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Effects of Thinning on Growth, Yield and Stem Quality of *Pinus patula* at Sao Hill Forest Plantation, Mufindi District, Tanzania

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ABSTRACT

Pinus patula is one of the most important plantation species grown in Eastern and Southern Africa. Its growth rate and yield vary considerably depending on site conditions, management techniques and genetic quality of the trees. It has been suspected that thinning of softwood plantations in Tanzania has been neglected resulting in lower standing volume being distributed into many small trees of poor form. This study assessed the effects of thinning on growth, yield and stem quality of *Pinus patula* at Sao Hill Forest Plantation located in Southern Highland part of Tanzania. In a systematically established plots; diameter of all trees, a total height of three trees and stem quality of four classes were recorded. An independent t-test was used to test for significant difference in stand parameters and Mann-Whitney U test was used to test stem quality between thinned and unthinned stand. Results showed that thinning significantly increased growth and yield of *Pinus patula*. Thinning improves stem quality by 9% resulting in trees having straight and good stem form. Thinned stands yielded higher volume than unthinned stands. Therefore, this study recommends that pine plantations should be timely thinned as per used thinning schedule to ensure that more volume is attained.

Key words: Sao Hill Forest Plantation - *Pinus patula* - Thinned stand - Unthinned stand - Stem quality

INTRODUCTION

Thinning removes surplus trees to concentrate timber production on a limited number of the best trees in the plantation resulting in increased diameter growth and producing more valuable larger diameter trees (Elia 2014). Thinning is a silviculture tool to reduce competition among trees as trees grow with age. Thus, thinning results in greater availability of light, water and nutrients to the remaining trees. This contributes to accelerated diameter growth (Demers *et al.* 2016 in Dangal and Das 2018). The effect is more significant in younger stands where diameter at breast height (Dbh) increment is positively correlated with thinning intensity. However, based on diameter classes, thinning seems to promote the growth of large trees more strongly than that of small trees. This is because bigger trees are more capable of resources utilization in such a way that can take advantage of the increase in resource availability as a result of thinning and eventually to use these resources for growth (Kim *et al.* 2016, Neumann and Hasenauer 2021). For instance, the study done on *Pinus sylvestris L* over 12-year post-thinning period by Peltola *et al.* (2002) found out that the large trees (Dbh 10.4–13+ cm) had the highest diameter growth in all the stand density classes while the medium-sized trees of 8–10.5 cm Dbh grew better in diameter than the small trees (Dbh 5.5–7.9 cm).

The stand basal area is directly related to stand volume as the gross volume increase with an increase in basal area (Malimbwi 1997, Allen *et al.* 2021). The effect of thinning on stand volume growth is strongly site dependent, but heavy thinning usually leads to a reduction in basal area and volume growth as compared with unthinned stand growing under similar site conditions (Skovsgaard 2009). There is a general agreement that with increasing thinning intensity, there is an increasing shift of the dimension and volume from small and medium diameter classes into the higher diameter classes or right skewness (Radoglou and Raftoyannis 2003).

Stem quality can be viewed in two ways: the external quality and internal quality. The study focused on external quality which includes dimensions like diameter and height, roundness, straightness of the stem, number and size of the branches (Kellomaki 1980 in Mtakwa 2014). Straightness is considered to be the most fundamental characteristic of stem quality across all the factors which help to determine the value of the product. Trees of greater diameter are considered to be of higher quality except for certain special uses such as pit props, poles and others. Apart from affecting the quantity of usable timber from a stand, thinning also affects the quality of tree. Removal of leaning, basal sweep or crooked stems trees reduces the amount of poor-quality wood remaining in the stand and the trees left to grow will have a higher percentage of utilization (Shepherd 1986 in Gumadi 2019). Stem quality is improved by thinning as poor-quality stems are removed during the operation (Piotto *et al. 2003*, Chamshama 2014).

It has been observed that thinning of softwood plantations in Tanzania among other plantations has been neglected resulting in lower standing volume being distributed into many small trees of poor form. However, little efforts have been made to show the effects of thinning on growth, yield and stem quality of unthinned compared to thinned trees in Tanzania. Gumadi (2019) and Malimbwi *et al*. 1992 conducted research on the effects of thinning but they focused on different species such as *Tectona grandis* and different silviculture practice such as spacing. Therefore, aims of this study were to assess the effects of thinning on stand growth, yield and stem quality for *Pinus patula* grown at Sao Hill Forest Plantation. This study focused on *Pinus patula* because the species is dominant at Sao Hill Forest Plantation and generate more revenue compared to other species. The results of this study can be useful to different stakeholders involving in *Pinus patula* management for sawntimber production.

METHODOLOGY

Description of study area

This study was conducted at Sao Hill Forest Plantation. It is found in Southern highlands of Tanzania at Mufindi District (Figure 1). The plantation extends in several Divisions and Wards of Mufindi District and it lies between 8°15’ – 8°41’ S and 35°6’– 35°45’ E. The altitudes range from 1400 m a.s.l to 2000 m a.s.l. The rainy season at Mufindi District starts from November to June with peak rainfall occurring in February and March. The area receives mean annual rainfall ranging from 750 to 2010 mm and temperature ranging from 15^{0}C to 25^{0}C per annum (Mgeni and Price 1993, Ngaga 2011). The plantation covers a total area of about 45,000 ha. The soil is moderately acidic, well drained and of various types mainly dystric nitrosols in association with orthic acrisols (Ngaga 2011). The natural vegetation adjacent to most of the compartments is the poorly stocked Miombo woodland constituting grasslands with scattered trees and shrubs such as *Brachystegia spiciformis*, *Julbemadia globiflora*, *Dombeya* *rotundifolia*, *Erythrina caffra* and *Albizia antunesiana* (Mhando *et al*. 1993).

The plantation is divided into four Divisions which are under management of Sao Hill Forest. Data for this study was collected on Division II which has a total land area of 11,169.8 ha and the total planted area is 10,239.18 ha. It is further divided into five Ranges namely: Sao Hill, Matanana, Nyololo, Kibidula/Mkewe and Makalala. The Division is bordered by a section of the famous little Ruaha river to the East beyond which is Division I; Nyololo and Nzivi villages on the South East; Kisada village on the South – West; and Kibidula Seventh Day Adventist Mission, Matanana, Mtula and Sao Hill villages on the West. The old Great North Road forms the plantation boundary on the North - West and to the North the Division is bordered by Mafinga National Service camp and Makalala Mission. The natural vegetation in the Division was originally typical montane open grasslands with occasional patches of Miombo clusters and riverine trees in the valleys. Sao Hill Forest Plantation was taken for study because they had compartments that met age and site class requirements for sampling. The study area is shown in Figure 1.

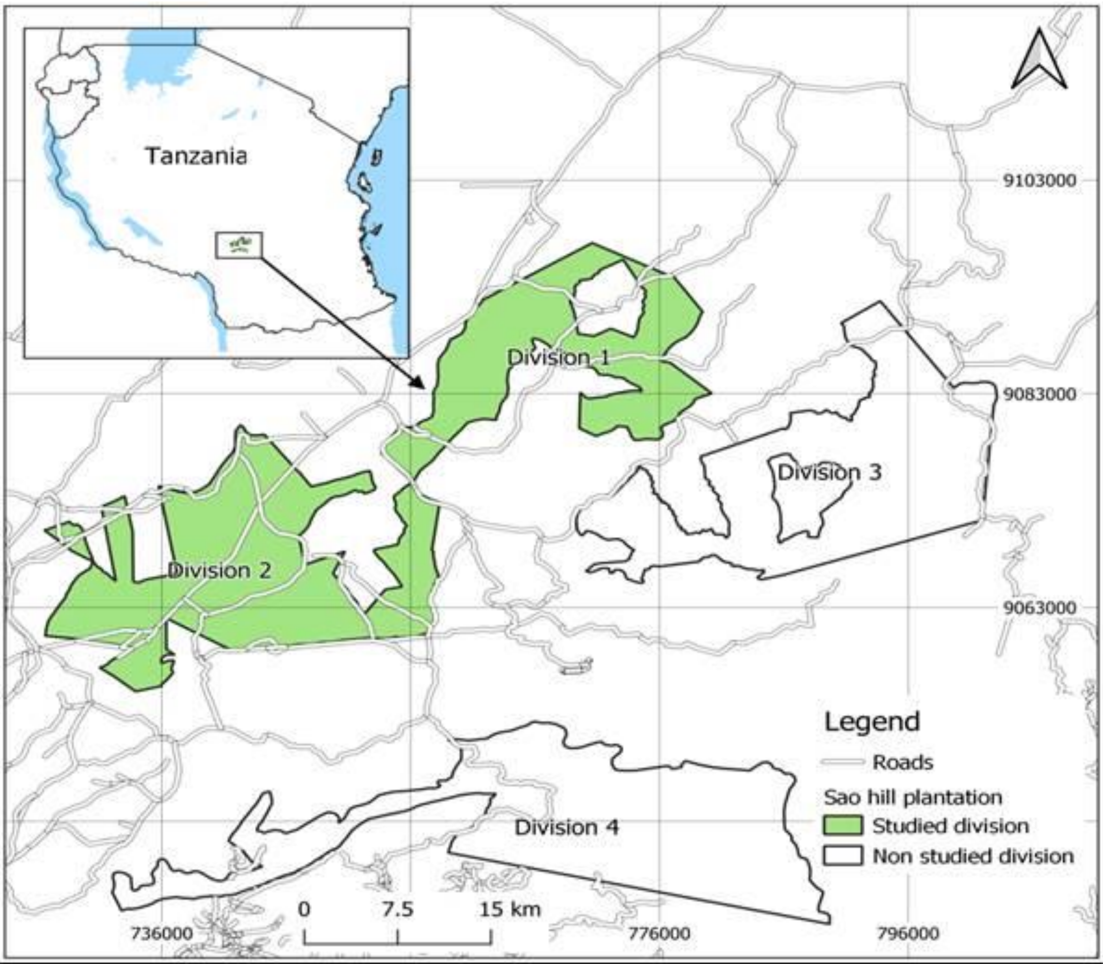

FIGURE 1: MAP SHOWING LOCATION OF DIVISION II AT SAO HILL FOREST PLANTATION (SOURCE: AUTHOR)

Sampling procedures

Reconnaissance survey

To be able to select the appropriate compartment for sampling, a reconnaissance survey was carried out in 16 unthinned and 26 thinned compartments (Table 1). The compartments information such as age, size, location, and species planted and the thinning status were obtained from the compartment register. This was to ensure a fair comparison of compartments with similar site and age classes. In each compartment, seven plots with an area of 0.03 ha and 9.78 m radius delivered from plot area (Malimbwi et al. 2016) each plot were laid out with a random start of the first plot at 50 m from a compartment boundary to avoid edge effects. In each plot, the height of the three largest trees in terms of diameter were measured.

Site class determination

The dominant height data collected during the reconnaissance campaign were used to identify the site classes of the visited compartments. According to Malimbwi et al. (2016), there are four site classes at Sao Hill Forest Plantation namely I, II, III and IV (Figure 2) which vary depending on their dominant height (Hdom) and age. Productivity range in site classes from highest (site class I) to lowest (site class IV). The collected Hdom – Age data were compared to the site indices curves generated by Malimbwi et al. (2016) whereby the corresponding site class of that compartment was identified.Table 1: The age class distribution of visited compartments during reconnaissance**.**

Table 1: The age class distribution of visited compartments during reconnaissance

Age class (Years)	Division		Thinning status	
	I	II	Thinned	Unthinned
12 - 15	10	4	5	9
16 - 20	0	28	21	7
> 20	0	0	0	0
Total	**10**	**32**	**26**	**16**

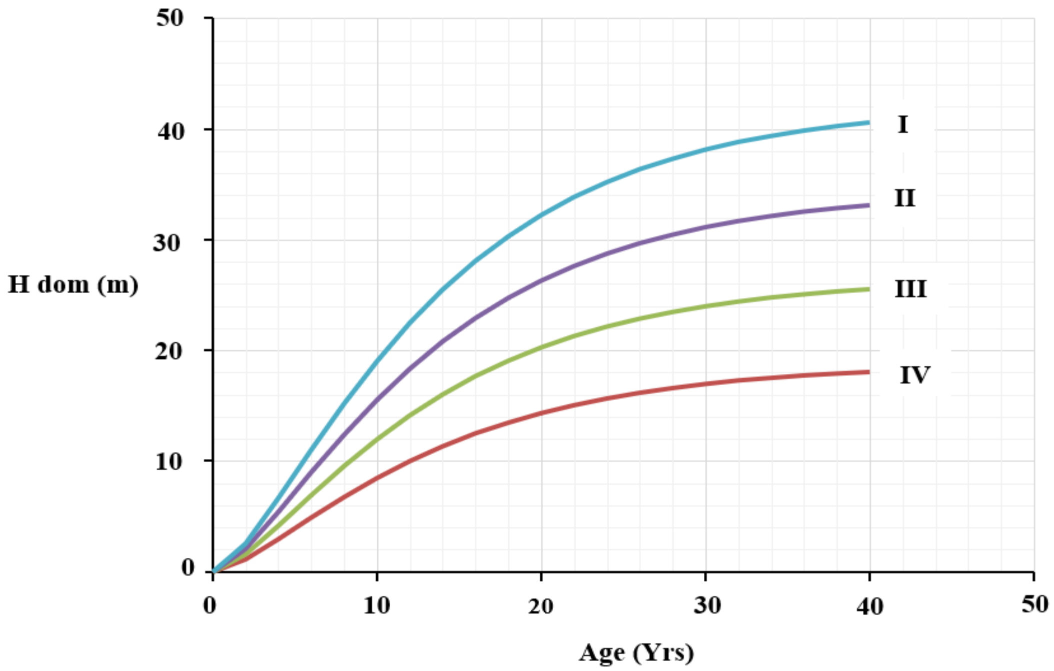

Figure 2: Site index curve for *Pinus patula* at Sao Hill Forest Plantation. *Source*: Malimbwi *et al*. (2016)**.**

Sampling design

The compartment identified during reconnaissance survey were stratified based on thinning status, site class and age. Then the selection of thinned and unthinned compartments was done by considering their comparability in term of site class and age. The selected thinned compartments were well thinned so that the effect of thinning could be articulated. A total of 6 compartments which fit the criteria were selected and used in data collection. In each compartment, circular plots of 0.03 ha of radius 9.78 m delivered from plot area (Malimbwi *et al*. 2016) were systematically established at an interval in every compartment (Table 2). Plantation maps were used in transect layout and plot allocation prior to field work. In transect laying-out, the first transect was laid at half transect distance from the compartment border to avoid border effects, this was also the case for the first plot. The distance between transects and plots varied for different compartments as indicated in Table 2.

Table 2: Compartments selected and used to assess effects of thinning on growth, yield and stem quality of *P. patula* at Sao Hill Forest Plantation

Compartment Name	Compartment size (ha)	Age (yrs)	Hdom (m)	Thinning status	Distance between transect (m)	Distance between plots (m)	No. of plots
2/S16b/10	37.8	18	23.9	2nd thinning	100	100	30
2/MT5/31	50.9	18	25.6	Unthinned	150	100	30
2/S16a/34	33.5	19	22.9	2nd thinning	100	100	30
2/MT5/24	32.2	19	26.6	Unthinned	100	100	30
2/S16a/31	21.6	19	25.0	2nd thinning	100	50	30
2/MT5/34.2	19.5	19	25.6	Unthinned	100	50	30

Table 3: Stem quality classificationf

Description	Stem quality class
a). Straight to the top and good stem form b). Straight and good stem form but with one slight bend less than 1m in length	1
a). Straight to the top and good stem form but with one slight bend less than 1 m in length b). Straight to the top and good stem form but with slight bend less than 1 m in length or crooked mid top forks	2
a). Straight to the top and good stem form but with one slight bend less than 1 m in length b). Straight to the top and good stem form but with slight bend less than 1 m in length or crooked mid top forks c). Straight to the top and good stem form with buttresses within 1 m height.	3
a). Seriously crook, excess taper and buttressed beyond 2 m height	4

Source: Mugasha *et al*. (1996)

Data Collection

Direct field measurement was used to measure Dbh of all trees in the plot to the nearest 10th of a cm using a caliper. The total tree height for three trees (one small, one medium and one fattest diameter tree) were measured by using hypsometer. Also, on each plot, stem quality class of all trees were determined by using subjective ranking using four quality classes 1, 2, 3 and 4 adopted from Mugasha *et al*. (1996) (Table 3).

Data Analysis

Growth and yield for thinned and un-thinned *Pinus patula*

The stand parameters used to describe growth and yield were Quadratic Mean Diameter (cm), basal area per hectare (m^2/ha) and volume per hectare (m^3/ha). Quadratic Mean Diameter (QMD) was used instead of arithmetic mean diameter (Dbh) because it gives the greater weight to larger trees and it is equal to or larger than the arithmetical mean diameter at an amount that depends on the variance (Curtis and Marshall 2000).

The Quadratic mean diameter (QMD) was computed as a square root of arithmetic mean of squared value (Curtis and Marshall 2000). It was estimated by using the equation $QMD = \sqrt{(\sum di^2)/n}$ whereby QMD is the quadratic mean diameter in cm, di is the diameter at breast height of i^{th} tree and n is the total number of the trees.

The tree basal areas (BA) in a compartment were estimated by using the standard formula $BA = \pi(dbh)^2/4x10000$ where π is the pi which is equivalent to 3.14. Results were divided by plot area (ha) to obtain basal area per hectare (m^2/ha).

Estimation of Height (H) for trees that were measured for Dbh alone was done by using the equation developed from Regression equation. The resulting natural logarithm equation was $H = 9.2357 \ln(dbh) – 4.7924$.

Tree volume was estimated using the equation developed by Malimbwi *et al.* (2016). The equation is $V = exp\ (-9.04925 + 1.114781*\ln(height) + 1.5496*\ln(dbh)$ where; V is tree volume (m^3) and dbh is diameter at breast height (cm). Volume was divided by plot area in order to obtain volume per hectare (m^3/ha). Comparison of growth and yield parameters between thinned and unthinned compartments was firstly done by using deviations percent between thinned and unthinned for each age and site class. Independent t-test was used to determine whether the mean values between thinned and unthinned stands differ significantly.

Stem quality of *Pinus patula* in thinned and un-thinned stands

Percentage of trees in each of the four quality classes was computed. A Mann-Whitney U test was performed to assess whether the stem quality of thinned stands is significantly different from un-thinned stands.

RESULTS

Quadratic mean diameter

Thinned compartments had a higher Quadratic Mean Diameter (QMD) compared to unthinned compartments that ranged from 11% to 18% percentage deviation (Table 4). Results in Table 4 indicated that thinned compartments were significantly different from unthinned compartments with p-values of 0.02 and 0.01 but thinned compartment 2/S16a/34 were not significantly different to unthinned compartment 2/MT5/24 with p-value of 0.19.

Stand basal area

Thinned compartments had higher basal area values than unthinned compartments. The basal area per hectare results indicated that only thinned compartment 2/S16a/34 had no significant different from unthinned compartment 2/MT5/24 with p-values of 0.18 (Table 5).

Table 4: Summary of stand Dbh for thinned and unthinned *Pinus patula* at Sao Hill Forest Plantation

Thinning status	Compartment	Age (year)	Dbh (cm)	Deviation (cm)	Deviation %	p-value
2nd Thinning	2/S16b/10	18	25.9 ± 0.3	4.5	17%	0.01*
Unthinned	2/MT5/31	18	21.4 ± 0.4			
2nd Thinning	2/S16a/34	19	27.6 ± 0.6	4.9	18%	0.19
Unthinned	2/MT5/24	19	22.7 ± 0.01			
2nd Thinning	2/S16a/31	19	23.5 ± 0.4	2.6	11%	0.02*
Unthinned	2/MT5/34.2	19	21.0 ± 0.4			

*Significant at p = 0.05

Table 5 Summary of stand basal area per ha for thinned and unthinned Pinus patula at Sao Hill Forest Plantation

Thinning status	Compartment	Age (years)	Basal area/ha (m^2/ha)	Deviation (m^2/ha)	Deviation %	p-value
2nd Thinning	2/S16b/10	18	48.46 ± 0.01	7.9	16%	0.02*
Unthinned	2/MT5/31	18	40.59 ± 0.02			
2nd Thinning	2/S16a/34	19	50.01 ± 0.02	6.9	14%	0.18
Unthinned	2/MT5/24	19	43.12 ± 0.01			
2nd Thinning	2/S16a/31	19	43.88 ± 0.02	3.6	8%	0.0001*
Unthinned	2/MT5/34.2	19	40.31 ± 0.02			

***Significant at p = 0.05**

Stand volume per hectare

Thinned compartments had high volume per ha values compared to unthinned compartments (Table 6). The mean deviation percentage ranged from 20% to 33%. The mean volume per ha of thinned stands ranged from 537.75 ± 0.61 m^3/ha to 743.22 ± 0.98 m^3/ha and unthinned stands were from 429.65 ± 0.58 m^3/ha to 500.59 ± 0.38 m^3/ha. Results indicated that volume per hectare of thinned compartments were significantly different from unthinned compartments with p-values of 0.01, 0.001 and 0.04.

Effect of thinning on stem quality

The thinned and unthinned compartments assessed were dominated mostly by trees which are straight to the top and good stem form at 76% for thinned compartment compared to 67% of unthinned compartments (Figure 3). This means, thinned stands had an advantage of improving quality of trees by increasing straightness by 9%. About 19% of trees in thinned compartments are straight to the top and good stem form but with one slight bend or buttresses less than 1 m in height compared to 21% of trees for unthinned compartments. About 5% of trees in thinned compartments and 12% of trees in unthinned compartments are slightly crooked, slightly taper and buttressed within 2 m height. Almost, less than 1% of trees in thinned and unthinned compartments have serious crook, excess taper and buttressed beyond 2 m height. Thinning tends to increase straightness to the trees and reduce serious crooked, excess taper and buttressed trees when it is done properly. A statistical test for stem quality of thinned compartments showed that they were significantly different to unthinned compartments with p = 0.000.

Table 6 Summary of stand volume per ha for thinned and unthinned *Pinus patula* at Sao Hill Forest Plantation

Thinning status	Compartment	Age (years)	Volume/ha (m^3/ha)	Deviation	Deviation %	p-value
2nd Thinning	2/S16b/10	18	656.63 ± 0.54	211.5	32%	0.001*
Unthinned	2/MT5/31	18	445.13 ± 0.48			
2nd Thinning	2/S16a/34	19	743.22 ± 0.98	242.6	33%	0.001*
Unthinned	2/MT5/24	19	500.59 ± 0.38			
2nd Thinning	2/S16a/31	19	537.75 ± 0.61	108.1	20%	0.04*
Unthinned	2/MT5/34.2	19	429.65 ± 0.58			

***Significant at p = 0.05**

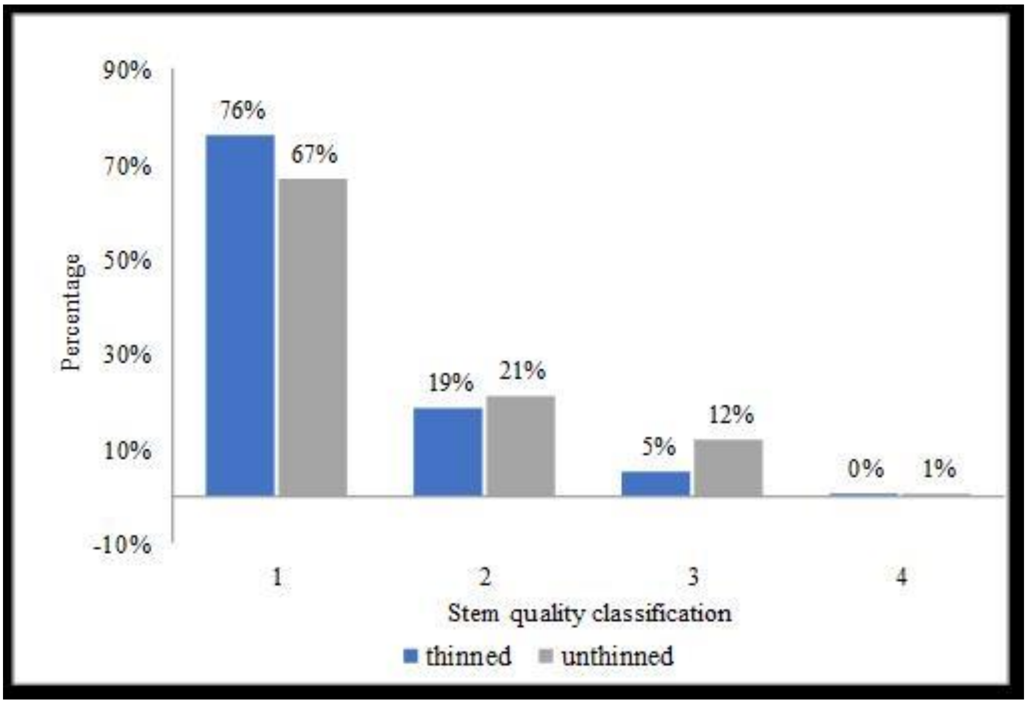

Figure 3: Percentage of stem quality classification on thinned and unthinned compartments at Sao Hill Forest Plantation

DISCUSSION

The simulated Dbh results by Malimbwi *et al*. (2016) for thinned compartments at age 18 and 19 years were 27.8 and 28.4 cm respectively which are higher than 25.9 cm and 23.5 – 27.6 cm for 18 and 19 years respectively obtained in this study. The reason is due to inadequate thinning observed which limits the space for diameter growth meaning that proper thinning was needed to reduce the trees competition for light, water and nutrients in order to increase tree diameter growth in stands (Hitsuma *et al*. 2021). Likewise, Malimbwi *et al*. (2016) found out that Dbh results for unthinned compartments at an age 18 and 19 years were higher than those obtained in this study because of overstocking in unthinned stands in this study as diameter increases with decrease on stand density (Makinen and Isomaki 2004). Results in Table 4 indicated that thinned compartments were significantly different from unthinned compartments with p-values of 0.02 and 0.0001 but thinned compartment 2/S16a/34 were not significantly different to unthinned compartment 2/MT5/24 with p-value of 0.19. This situation possibly was the result of delayed thinning as trees fail to show difference in diameter increment within a time after thinning. However, given the higher stem density of the thinned compartment compared to the density directed by the Technical Order; there is a possibility to attain more diameter increment on trees if thinning could have been performed properly (Radoglou and Raftoyannis 2003).

The results on basal area contradict with other studies conducted by Malimbwi *et al*. (2016) on *Pinus patula* and Skovsgaard (2009) on Scots pine that reported basal area to be high in unthinned compared to thinned compartments. The reason for the difference may be due to inadequate thinning performed, high level of fertility and availability of soil water in thinned stand that contributed to the observed difference (Makinen and Isomaki 2014). For a given site condition and a given spacing or initial stem number at stand establishment, the unthinned stand will support the highest possible basal area of live trees at any stage of stand development (Skovsgaard 2009).

The volume per ha results obtained are in contrary to other studies conducted by Akyoo (2017) and Elia (2014) who reported the average volume per ha in unthinned forest to be higher than in thinned compartments. The high volume in thinned compartment is associated with large tree Dbh in thinned compartment. The large tree Dbh is caused by enough space between trees that trigger the tree to increase in width (Makinen and Isomaki 2014). Also, the study results implied that there was a possibility of many small-sized diameter trees in unthinned compartments causing standing volume to be distributed in many small trees (Chamshama and Malimbwi 1996) resulting to smaller volume/ha than corresponding thinned compartments.

The relative high number of straight stems in thinned compartments could primary be associated with selective removal of crooked stems during thinning operations. Some studies found out that, there were a high percentage of a good quality stem aligned the stem form to increase with decreasing in stand density (Chamshama and Phillip 1980, Pérez and Kanninen 2005, Saarinen *et al*. 2020). Furthermore, thinning operation when properly carried out tend to increase trees spacing resulting to a significant effect on stem straightness with the most widely spaced trees having the worst mean stem straightness (Erasmus *et al*. 2018). However, the comparative low percent of straight trees in unthinned compartments could be due to seed sources problem and high competition of nutrients when the unthinned stand density was higher. There is low competition in thinned stands which can allow a tree to attain its desired diameter and stem form (Pérez and Kanninen 2005). The presence of few stems with defects observed in thinned compartments possibly were due to inadequate thinning, lack of serious quality consideration during thinning and cattle grazing in young stands resulted in seedling damage and poor stem quality in general for *Pinus patula* (Okama and Chamshama 1988, Maliondo and Chamshama 1996). The trees which have been found to have poor qualities were in compartments which have not been properly maintained. So, quality of stands can be improved by establishing them in the good sites and using proper tending techniques (Mwasomola 2008).

CONCLUSION AND RECOMMENDATIONS

Thinning practice had significant role in increment as the study showed that thinned stands yielded more increment than the unthinned stands. Positive effects of thinning on stand mean Dbh, basal area per hectare and volume per hectare has been observed. This can affect timber volume and revenue collection of final products. Thinned compartments were dominated by trees with straight and good stem form by difference of 9% compared to unthinned compartments which means Sao Hill Forest Plantation has suitable trees that can be sold at good Price at the markets if silvicultural practices will be maintained and properly implemented. To ensure high growth and yield of *Pinus patula* at Sao Hill Forest Plantation, it is recommended that the entire plantation to be thinned according to government thinning schedule as stated in Technical Order No. 1 of 2003 to encourage large diameter trees that can produce different sizes of timber to suit local and international market demand.

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