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Thinning compliance and its effects on growth, yield and stem quality of *Tectona grandis* at Mtibwa Forest Plantation, Morogoro, Tanzania

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ABSTRACT

Observing thinning schedule in commercial tree plantation is crucial if the final crop of desirable quality is required. However, there is limited information on thinning compliance to thinning schedule of *Tectona grandis* (Teak) in Tanzania. This study was undertaken to assess thinning compliance and its effects on the growth and yield of Teak at Mtibwa Forest Plantation, Morogoro, Tanzania. Ninety-two (92) circular plots of 9.78m radius were laid in 23 purposively selected compartments. Thinning history, heights of 3 fattest trees, breast height diameter (Dbh), and stem quality of trees in a plot were recorded. Results show that 57% of the thinned area is overstocked compared to the thinning schedule whereby the second and third thinnings had significantly higher ($P < 0.05$) stems per hectare (SPH). Inadequate thinning affects Dbh growth by 6-10% but dominant height (Hdom) is unaffected. SPH, basal area (BA), and volume (Vol) are higher by 15-69%, 4-118%, and 3-149% respectively. Results indicate that 73-80% of trees in compartments have stem quality 2. Generally, thinning is delayed, and lighter than recommended in the thinning schedule with negative effects to stand growth and yield. Compliance with the thinning schedule is recommended to attain the projected growth at rotation age.

Keywords: Compartments - Stocking - Site class – Thinning schedule – Yield table.

INTRODUCTION

Thinning is among the important silvicultural operations that increase the growing space available to the residual trees and ensure effective stand growth and yield at rotation age (Chamshama and Malimbwi 1996, Chamshama 2014, Mgoo *et al.* 2022). It allows the site's growing potential to be taped by fewer, larger trees instead of many small trees (FAO 2002, Kanninen *et al*. 2004). According to Morataya *et al*. (1999) inadequate and too long delayed thinning leads to a serious reduction in diameter increments through increased canopy closure and decreased tree crown length and lateral expansion. Therefore, Thinning being an important silvicultural operation should be done at the right time, in the right way and with the right intensity.

In Tanzania, management of industrial wood plantations is guided by established technical specifications including those of thinning (Nshubemuki *et al.* 2001). According to FBD (2003), first thinning of Teak for public plantations at spacing of

2.5m x 2.5m is recommended at the age of 5 years and later at ages of 10 and 15 years. The recent technical order (FBD 2021) reaffirms the previous technical order of 2003 but with slight modifications (with two thinnings only at the age of 5 years and 15 years at spacing of 2.5m x 2.5m and at the age of 8years and 13 years at spacing of 3.0m x 3.0m). Elsewhere, for example in Latin America, a first non-commercial early thinning is recommended at the ages of 3 - 6 years (Morataya *et al*. 1999). The average height which accounts for the effect of site quality on the stocking is also used to prescribe thinning operations. In Costa Rica, first thinning is recommended when trees reach 8.0 m height, at 3 - 6 years old (Chaves *et al*. 2016). All these differences are guided by the expectations of desired commercial end products determined by the existing site quality, initial spacing and survival of the crop.

Despite the importance of thinning in attaining the desirable crop at the end of rotation age, thinning operations in many public plantations in Tanzania do not comply with the prescribed schedules (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, Mgoo *et al.* 2022). According to Mgoo *et al* (2022) thinning and timing promoted positively Dbh and Volume growth.

However, little information on thinning compliance and its effects on the growth and yield of Teak is available in Tanzania. This study aims at filling the existing knowledge gap and contributes to improved management of woodlots and plantations. The objectives of this study were to; i) assess thinning compliance and its effects on the growth and yield of Teak at Mtibwa Forest Plantation (MFP) in Morogoro, Tanzania, and ii) to assessed the effects of thinning on the stem quality of this plantation. It is envisaged that findings from this study will be useful in designing improved management of Teak plantations for better productivity and profit.

MATERIALS AND METHODS

Study area

The study was conducted at Mtibwa Forest Plantation (MFP) with 12,266 ha located in Mvomero District, Morogoro Region, Tanzania at latitude 6° - 6° 10'S and longitude 37° 40' - 37° 45' E and approximately 640 m above sea level. The area receives long rains from March to May. These are followed by a long dry season lasting until October. Short rains are from November to December. The average mean annual rainfall is 1,217 mm. Since this is marginal for Teak growth, it is supplemented by sub-surface underground water. Temperatures are high particularly from January to March. Mid-day temperatures vary from 14 °C to 36 °C (MNRT 2018). The topography varies from flat to gentle slopes and there are several low-lying hills. The soils are progressively more fertile down the catena and are smooth and fairly strong compacting to alluvial and fertile. The soils have high capacities for water retention and at the same time very poor drainage (MNRT 2018).

Sampling design

The plantation was stratified into four age groups 6-10, 11-15, 16-20, and > 20 years to accommodate different thinning schedules. Before fieldwork, the plantation map of 2010 and QGIS program version 2.16.3 was used to plan the transects and plots layout. Then, all sampled compartments were surveyed using Global Positioning System (GPS) to obtain shape files for actual area determination before data collection. This involved eliminating water lodged sections with no trees. Four transects were designed whereby 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. The first transect was laid at half distance from the compartment border to avoid the edge effect. Then, 92 circular plots of 9.78 m radius each were laid out in 23 purposively selected compartments based on the stated age groups within the plantation. The distance between plots in a compartment was determined by dividing the total length of four transects by the number of plots (Malimbwi 1997). The actual positions of plots in the forest were located by GPS using extracted location coordinates from the QGIS.

Data collection

The actual data collection was conducted in 2018. In each plot, thinning history, diameter at breast height (Dbh) of all trees, stocking (stem per ha), stem quality of all trees using four quality classes (Table 1), and height of 3 fattest trees were recorded. Stem quality assessment in the field took into consideration the merchantable height and tree form (Mugasha *et al*. 1996). The Dbh was measured using a calliper (for compartment < 10 years) and diameter tape (for compartment > 10 years). The height of trees was measured using a Suunto hypsometer while plot centre locations were determined using a standardized GPS.

Table 1: Stem quality classification at Mtibwa Forest Plantation, Morogoro, Tanzania

Description	Stem quality class
a) Straight to the top and good stem form b) Straight and good stem form but with straight top forks	1
a) Straight and good stem form but with one slight bend less than 1 m in length b) Straight and good stem form but slightly bent or crooked with mid/top forks c) Straight and good stem form but with buttresses within 1 m height	2
a) Slight bends less than 1 m at bottom and top with a straight middle part b) One slight bend more than 1 m in length c) Slight crook, slight taper, buttressed within 2 m height	3
a) Serious crook, excess taper, and buttressed beyond 2 m height	4

Source: Slightly modified from Mugasha *et al.* (1996).

Data analysis

The collected data were analysed for compliance in thinning and its effects on the growth and yield of Teak and on stem quality of the plantation. Thinning schedule of 2003 was used (FBD 2003, Table 2). The total area (ha) of thinned and unthinned compartments was determined from shape files in QGIS. Adequacy of thinning for thinned compartments was determined by computing the deviations in percentages (%) between the remaining SPH and the scheduled values. In addition, a paired Student's t-test was run at plot level to test for significant differences between measured and scheduled SPH.

Table: 2: Thinning schedules for industrial public teak forest plantations in Tanzania

Species	Age (years)	Stems per ha
T. grandis (Planted at 2.5 x 2.5 m spacing)	0	1600
	5	800
	10	400
	15	300
	30-40	0

Source*:* FBD (2003) and Ngaga (2011)

Lastly, thinning timing was computed by deducting the age the stand was supposed to be thinned from the actual thinning age to determine whether it was timely, earlier, or delayed. Furthermore, yield tables for Teak by (Malimbwi 2016) were used to compare with study stand parameters (Dbh, SPH, Hdom, BA, Vol, VMAI) for sampled compartments. However, quadratic mean Dbh was used instead of arithmetic mean in making a comparison because yield table

Dbh is quadratic mean Dbh derived from the mean tree basal area (Equation 1) (Gadon and Hui 1998). Deviations between measured and yield table values were calculated for each site class and presented in percentages.

$$Dg = \frac{\sqrt{BA}}{0.0000785 \times SPH} \text{ …… Equation 1}$$

Where:

Dg = quadratic mean diameter (cm),
BA = stand basal area (m^2/ha),
SPH = number of stems per ha.

Average Hdom per compartment was calculated and the appropriate site class for each compartment was determined by using the site index curves developed by Malimbwi (2016). The percentage of trees in each of the four quality classes was computed for both thinned and unthinned stands. All analyses were conducted using R free software version 3.4.2 (R Development Team 2017) and Ms Excel 2013.

RESULTS AND DISCUSSION

Compliance with Teak thinning schedule

Adequacy of thinning

Results show that there is a decrease in number of stems per ha from the lower age group (6-10 years) with 918 stems/ha toward the higher age group (>20 years) with 211 stems/ha due to thinning operations (Figure 1). However, stands aged 6 to 20 years were overstocked compared to the expected amount as per thinning schedule. The extreme overstocking was for stands of age between 11-15 years whereby 254 more stems per ha than the expected amount was observed. The understocking was observed in stands with more than 20 years with 89 less stems per ha than the expected amount (Figure 2).

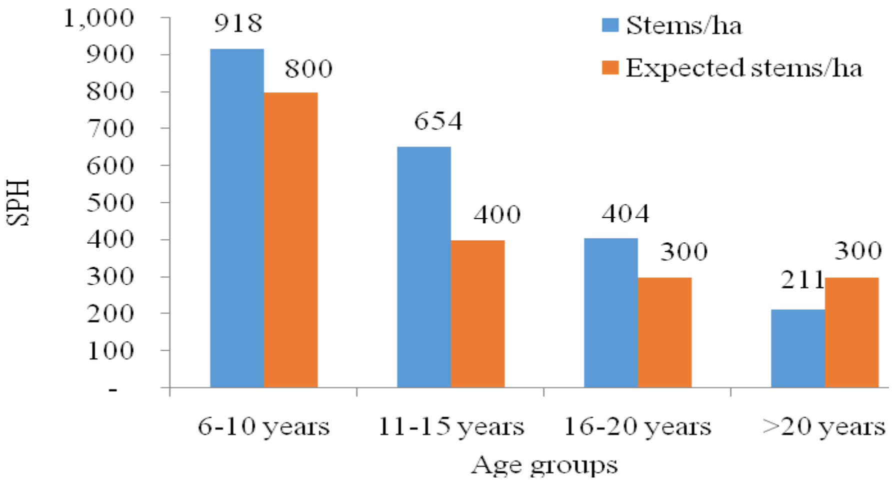


Figure 1: Measured and expected SPH by age groups at Mtibwa Forest Plantation, Morogoro, Tanzania

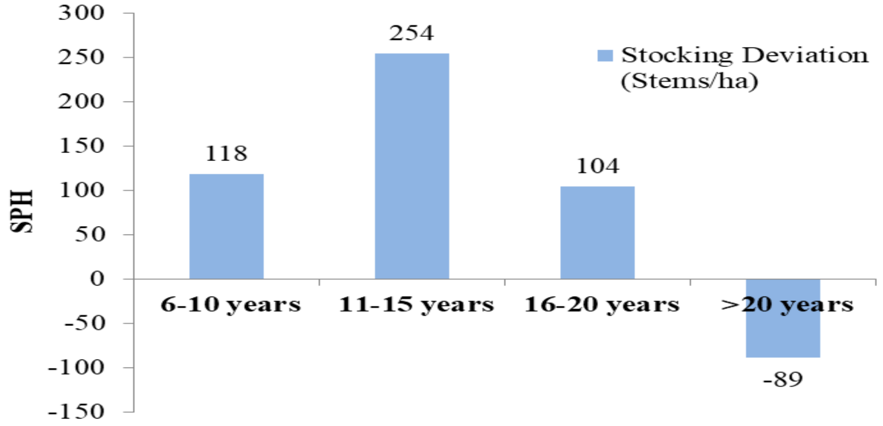


Figure 2: The stocking deviation (stems/ha) from the expected SPH by age groups at Mtibwa Forest Plantation, Morogoro, Tanzania

Timing of thinning

The understocking was possibly caused by the reported illegal cutting and wind throw in older compartments while the overstocking in younger stands was caused by inadequate thinning operations. SAIF (2000) suggests an allowable 10% deviation of the prescribed SPH. This was at least observed in the first thinning operations with 13% but the second and third operations had higher deviations of 39% and 26% respectively indicating low adherence to thinning prescriptions (Table 3). These results are in agreement with Tewari *et al*. (2014) in Karnataka, India, and Laswai *et al*. (2016) also Mgoo *et al.* (2022) in Tanzania which revealed that thinning prescriptions were lighter and not always rigorously adhered to.

Table 3: SPH deviation by age groups in percentage at Mtibwa Forest Plantation, Morogoro, Tanzania

SN	Age group (years)	Number of compartments	Scheduled value	Measured SPH	SPH Deviation	SPH Deviation (%)	*P*-value
1.	6-10 (n = 24)	6	800	918	118	13	0.08
2.	11-15 (n = 28)	7	400	654	254	39	0.00
3.	16-20 (n = 8)	2	300	404	104	26	0.04
4.	>20 (n = 32)	8	300	211	(89)	(30)	0.00

Results revealed that most thinning operations were delayed for one year and two years (Table 4). About 80% of all first thinnings were delayed for two years. Second thinnings were observed to be timely carried out by 25%. However, one-year and two years delays for second thinnings were by 37.5% each. Third thinnings were delayed for one year and two years by 50% each. Similar results were observed in Costa Rica with two years of delayed thinning of Teak plantations (Kanninen *et al*. 2004). The observed delays in MFP are probably due to a lack of priority in planning thinning operations and technical incompetence. Other reasons are shortage of funds and lack of markets for unsawn thinnings especially the first thinnings (Chamshama 2011, Mgoo *et al.* 2022, Ngaga 2011).

Effects of site quality and thinning on Teak growth and yield

Results indicated that 37% (231.53 ha), 54% (332.63 ha), and 9% (54.46 ha) of surveyed compartments belong to site classes I, II, and III respectively as presented in Table 5. Trees in each site class respond differently in terms of growth and

Table 4: Timing of thinning operations at Mtibwa Forest Plantation, Morogoro, Tanzania

S/N	Compartment name	Planting year	Compartment age (years)	Actual 1st thinning year	Scheduled 1st thinning year	First thinning timing	Thinning delay (years)
First thinning							
1	MT IV	2012	6	Not thinned	2017	Delayed 1st thinning	1
2	MT V A	2010	8	2017	2015	Delayed 1st thinning	2
3	MT V B	2010	8	2017	2015	Delayed 1st thinning	2
4	MT V C	2010	8	2017	2015	Delayed 1st thinning	2
5	MT V D	2010	8	2017	2015	Delayed 1st thinning	2
Second thinning							
1	MT VII A	2008	10	2018	2018	Timely 2nd thinning	0
2	MT X A	2007	11	2018	2017	Delayed 2nd thinning	1
3	MT X A	2007	11	2018	2017	Delayed 2nd thinning	1
4	MT X C	2007	11	2018	2017	Delayed 2nd thinning	1
5	MT VII B	2006	12	2018	2016	Delayed 2nd thinning	2
6	MT VIII A	2006	12	2018	2016	Delayed 2nd thinning	2
7	MT VIII B	2006	12	2018	2016	Delayed 2nd thinning	2
8	LR XXIV & LR XXVI	2006	12	2016	2016	Timely 2nd thinning	0
Third thinning							
1	LR II	2000	18	2016	2015	Delayed 3rd thinning	1
2	LR III	1999	19	2016	2014	Delayed 3rd thinning	2

Table 5: List of surveyed compartments showing blocks, ages, areas, and site classes at Mtibwa Forest Plantation, Morogoro Tanzania

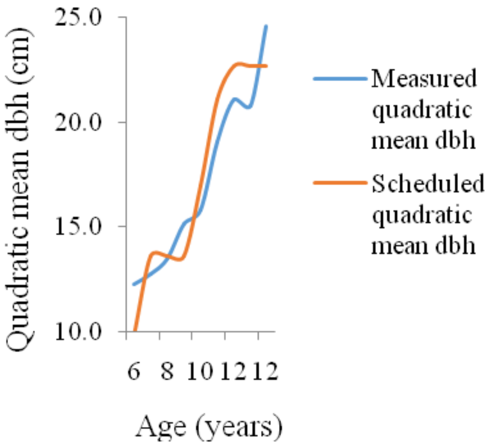
SN	Comp name	Age (years)	Comp area (ha)	Site class
1	MT IV	6	54.3	I
2	MT V A	8	17.95	I
3	MT V B	8	27.84	I
4	MT V C	8	32.86	I
5	MT V D	8	37.3	II
6	MT VII A	10	41.83	I
7	MT X A	11	38.79	II
8	MT X B	11	7.15	I
9	MT X C	11	19.58	II
10	MT VII B	12	47.25	II
11	MT VIII A	12	24.26	I
12	MT VIII B	12	56.5	I
13	LR XXIV & LR XXVI	12	7.6	I
14	LR II	18	5.76	II
15	LR III	19	7.3	III
16	LR XXI i	38	34.56	II
17	LR XVII i & ii	40	29.63	II
18	LR XIII i	45	22.56	III
19	LR XIII ii & iii	45	31.19	II
20	LR XIII iv & v	45	21.31	II
21	LR XIII vi	45	19	II
22	LR XII i	46	15.67	II
23	LR XII ii & iii	46	18.43	III

yield parameters when subjected to thinning treatments

Effect of thinning on Teak growth and yield in site class I compartments

Inadequate thinning affected Dbh growth by 6 to 10% with few exceptions at 6, 8, and 12 years due to the existence of older coppice sprout and natural regenerants in site class I compartments (Figure 3a). Adequately thinned Teak stands produce higher diameter increments and consequently increased the size of logs over low-thinned or unthinned stands (Malimbwi *et al*. 1992a, Maliondo and Chamshama 1996, Kanninen *et al*. 2004). Moreover, Hdom obtained in this study agrees with the yield table values of Malimbwi (2016). However, few exceptions were observed probably due to the presence of coppice sprouts and natural regenerants as described in the preceding section (Figure 3b). These results are in agreement with other research (Malimbwi *et al*. 1992a, Malimbwi 1997) on thinning versus height growth as height growth of trees is usually little or not affected by thinning at all. They also demonstrate the ability of the yield tables to predict growth.

Stocking results indicate that all compartments are variously overstocked from 15 to 69% except compartment number MT VC which is understocked by 30% (Figure 3c). This exception is due to poor survival, no blanking, and serious *Senna siamea* invasiveness which was observed in the compartment.



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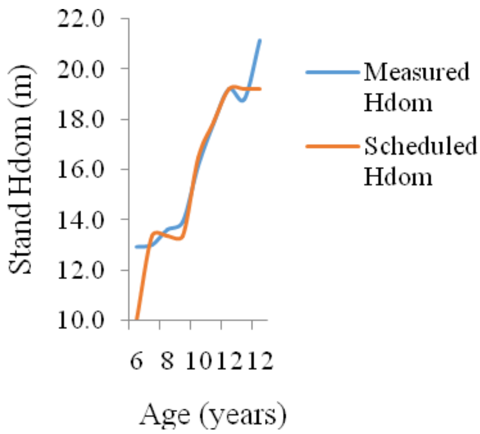

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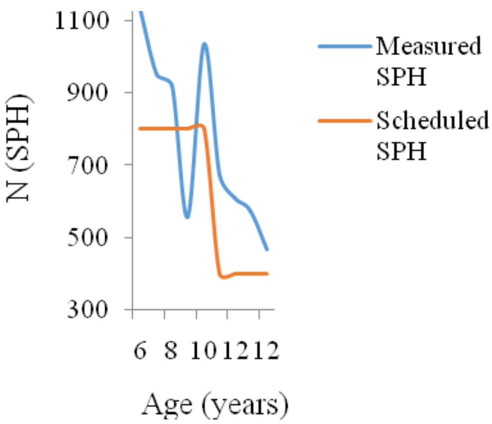

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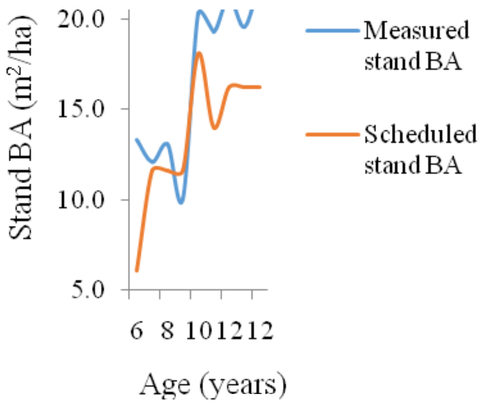

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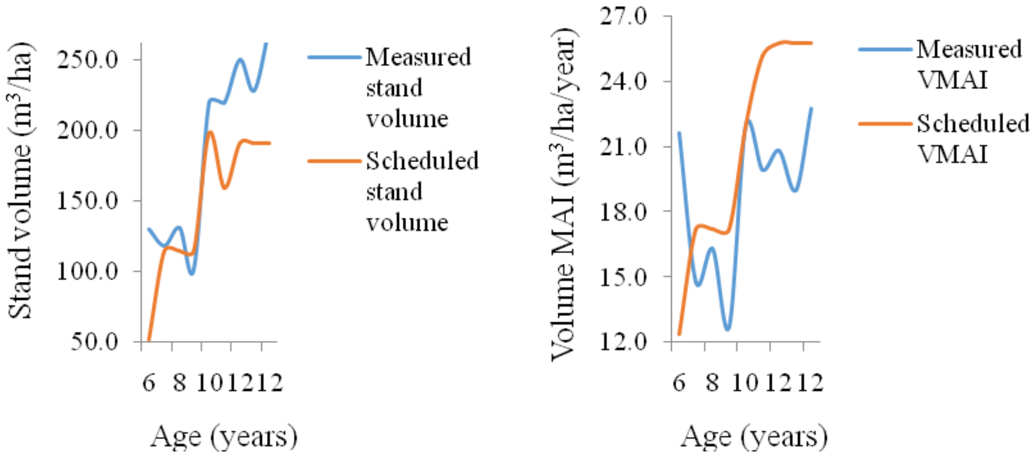


Figure 3: Effect of thinning on quadratic mean Dbh (a), Hdom (b), SPH (c), BA (d), Vol (e), and VMAI (f) for site class I at Mtibwa Forest Plantation, Morogoro, Tanzania

However, overstocking indicated inadequate thinning due to several reasons including technical difficulties in thinning stands established through coppice sprouts and natural regenerants management (Kwame *et al*. 2014) and lack of markets for first and second thinnings as already observed. Stand BA results indicated that most compartments have values beyond yield table values by 4 to 118% except for MT V C which is lower by 13% due to reasons given earlier (Figure 3d). Furthermore, a similar trend was observed for stand Vol (Figure 3e) because BA is directly related to stand Vol (Malimbwi 1997). The higher values indicated the effects of inadequate thinning on younger stands (Chamshama and Malimbwi 1996). VMAI results indicated most of the compartments to be having figures below yield table figures by 5% to 26% (Figure 3f) except for unthinned compartment number MT IV with figures higher by 74% because the high VMAI per ha is obtained in unthinned stands (Kollert and Kleine 2017). Another exception was MT VII A with equal VMAI figure yet somewhat coppiced and just timely marked for second thinning. The general trend observed was due to inadequacy in thinning operations making it difficult for trees to fully utilize site potential for growth which is meant following thinning (Chamshama and Malimbwi 1996, FAO 2002, Mgoo *et al*. 2022, Pérez and Kanninen 2005).

Effect of thinning on Teak growth and yield in site class II compartments

Results for Dbh indicate the intersection points at ages 8, 12, and 45 years for 6 compartments numbers MT V D, MT VII B, LR XII i, LR XIII ii/iii, LR XIII iv/v, and LR XIII vi (Figure 4a). This agreement between measured and scheduled quadratic mean Dbh was likely due to the presence of prescribed SPH at given ages in the compartments. However, relatively lower values of 6% were observed in compartment number LR XVII i and ii aged 40 years. This was caused by the fact that the compartment was relatively overstocked and even serious in compartments numbers MT X A by 17% and MT X C by 21% which had almost double the SPH than the prescribed ones at 11 years. On the other hand, a relatively higher value of 13% was observed at age 38 years for compartment number LR XXI i because it was relatively understocked. All these results agree with various studies (Malimbwi *et al*. 1992b, Maliondo and Chamshama 1996, Kanninen *et al*. 2004).

Hdom agrees with yield table values (Figure 4b). However, few exceptions were observed. Relatively lower values of 9% were observed in compartment number MT

X C at 11 years possibly due to observed high soil variability in the compartment and by 6% in compartment LR XIII iv/v at 45 years possibly due to reported high/crown thinning in the past. Besides, a relatively higher value of 8% was observed in compartments number MT VII B at 12 years possibly due to the edge effect as the compartment is at the edge of the plantation. These results are in agreement with other research (Malimbwi 1997, Malimbwi *et al*. 1992a) that the height growth of trees is usually little or not affected by thinning at all.

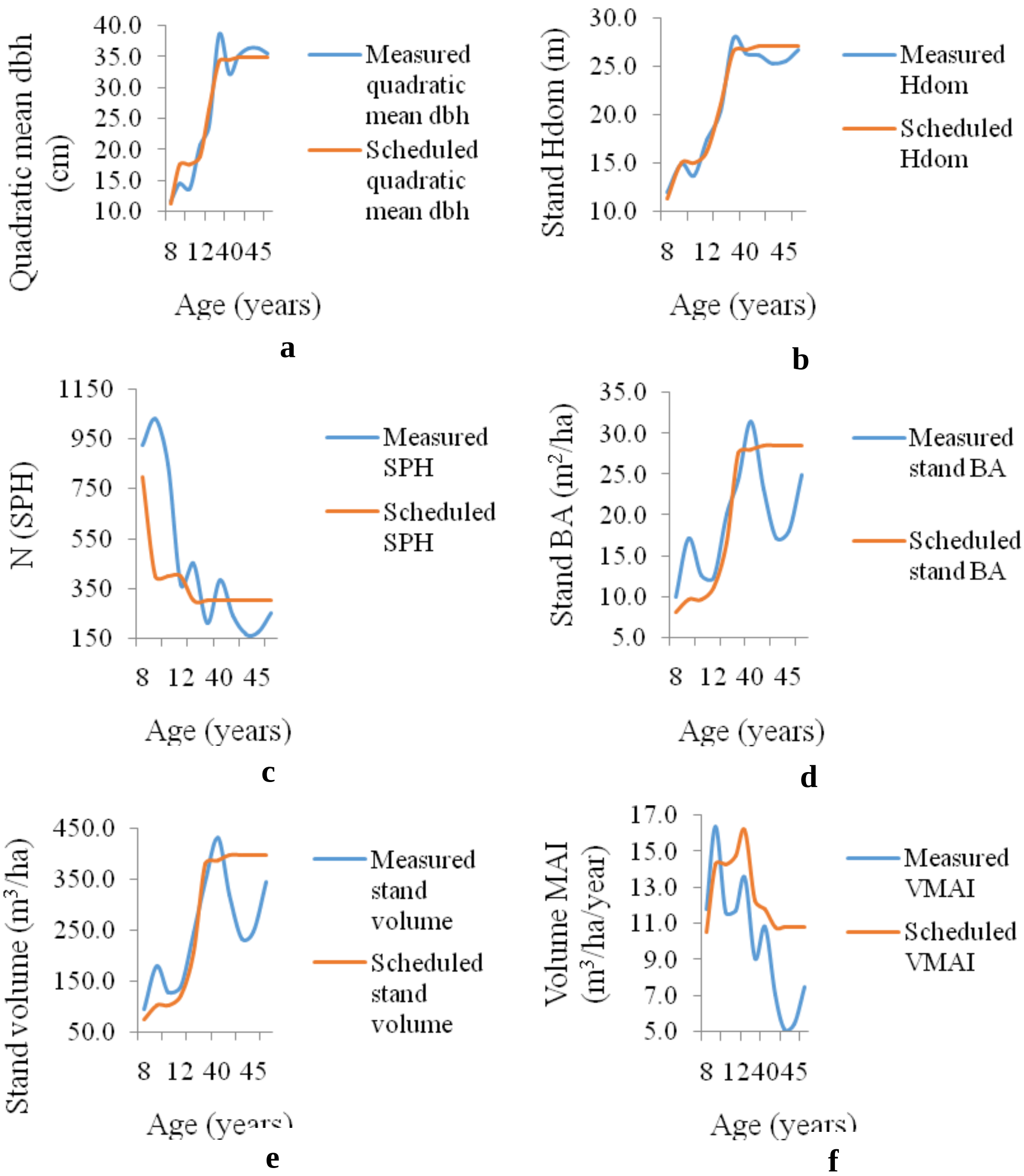


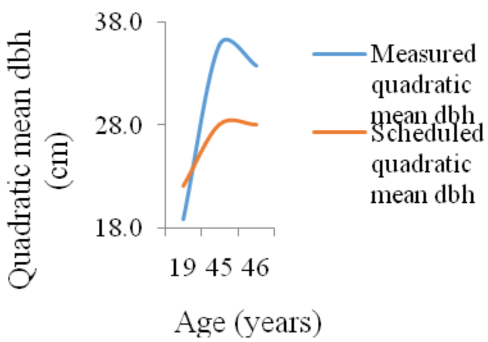
Figure 4: Effect of thinning on quadratic mean Dbh (a), Hdom (b), SPH (c), BA (d), Vol (e), and VMAI (f) for site class II at Mtibwa Forest Plantation, Morogoro Tanzania

Stocking results indicate that all compartments are overstocked except compartments MT VIIB aged 12 years with almost the same SPH as prescribed, LR XXI i aged 38 years, LR XIII iv/v, LR XIII vi both aged 45 years, and LR XII i aged 46 years that are understocked due to wind throw and illegal cutting (Figure 4c). Generally, overstocking indicated inadequate thinning due to several reasons including technical difficulties in thinning stands established through coppice sprouts and natural regenerants management e.g., MT VD aged 8 years, MT XA and MT XC aged 11 years as well as the traditional attitude by foresters against waste aggravated by lack of reliable market for third thinnings in LR II aged 18 years. Stand BA results indicated that most younger compartments have values beyond yield table values from 11% to 78% except for understocked compartments LR XXI i aged 38 years, LR XIII ii/iii, LR XIII iv/v, LR XIII vi all aged 45 years and LR XII i aged 46 years due to reasons given earlier for stocking (Figure 4d).

Moreover, a similar trend was observed for stand Vol (Figure 4e) because BA is directly related to stand Vol (Malimbwi 1997). The higher values from 12% to 76% indicated the effect of inadequate thinning on stands signifying that there were many relatively small trees resulting in the standing Vol distribution on many small trees rather than just a few of greater value per cubic metre (Chamshama and Malimbwi 1996, Mgoo *et al.* 2022). Results for VMAI indicated most compartments to have figures below yield table figures between 8% to 52% except for critically inadequately thinned compartment number MT X A aged 11 years with over double the prescribed SPH and both overstocked and somewhat coppiced and naturally regenerated MT V D (Figure 4f). This is because high VMAI per ha is common in unthinned stands (Kollert and Kleine 2017). The general trend observed was due to inadequacy in thinning operations making it difficult for trees to fully utilize site potential for growth which is meant following thinning (Chamshama and Malimbwi 1996, FAO 2002, Pérez and Kanninen 2005).

Effect of thinning on Teak growth and yield in site class III compartments

Quadratic mean Dbh results indicated relatively higher values of 27% and 20% for compartments number LR XIII i aged 45 years and LR XII ii/iii aged 46 respectively possibly due to understocking allowing space for Dbh growth (Figure 5a). However, relatively lower Dbh values by 14% were observed in LR III aged 19 years due to overstocking leading to low site potential utilization for growth. Relatively lower Hdom values by 10% in LR III aged 19 years possibly due to reported third crown thinning. A relatively higher Hdom value by 11% in LR XIII i aged 45 years possibly due to edge effect and over maturity and a similar value in LR XII ii aged 46 years indicating the ability of the yield tables to predict growth (Figure 5b). The SPH for compartments LR XIII i and LR XII ii/iii aged 45 and 46 years respectively are relatively lower by 50% and 61% respectively than the prescribed most likely due to wind throw and illegal cutting in these over matured stands (Figure 5c).



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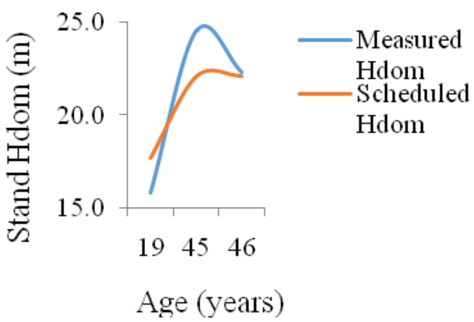

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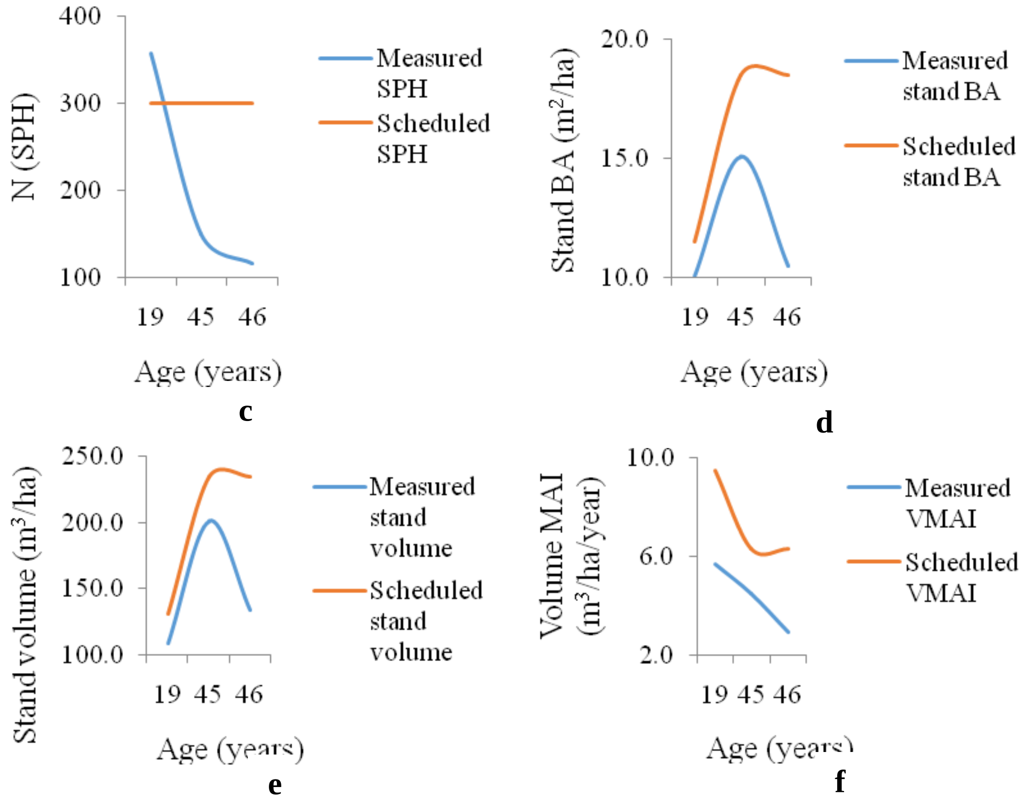

Figure 5: Effect of thinning on quadratic mean Dbh (a), Hdom (b), SPH (c), BA (d), Vol (e), and VMAI (f) for site class III at Mtibwa Forest Plantation, Morogoro Tanzania

Relatively lower stand BA values of 13% to 43% were observed for all three compartments (Figure 5d). This was due to understocking by about 50% and 61% in LR XIII i and LR XII ii/iii aged 45 and 46 years respectively. A similar trend was observed for stand Vol (Figure 5e) as BA is directly related to stand Vol (Ngaga 2011). Values for VMAI were relatively lower than the prescribed ones (Figure 5f). This could be due to the inadequate thinnings in the past. Inadequate thinnings create a difficulty for trees to fully utilize site potential for growth which is meant following thinning (Chamshama and Malimbwi 1996, FAO 2002, Mgoo *et al.* 2022, Pérez and Kanninen 2005).

Effect of thinning on stem quality

Results indicated that most of the stems in compartments have stem quality 2 with 76%, 73%, 80%, and 74% for age groups 6 - 10, 11 - 15, 16 - 20, and > 20 years respectively (Figure 6). However, compartments in age groups 6 – 10 and 11 – 15 years showed to respond to their first and second thinnings by having 9% and 16% stem quality 1 respectively. On the other hand, compartments in age groups 16 – 20 and > 20 years showed to have 19% and 20% respectively of stems with stem quality 3 possibly due to the past high thinnings in those compartments. In addition, the presence of stems (3%) with stem quality 4 for compartments aged 6 – 10 years and 3% for compartments > 20 years signals the effects of improper selection of stems for removal, lack of serious quality considerations (Maliondo and Chamshama 1996, Okama and Chamshama 1998), especially in compartments MT V B and MT VII A and high thinning respectively. Generally, it was difficult to establish the effects of thinning on stem quality because there were not enough unthinned compartments. The noticed difficulty was perhaps due to reports that Mtibwa provenances were mostly straight, with good self-pruning properties and branch-free boles by more than 50% (Madoffe and Maghembe 1988).

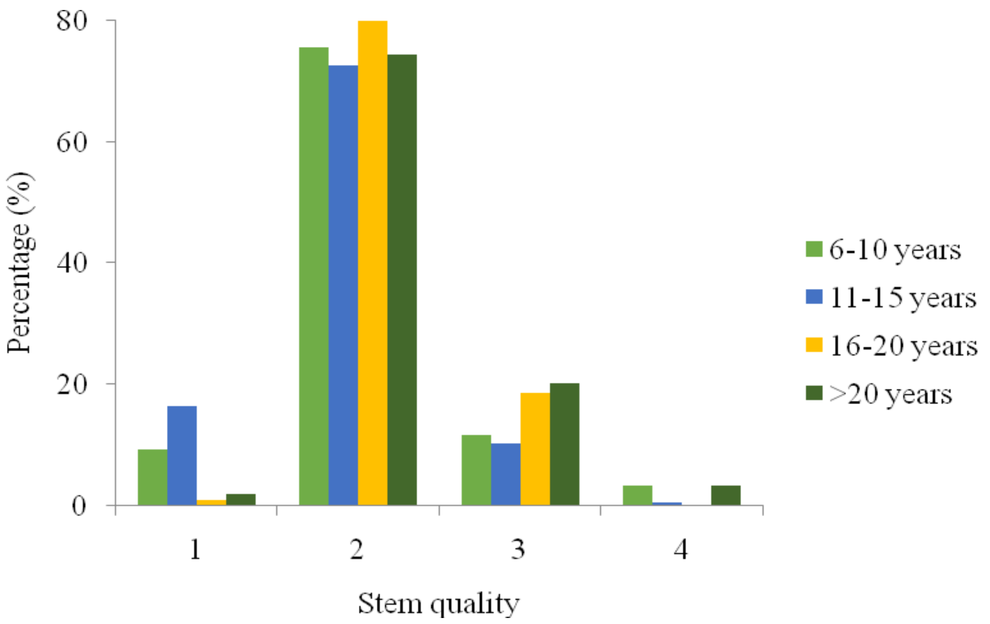

Figure 6: Stem quality percentage distribution by age groups at Mtibwa Forest Plantation, Morogoro Tanzania

CONCLUSIONS AND RECOMMENDATIONS

Though thinning operations appear to be performed, they are delayed and still lighter than recommended in the thinning schedule thus not meeting the compliance. The negative effects of inadequate thinning on stand quadratic mean Dbh, BA, SPH, Vol and VMAI have been observed to be serious. The consequences in the future would be a failure to attain a maximum Dbh of 40 cm and meet revenue objectives thus low sawmill recovery given the fact that the plantation is primarily managed for timber and not poles production. Despite that most of the stems in compartments have stem quality 2, it was difficult to establish the effect of thinning on stem quality as there were not enough unthinned compartments for comparison in the plantation.

It is recommended that on each thinning, preference should be given to the retention of the prescribed and most vigorous trees (dominants, straight stem, no diseases or stem defects, and well-formed crown), besides selecting trees to keep a relatively even spacing. Unless compartments are properly thinned and brought to normal as per the yield table, future yield predictions must be made by multiplying the relative correction factor by the scheduled values to have reliable future yield estimates at respective ages and site classes for management planning. Finally, the following studies are recommended: the effect of inadequate or lack of thinning on revenue generation and the allowable safe deviations in Dbh, Hdom, stand BA, stand Vol, and Stand VMAI like the available 10% for SPH.

REFERENCES

Chamshama, S.A.O. & Malimbwi, R.E. 1996. Thinning softwood plantation forests in Tanzania. Faculty of Forestry, Sokoine University of Agriculture, Record No. 63:41 – 49.

Chamshama, S.A.O. 2011. *Plantation forestry in Eastern and North Eastern African. Regional synthesis*. African Forest Forum. Nairobi, Kenya. 72 pp.

Chamshama, S.A.O. 2014. Plantation Silviculture in the Tropics. A compendium. Department of Ecosystems and Conservation, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, Morogoro. 93 pp.

Chaves, E., Chinchilla, O. & Mora, F. 2016. Comparación de dos sistemas de aclareos en plantaciones de Tectona grandis lf en la península de Nicoya, Costa Rica. *Revista Forestal Venezolana* 2(57):131 – 145.

FAO 2002. Forest plantation productivity. Report based on the work of W.J. Libby and C. Palmberg-Lerche. Forest Plantation Thematic Papers, Working Paper 3. Forest Resources Development Service, Forest Resources Division. FAO, Rome (*unpublished*). 29 pp.

FBD 2003. Technical specifications for management of forest plantations in Tanzania. *Technical Order No 1 of 2003*. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism. Dar es Salaam, Tanzania. 8 pp.

FBD 2021. Technical Order No 1 of 2021. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism. Dodoma, Tanzania. pp 1-13.

Kanninen, M., Pérez, D., Montero, M. & Viquez, E. 2004. Intensity and timing of the first thinning of *Tectona grandis* plantations in Costa Rica: Results of a thinning trial. *Forest Ecology and Management* 203:89 – 99.

Kollert, W. & Kleine, M. 2017. *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series Volume 36. Vienna. 108 pp.

KVTC 2019. Kilombero Valley Teak Co Ltd. [https://www.kvtc-tz.com/teak/]

Kwame, O., Adjei, L.E. & Richmond, O. 2014. Assessing the growth performance of Teak (*Tectona grandis* Linn. f.) coppice two years after clearcut harvesting. *International Journal of Agronomy and Agricultural Research* 5 (6): 36 – 41.

Laswai, F., Malimbwi, R.E., Chamshama, S.A.O. & Abdallah J.M. 2016. Determination of rotation age of *Pinus patula* and *Tectona grandis* in some public sector forest plantations, Tanzania. Tanzania Forest Services Agency, Dar es Salaam, Tanzania. 42 pp.

Madoffe, S.S. & Maghembe, J.A. 1988. Performance of Teak (*Tectona grandis* L.f.) provenances seventeen years after planting at Longuza, Tanzania. *Silvae Genetica* 37:175 – 178.

Malimbwi, R.E. 1997. Fundamentals of forest mensuration. A Compendium. Faculty of Forestry, Sokoine University of Agriculture, Morogoro. 94 pp.

Malimbwi, R.E. 2016. Development of yield tables for seven Tanzania Forest Service Agency Forest plantations in Tanzania. Tanzania Forest Services Agency, Dar es Salaam, Tanzania. 39 pp.

Malimbwi, R.E., Persson, A., Iddi, S., Chamshama, S.A.O. & Mwihomeke, S.T. 1992a. Effects of spacing on yield and some wood properties of *Cupressus lusitanica* at Rongai, Northern Tanzania. *Forestry* 65(1):73 – 82.

Malimbwi, R.E., Persson, A., Iddi, S., Chamshama, S.A.O. & Mwihomeke,

S. T. 1992b. Effects of spacing on yield and some wood properties of *Pinus patula* at Rongai, Northern Tanzania. *Forestry* 53:297 – 306.

Maliondo, S.M.S. & Chamshama, S.A.O. 1996. Role of intensive silviculture on increasing plantation productivity in Tanzania. Faculty of Forestry, Sokoine University of Agriculture, Record No. 63:50 – 58.

Mgoo, O.S., Mwambusi, J.N. & Chamashama, S.A.O. 2022. Effects of Thinning Regimes on Growth and Yield of *Tectona grandis* at Longuza Forest Plantation, Muheza District, Tanzania. *Tanzania Journal of Forestry and Nature Conservation* 91(2):1 – 26.

MNRT 2018. *Management plan for Mtibwa forest plantation, five years plan 2018 – 2023.* Tanzania Forest Services Agency, Dar es salaam. 99 pp.

Morataya, R., Galloway, G., Berninger, F. & Kanninen, M. 1999. Foliage biomass sapwood (area and volume) relationships of *Tectona grandis* Linn.f. and *Gmelina arborea* Roxb: Silviculturalimplications. *Forest Ecology and Management* 113(2/3):231 – 239.

Mugasha, A.G., Chamshama, S.A.O., Iddi, S. & Nshubemuki, L. 1996. Survival, growth and wood density of *Pinus kesiya* and *Pinus oorcapa* provenances at Kihanga arboretum, Sao Hill. *Forest Ecology and Management* 87:1 – 11.

Ngaga, Y.M. 2011. Forest plantations and woodlots in Tanzania. *African Forest Forum Working Paper Series* 1(16):1 – 80.

Nshubemuki, L., Chamshama, S.A.O. & Mugasha, A.G. 2001. Technical specifications on management of forest plantations in Tanzania. Forestry and Beekeeping Division. Ministry of Natural Resources and Tourism, Dar es Salaam. 50pp.

Okama, J.I. & Chamshama, S.A.O. 1998. Thinning of *Cupressus lusitanica* on Mount Meru, Northern Tanzania. *Tanzania Journal of Science* 14:145 – 154.

Palanisamy K., Hegde M. & Yi J.S. 2009. Teak (*Tectona grandis* Linn. f.): A renowned commercial timber species. J. For. Environ. Sci. 2009; 25:1–24.

Pérez, D. & Kanninen, M. 2005. Stand growth scenarios for *Tectona grandis* plantations in Costa Rica. *Forest Ecology and Management* 210(1–3):425 – 441.

R Core Team 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [https://www.R-project.org/].

SAIF 2000. *South African forestry handbook Volume 1*. South African Institute of Forestry (SAIF), V & R Printers, Pretoria, South Africa. 416 pp.

Tewari, V.P., Álvarez-gonzález, J.G. & García, O. 2014. Developing a dynamic growth model for Teak plantations in India. *Forest Ecosystems* 1(9):1 – 10.