existing Structural Plan Implementation Situation in Injibara Town, Amhara Regional State, Ethiopia.*International Journal of Advanced Multidisciplinary Research*, pp. 14-16.

Zobel, B. and Talbert, J. (1991). Applied Forest Tree Improvement.Wavel and Press, Inc. pp. 376-407.