ROTATION AGE AND FIBRE LENGTH OF *PINUS PATULA* AT SAO HILL FOREST PLANTATION, TANZANIA

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ABSTRACT

This study determined the rotation age of *Pinus patula* grown at Sao Hill forest plantation based on growth, yield, wood properties, and economic analysis. Previous Technical Orders on rotation age were not based on these considerations. Growth, yield, wood properties, revenue, and management costs data were collected and analysed using standard procedures. The results indicate that there were fewer and lighter prunings and thinnings than specified in the respective schedules. Many trees were found to have breast height diameter below 40 cm in all compartments except one. Growth and yield results showed that for *P. patula* grown at Sao Hill, the equity point of Mean Annual Increment (MAI) and Current Annual Increment (CAI) were achieved at between 16 and 17 years with the maximum MAI being maintained until about 20 years. Basic density and mechanical properties showed that strong wood was obtained when trees were 16 years and above and these properties increased with age. The mean fibre length for 5 - 25 years old *P. patula* was found to range from 2.29 to 3.53 mm and increased with age. Fibre lengths from 11 years and above exceed the minimum (3 mm) considered suitable for pulp and paper production. Based on economic analysis, net present value (NPV) was attained at between 16 and 17 years. Based on considerations of growth and yield, wood properties and economics of rotation age; *P. patula* from Sao Hill is recommended to be harvested at 18 years for timber and 11 years for pulp and paper production.

Keywords: Rotation age, fibre length, *Pinus patula*, Sao Hill Forest Plantation

INTRODUCTION

Large scale forest plantations based on exotic tree species commenced in various parts of the country in the early 1950s. The objectives of establishing forest plantations were to ensure sustainable supply of forest products to the forest based industries, communities, and to have the supply for export. A total of 19 state owned industrial plantations have been established covering about 95,000 ha (MNRT, 2015). Of the 19 plantations, Sao Hill which was established in 1939 is the largest with a total area of 135,903 ha of which 86,000 ha are good for planting trees. Currently, the planted area in Sao Hill plantation is 56,000 ha while about 30,000 ha are reserved for extension (Management plan, 2017). The main species planted at Sao Hill are *Pinus patula*, *P. elliottii,* and *E. saligna* (Ngaga, 2011).

The management of public sector plantations including Sao Hill is guided by Technical Orders, which have been revised regularly as relevant research information became available. Rotation age for sawn timber has varied since the1950s. In 1956, the first Technical Order for thinning *P. patula, P. radiata, C. lusitanica* and C. *benthamii* was issued and had 6 thinnings and rotation age of 40 years (Forest Department, 1956). In 1962, a revised Technical Order for *P. patula* and *C. lusitanica* was issued. The Technical Order too had

5 thinnings and the rotation ages were reduced to 25 years for site class I, 30 years for site class II, and 35 years for site class III (Forest Division, 1962). The thinning schedule for *P. patula* was revised in 1970 by reducing thinnings from 5 to 4 (Forest Division, 1970) while the rotation ages were retained. In 2003, a Technical Order was issued for Pines, Cypress and *T. grandis* with the rotation age of 25 - 30 years for Pines and Cypress, and 30 - 40 years for Teak (FBD, 2003).

This study reviewed the rotation ages of *Pinus patula* at Sao Hill forest plantation based on growth yield, wood properties, and economic analysis of which in the previous technical orders were not considered.

METHODOLOGY

Study Area

The research was conducted at Sao Hill Forest Plantation (8°15' – 8° 41' S and 35° 6'– 35° 45' E), Iringa Region in the Southern Highlands of Tanzania. The altitude of the study area ranges from 1400 to 2000 m.a.s.l. The area receives annual rainfall ranging from 750 to 2010 mm (**Fig. 1**) falling between November and April, and temperatures range from 15°C to 25°C per annum (MDC, 2006; Ngaga, 2011). The soil is moderately acidic, well drained and of various types mainly dystricnitosols in association with orthicacrisols (Ngegba, 1998; Ngaga, 2011). The plantation is divided into four divisions namely: Division I, II, III and IV with an area of 17,140.13 ha, 10,239.18 ha, 49,480 ha and 23,370 ha respectively (Sao Hill Forest Plantation, 2013).

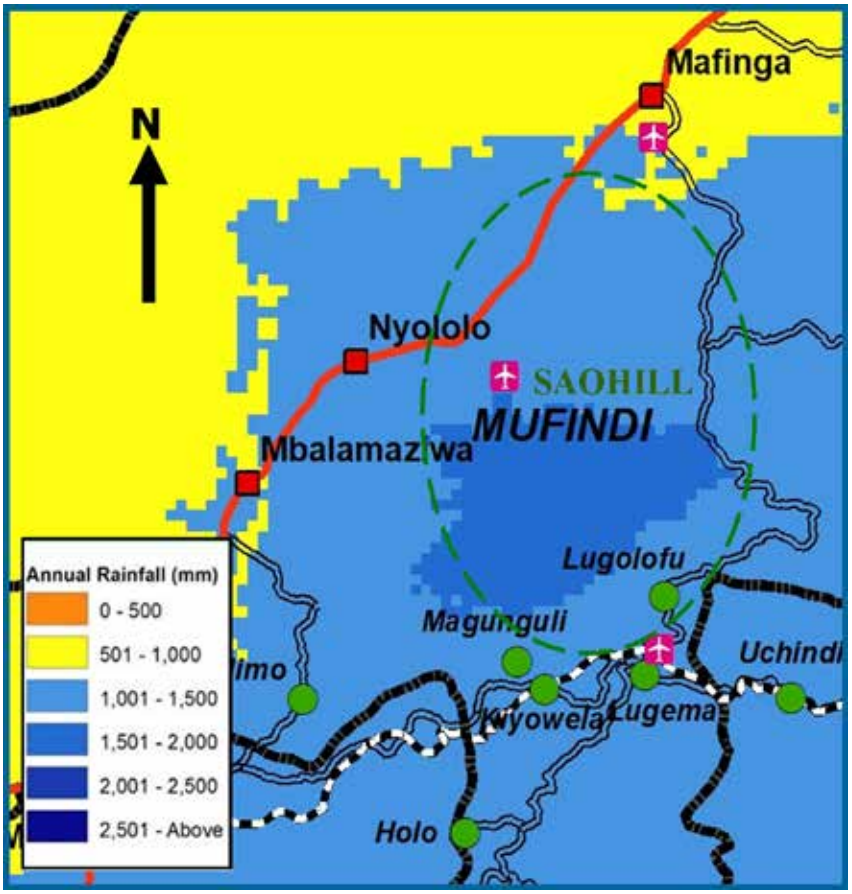

Figure 1: Sketch of Rainfall distribution in some parts of the Sao Hill Forest Plantation
Source: PFP (2017)

Methods

Growth and yield data

The sampling design used was systematic. Data collection was guided by the requirements of different models that needed to be developed before being integrated to a yield model. The data capture for developing the models was carried out in temporary sample plots, 60 - 100 per plantation with circular shape and variable sizes (to contain 15 – 20 trees) distributed to cover site and age variations in the plantation. In each plot, the following measurements were taken: diameter at breast height (Dbh) of all trees, bark thickness, height of the sample trees (intermediate Dbh), and dominant height of 2 to 3 fattest trees per plot. In addition, one dominant tree in each plot with the age of above 15 years old was felled for ring counting. Each tree was cross-cut at an interval of 4 m and annual growth rings were counted at the top end of each log.

Wood utilization properties data

Sampling design was purposive whereby trees which were free from defects and of three sizes were selected for physical, mechanical, and fibre length determination. A total of 252 wood disk samples from trees aged from 5 to 30 years and 132 wood billets from trees aged from 15 – 30 years were collected for physical and fibre length and mechanical properties test sample extraction, respectively in the four forest divisions. Each age was represented by three trees: large, medium, and small sized Dbh. Five cm (width) disks and billets with 120 cm long were cut from the felled trees at Dbh, 25%, 50% and 75% of the total tree height. The wood samples were subjected to air drying before testing.

Physical and Mechanical properties

Physical and mechanical properties were determined using various methods as follows:

***Moisture content*:** Wood samples were weighed green and oven dried at 103 ± 2^0C to constant weight. The weight of each sample was recorded for the determination of moisture content.

Basic density (BD): For each tree, 20 specimens were measured (10 butt, 6 middle, and 4 top). The volume of each specimen was determined by water displacement method. The samples were dried at 103 ± 2°C to constant weight.

***Static bending*:** This was measured using Hounsfield Tensometer machine. In this test, 30 specimens per tree (10 butt, 10 middle, and 10 top) were measured. A specimen measuring 20 x 20 x 300 millimetre (mm) was supported over a span length of 280 mm. The load of the force plate and the corresponding deflection were recorded from the dial gauge manually. Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were determined.

Impact bending (IB): This was measured using Hatt Turner Machine. A total of 15 specimens per tree were measured (5 butt, 5 middle and 5 top). A hammer with a weight of 1.5 kilogrammes (kg) was released towards a stationary specimen (20 x 20 x 300 mm) at variable distances until the breakage and the height of hammer drop was recorded in cm.

Compression parallel to the grain (CPG): In this test, 30 specimens per tree (10 butt, 10 middle, and 10 top) were measured. CPG was measured using Hounsfield Tensometer machine. Each specimen with the dimensions of 20 x 20 x 60 mm was compressed in the direction of the length of a sample at a constant rate. The force that caused the crushing of the wood was recorded.

Shear strength (SS): A total of 30 specimens per tree (10 butt, 10 middle, and 10 top) were measured for

SS. SS was measured using Hounsfield Tensometer machine. Specimens with dimensions of 20 x 20 x 20 mm were each subjected to a force which tends to force one portion of it to move over the other in the direction parallel to grains using machine. This aimed at measuring the ability of wood to resist the force. The maximum force used in this test was recorded.

Hardness of wood (Hard): A total of 30 specimens per tree (10 butt, 10 middle, and 10 top) were measured for hardness of the wood using Hounsfield Tensometer machine. Specimens with dimensions of 2 x 2 x 4.5 cm were used and whose maximum load which was required to penetrate a steel ball of 1.128 cm to half of its diameter radially, tangentially, or end surfaces of the specimen was determined and recorded.

Fibre length (FL)

A total of 9 specimen splinters measuring 2 x 2 x 10 mm per tree (3 at Dbh, 2 at 25%, 2 at 50% and 2 at 75%) were taken. Splinters were macerated with a 1:1 solution of glacial acetic acid and hydrogen peroxide at about 60°C for a period of 24 hours for cell dissociation. After maceration, pulps were washed with distilled water and then shaken gently in the distilled water until individual fibres of the wood were separated. The macerated fibres were thoroughly mixed and then stained with safranin solution and spread on a glass slide. Thirty straight and unbroken fibres from each sample (equivalent to a total of 270 fibres per tree) were randomly selected for measurement using a projecting microscope to obtain the mean fibre length from each age.

Economic Rotation Age

In order to estimate the net present value (NPV) at the respective age of forest stands, the following were collected: data of growing stock of each site class for each forest plantation (Malimbwi *et al.,* 2016), revenues in Tanzania Shillings per cubic meter (TZS/m^3), and management costs (TZS/ha). It was assumed that only a single product that is timber at rotation age and thinning at 10 and 15 years would be harvested from the forest stands. Interest rates were obtained from literature and commercial bank data.

Data Analysis

Growth and yield data

The analysis of data on growth and yield involved the determination of site index curves model, height-Dbh model, single tree volume model, basal area growth model, stand volume model, mortality model, and simulation of thinning (Malimbwi *et al.,* 2016). These models were eventually integrated into growth and yield models (Malimbwi *et al.,* 2016).

Wood utilisation properties

The determination of fibre length, moisture content, BD, MOE, MOR, HARD, IB, CPG and SS were done using standard procedures as described in the British Standards (1957), ISO (1975) and Franklin Method (Smook, 2003; San *et al.,* 2016). The variations were determined using analysis of variance (ANOVA) procedure to compare means at $p \leq 0.05$.

Economic analysis of rotation age

The average net value was calculated for the period between 10 years and 25 years of age. The standing and thinning volumes were estimated by the present cutting value method (Osavec *et al.,* 2011) and the current annual increment (CAI) and the mean annual increment (MAI) data from Malimbwi *et al.* (2016). Nursery, land preparation, planting, beating up, weeding, pruning, thinning and the like including overheads were used to estimate the costs. These costs were assumed to decrease by 0.05% with an increase in the age of the plantation. This means that young plantations had higher costs than older ones. The net value was calculated by multiplying the average revenue in TZS/m^3 by the attained volume due to the

standing trees and thinning. The overall interest rate of commercial banks in Tanzania is around 16% and 14%. Therefore, for the determination of the NPV in this study, an interest of 15% was used.

$$NPV = P \quad (B - C).$$

Where: *NPV* = net present value at a discount rate *r* using the discount factor $1/(1+r)^t$, for year *t*,

B = benefits, and

C = costs.

The NPV was estimated for each age. Rotation age was the age with highest NPV.

RESULTS AND DISCUSSION

Spacing, Pruning, and Thinning Operations in the Assessed Compartments

The data for this study were taken from *P. patula* grown at initial spacings of 2.5 x 2.5 m, 2.5 x 3.0 m and 3.0 x 3.0 m. Since 2003, spacing for *P. patula* has been changed to 3.0 x 3.0 m (FBD, 2003). Pruning and thinning are silvicultural operations which are carried out in the plantations to produce knot free timber and utilizable size (40 cm mean Dbh at rotation age) respectively. Knot free timber is expected to fetch a higher price than timber with knots, and which is sufficient to off-set the pruning costs. Pruning and thinning operations in the assessed compartments are shown in **Table 1**. The Table shows that two compartments in Division 1 at the ages of 21 and 22 years received all three prunings while those at the age of 19 years received two prunings. Two compartments of *P. patula* with 15 and 23 years received one pruning (i.e. access pruning). In Division 2, the compartment with trees at the age of 30 years received all three prunings while trees at the ages of 16 and 18 years received one pruning, that is, access pruning only **(Table 1).**

Table 1: Pruning and thinning history for *P. patula* at Sao Hill forest plantation

Division & Compartment	Age (years)	No of prunings	No of thinnings
Division No. 1 (Irundi Sao Hill)			
1 Irundi No.4aii (1/ID/4aii)	23	1 (Access pruning)	1
1 Irundi No.5C (1/R/5C)	21	3	2
1 Irundi No.6F (1/R/6F)	22	3	2
1 Irundi No.8a (1/R/8a)	19	2	2
1 Irundi No.12ai/4 (1/R/12ai/4)	15	1 (Access pruning)	2
Division No. 2 (Kibidula & Matanana Sao Hill)			
2Kibidula No. 2-23 (2KB 2-23)	16	1(Access pruning)	2
2Matanana No. 4-3 (2MT 4-3)	18	1(Access pruning)	1
2Matanana No. 5-9 (2MT 5-9)	30	3	1 Mechanical
Division No. 3 (Ihalimba Sao Hill)			
3Ihalimba No 4-3 (3KL4-3)	25	1(Access pruning)	2
Division No. 4 (Magunguli Sao Hill)			
4Magunguli No. 2 (4MAG2)	20	1 (Access pruning)	1
4Magunguli No. 1-1 (4MAG1-1)	28	1(Access pruning)	2

Thinning operations were found to be fewer and lighter than specified in the respective schedules, resulting in many small diameters stems per ha (SPH) **(Fig. 2 and 3).** Figure 2 shows that all compartments except one had Dbh lower than the recommended 40 cm at the rotation age (Forest Division, 1970). Figure 3 shows further that all compartments except one had higher stocking than recommended in the Technical Order. The main reason given for the neglect of pruning and thinning operations is budgetary constraints. The neglect of both pruning and thinning operations in public sector plantations has been pointed out in previous studies (Chamshama and Nshubemuki, 2011; Nshubemuki *et al.,* 2011). This causes knotty and small diameters trees resulting in poor quality timber, low recovery, and consequently low financial returns.

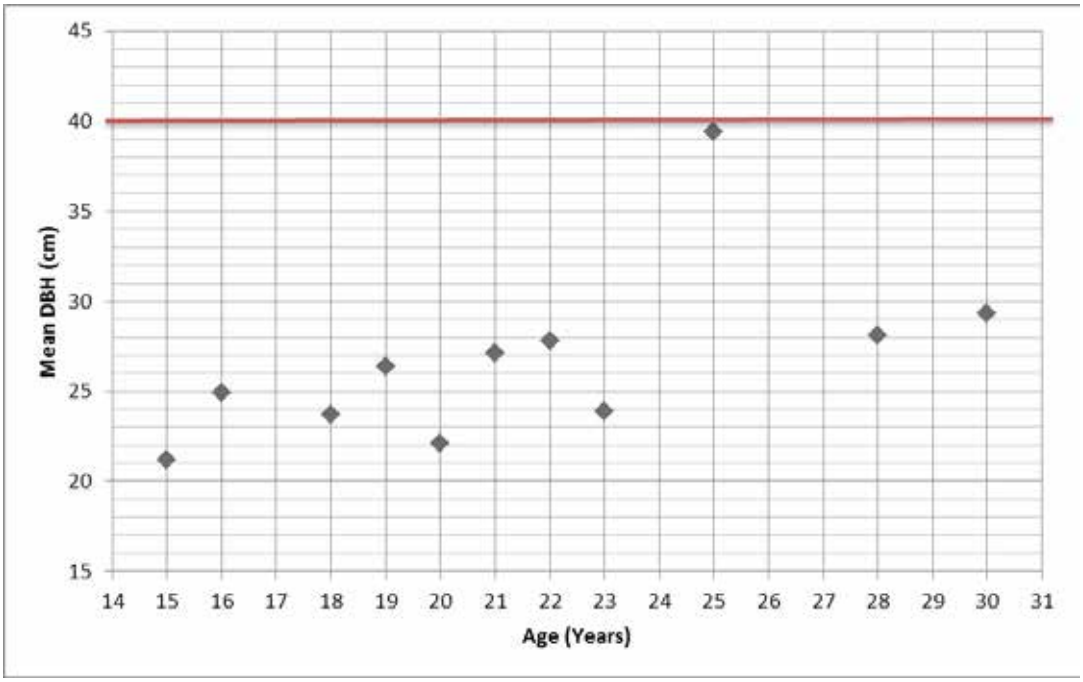

Figure 2: Mean Dbh against age for *P. patula* at Sao Hill Forest Plantation

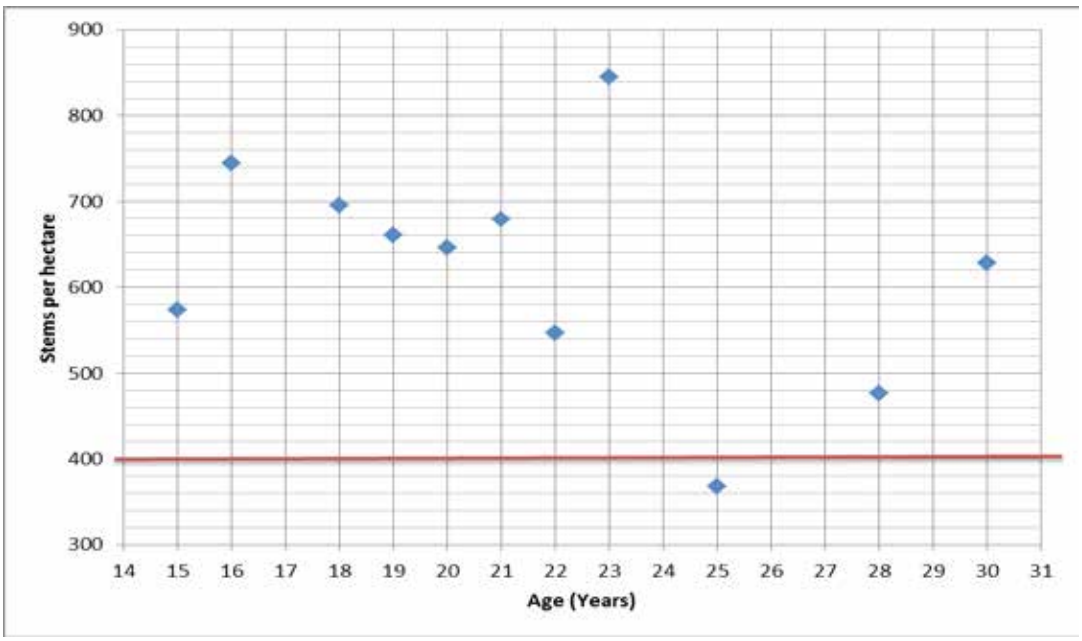

Figure 3: Mean SPH against age for *P. patula* at Sao Hill Forest Plantation

Growth and Yield

The composite models for developing yield tables for *P. patula* were developed as shown in **Table 2.** All the models had good fits with R^2 ranging from 0.75 (Height - Dbh model) to 0. 99 (stand volume model). The site index curves depict height growth driven by age for four site classes for each species **(Fig. 4).** The stand basal area is a function of the surviving number of stems and the dominant height at that particular age. The stand volume is explained by dominant height and stand basal area with almost a perfect fit of R^2 0.99 from the raw data. The integration of these models resulted into the yield tables for *P. patula* (Malimbwi *et al.,* 2016).

Table 2: Composite models for yield table development of *P. patula* in Sao Hill forest plantation

Model name	Equation	R^2	n
Site index curves model	$Hdom = 1.564354 \times site \times (1 - \exp(-0.092288 \times Age))^{1.571869}$	0.95	1130
Height-Dbh model	$height = 1.3 + \frac{dbh^2}{13.63898 + 0.026482 \times \mathrm{dbh}^2}$	0.75	793
Single tree volume model	$vol = \exp(-9.04925 + 1.14781 \times \ln(height) + 1.5496 \times \ln(dbh)$	0.85	154
Basal area growth model	BA = $\exp(-5.2143 + 0.6539 \times \ln(N) + 1.3984 \times \ln(Hdom)$ $\exp(-5.2143 + 0.6539 \times \ln(N) + 1.3984 \times \ln(Hdom)$	0.96	373
Stand volume model	$Stand\ vol = \exp(0.6366 + 1.1176 \times \ln(BA) + 0.4472 \times \ln(Hdom)$	0.99	328
Mortality model	$N2 = 1408 \times exp(-0.0341 \times Age)$		120

Where; Hdom = dominant height (m); dbh = diameter at breast height (cm), site = site index (m); BA = stand basal area M^2/ha); volume = single tree volume (m^3); Volume = stand volume m^3/ha)

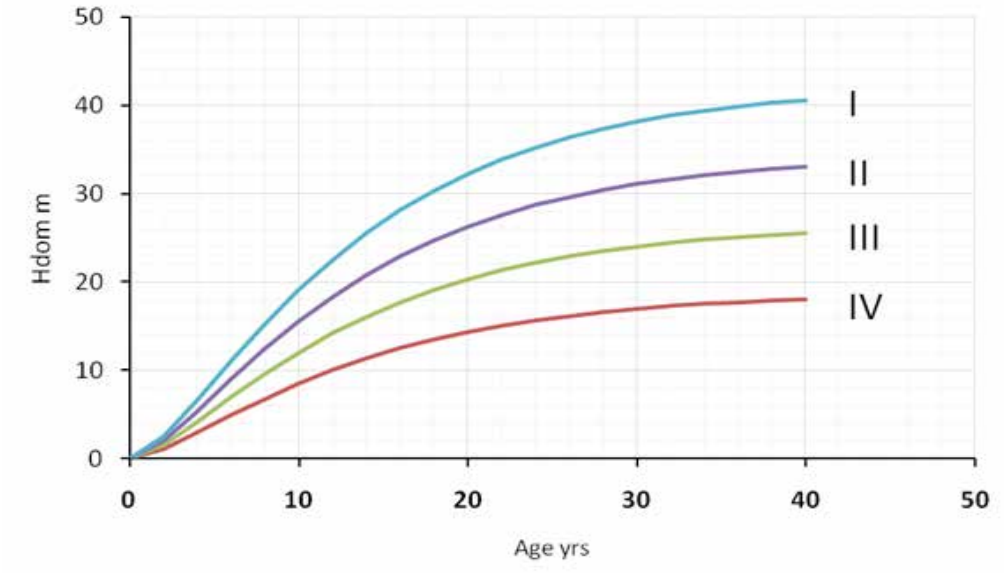

Figure 4: Site index curves for *P. patula* in Sao Hill Forest Plantation

Source: Malimbwi *et al.* (2016)

For a compartment of known age and dominant height, the site class is selected from the site index curves (**Fig. 4**) which in turn indicates the appropriate yield class for forecasting yield from the yield table.

Optimum Rotation Age Based on Growth

Optimal rotation age is the age when volume MAI is at maximum. It is also the age when MAI is equal to volume CAI. The equity point of MAI and CAI was achieved between 16 and 17 years with the maximum MAI being maintained until about 20 years when it starts falling irrespective of the site classes **(Fig. 5).** This could be attributed to improper management of the sites as the yield table assumed the properly managed stands while the empirical data were from improperly managed stands. It is expected that data from properly managed stands would differentiate rotation age by site classes whereby better sites are expected to mature earlier than poorer sites.

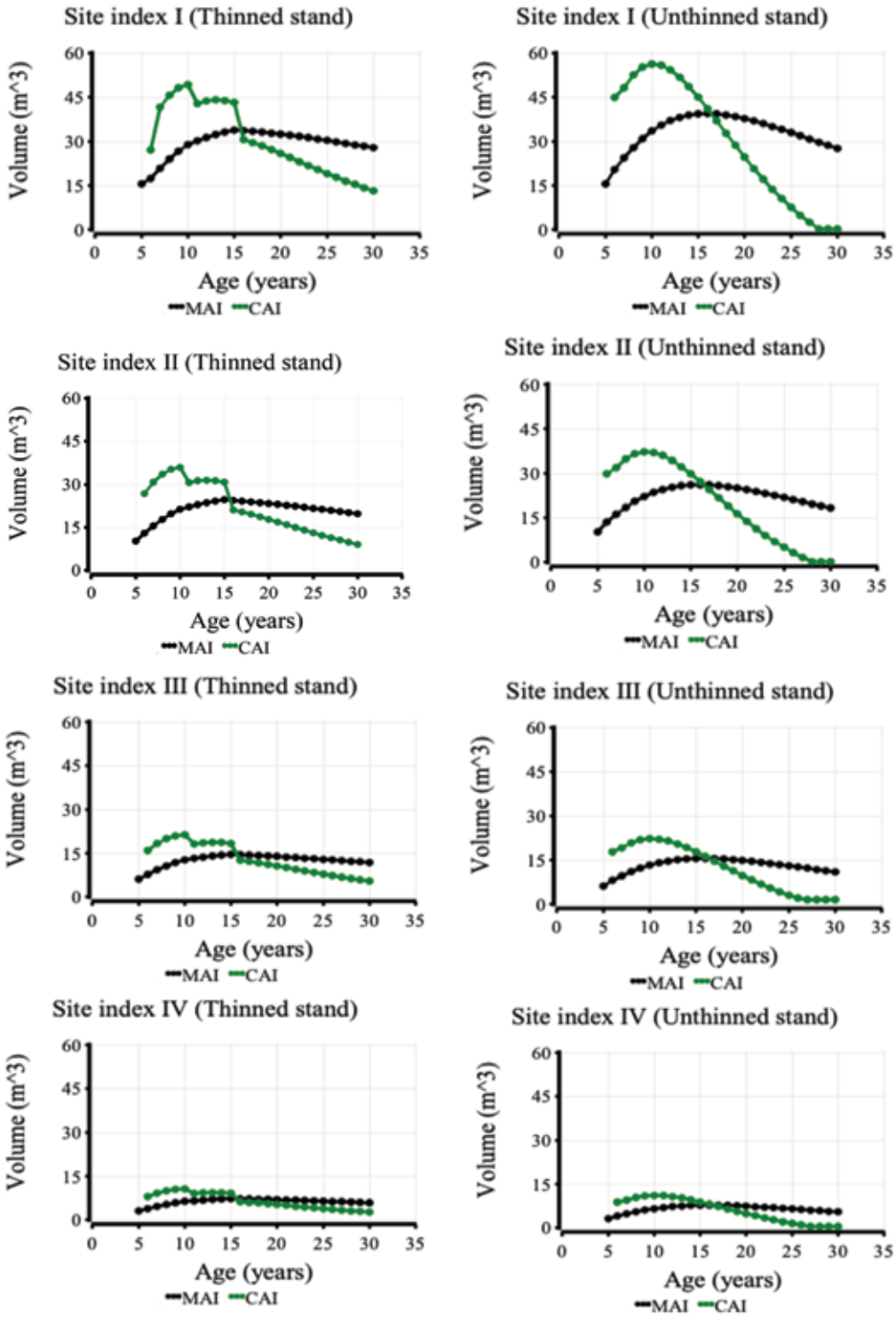

Figure 5: MAI and CAI for thinned and unthinned stands of *P. patula* for different site classes in Sao Hill Forest Plantation

Source: Malimbwi *et al.* (2016)

Taking into account all these observations, the yield studies recommend rotation ages for *P. patula* in Tanzania to be from 18 years of age (Malimbwi, 2016a&b) irrespective of the site class. Earlier rotation age for this species was 25 years. This study therefore shows that the rotation ages of *P. patula* which is grown at Sao Hill forest plantation could be reduced without affecting annual volume growth.

Wood Properties

Basic density of P. Patula

The BD of *P. patula* wood from Sao Hill Forest Plantation ranged from 330.8 to 433.3 kg/m^3 and increased with age from 15 to 19 years and then dropped at years 20 and 21 and increased at year 28, and dropped again when the trees attained 30 years of age **(Table 3).** Based on FAO (2010) standards, wood from *P. patula* harvested from the plantation below 18 years was weak since it had BD which was less or equal to 400 kg/m^3. According to FAO (2010), wood with BD ≥ 401 and ≤ 500 is fairly strong hence *P. patula* can be harvested at age ≥ 18 years.

Table 3: Mean basic density for *P. patula* grown in Sao Hill Forest Plantation

Test Parameter	Age (Years)										
	15	**16**	**18**	**19**	**20**	**21**	**22**	**23**	**25**	**28**	**30**
BD in Kg/ m^3	330.8 *(0.06)	355.3 (0.09)	402.7 (0.09)	413.9 (0.07)	404.3 (0.09)	401.5 (0.05)	409.8 (0.07)	412.4 (0.08)	414.3 (0.09)	433.3 (0.11)	407.6 (0.09)

*Values in brackets are the standard deviations

Mechanical properties

The mean strength properties for *P. patula* wood are shown in **Table 4**. The mean strength properties between 18 – 19 and 21 - 25 years old trees did not differ significantly ($p \leq 0.05$), but differed from those of 20 and 28 years ($p \geq 0.05$). The significant differences which were obtained might be contributed by the variety of *P. patula* planted, seed source, soil in the site and climatic condition. Wood from 15 years old tree was weak and that of 16 years was fairly strong. Strong wood was from 18 years and above. The minimum and maximum values for MOE were 7135 and 9567 N/mm^2 respectively, MOR were 53 and 77 N/mm^2 respectively, CPG were 29 and 40 N/mm^2 respectively, impact bending were 42 and 59 cm respectively, hardness were 2085 and 3262 N respectively and then SS were 14.5 and 21.7 N/mm^2 respectively **(Table 4).** The MOE, MOR, CPG and SS obtained in this study are within the values of *P. patula* of 17, 22 and 30 years old from Kenya and 15 and 25 years recorded by Bryce (1967) and revised by Chihongo (1999) but are a little bit higher than that of Kiwira and Kawetire forest plantations which is reported by Laswai *et al.* (2016). The differences seen might have been caused by climatic condition, soils, seed sources, and management practices. The FAO (2010) standards for mechanical properties are usually based on four strength properties namely MOE, MOR, CPG and SS. The minimum values of strength properties for wood to be considered strong are MOE ≥7500N/mm^2; MOR ≥ 20 N/mm^2 and CPG values ≥ 13N/mm^2 (FAO, 2010). Based on these standards, the minimum age for harvesting *P. patula* at Sao Hill should be 18 years.

Table 4: Strength properties of *P. patula* from Sao Hill forest plantation

Test parameter	Age (Years)										
	15	**16**	**18**	**19**	**20**	**21**	**22**	**23**	**25**	**28**	**30**
MOE (N/mm^2)	7135	7605	8568	8466	9567	8574	8549	8564	8446	8959	8638
MOR (N/mm^2)	53	58	67	67	77	65	69	67	60	71	68
Comp (CPG) (N/mm^2)	29.0	34.2	36.2	35.7	40.2	35.1	35.9	35.5	36.7	38.7	35.9
Shear(N/mm^2)	13.7	15.6	16.4	16.9	20.1	16.4	16.6	16.9	16.9	19	17.3
Hardness (N)	2085	2433	2556	2663	3262	2481	2471	2421	2501	3265	2468
Impact bending (cm)	42.9	45.9	56.1	56.4	57.9	56.9	56.6	56.9	57.4	59.4	58.2

Fibre length

Fibre length results for *P. patula* are presented in **Table 5**. They ranged from 0.26 to 6.98 mm and increased with age, with the mean values ranging from 2.29 to 3.53 mm. A rapid increase occurred in the first 10 years. The fibre lengths of the current study are within the values reported for Pine species (Muneri and Balodis, 1998; Shimoyama and Wiecheteck, 1993 in de Almeida *et al.,* 2016; Anoop *et al.,* 2014; Castelo *et al.,* 2008 in de Almeida *et al.,* 2016).

Fibre length generally influences the tearing strength of paper. The greater the fibre length, the higher the tearing resistance is. However, as Zobel and van Buijtenen (1989) reported, cell size has no significant effect on tensile strength of paper. This may also apply to *P. patula* at Sao Hill Forest Plantation.

Based on International Association of Wood Anatomists (IAWA) classification, the fibres of all major softwood species of the world are long. In general, the higher the fibre length of a specific species, the more suitable it is for the production of paper. But researches have shown that the suitability threshold of tracheid fibres for softwood species which is commonly used for papermaking have fibres of approximately 3 mm long with good tear strength. Trees with the age of 11 years and above were found to have fibre with 3 mm and above, and hence *P. patula* of 11 years old at Sao Hill Forest Plantation has fibre length within this range and hence is suitable for paper production.

Table 5: Fibre length of *Pinus patula* from Sao Hill Forest Plantation

Age	Mean	SD	Minimum	Maximum
5	2.29	0.67	1.02	4.86
6	2.47	0.85	0.86	5.56
7	2.52	0.69	0.79	5.55
8	2.62	0.83	0.99	5.31
9	2.63	0.82	1.26	5.90
10	2.81	0.81	0.63	5.78
11	3.17	0.90	0.86	6.80
12	3.15	1.12	0.69	6.57
13	3.16	1.11	0.63	6.53
14	3.33	1.06	1.24	6.54
15	2.84	0.96	0.53	6.73
18	3.44	1.38	0.26	6.85
20	3.53	1.28	0.90	6.98
22	3.07	1.10	1.00	6.83
25	3.46	1.17	0.75	6.89

Economic Analysis of Rotation Age

The costs for the estimation of the rotation age were the average of the silviculture, protection, road maintenance, culverts, bridges, and administration costs of the plantations.

Management costs

The management costs included direct costs (Silviculture and Protection costs) and indirect costs (Maintenance and administrative costs) as indicated in **Table 6.**

Table 6: Management costs estimates (TZS) for *P. patula* grown at Sao Hill Forest Plantation per ha

Age	Nursery costs	Land preparation	Planting	beating Up	Weeding	Pruning	Protection(Patrol, fire line, boundary clearing & fire campaign)
5	1,224,000	153000	153,000	45,900	122,400	122,400	622200
6	1,236,240	154,530	154,530	46,359	123,624	123,624	628,422
7	1,248,602	156,075	156,075	46,823	124,860	124,860	634,706
8	1,261,088	157,636	157,636	47,291	126,109	126,109	641,053
9	1,273,699	159,212	159,212	47,764	127,370	127,370	647,464
10	1,286,436	160,805	160,805	48,241	128,644	128,644	653,938
11	1,299,301	162,413	162,413	48,724	129,930	129,930	660,478
12	1,312,294	164,037	164,037	49,211	131,229	131,229	667,083
13	1,325,417	165,677	165,677	49,703	132,542	132,542	673,753
14	1,338,671	167,334	167,334	50,200	133,867	133,867	680,491
15	1,352,057	169,007	169,007	50,702	135,206	135,206	687,296
16	1,365,578	170,697	170,697	51,209	136,558	136,558	694,169
17	1,379,234	172,404	172,404	51,721	137,923	137,923	701,111
18	1,393,026	174,128	174,128	52,238	139,303	139,303	708,122
19	1,406,956	175,870	175,870	52,761	140,696	140,696	715,203
20	1,421,026	177,628	177,628	53,288	142,103	142,103	722,355
21	1,435,236	179,405	179,405	53,821	143,524	143,524	729,578
22	1,449,589	181,199	181,199	54,360	144,959	144,959	736,874
23	1,464,085	183,011	183,011	54,903	146,408	146,408	744,243
24	1,478,725	184,841	184,841	55,452	147,873	147,873	751,685
25	1,493,513	186,689	186,689	56,007	149,351	149,351	759,202
26	1,508,448	188,556	188,556	56,567	150,845	150,845	766,794

Revenues

Table 7 shows that revenue is dependent on age and volume of the trees. The actual revenues are not segregated by species but the dominant species is *P. patula,* therefore most of the revenues are assumed to be generated from this species. The lowest revenue TZS 15.5 billion was recorded in 2008/2009 and the highest was TZS 36.1 billion which was recorded in year 2015/2016. On average, *P. patula* yielded revenue of TZS 11,896,208.00.

Table 7: Revenues for *P. patula* in Sao Hill Forest Plantation

Age	Volume (m^3)	Total revenue (TZS)
5	51.3	216,794
6	78	329,628
7	108.7	459,366
8	142.3	601,360
9	177.6	750,538
10	155.7	657,988
11	186.3	787,304
12	217.5	919,155
13	249	1,052,274
14	280.3	1,184,548
15	218.2	922,113
16	239.2	1,010,859
17	259.6	1,097,070
18	279.2	1,179,899
19	297.9	1,258,925
20	315.7	1,334,148
21	332.6	1,405,568
22	348.5	1,472,761
23	363.4	1,535,728
24	377.5	1,595,315
25	390.5	1,650,253
26	402.7	1,701,810
27	414.1	1,749,987
28	424.6	1,794,360
29	434.4	1,835,774
30	443.5	1,874,231

Economic Rotation Age Estimation

The estimations of the *P. patula* stand value (clear-felling and thinning) and forest management costs (silvicultural costs and administrative and infrastructure maintenance costs) from **Figure 6**, show that the optimum economic rotation is between 15 and 16 years. The growth data used were for site class II because this is the average site class at Sao Hill Forest Plantation. Therefore, it is economically reasonable to start harvesting *P. patula* stands at 16 years old. This implies that the age of between 16 and 17 years is the growth period that generates maximum value from a stand of timber at Sao Hill Forest Plantation.

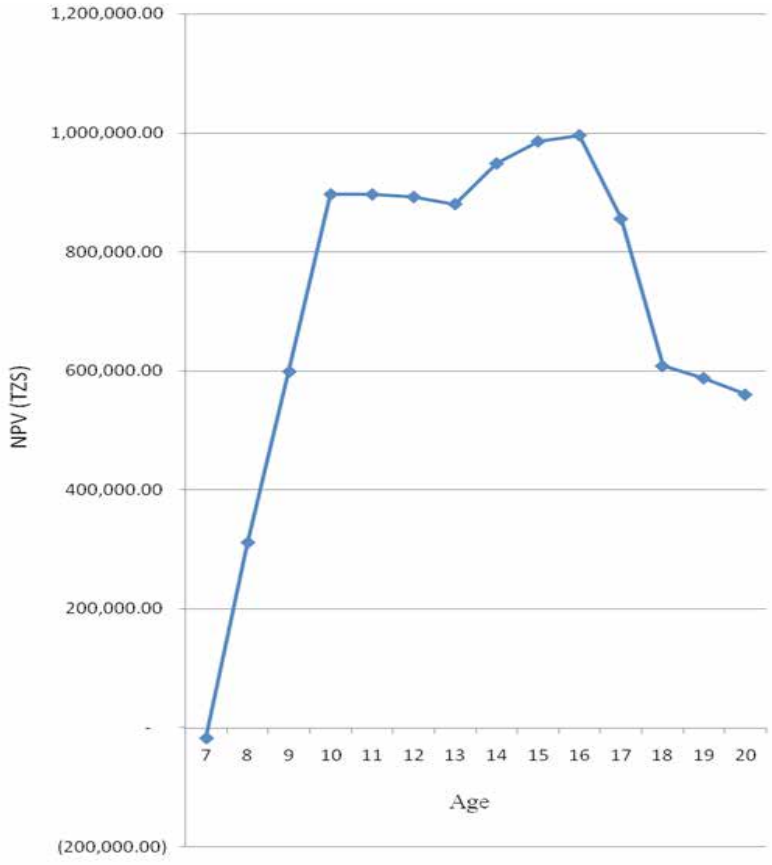

Figure 6: Economic rotation age of *P. patula* at Sao Hill Forest Plantation for site class II

CONCLUSION AND RECOMMENDATIONS

Compartments grown with *P. patula* at Sao Hill forest plantation, received fewer and lighter pruning and thinning operations than specified in the respective schedules, resulting in many small diameter stems. Based on economic analysis, the optimum rotation age for *P. patula* is between 16 and 17 years. Based on growth and yield, wood properties and on economics of rotation age, *P. patula* from Sao Hill forest plantation is recommended to be harvested at 18 years. With proper thinning, trees will attain the recommended mean diameter and thus improve recovery. However, the thinning schedule for *P. patula* needs to be revised taking into consideration the shortening of the rotation age. The test of *P. patula* wood from improved trees is needed once the trees reach 15 years old to see if the rotation age could be reduced further. For commercial purposes, *P. patula* can be harvested at the age from 11 years old for production of pulp and paper and 18 years for timber.

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REFERENCES

Almeida, C.C.F., Rios, P.D., Cunha, A.B., Ampesan, C.G.M, Spanhol, A., Kniess, D.D.C. and Vieira, H.C. 2015. Tracheid morphology of *Cupressus lusitanica* Mill. Wood for pulp production. In: *The Proceedings of 7th International Colloquium on Eucalyptus Pulp*, May 26-29, 2015. Victoria, Espirito Santo, Brazil.

Anoop, E.V., Ajayghosh, V., Nijil, J.M. and Jijeesh, C.M. 2014. Evaluation of pulp wood quality of selected tropical pines raised in the high ranges of Idukki District, Kerala. *Journal of Tropical Agriculture,* 521: 59 – 66.

British standard 373. 1957. *Methods of testing small clear specimens of Timber*. British Standard Institution. London. 27pp.

Bryce, J.M. 1967. *Text book of Commercial Timbers of Tanzania.* Forest Division, Ministry of Agriculture and Cooperatives. 286pp.

Chamshama, S.A.O. and Nshubemuki, L. 2011. Plantation forestry management in Tanzania: Current situation and future focus. In: *The Proceedings of the Workshop on Insect Pests, Diseases and Soil Problems in Forest Plantations*. (Nshubemuki *et al*. Eds.), TAFORI/SUA. pp. 45-75.

Chihongo, A.W. 2003. *Text book of commercial Timbers of Tanzania.* Revised Version, Third Edition. Tanzania Forestry Research Institute, Morogoro, Tanzania. 315pp.

de Almeida, C.C.F., Rios, P.D., da Cunha, A.B., Ampessan, C.G.M. and Spanhol, A. 2016. Applicability evaluation of *Cupressus lusitanica* for pulp production. Maderas. *Ciencia y tecnología,* 184: 651 - 662,

FAO. 2010. Wood density classification. www.fao.org/docrep/015/i2433/i2433e02.

FBD. 2003. *Technical Specifications for Management of Forest Plantations in Tanzania.* Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism. Dar es Salaam, Tanzania. 8pp.

Ferriera, A.L., Severo, E.T.D. and Calonego, F.W. 2011. Determination of fiber length and juvenile and mature wood zones from Hevea brasiliensis trees grown in Brazil. *Europen Journal of Wood Production*, 69: 659–662

Forest Department. 1956. *Thinning schedules*. Forest Department Technical Order No. 1 of 1956 Forest Department, Ministry of Lands, Forests and Wildlife, Morogoro. 4pp.

Forest Division. 1962. *Pruning and Thinning Schedules Cancelling T.O.S. 1 and 2 of 1956*. Forest Department Technical Order No. 17 of 1962. Forest Department, Ministry of Lands, Forests and Wildlife, Dar- es- Salaam. 6pp.

Forest Division. 1970. *Omission of first thinning in pines*. Technical Order No. 24, Forest Division, Dar es Salaam. 5pp.

Hyytiainen, K. 1992. *Forest Management Plan for Longuza Teak Plantation*. Technical Paper No. 2. FBD/Forest and Park Services. 102pp.

ISO 3133. 1975. *Wood Determination of Ultimate Strength in Static Bending*. First edition. UDC 674.03.539.384. Switzerland.

Laswai, F., Malimbwi, R.E., Chamshama, S.A.O. and Abdallah, J.M. 2016. Determination of Rotation age of *Pinus patula* and *Tectona grandis* in some public sector Forest plantations, Tanzania. *Journal of Tanzania Association of Foresters.*

Malimbwi, R.E., Mugasha, W.A. and Mauya, E. 2016. *Pinus patula* Yield Tables for Sao Hill Forest Plantations, Tanzania. Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture.

Malimbwi, R.E. 2016a. *Development of yield tables for seven Tanzania Forest Service Agency forest plantations in Tanzania*. Yield tables for *Pinus Patula* Forest plantations. Report. Department of Forest Resources Assessment& Management, Sokoine University of Agriculture. 40pp.

Malimbwi, R.E. 2016b. *Development of yield tables for seven Tanzania Forest Service Agency forest plantations in Tanzania*. Yield tables for *Tectona grandis* forest plantations. Report. Department of Forest Resources Assessment& Management, Sokoine University of Agriculture. 38pp.

MNRT. 2015. *Budget Speech for 2015/2016*. Ministry of Natural Resources and Tourism, Dar Es Salaam. 16pp.

Mtuy, M.C.P. 1996. *Forest Plantation Management in Tanzania: Past, Present and Future*. Faculty of Forestry, Sokoine University of Agriculture. Record No. 63: 4-6.

Muneri, A. and Balodis, V. 1998. Variation in wood density and tracheid length in *Pinus patula* grown in Zimbabwe. *South African Forestry Journal,* 182: 41 - 50

Ngaga, Y.M. 2011. *An analytical study of public forest plantations in Tanzania*. African Forest Forum, Nairobi, Kenya. 112pp.

Nshubemuki, L., Chamshama, S.A.O. and 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.

Osavec, S., Beljan, K., Krajter, S. and Peršun, D. 2011. Calculation of Economic Rotation Period for Even-Aged Stand in Croatia. *South-east Eur. For.* 22: 109-113

SAS. 2000. *SAS Version 8*. SAS Institute Inc., Cary, N. C, USA. 1028pp.

Zobel, B. J. and Van Buijtenen, J. P. 1989. *Wood Variation: Its Causes and Control*. Springer Verlag, New York. 363pp.