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Effects of Thinning Regimes on Growth and Yield of *Tectona Grandis* at Longuza Forest Plantation, Muheza District, Tanzania

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ABSTRACT

Thinning regime implies stands thinned at successive intervals, type, and intensity influencing growth and yield. Teak Forests in Tanzania are the main source of hardwood raw materials however thinning operations are not properly implemented. The purpose of this study was to determine whether thinned stands could impair the eventual projected growth and yield. Growth and yield data were collected from 168 purposively selected circular plots of radius 9.78 m distributed systematically in 9 thinned compartments in three thinning regimes. Thinning history, tree diameter, and total height of three fattest trees were recorded. Simple *t*-test was used to compare whether thinned stands were significantly different from Teak yield table values in Dbh, volume, and stocking. Results show that 88.9% and 11.1% of thinned compartments were understocked and well stocked respectively based on the Teak yield table. Also, 100% and 75% of first and second thinnings respectively were well timed whereas 25% of second thinning was delayed. Among surveyed compartments, 66.7% and 33.3% belong to site classes I and II respectively. Effects of adequate and timely thinning on Dbh and volume were 2-42% and 9-53% respectively. Thinning and timing promoted positively Dbh and Volume growth. Adequate and timely thinning treatments are recommended.

Keywords: *Tectona grandis* - thinning regimes - growth - yield - Longuza

INTRODUCTION

Teak (*Tectona grandis* L.f.) forest plantations are important in the world due to their production of valuable hardwood products. Teak is planted in about 70 tropical countries throughout tropical Asia, Africa, Latin America, and Oceania. Having good dimensional stability, high natural durability, and resistance to termites, fungus, water, and weather made the tree most valuable in the global timber market. Due to its successful cultivation, *Tectona grandis* plantations are estimated to occupy almost 7 million hectares (ha) globally (Kollert and Kleine 2017, Midgley *et al.* 2015, Seta *et al.* 2021) with about 80%, 10%, and 6% of the area contributed by Asia, Africa and America respectively (Carle *et al*. 2002, Dangal and Das 2018, Kollert and Cheburini 2012, Kollert and Kleine 2017). Moreover, the mean annual increment (MAI) of planted Teak forests ranges from 2 m^3 $ha^{-1}year^{-1}$ to 14 m^3 $ha^{-1}year^{-1}$. Regardless of extensive Teak cultivation, they have little contribution to global wood raw material production (Bauhus and Schmerbeck 2010). Therefore, there is a need to extend and improve the productivity of Teak plantations through using germplasm of high genetic quality and intensive management including thinning to maintain wood supply in the demanding market (Lautenschlager 2000, Seta *et al.* 2021, Pérez and Kanninen 2005).

The recent dependency on wood materials for building and construction purposes has increased the demand for higher quality poles, lumber, flooring, and furniture. Indeed, the increased demand for wood puts natural forests under pressure and results in deforestation and degradation hence the shrinking of natural forests (Bauhus and Schmerbeck 2010, Dudley *et al*. 2014). To avoid wood dependency on these natural forests, Teak forest plantations should serve the purpose (Bauhus and Schmerbeck 2010, Griess and Knoke 2011). Teak wood has gained a higher reputation due to its good appearance, texture, colour, and market demands making it valuable worldwide (Kanninen *et al.* 2004). On the contrary, various reports showed that thinning operations in many public plantations do not follow the prescribed schedules (Munishi and Chamshama 1994, Nshubemuki *et al*. 2001, Ngaga 2011). Thinning whenever carried out has been fewer and lighter than recommended, resulting in the standing volume being distributed on many small trees rather than a few ones of better value per cubic meter (Chamshama and Malimbwi 1996).

Monitoring growth and yield dynamics are essential to facilitate adequate management responses (Gumadi 2019). While the main source of plantation hardwood raw materials in Tanzania is the Teak plantation forests, their thinning operations are inadequately managed and inappropriately implemented. However, little is known on the effects of thinning operations on the growth and yield of *Tectona grandis* at Longuza Forest Plantation in Tanzania. This study aimed to fill the knowledge gap for *Tectona grandis* grown at Longuza Forest Plantation. The results are expected to provide basic information for future management practices of Teak plantations with regards to thinning to improve stand yield and utilization of Teak in woodlots.

MATERIALS AND METHODS

Location and Description of the Study area

This study was conducted at Longuza Forest Plantation, Tanzania which borders the foothills of the Eastern Arc Mountains (Figure 1). The plantation occupies an area of 3,496.31 ha. The planted area for *Tectona grandis* is about 2,025.82 ha, 1,032.05 ha is the natural forest, 430.81 ha is the extension area and 24.36 ha is planted with *Teminalia* sp, *Cedrela odorata,* and *Milicia excelsa.* The plantation is divided into four ranges which are under the management of the Longuza Forest Plantation Headquarter. Longuza (LG) range has a total area of 1,541.97 ha, Kihuhwi Sigi (KS) range has a total area of 921.43 ha, Kihuhwi range (KH) has a total area of 605.91 ha and Kolekole (KL) range has a total area of 303 ha. The KH range is further subdivided into sub-range of Kwani forest with a total area of 124 ha (MNRT, 2018). The study sites were in three ranges namely KH; KS and LG. The environmental characteristics of the study area are shown in Table 1

Table 1: Environmental conditions of Longuza Forest Plantation

Characteristic	Condition
Altitude (m, above sea level)	160-560
Precipitation (mm year^{-1})	1,500
Temperature (°C)	Maximum (26-32) - minimum (15-20)
Soil depth (cm)	shallow (<20)- deep (>120)
Soil (pH)	Neutral (4.5-5.0) – Acidic (6.6-7.3)
Soil type	Loam
Rock type	Pre – Cambrian

Source: Malimbwi *et al.* (1998), MNRT (2018), Ngaga (2011), Sibomana *et al.* (1997), Van Zyl (2005), Zahabu *et al*. (2015)

Study Design

In this study, the compartments were grouped into three age strata (5-9, 10-14, and >15 years) to obtain the correct age for the thinning schedule. The samples were drawn from compartments that match with age strata and thinning cycle. A total of 9 compartments, 2 compartments in the KH range, 3 in the KS range, and 4 in the LG range were selected purposively to draw samples. Each compartment was selected based on a thinning schedule.

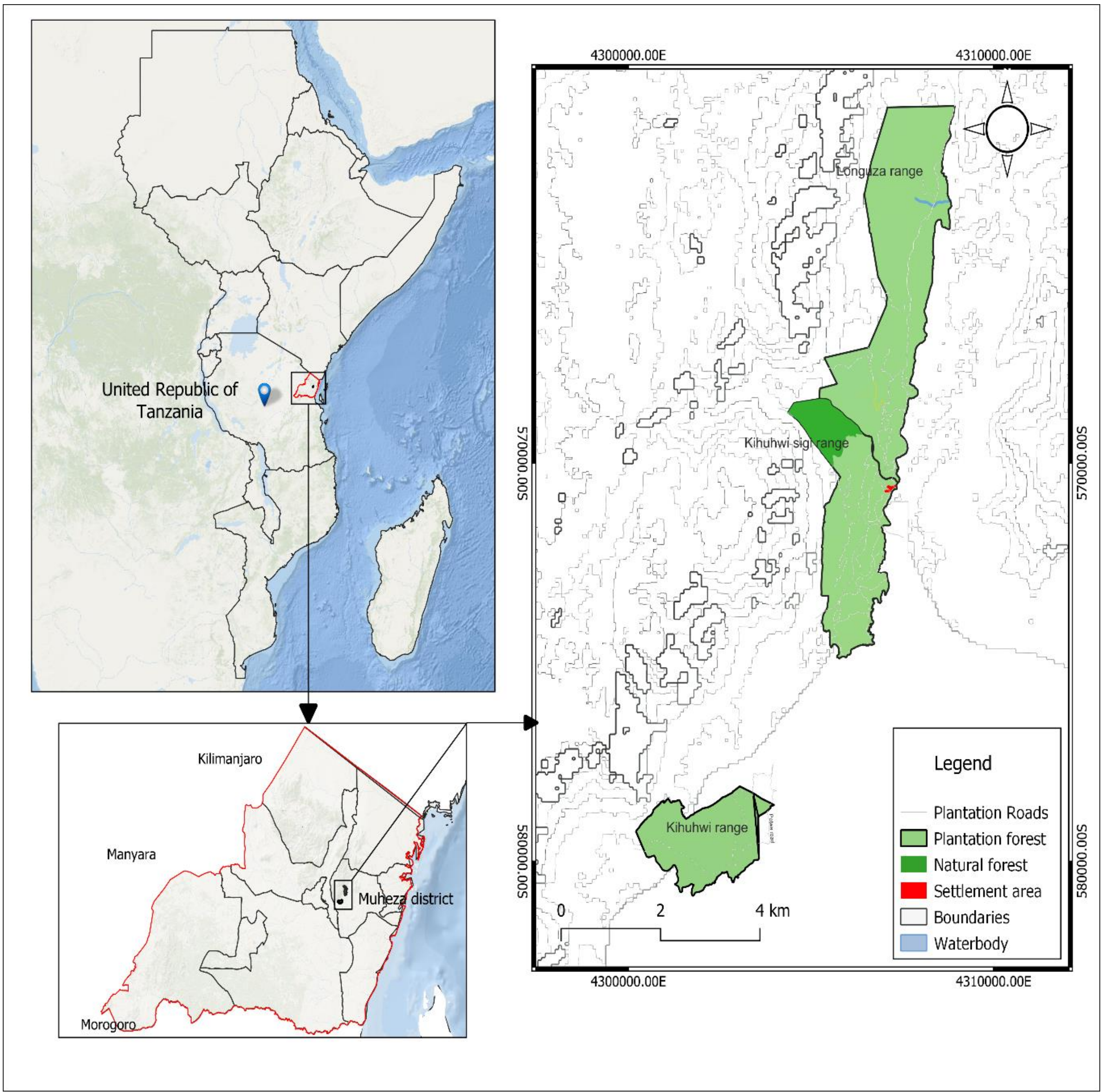

Figure 1: Map of Longuza Forest Plantation showing the location of study sites).

Sampling Design

Systematic sampling design as used to develop the Teak yield table by Malimbwi (2016) was adopted to establish; 1) circular shaped sample plots of radius 9.78 m, area of 300.33 m^2 (0.03 ha), 2) the accurate number of plots, 3) distance between plots, 4) transect distance and 5) appropriate sampling intensity to be applied for the surveyed compartment area. A reconnaissance survey was carried out in each compartment to decide the number of plots per compartment. The sampled compartment was surveyed before plot establishment to determine the correct area and to eliminate natural forests and swampy areas. Compartment maps were used to locate plots and lay out transects. Four transects were laid out in each sampled compartment. The distance between transects in a compartment was determined by dividing the distance of the widest part of the compartment by the number of transects and ranged from 100 m to 140 m. A total of 168 plots were laid out. The first plot was drawn randomly and the rest were laid out systematically at equal intervals of 100 m. The distance between plots was obtained by dividing the total transect length by the total number of plots (Table 2).

Table 2: Sampling procedure used in surveyed compartments

Thinning regime	Compartment	Age (years)	Area (ha)	Transect distance (m)	Sampling intensity (%)	Number of plots
1st Thinning	KH 12	6	33.8	120	0.02	23
1st Thinning	KH 13	7	28.1	120	0.02	23
1st Thinning	KS 1	8	47.3	140	0.025	31
2nd Thinning	LG 14	10	19.6	120	0.02	17
2nd Thinning	KS 11	11	23.6	140	0.03	19
2nd Thinning	LG 13	12	25.2	120	0.02	23
2nd Thinning	KS9B	13	5.4	100	0.02	6
2nd Thinning	LG 2	14	22.7	140	0.035	19
3rd Thinning	LG 13A	28	6.9	100	0.03	7

Data Collection

2.4.1 Growth and Yield of *Tectona grandis*

Forest inventory was carried out in each established plot in which Dbh (1.3 m above ground) of all trees was measured by using a caliper for compartments less than 10 years and compartments aged 10 years and above the Dbh was measured using diameter tape and counted. Height for the three fattest trees per plot was measured for total tree height using the Suunto hypsometer.

Thinning Adequacy and Timing

A compartment register was used to obtain data on the planting year and the age the compartment was supposed to be thinned. Through an interview, the Plantation Conservator provided information concerning thinning history, un-thinned, thinned and last thinning years on each selected compartment and were recorded.

Data Analysis

Growth and Yield of *Tectona grandis*

The stand parameters used to describe growth and yield were Dbh, dominant height, volume per ha, and stand density. Based on the Teak yield table for Longuza Forest Plantation produced by Malimbwi (2016), different models for tree and stand parameter estimation were adopted. The average Dbh was computed by summing Dbh (cm) in plots divided by the total number of trees measured. The estimation of height (H) for trees that were measured for Dbh alone was done by using Equation 1 (Table 3). The average dominant height estimation was done by summing the height of trees divided by the total trees measured. Stand volume per ha was estimated by using Equation 2 (Table 3). Stand density per ha was obtained by using Equation 3 (Table 3).

Table 3: Formulas used to estimate observed stand parameters

Equation	Equation no.	Source
$H = 1.3 + ((Dbh^2) \div (7.9693 + 0.03006 \times Dbh^2))$	1	Malimbwi (2016)
$V = \exp(1.033835 + 0.489679 \times \ln(H) + 0.9954 \times \ln(BA))$	2	Malimbwi (2016)
$N = 1/n((\sum ni)/ai)$	3	Malimbwi (2016)

Note: H is the total tree height, Dbh is the diameter at breast height, V is the volume, N is the number of stems, *n* is the number of plots surveyed, n_i is the number of stems per plot, a_i is the plot area, *ln* is the natural logarithm and *exp* is the exponential.

The measured values were compared to mean values obtained in the Teak yield table produced by Malimbwi (2016). However, the Teak yield table was developed meant to predict growth and yield for properly thinned stands. One sample t-test was used to test whether measured values differ significantly from the Teak yield table values.

Thinning Adequacy and Timing

Compartment tree density was computed to obtain the number of stems that remained after thinning. The tree density was determined by dividing the number of stems in a plot by plot area. The number of stems per ha that remained after thinning was obtained by dividing the number of stems in a plot by a plot area. Adequacy of thinning for thinned compartments was determined by calculating the remaining number of stems per ha and the deviation from scheduled values expressed in percentages. Thinning timing was obtained by deducting the age the compartment was supposed to be thinned as indicated in thinning schedule from the actual thinning age using the information from the Plantation Conservator and compartment register to determine whether the thinning was timely, earlier, or delayed. One sample t-test was used to test whether each compartment density after thinning differs significantly from the scheduled density in the thinning schedule.

Site Class Determination

The obtained dominant height and age were matched in the site index curves of the *Tectona grandis* produced by Malimbwi (2016) to determine site classes for the surveyed compartments (Figure 2). Site class I is the best, followed by site class II and lastly site class III. The corresponding site indices are 26, 22, and 18 m at the reference age of 20 years. All analyses were done using MS excel 2013 and SPSS software.

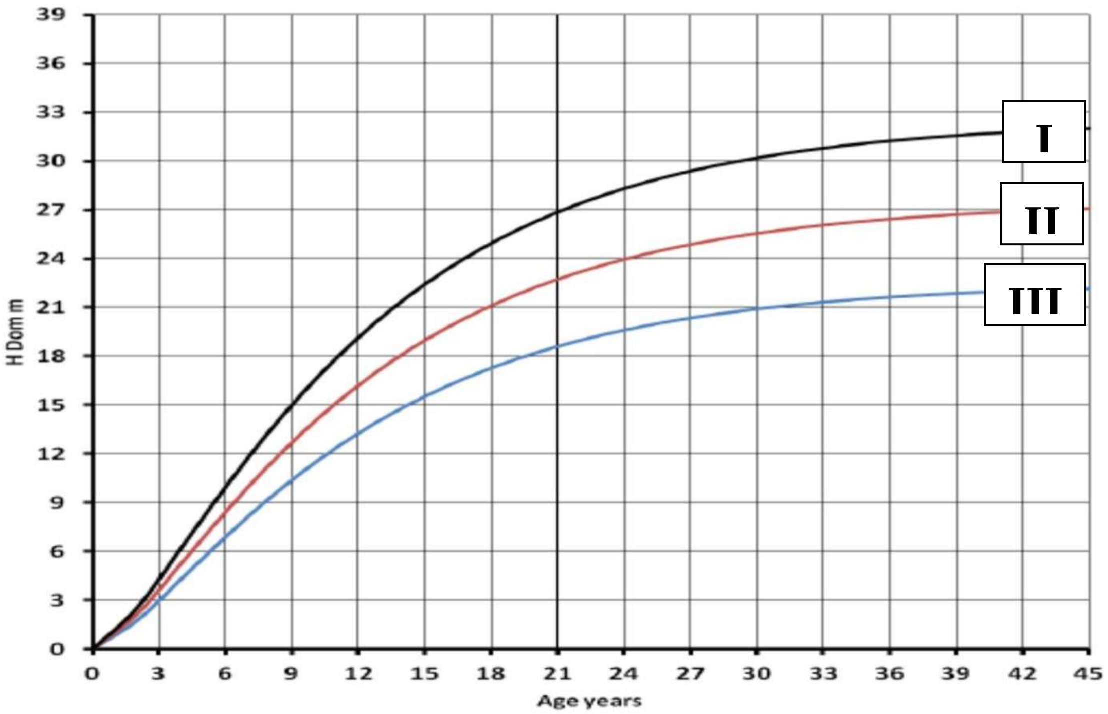

Figure 2: Site index curves for *T. grandis* in Tanzania. Roman I, II and III represent site classes one, two, and three respectively. ***Source***: Malimbwi (2016).

RESULTS

Thinning Adequacy and Timing

Results showed that in 9 surveyed compartments, 8 compartments were understocked with negative deviation ranging from 5% to 27%. However, overstocking was observed in one compartment aged 28 years. Compartments that received first and second thinning treatments had average stems per ha of 675 and 366 with an average negative deviation of 15.7% and 8.6% respectively whereas third thinning had stems per ha of 348 with a deviation of 16% (Table 4).

Results of One sample T-test showed that the mean of the observed stems per hectare values in three compartments (33.3%) of second thinning treatment of KS11, KS9B, and LG 2 was not statistically significant at the 0.05 level of significance ($p > 0.05$) from the test value = 400 of Teak yield table (Table 5).

Table 4: Post thinning results on stocking (stems ha^{-1}) for surveyed compartments in Longuza Forest Plantation

Thinning regime	Compartment	Age (years)	N/ha	*N/ha	Deviation	Deviation %
1st Thinning	KH 12	6	728	800	(72)	(9)
1st Thinning	KH 13	7	714	800	(86)	(11)
1st Thinning	KS 1	8	583	800	(217)	(27)
2nd Thinning	LG 14	10	365	400	(35)	(9)
2nd Thinning	KS 11	11	372	400	(28)	(7)
2nd Thinning	LG 13	12	357	400	(43)	(11)
2nd Thinning	KS9B	13	356	400	(44)	(11)
2nd Thinning	LG 2	14	379	400	(21)	(5)
3rd Thinning	LG 13A	28	348	300	48	16

Figures in (brackets) represent a negative deviation
* Stand for value scheduled in the Teak yield table for *Tectona grandis*

Table 5: One sample T-test Results on Stocking

Thinning regime	Compartment name	Mean	Standard Deviation	t-statistic	Degree of freedom	P-value	Mean Differences	95% Confidence interval of the Difference	
								Lower	Upper
2nd Thinning	KS 11	371.93	65.04	-1.881	18	0.076[b]	-28.07	-59.41	3.28
2nd Thinning	KS 9B	355.55	54.43	-2	5	0.102[b]	-44.44	-101.57	12.68
2nd Thinning	LG 2	378.95	48.69	-1.884	18	0.076[b]	-21.05	-44.52	2.42

[b] stands for insignificant p-values.

Results revealed that 7 compartments out of 9 received thinning treatments on time. Nevertheless, 100% of first thinning was done on time, and about 80% of second thinning was observed to be timely carried out while about 20% of second thinning and third thinning treatments in one compartment were delayed for one year (Table 6).

Site Classes of the Surveyed Compartments

Results revealed that 7 out of 9 surveyed compartments belong to site class I and 2 compartments belong to site class II. However, results indicated that 66.7% (141.7 ha), and 33.3% (70.9 ha) of surveyed compartments belong to site classes I, and II respectively. In addition, 52.5% (74.4 ha) are from the LG range, 43.7% (61.9 ha) are from the KH range and 3.8% (5.4 ha) are from the KS range and 100% (70.9 ha) of all site class II compartments are from KS range (Table 7 and Figure 3).

Table 6: Timing of thinning operations for surveyed compartments in Longuza Forest Plantation

Thinning regime	Compartment	Planting year	Age (years)	Actual stocking (N/ha)	Actual thinning year	Scheduled thinning year	Thinning timing (years)	Timing status
1st Thinning	KH 12	2015	6	728	2020	2020	0	Timely
1st Thinning	KH 13	2014	7	714	2019	2019	0	Timely
1st Thinning	KS 1	2013	8	583	2018	2018	0	Timely
2nd Thinning	LG 14	2011	10	365	2020	2020	0	Timely
2nd Thinning	KS 11	2010	11	372	2020	2020	0	Timely
2nd Thinning	LG 13	2009	12	357	2019	2019	0	Timely
2nd Thinning	KS9B	2008	13	356	2018	2018	0	Timely
2nd Thinning	LG 2	2007	14	379	2018	2017	+1	Delayed
3rd Thinning	LG 13A	1993	28	348	2008	2007	+1	Delayed

Table 7: Site classes of the surveyed compartments in Longuza Forest Plantation

Compartment name	Age (Years)	Area (ha)	Dominant height (m)	Site class	Thinning Status	Thinning regime	Range
KH 12	6	33.8	11.5	I	Thinned	1st	Kihuhwi
KH 13	7	28.1	12.4	I	Thinned	1st	Kihuhwi
KS 1	8	47.3	11.1	II	Thinned	1st	Kihuhwi Sigi
LG 14	10	19.6	19.5	I	Thinned	2nd	Longuza
KS 11	11	23.6	14.8	II	Thinned	2nd	Kihuhwi Sigi
LG 13	12	25.2	21.7	I	Thinned	2nd	Longuza
KS 9B	13	5.4	22.5	I	Thinned	2nd	Kihuhwi Sigi
LG 2	14	22.7	23.3	I	Thinned	2nd	Longuza
LG 13A	28	6.9	29.9	I	Thinned	3rd	Longuza

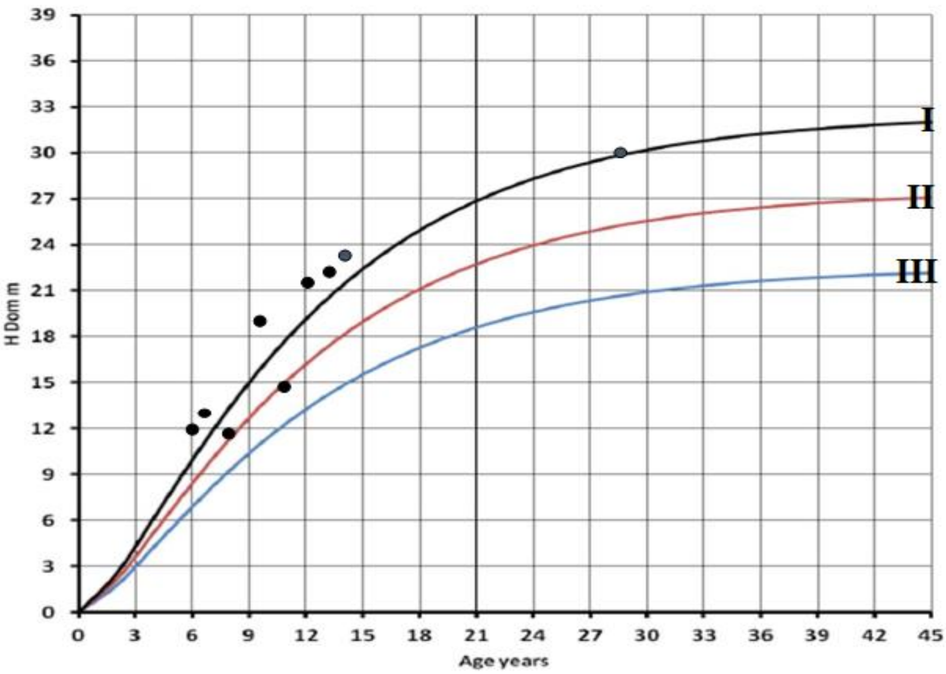

Figure 3: Site classes for the surveyed compartments. Roman I, II, and III represent site classes one, two, and three respectively

Effects of Thinning on Diameter Growth

In the first, second, and third thinned compartments, results revealed that thinning affects diameter growth. For site class I, results showed that observed values deviated from 20% to negative 36% in the first, second, and third thinning treatments. For site class II, results revealed that observed values deviated by 2% and 42% in the first and second thinnings respectively. (Table 8).

However, a statistical result of One sample T-test showed that the mean of the observed Dbh in five compartments in site class I revealed that first, second, and third thinning in compartments KH 12, KH 13, LG 13, LG 2, and LG13A was statistically significant at the 0.05 level of significance ($P<0.05$) from the test value = 9.8, 11.7, 22.7, 25.6 and 38.5 respectively of teak yield table values. The observed results of One sample T-test in three compartments of second thinning of KS9B, KS11, and LG 14 revealed that the mean of the observed Dbh was not statistically significant at the 0.05 level of significance ($P>0.05$) from the test value = 24.2, 17.6 and 19.3 respectively. Nonetheless, the statistical result indicated that the first thinning operation in compartment KS 1 was statistically significant at 0.05 level of significance (P<0.05) from the test value = 11.3 of teak yield table value while the second thinning operation in compartment KS 11 was not statistically significant at 0.05 level of significance from the test value = 17.6 of teak yield table value (Table 9).

Table 8: Summary of post-thinning results on diameter (cm) growth at Longuza Forest Plantation

Thinning regime	Compartment	Age (years)	Dbh (cm)	*Dbh (cm)	Deviation	Deviation %	Site class
1st Thinning	KH 12	6	13.7	9.8	4	40	I
1st Thinning	KH 13	7	14.0	11.7	2	20	I
1st Thinning	KS 1	8	16.1	11.3	5	42	II
2nd Thinning	LG 14	10	18.3	19.3	(1)	(5)	I
2nd Thinning	KS 11	11	17.9	17.6	0.3	2	II
2nd Thinning	LG 13	12	19.5	22.7	(3.2)	(14)	I
2nd Thinning	KS9B	13	23.9	24.2	(0.3)	(1)	I
2nd Thinning	LG 2	14	20.7	25.6	(5)	(19)	I
3rd Thinning	LG 13A	28	24.5	38.5	(14)	(36)	I

Figures in ( ) represent a negative deviation

* Stand for value scheduled in the Teak yield table for *Tectona grandis*

Table 9: One sample T-test Results on Diameter Growth

Thinning regime	Compart ment name	Mean	Standard Deviation	t-statistic	Degree of freedom	P-value	Mean Differences	95% Confidence interval of the Difference	
								Lower	Upper
1st Thinning	KH 12	13.75	1.17	16.174	22	0.00[a]	3.95	3.44	4.46
1st Thinning	KH 13	14.05	0.88	12.684	22	0.00[a]	2.34	-109.24	61.77
1st Thinning	KS 1	16.05	1.90	13.92	30	0.00[a]	4.75	4.05	5.45
2nd Thinning	LG 13	19.45	2.5	-6.129	22	0.00[a]	-3.24	-4.34	-2.19
2nd Thinning	KS 11	17.89	1.46	0.884	18	0.38[b]	0.29	-0.41	1.00
2nd Thinning	LG 2	20.74	1.74	-11.892	18	0.00[a]	-4.85	5.71	-3.99
3rd Thinning	LG 13A	24.49	4.03	-9.19	6	0.00[a]	-14.01	-17.74	-10.28

[a] and [b] stand for significant and insignificant p-values respectively

Effect of Thinning on Stand Yield

Results revealed significant differences between observed values and Teak yield table values in 7 out of 9 compartments. In site class I compartments, the mean percentage deviation ranged from 9% to 53% while in site class II compartments, the percentage deviation ranged from negative 9% and 23%. First site class compartments had higher observed values than Teak yield table values ranging from 9% to 53%. In site class II, compartments KS 1 and KS 11 had a negative deviation percentage of 9% and 23% respectively (Table 10).

The results of One sample T-test indicated that in observed compartments, 85.7% of site class one in compartments KH 12, KH 13, LG 14, LG 13, KS 9B, and LG 2 was statistically significant at a 0.05 level of significance (P<0.05) from test value 52.1, 80.4, 128.5, 191, 223.7, and 256.8 respectively of Teak yield table values while statistical result in compartment LG 13A was not statistically significant at 0.05 level of significance (P>0.05) from test value = 508.9 of Teak yield table. In addition, compartment KS 1 was statistically significant (P<0.05) and statistically insignificant was observed in compartment KS 11 (P>0.05) at 0.05 level of significant from the test value 73.7 and 102.2 respectively of Teak yield table (Table 11).

Table 10: Summary of post-thinning results on volume yield ($m^3\ ha^{-1}$) in Longuza Forest Plantation

Thinning regime	Compartment	Age (years)	V (m^3/ha)	*V (m^3/ha)	Deviation	Deviation %	Site class
1st Thinning	KH 12	6	72.9	52.1	21	40	I
1st Thinning	KH 13	7	87.3	80.4	7	9	I
1st Thinning	KS 1	8	56.8	73.7	(17)	(23)	II
2nd Thinning	LG 14	10	196.1	128.5	68	53	I
2nd Thinning	KS 11	11	93.5	102.2	(9)	(9)	II
2nd Thinning	LG 13	12	253.1	191.0	62	33	I
2nd Thinning	KS9B	13	271.6	223.7	48	21	I
2nd Thinning	LG 2	14	314.5	256.8	58	22	I
3rd Thinning	LG 13A	28	574.9	508.9	66	13	I

Figures in ( ) represent a negative deviation

* Stands for value scheduled in the Teak yield table for *Tectona grandis*

Table 11: One sample T-test Results on Stand Yield

Thinning regime	Compartment name	Mean	Standard Deviation	t-statistic	Degree of freedom	P-value	Mean Differences	95% Confidence interval of the Difference	
								Lower	Upper
1st Thinning	KH 12	72.88	9.66	10.323	22	0.00 [a]	20.79	16.61	24.96
1st Thinning	KH 13	87.25	14.09	2.331	22	0.29 [b]	6.85	0.76	12.94
1st Thinning	KS 1	56.78	11.92	-7.899	30	0.00 [a]	-16.92	21.29	-12.54
2nd Thinning	LG 14	196.06	72.12	3.862	16	0.01 [a]	67.56	30.47	104.64
2nd Thinning	LG 13	253.06	63.52	4.686	22	0.00 [a]	62.06	34.59	89.53
2nd Thinning	KS 9B	271.63	22.04	5.327	5	0.03 [a]	47.93	24.79	71.05
2nd Thinning	KS 11	93.52	24.95	-1.516	18	0.14 [b]	-8.68	-20.71	3.35
2nd Thinning	LG 2	314.45	74.74	3.363	18	0.00 [a]	57.65	21.63	93.68
3rd Thinning	LG 13A	574.94	94.15	1.86	6	0.11 [b]	66.04	-21.03	153.11

[a] and [b] stand for significant and insignificant p-values respectively

DISCUSSION

Thinning positively affected stand growth parameters and yield. This may be the reduction of site growth competition among nearby trees. However, the study revealed that the implementation of thinning treatments timely relieves both horizontal and vertical competition. Furthermore, thinning practice reduced stand density which influenced the growth of stand parameters since Teak is a light demander and does not grow well in congested trees (Pandey and Brown 2000, Štefančík *et al.* 2018). It was noted that after a thinning treatment, reduced competition for light, nutrients, and moisture raised the growth of the remaining individuals especially radial growth as reported by Pérez and Kanninen (2005), Budiadi and Ishi (2017), Kokutse *et al.* (2010), Pandey and Brown (2000) and Seta *et al.* (2021).

Thinning Adequacy

In this study, understocked and overstocked stands were observed. However, 7 compartments had an allowable stem deviation of 10% as proposed by SAIF (2000) except compartments KS 1 and LG 13A with 27% and 16% respectively. On average, first and second thinning operations were adequately implemented indicating adherence to the Teak thinning schedule in the Technical Order. The observed differences were probably due to a lack of technical and competent skilled staff. Similar results were reported by Tewari *et al.* (2014) in Karnataka, India, and Laswai *et al.* (2016) in Tanzania which revealed thinning was lighter than recommended in the Technical Order. On the other hand, the study conducted by Pérez and Kanninen (2005a) in Costa Rica observed higher stand densities than recommended.

Thinning Timing

In this study, it was observed that all compartments that received first and three compartments that received second thinning were timely carried out as per the thinning schedule. However, results revealed that second thinning in one compartment and third thinning were delayed. The results are in agreement with the study by Kaninnen *et al.* (2004) and Gumadi (2019) who observed thinning delays for one year for the second and third thinnings. The observed delays are probably due to a lack of priority in planning thinning operations and technical incompetence and improper supervision, and a lack of commitment among staff (Gumadi, 2019). The study on thinning timing by Chamshama (2011) and Ngaga (2011) revealed that thinning delays are caused by a shortage of funds.

Growth and Yield of *Tectona grandis*

Results showed that thinning affected Dbh growth. Nevertheless, understocked compartments as a result of heavy thinning operation opened wider space reducing competition for raw materials which is beneficial for greater Dbh increment. These findings are in agreement with various researchers (Budiadi and Ishi 2017, Malimbwi *et al.* 1992, Maliondo and Chamshama 1996, Miller 2000, Kanninen *et al.* 2004, Mäkinen and Isomäki 2004, Pérez and Kanninen 2005, Kokutse *et al.* 2010, Pandey and Brown 2000, Rytter 2013, Saarinen *et al.* 2020, Seta *et al*. 2021, Simard *et al*. 2004). Meanwhile adequately and timely thinned stands can produce higher diameter increments as a result of a higher turnover rate of the crown as new leaves quickly adapt to the better environment (Malimbwi *et al*. 1992, Maliondo and Chamshama 1996, Kanninen *et al*. 2004). However, observed low diameters in compartments LG 2 and LG 13A were aggravated by delayed thinning.

The study found that early thinning had a positive influence on volume increment. Similar results were reported by Piotto *et al*. (2003), Simard *et al*, (2004), and Štefančík *et al.* (2018). There was a higher impact of volume increment in thinned compartments. Similar results were obtained by Aiso-Sanada *et al.* (2019), Cassidy *et al.* (2012), Perez and kanninen (2005), Saarinen *et al.* (2020), Seta *et al.* (2021) and Yahya *et al.* (2011) on the study of volume growth after thinning. The changes in volume were highly promoted by deduction in the number of stems after each consecutive thinning. However higher volume growth observed in compartment LG 13A was due to overstocking. Similar results were obtained by Chamshama and Malimbwi (1996) revealing that higher volumes are possible in stands with fewer and lighter thinning than recommended, resulting in the standing volume being distributed on many small trees rather than a few ones of better value per cubic meter.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Generally, thinning operation and timing had a positive effect on the diameter growth and timber yield. The first and second thinning operations were over-thinned while the third thinning operation was lighter than specified in the Technical Order resulting in small diameter individuals whereas obtained higher volume was distributed in the small diameter stems. However, while timber volume increment drops after the first heavy thinning, it recovers quickly after the second thinning. Stand density in the first and second thinning operations was low except in the third thinning operation. The study revealed that thinning improved stand parameters. Although delayed thinning was performed in compartments LG 2 and LG 13A failed to attain the maximum Dbh as the Teak yield table recommends, the consequences would be loss of maximum yield as the crop attains commercial thinning and final harvesting age. The consequences in the future would be a failure to meet revenue objectives.

Recommendations

Thinning is the integral silvicultural operation in a forest plantation. Moreover, thinning schedules for Teak are important for producing high-quality timber which has a higher value for national and international markets when implemented correctly. However, thinning schedules have to be implemented on time as stipulated in the Technical Order so that the estimated mean diameter of 40 cm at clear-felling is attained. To ensure positive effects of thinning regime as per Technical Order No 1 of 2021 the spacing of 3 m x 3 m is recommended as this will ensure reduced competition of resources of young growing individuals hence fast growth and maximum yield in the future for Longuza Forest Plantation.

However, as observed that the lack and or shortage of funds causes delays, it is recommended that sufficient funds be adequately allocated and disbursed timely.

Due to technical incompetence and inadequate competent staff, it is recommended to make close follow up and timely implementation of operations as recommended in the Technical Order.

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