Philippine Journal of Science
148 (2): 237-248, June 2019
ISSN 0031 - 7683
Date Received: 26 Sep 2018

Properties and Utilization of Young-age Yemane (*Gmelina arborea* Roxb.) for Lumber Production

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This paper presents the lumber recovery and lumber grade yields; strength properties, namely modulus of rupture, stress at proportional limit, and modulus of elasticity in static bending; compression parallel- and perpendicular-to-grain; shear; hardness; and toughness, including the cost-benefits, of 4-, 6- and 8-year old yemane (*Gmelina arborea* Roxb.) for lumber production. The study was conducted to evaluate the effects of age and sites on these properties, recommend its end-uses, and evaluate the cost-benefits of converting the species at different ages for lumber production. The experimental materials consisted of three trees each from three sites in Caraga Region, Philippines, namely: Pating-ay, Prosperidad, Agusan del Sur (Site 1); Nong-nong, Butuan City (Site 2); and Las Nieves, Agusan del Norte (Site 3). Standard procedures for testing the abovementioned properties were followed. In the absence of lumber grading rules for industrial tree plantation species, individual boards were graded in green condition based on the U.S. National Hardwood Lumber Association standards. On the average, the 8-year-old trees obtained the highest average percent lumber recovery with 55.78%, 56%, and 54.89% for Site 1, Site 2, and Site 3, respectively. The trend of lumber recovery among sites also held true, with the 4- and 6-year old trees with values of 52% and 53.67% for Site 1, 51% and 53.33% for Site 2, and 51% and 52.11% for Site 3. Generally, the mechanical properties of 4-, 6-, and 8-year olds fell under moderately low (Class IV). All indicators show the viability of processing yemane from different diameters, ranging from 16.29 cm to 20.64 cm, belonging under 6- and 8-year-olds.

Keywords: cost-benefit, lumber recovery and grades, mechanical properties, young-age *Gmelina arborea* Roxb.

INTRODUCTION

Yemane is among the fast-growing industrial tree plantation species (ITPS) currently being used as an alternative to fast depleting premium and commercially used timber species. One of the many advantages of yemane over other fast growing species is its capacity to quickly produce coppices of more than five stems, which can be thinned by choice and which can provide quick soil cover after cutting (Perino 2003). Of the total 56,556 m^3 yemane log production in the country, Region VIII has the highest log production with 15,807 m^3 (28%) followed by Caraga with 12,679 m^3 (22%) (FMB 2017). The National Greening Program of the Department of Environment and Natural Resources (DENR) intercropped yemane with agricultural and fruit trees as raw material source for furniture production (PhilForest 2015).

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Mechanical properties (static bending, compression parallel-to-grain, compression perpendicular-to-grain, shear, hardness, and toughness) are among the most important properties in determining the end-uses of timber, particularly for construction purposes. Of equal importance are lumber recovery and lumber grade yield resulting from sawing of a certain volume of log. Similarly, the cost-benefit as indicated by profitability indicators – return of investment (ROI), payback period, net present value (NPV), and internal rate of return (IRR) – are necessary component in assessing the viability and profitability for conversion of yemane logs into lumber production.

Previous studies showed that the benefit-cost ratio for conversion of yemane into lumber was higher than for paper pulp. These findings were based on the study conducted on 5-, 10-, and 15-year-old yemane trees collected from a plantation in Diadi, Nueva Vizcaya, Philippines (Region II). The diameter at breast height (dbh) ranged from 21 to 38 cm and total height ranged from 13 to 16 m. The effects of age on the properties of yemane showed large differences among trees of the same age, as well as different ages and localities. Although the effect of the interaction between age and tree was significant, percent variance contribution was rather small as compared with age and height level effects. The mechanical properties classification indicates that at 5–12 y old, yemane falls under moderately low strength (Class IV) and at 13–15 y old under medium strength (Class III). The strength classification in the latter ages indicates the species suitability for conversion into lumber for medium construction as in-house construction (*i.e.*, flooring, door, and window frames); medium-grade furniture; and cabinets. A 5-year-old may be used or wood carving and sculpture, conventional furniture, and venetian blinds (Alipon 1992).

It was also reported that the mechanical properties of 10-year-old yemane from Nueva Vizcaya were higher than the 10-year-old from Casiguran, Aurora (Region III) – attributed to differences in site conditions (Alipon and Bondad 2011). The strength properties of yemane – particularly the modulus of rupture (MOR, MPa); modulus of elasticity (MOE, GPa); and compression parallel-to-grain (C//, MPa) – significantly increased as a tree aged. There was about 44.8% increase in strength properties from 18 to 28 year and 19.1% increase from 28 to 36 years (Ogunsanwo 2011). Tenorio and Muñoz (2011) reported that the mechanical properties of laminated veneer lumber and plywood panels from 12–14-year-old yemane were similar to those of solid wood.

Traditionally, farmers have to wait for 10–12 years before ITPS could be harvested and gain profits from its sale. It may be feasible to further lower the harvesting age to 6–8 or even at 4 years old if the properties of younger trees would not significantly differ from the older ones. For lumber production, 4–8-year-old yemane trees may also be harvested to sustain the large demand by the wood-based industry, particularly in the wake of the Philippine Executive Order 23 dated 2011 that imposed a moratorium on the harvesting of timber in natural and second-growth forests. Exempted from the log ban are yemane and other ITPS, which are cheaper and faster-growing than the traditional tree species.

ITPS are gaining prominence as the main source of wood for the country's log processors. Their use, in fact, has become a major strategy for meeting the wood-based industries' demand for sustained raw materials supply. ITPS are grown, harvested, and processed by wood processing mills in Region XIII (Caraga) and nearby provinces such as Misamis Oriental and Bukidnon. At present, thousands of Filipinos are actively engaged in ITPS production [*Pers. Comm.*, For E. Villanueva (2014), For Dennis Gilbero (2018), DENR Caraga].

To date, no studies have yet been conducted on assessing the utilization of young-age yemane for lumber production.

In view of the foregoing, the study aimed to discuss the efficient and maximum utilization of yemane at younger age for lumber production. It is expected that the best end-uses of the species per age from a particular locality/site can be assessed and the profitable rotation age to harvest ITPS at younger age could be provided to plantation growers/farmers of the particular site. This study specifically aimed to: 1) determine the lumber recovery, grade, and mechanical properties of 4-, 6-, and 8-year-old yemane from different sites in Caraga Region; 2) evaluate the cost-benefit for lumber production at said ages; and 3) recommend the optimum harvesting/rotation age of the above species for various end-uses.

MATERIALS AND METHODS

Materials

Experimental materials. The materials consisted of three trees per age per site (4-, 6-, and 8-year-old) from three different sites in Caraga: Pating-ay, Prosperidad, Agusan del Sur (Site 1); Nong-nong, Butuan City (Site 2); and Las Nieves, Agusan del Norte (Site 3). Caraga or Region XIII, composed of five provinces and six cities, lies on the northeastern portion of Mindanao. Its total land area is 18,846.97 km^2 where 71.22% is forestland and 28.78% is alienable and disposable land. The region is characterized by mountainous areas and flat and rolling lands. Photos of 3–4-year-old yemane plantation and 8-year-old yemane logs are shown in Figures 1 and 2.

Figure 1. 3- to 4-year-old yemane plantation.

Figure 2. 8-year-old yemane logs.

Collection, testing, and evaluation method. From each tree, three bolts about 3 m long were taken starting from the ground level representing the butt, middle, and top portions. Each bolt was sawn into lumber. The lumber recovered were computed and graded.

For mechanical properties samples, two quarter-sawn lumber 50 mm (width) x 50 mm (thick) x 2–3 m (length) in dimension were selected from the logs used for lumber recovery and grading. Six pieces of lumber were taken from each tree as follows: the first 2–3 m log was from the bottom (butt), the second 2–3 m was from the middle, and third 2–3 m was from the top.

Two samples for each mechanical property test in green condition and two samples for 12% MC per height levels were used. There were twelve samples for each mechanical property tests in green and at 12% moisture content (MC).

Overall, the total number of samples (N) for each mechanical property test was 162 (3 age class x 3 sites x 3 trees/age/site x 3 height levels x 2 samples/ tree/age class/ height level = 162 samples) in green condition and 162 samples at 12% MC (dry condition).

The sampling scheme used in the study is shown in Figure 3.

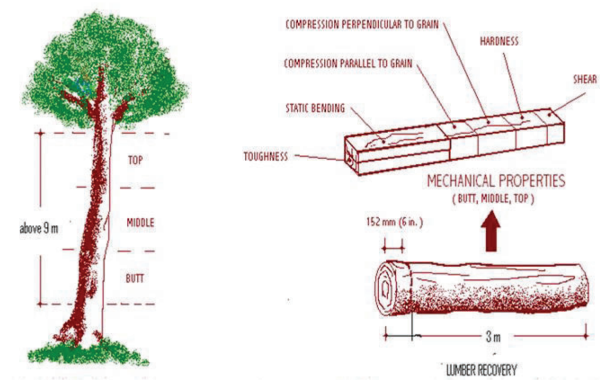

Figure 3. Sampling scheme used in the study.

The FPRDI Wood Mizer was used in processing the logs into lumber. The cutting sequence during sawing operation was diagrammed and resulting lumber marked appropriately with lumber crayon. The code of each lumber indicated the species, log number, and sequence of cut. All defects were diagrammed in the form of square with X and Y coordinates to define size and location on the board surface.

The average lumber recovery of yemane by log size and manner of log breakdown such as processing rate (PR) and lumber processing rate (LPR) was computed. In the absence of lumber grading standards for ITPS such as yemane, lumber grade yield per log was evaluated based on standards of the National Hardwood Lumber Association (NHLA 1990).

Scaling of Logs

Both big and small end diameters inside bark (dib) of each log were measured and gross volume determined using the Brereton formula:

$$V = 0.7854D^2L$$

where:

V = volume, m^3
D = average diameter, cm (inside bark of the big and smiall-end diameters)
L = length, m

Log was coded and volume properly recorded.

Sawing and Data Collection

The sawmilling trials were conducted at the FPRDI using the mobile horizontal bandmill (Wood Mizer). Machine has no effect on grading. Lumber grading is primarily based on the size and number of defects and also on the amount of clear or sound usable stock in a piece.

All lumber processed by modified live-sawing around and sawing method representing different log diameters, length, and type of blade was segregated. The total volume recovered from each log was computed and lumber yield in percent determined based on the log gross volume.

Result was tabulated for the analysis of the effects of sites, age, and height on the log diameter and length, log and lumber volume, lumber recovery (LR), processing rate (PR), and lumber recovery factor (LRF). Lumber sawn from each log was tallied and graded according to National Hardwoods Lumber Association standards (NHLA 1990).

Mechanical Properties

The mechanical properties were tested using the standard procedure of the American Society for Testing Materials Designation (D143-52) (ASTM 2005) for small clear specimens of timber.

Except for toughness where the US Forest Products Laboratory type testing machine was used, all strength properties were tested using the Shimadzu Universal Testing Machine (2–10-ton load capacity).

The sizes of samples for each property and method of tests were as follows:

Static bending. Test was conducted on 25 x 25 x 400 mm specimens. Actual size was measured. Load was applied through the bearing block to the tangential surface nearest the pith. Loading speed was maintained at 1.3 mm/min. The maximum load and deflection were recorded.

Compression parallel to grain. Test was conducted on 25 x 25 x 100 mm specimens. Load was applied axially through a spherical bearing block of the self-aligning type jig to ensure uniform distribution of stress over the whole cross-section of the specimens. Loading speed during testing was 0.30 mm/min. Load and deformation readings were taken up to maximum load.

Compression perpendicular to grain. Test was conducted on 50 x 50 x 150 mm specimens. Actual size was measured. Load was applied through a metal bearing plate 50 mm in width, placed across the upper surface of the specimen at equal distances from the ends and at right angles to the length. Actual bearing plate was measured. The loading speed was applied at 0.30 mm/min.

Shear parallel to grain. Test was conducted on 50 x 50 x 63 mm specimens notched to produce failure on a 50 x 50 mm surface. The actual dimensions of the shearing surface were measured and the loading speed was 6.0 mm/min.

Hardness. Test was conducted on 50 x 50 x 150 mm specimens. Load was applied on the side (radial and tangential) and end grain surfaces of the samples using a 12.28 mm steel ball to embed 1/2 its diameter. Loading speed was 6.0 mm/min.

Toughness. Test was conducted on 20 x 20 x 280 mm specimens using the United States (US) Forest Products Laboratory toughness testing machine. Load was applied on the radial and tangential surfaces of alternate specimens at the center of a 240 mm span through steel connected through a chain to the drum by a swing of the pendulum. Initial and final angles on the scale of the machine were noted and toughness values were taken from the energy table prepared for the purpose.

Cost Analysis (UNIDO 1986)

Two scenarios of analyses were used: (1) a sawmill enterprise starting the business of converting logs into lumber, thus an amount of loan is assumed to be included in the investment; and (2) a sawmill enterprise that had already existed for more than five years and has already recouped the investment cost.

Income and cash flow statements were done to determine the profitability of sawmilling logs from different age classes. Discounted and undiscounted indicators were used.

RESULTS AND DISCUSSION

Lumber Recovery and Lumber Grading

Table 1 shows the summary of LR, PR, and LRF of yemane logs sawn by age classes.

Percentage of lumber recovery increases with tree age due to corresponding increase in diameter. On the average, the 8-year-old trees obtained the highest average percent lumber recovery with 55.78%, 56%, and 54.89% for Site 1, Site 2, and Site 3, respectively. The trend also held true with the 4- and 6-year-old trees with 52% and 53.67% for Site 1, 51% and 53.33% for Site 2, and 51% and 52.11% for Site 3.

The range of yemane lumber recovered from 4-year-old trees (51–52%) was lower than those from the 6-year-old (52.11–53.87%) and 8-year-old (54.89–56.00%). The low percentage of lumber recovered can be explained by the effect of taper. Most of the logs from the younger trees are fluted butt logs. When logs are sawn full-length, the difference between the small and big diameter is considerable resulting

Table 1. LR, PR, and LRF of yemane logs sawn by age classes.

Site/Source	Ave. Dia. (cm)	Ave. Length (m)	Gross Log Vol. (m^3)	Gross Lumber Vol. (m^3)	LR (%)	Ave. PR (m^3/h)	Ave. LRF (bdft/m^3)
Site 1							
4 y old	13.70	1.85	0.2499	0.1294	51.00	0.313	217.31
6 y old	16.00	2.00	0.3562	0.1921	53.33	0.359	226.12
8 y old	21.33	2.00	0.6510	0.3665	56.00	0.466	237.43
Site 2							
4 y old	14.1	1.87	0.2697	0.1411	52.00	0.403	219.78
6 y old	16.44	1.89	0.3681	0.1986	53.67	0.546	227.41
8 y old	20.80	1.91	0.5911	0.3322	55.78	0.568	238.23
Site 3							
4 y old	12.20	1.83	0.1967	0.1005	51.00	0.321	214.71
6 y old	16.44	1.87	0.362	0.1901	52.11	0.562	220.84
8 y old	20.13	1.89	0.5728	0.3178	54.89	0.593	232.86

Table 2. Lumber grade yields of yemane at different sites and age classes.

Site	Age Class	Lumber Tally (m^3)	Lumber Grade Distribution (%)				Total (%)
			1C	2C	3C	BG	
1. Pating-ay, Prosperidad, Agusan del Sur	8 y old	0.3665	46	27	23	4	100
	6 y old	0.1921	15	35	39	11	100
	4 y old	0.1294	9	29	48	14	100
2. Nong-nong, Butuan City	8 y old	0.3322	48	31	19	2	100
	6 y old	0.1986	19	37	41	3	100
	4 y old	0.1411	13	34	50	3	100
3. Las Nieves, Agusan del Norte	8 y old	0.3178	41	26	24	9	100
	6 y old	0.1901	13	33	40	13	100
	4 y old	0.1005	8	27	46	19	100

to loss of large volumes in the form of slabs and edgings. On the other hand, the larger logs produced bigger lumber sizes resulting to an improvement in lumber recovery factor (LRF) and higher processing rate (PR). The processing rate of 0.568 m^3/h from Site 1 for the 8-year-old means that about 4.54 m^3 (1925 bdft) can be produced in 8-hour operation.

The lumber grade yield of yemane at different sites and age classes is shown in Table 2, while the average lumber grade yield per age from three different sites in Table 3.

For all logs, the results indicated an improvement in percentage recovery of No. 1 Common (No. 1C) as the tree aged. According to the US NHLA, No. 1C Grade requires minimum size of board at 75 mm x 100 mm (3 in x 4 in) and allows 66 2/3% of their surface measure (SM) to be cut into clear material. SM is the surface area of a board in square mm determined by width of board (mm) and fractions x length (m) divide by 12.

For the 8-year-old samples, the lumber grade yields were 45% for No. 1C, 28% for No. 2C, 22% for No. 3C, and 5% for Below Grade (BG), respectively. On the other hand, the lumber recovered from 6-year-old trees were 16% for No. 1C, 35% for No. 2C, 40% for No. 3C, and 9% for BG. The average values of lumber produced from the 4-year-old samples yielded lower grade of No. 3C with 48%. The greater proportion of the No. 1C lumber grades for the 8-year-old samples is attributed to better quality of lumber produced from bigger logs due to higher quantity of clearwood along the outer portion by excluding or "boxing" undesirable defects such as pith.

Table 3. Average lumber grade yield of yemane per age from three different sites.

Lumber Grade (%)	4 y old	6 y old	8 y old
1C	10.0	16.0	45.0
2C	30.0	35.0	28.0
3C	48.0	40.0	22.0
BG	12.0	9.0	5.0
Total	100	100	100

Table 4. ANOVA for lumber recovery (LR), processing rate (PR), and lumber recovery factor (LRF) of yemane.

Source of Variation	df		Length		Log Vol.		Lumber Vol.	
		F-value	MS	*F*-value	MS	*F*-value	MS	*F*-value
Site	2	3.68*	0.050	22.78**	0.000	4.71*	0.0001	5.02**
Age	2	402.4**	0.049	22.44**	0.012	338.8**	0.004	307.1**
Site*Age	4	4.08**	0.012	5.50**	0.000	2.74*	0.000	2.09ns
Height	2	134.0**	0.013	5.92**	0.004	114.2**	0.001	112.7**
Site*Height	4	0.59ns	0.002	0.84ns	0.000	0.97ns	0.000	1.18ns
Age*Height	4	0.89ns	0.001	0.30ns	0.000	5.23**	0.000	6.01**
Site*Age* Height	8	1.59ns	0.002	1.08ns	0.000	2.02ns	0.000	1.84ns
Error	54		0.002		0.000		0.0000	
R^2			72		95		94	
CV			2.46		13.1		14.9	

Table 4. Continuation…

Source of Variation	LR		PR		LRF	
	MS	*F*-value	MS	*F*-value	MS	*F*-value
Site	11.44	9.46**	0.129	69.38**	234.7	11.44**
Age	123.8	102.3**	0.279	149.8**	2439.5	118.8**
Site*Age	0.537	0.44ns	0.024	12.81**	4.98	0.24ns
Height	102.11	84.80**	0.004	2.06ns	1973.0	96.12**
Site*Height	3.44	2.85*	0.004	2.06ns	52.69	2.57*
Age*Height	2.04	1.68ns	0.004	2.06ns	33.04	1.61ns
Site*Age* Height	1.09	0.90ns	0.004	2.39*	20.84	1.02ns
Error	1.21		0.002		20.53	
R^2	89		92		90	
CV	2.06		9.40		2.00	

Notes:
**Highly significant at 99% probability level
*Significant at 95% probability level
ns – not significant

The difference on log and lumber features of yemane among sites, ages, and heights was statistically significant except in PR at different height levels. The interaction between site and age was also significant except in lumber volume and lumber recovery. The interactions among age x height, site x height, and site x age x height were not generally significant (Table 4).

The Duncan Multiple Range Test (DMRT) in Table 5 showed that log volume, LR, PR, and LRF of yemane were statistically highest in Site 2 and butt portion of 8-year-old. The results can be attributed to larger log diameter in Site 2 (17.1 cm) than in Site 1 (16.9 cm) and Site 3 (16.5 cm). Evidently, all these factors are closely related to log size, as the values for the butt logs were found to be higher than the uppers or top logs.

Mechanical Properties

ANOVA for mechanical properties of yemane in green condition and at 12% MC (dry condition) is presented in Tables 6 and 7.

The effect of site and age on the mechanical properties of yemane in green condition was significant except in hardness, end (site), tangential toughness, and compression parallel-to-grain (age). At 12% MC, the

Table 5. DMRT for LR, PR, and LRF for yemane.

Source of Variation	df	Log			Lumber			
		Diameter	Length	Volume	Volume	LR	PR	LRF
		(cm)	(m)	(m^3)	(m^3)	(%)	(m^3/h)	(bdft/m^3)
Site	1	16.9ab	1.95a	0.047a	0.025a	53.56a	0.379b	226.95a
	2	17.1a	1.89b	0.046a	0.025a	53.76a	0.506a	228.47a
	3	16.5b	1.86c	0.042b	0.023b	52.56b	0.491a	222.78c
Age	4	13.3c	1.85b	0.027c	0.014c	51.30c	0.346c	217.27c
	6	16.2b	1.91a	0.040b	0.022b	53.04b	0.489b	224.79b
	8	20.9a	1.93a	0.067a	0.038a	55.56a	0.542a	236.15a
Height	Butt	19.1a	1.92a	0.058a	0.032a	55.26a	0.522a	234.59a
	Mid	16.5b	1.90a	0.043b	0.023b	53.26b	0.457b	226.13b
	Top	14.8c	1.88b	0.034c	0.018c	51.37c	0.398c	217.49c

Note: Means with the same letter are not significantly different.

Table 6. ANOVA for mechanical properties of yemane in green condition.

Source of Variation	df	MOR, SB		SPL, SB		MOE, SB		Hardness, Side		Hardness, End	
		MS	*F*-value	MS	*F*-value	MS	F-value	MS	*F*-value	MS	*F*-value
Site (S)	2	543.3	7.29**	281.3	8.46**	53.7	26.8**	4.45	9.91**	1.52	2.29ns
Age (A)	2	436	5.85**	199.7	6**	22.1	8.25**	5.71	12.7**	4.59	6.93**
S X A	4	298.2	4.0**	120.8	3.63**	3.66	2.74*	3.23	7.18**	1.27	1.92ns
Height (H)	2	96.8	1.30ns	14.3	0.43ns	0.25	0.19ns	3.18	7.08**	0.11	0.16ns
S X H	4	170.6	2.29ns	55.5	1.67ns	3.89	2.90*	0.81	1.81ns	0.92	1.39ns
A X H	4	126.0	1.69ns	28.8	0.87ns	1.47	1.10ns	0.66	1.46ns	0.40	0.61ns
S x A x H	8	68.9	0.92ns	32.9	0.99ns	1.67	1.25ns	0.51	1.15ns	0.69	1.03ns
Error	135	74.5		33.2		1.34		0.45		0.66	
R^2		34		32		41		45		24	
CV		18.3		19.4		18.7		21.0		23.3	

Table 6 continuation . . . .

Source of Variation	df	Toughness, Radial		Toughness, Tangential		Toughness, Radial + Tangential		Shear, Radial		Shear, Tangential	
		MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value
Site (S)	2	799.8	7.45**	1074.2	9.42**	905.6	9.91**	28.6	27.7**	14.5	18.5**
Age (A)	2	431.9	4.03*	316.0	2.77ns	371.7	4.07*	7.23	7.0**	4.87	6.23**
S X A	4	245.8	2.29ns	227.6	2.00ns	230.2	2.52*	5.88	5.69**	4.21	5.39**
Height (H)	2	2853	26.6**	2242.1	19.7**	2535.7	27.8**	0.13	0.13ns	2.94	3.77*
S X H	4	334.7	3.12*	436.2	3.82**	376.9	4.13**	0.82	0.79ns	0.90	1.15ns
A X H	4	234.1	2.18ns	200.0	1.75ns	187.5	2.05ns	0.92	0.89ns	2.20	2.82*
S x A x H	8	209.4	1.95ns	339.7	2.98ns	216.3	2.37*	2.38	2.30*	3.11	3.98*
Error	135	107.3		114.1		91.4		1.03		0.78	
R^2		47		47		50		47		48	
CV		36.2		34.7		32.2		19.9		17.3	

Table 6 continuation . . . .

Source of Variation	df	Shear, Radial +Tangential		Compression, Parallel-to-Grain		Compression, Perpendicular-to-Grain	
		MS	*F*-value	MS	*F*-value	MS	*F*-value
Site (S)	2	18.3	25.4**	63.3	5.36**	23.5	15.6**
Age (A)	2	3.24	4.51*	3.90	0.33ns	17.2	11.4**
S X A	4	3.73	5.20**	38.5	3.27*	15.4	9.64**
Height(H)	2	1.08	1.50ns	36.0	3.05*	19.1	12.7**
S X H	4	0.72	1.00ns	21.9	1.86ns	0.69	0.45ns
A X H	4	0.81	1.13ns	36.6	3.10*	1.82	1.21ns
S x A x H	8	2.59	3.61**	44.3	3.75**	1.53	1.01ns
Error	135	0.717		11.8		1.51	
R^2		47		37		50	
CV		16.8		18.0		29.0	

Table 7. ANOVA for mechanical properties of yemane at 12% MC.

Source of Variation	df	MOR, SB		SPL, SB		MOE, SB		Hardness, Side		Hardness, End	
		MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value
Site (S)	2	31.5	0.27ns	535.4	10.5**	27.0	18.2**	1.51	3.52*	0.72	1.66ns
Age (A)	2	130.7	1.11ns	24.3	0.48ns	9.95	6.71**	2.65	6.20**	2.63	6.08**
S X A	4	726.1	6.16**	317.4	6.23**	8.73	5.89**	0.87	2.03ns	0.79	1.82ns
Height(H)	2	1506	12.8**	390.5	7.67**	2.91	1.96ns	0.17	0.40ns	0.12	0.27ns
S X H	4	31.5	0.27ns	11.0	0.22ns	2.29	1.54ns	1.14	2.67*	0.80	1.84ns
A X H	4	365.0	3.10*	87.6	1.72ns	1.69	1.14ns	0.18	0.41ns	0.20	0.45ns
S x A x H	8	350.0	2.97**	94.8	1.86ns	1.70	1.15ns	0.50	1.17ns	0.56	1.31ns
Error	135	117.9		50.9		1.48		0428		0.432	
R^2		40		39		42		27		24	
CV		17.6		19.6		16.0		24.0		22.0	

Table 7 continuation . . . .

Source of Variation	df	Toughness, Radial		Toughness, Tangential		Toughness, Radial + Tangential		Shear, Radial		Shear, Tangential	
		MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value	MS	*F*-value
Site (S)	2	355.9	6.38**	297.9	4.93**	300.5	6.52**	12.9	9.25**	16.0	9.10**
Age (A)	2	57.2	1.03ns	310.3	5.13**	175.5	3.891*	7.40	5.30**	1.30	0.74ns
S X A	4	162.4	2.91*	427.1	7.07**	259.8	5.64**	6.96	4.99**	9.20	5.22*
Height(H)	2	304.6	5.47**	226.0	3.74*	242.0	5.25**	2.58	1.85ns	4.97	2.82ns
S X H	4	220.0	3.95**	170.0	2.81*	168.7	3.66**	3.13	2.24ns	0.57	0.32ns
A X H	4	53.1	0.95ns	16.5	0.27ns	29.3	0.64ns	2.16	1.55ns	1.13	0.64ns
S x A x H	8	112.7	2.02*	150.1	2.48*	118.7	2.58ns	2.96	1.41ns	1.08	0.62ns
Error	135	55.7		60.4		46.1		1.40		1.76	
R^2		35		39		40		37		29	
CV		38.0		38.5		33.9		18.6		20.4	

Table 7 continuation . . . .

Source of Variation	df	Shear, Radial +Tangential		Compression, Parallel-to-Grain		Compression, Perpendicular-to-Grain	
		MS	*F*-value	MS	*F*-value	MS	*F*-value
Site (S)	2	14.8	12.0**	14.0	0.55ns	18.8	9.82**
Age (A)	2	3.63	2.96ns	50.4	1.99ns	1.51	0.79ns
S X A	4	7.07	5.75**	129.5	5.10**	4.96	2.59*
Height(H)	2	3.72	3.03ns	119.0	4.69*	2.40	1.25ns
S X H	4	1.52	1.23ns	63.6	2.51*	0.92	0.48ns
A X H	4	1.45	1.18ns	48.3	1.90ns	0.49	0.25ns
S x A x H	8	1.22	0.99ns	81.1	3.19**	1.34	0.70ns
Error	135	1.23		25.4		1.91	
R^2		36		37		24	
CV		17.2		17.7		34.3	

Notes:
**Highly significant at 99% probability level
*Significant at 95% probability level
ns – not significant

effect of site was also significant except in MOR, end hardness, and compression parallel-to-grain.

The significant effect of ages conforms to the findings of Ogunsanwo (2011), although his study on mechanical properties variations was conducted on 18-, 28-, and 36-year-old yemane. On the other hand, the significant effect of sites on mechanical properties conformed to the previous findings by Alipon and Bondad (2011), wherein the mechanical properties of 10-year-old trees from Nueva Vizcaya (Region II) were higher than the 10-year-old from Casiguran, Aurora (Region III). The yemane trees from the former site were planted in logged-over areas, while those in Nueva Vizcaya were planted in grasslands. Likewise, Casiguran, Aurora had Type III climate (has no very pronounced maximum rain period) whereas Nueva Vizcaya had Type II climate (has no dry season but has a very pronounced maximum rain period during November, December, and January). These factors may have caused some variation on tree growth, wood formation, and consequently on wood properties. Sanio (1972) explained that as the tree matures and grows in girth, the fusiform initials of the cambium increase in size and produce longer and often thicker-walls cells. Consequently, the mechanical properties increase as the tree gets older. Lantican (1975, 1976) discussed several factors such as age and sites affecting tree growth and consequently wood properties.

In general, the mechanical properties of yemane increased from 4- to 8-year-old both in green condition and 12% MC (dry condition) except in toughness (Figures 4 and 5). This exemption of toughness values is expected since in toughness tests, dry wood will not bend so far before failure occurs.

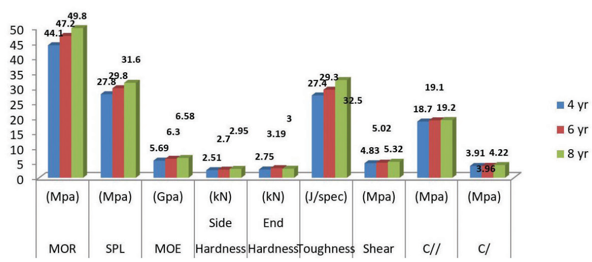

Figure 4. Mean mechanical properties of yemane in green condition at different ages.

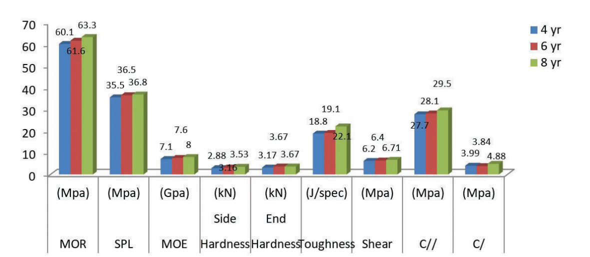

Figure 5. Mean mechanical properties of yemane at 12% MC (dry condition) at different ages.

The mechanical properties of yemane samples such hardness, compression parallel-to-grain (C//), and compression perpendicular-to-grain were highest in Site 2, shear and toughness in Site 3; and MOR, SPL, and MOE in Site 1 (Figures 6 and 7).

Based on FPRDI's strength grouping of Philippine timbers (FORPRIDECOM 1980), yemane together with some ITPSs and "Philippine mahogany" species are classified and compared as shown in Table 8.

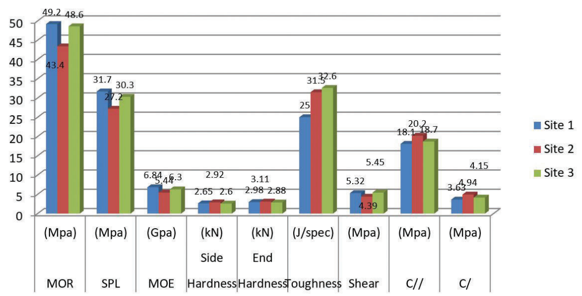

Figure 6. Mean mechanical properties of yemane in green condition from different sites.

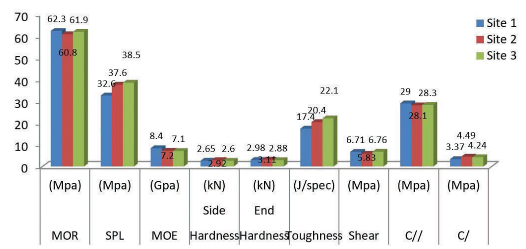

Figure 7. Mean mechanical properties of yemane at 12% MC (dry condition) from different sites.

As far as mechanical properties classification is concerned, yemane wood fell under moderately low at different ages and sites. The wood may be used for conventional furniture, pallets, wood carving and sculpture, crates, and other construction purposes requiring moderately low strength.

Collected from the same sites and with the same age, the strength classification of herein yemane was lower than that of previously reported strength properties of *Acacia mangium* (Alipon *et al.* 2017) although better than Falcata (Alipon *et al.* 2016). *Acacia mangium* even at 4–6-year-old fell under Medium Strength (Class III) and 8-year-old under Moderately High (Class II). On the other hand, Falcata's mechanical properties fell under Low Strength (Class V). The system of classification indicates descending level of strength from highest (Class I) to lowest (Class V).

Other than the three mentioned species, the other ITPSs and Philippine mahogany species were taken from previously studied species included in FPRDI Technical Bulletin (Alipon and Bondad 2008). Likewise, the mechanical properties of yemane at 4-,6-, and 8-year-olds are comparable with two Philippine mahogany species commercially used for lumber production, namely 'almon' [*Shorea almon* (Foxw.)] and 'mayapis' [*Shorea palosapis* (Blanco) Merr.]

Economic Analysis

Investment cost. Fixed investments, working capital requirements, and pre-operating expenses were calculated to determine the needed investment costs for processing logs into lumber. Cost analysis for sawmilling operation was based on the use of wood mizer in the conduct of this research. The list of equipment and their acquisition cost are as shown in Table 9.

Table 8. Strength classification of yemane together with some plantation and "Philippine mahogany" species.

Strength Class	Industrial Tree Plantation Species (ITPS)	Philippine Mahogany Species
Class I. High	Satinwood (*Chloroxylon swietenia* DC)	
Class II. Moderately High	*Acacia crassicarpa* *Acacia cincinnata* 'Ipil-ipil' [*Leucaena leucocephala* (Lam.) de Wit] ***Acacia mangium*** at 8 yr old	
Class III. Medium	Benguet pine (*Pinus kesiya* Royle ex Gordon) Big-leafed mahogany (*Swietenia macrophylla* King) Para rubber [*Hevea brasiliensis* (HBK.) Muell.-Arg.] ***Acacia mangium*** at 4–6 yr old	'Bagtikan' [*Parashorea malaanonan* (Blanco) Merr.] 'Lauan,' red (*Shorea negrosensis* Foxw.) 'Lauan,' white (*Shorea contorta* Vid.) 'Tangile' [*Shorea polysperma* (Blanco) Merr]
Class IV. Moderately Low	'Bagras' (*Eucalyptus deglupta* Blume) *Yemane (***Gmelina arborea*** Roxb.) at 4, 6, and 8 yr old	'Almon' (*Shorea almon* Foxw.) 'Mayapis' [*Shorea palosapis* (Blanco) Merr.]
Class V. Low	'Ilang-ilang' [*Cananga odorata* (Lamk.) Hook. F. & Thoms.] 'Kaatoan bangkal' [*Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp.] 'Kapok' [*Ceiba pentandra* (L.) Gaertn.] 'Lumbang' [*Aleurites moluccana* (L) Willd.] Spanish cedar (*Cedrela odorata* L.) African tulip (*Spathodea campanulata* Beauv.) 'Gubas' (*Endospermum peltatum* Merr.) Moluccan sau or Falcata [***Paraserianthes falcataria*** (L.) Nielsen] at 4, 6, and 8 yr old	'Tiaong' (*Shorea ovata* Dyer ex Brandis)

Table 9. List of equipment and their acquisition cost to be used for lumber production.

Equipment	Acquisition Cost Php (US$)
Wood mizer	1,500,000.00 (30,000.00)
Chainsaw	5,000.00 (1,100.00)
Workshop equipment/tools	17,000.00 (340.00)
Office equipment and furniture	10,000.00 (200.00)

The basic machineries/facilities were determined from existing sawmillers in Caraga Region. Fixed investments include land, building, sawmill shed, sets of equipment, and an office space which cost Php 2,652,000.00 (US$53,040.00)

Working capital was estimated at Php 560,060 (US$11,201.20) and includes provision for the inventory of logs and payment of direct labor for 10 days and provision for utilities and other materials for a month operation.

Pre-operating expenses covers expenses that are spent for transactions made prior to establishment of the sawmill. This is estimated at 10% of the investment cost and working capital.

Investment is assumed to come from the owner's equity and loan at 20% and 80%, respectively.

Production cost. Production cost of lumber from yemane varies on the volume requirements for logs processed and the output of sawmill for each specific log sizes. Processing rate and lumber recovery were considered in the operation. A summary of production cost for each diameter size is shown in Table 10.

The price of logs for diameters 13.33–20.64 cm falls under the pulpwood price of Php 1,600.00 (US$32.00) per m^3 of yemane logs. Cost of production is higher for the lowest diameter size coming from a 4-year-old plantation. The higher the average diameter size, the lower is the volume requirement to meet the 5.66 m^3 (2,400 bdft) production.

If diameter size is lower, more logs are needed to meet the plant capacity, thus the high cost of producing lumber from 13.33 cm diameter size. Lesser logs are needed as the diameter size increases, thus lower production cost. Average production costs were Php 7,916.08 (US$158.32/ m^3), Php 8,594.48 (US$171.89/ m^3), and Php 7,551.44 (US$151.03/$m^3$) for diameter class 13.33 cm, 16.29 cm, and 20.64 cm, respectively .

Profitability. Profitability of processing yemane logs into lumber is shown in Table 11. The selling price for yemane lumber in the market was Php 21.00 (US$0.42). Financial analysis showed that logs belonging to the 4-year-old group were not profitable to process because of high production cost. Logs belonging to 6-year-old and 8-year-old groups were profitable to produce, as shown by the results of profitability indicators. The ROI values are 47–48%. Payback period is within the third year of operation, while the internal rate of return (IRR) is also high at 23% and 74%, respectively. Both positive NPVs can be generated if yemane logs belonging to 6-year-old and 8-year-old groups are processed.

Table 10. Summary of production cost for each diameter size of yemane.

Ave. Dia. (cm)	Prod. Capacity		Cost per bdft
	Daily	Annual	
	m^3 (bdft)	m^3 (bdft)	Php (US$)
13.33 cm	3.07 (1,303)	809.43 (343,200)	18.67 (0.3734)
16.29 cm	4.24 (1,799)	1,1230.75 (475,200)	20.27(0.4054)
20.64 cm	4.29 (1,817)	1,131.34 (479,688)	17.81(0.3562)

US$1 = Php 50.00

Table 11. Profitability of processing yemane logs into lumber.

Average Diameter Size, cm (Age)		Profitability Indicators			
		ROI	Payback Period	NPV Php (US$)	IRR
13.33	(4 y old)	–		–	–
16.29	(6 y old)	47%	3.3 years	4,598,493 (91,968.69)	23%
20.64	(8 y old)	48%	2.1 years	17,317,189 (346,343.78)	74%

CONCLUSION AND RECOMMENDATIONS

The mechanical properties classification of 4-, 6-, and 8-year-old yemane fell under moderately low strength (Class IV). The lumber from these three ages can be used for conventional furniture, pallets, wood carving and sculpture, crates, and other construction purposes requiring moderately low strength.

The 4-year-old logs are not profitable to process into lumber since they entail higher production cost. Logs belonging to 6- and 8-year-old groups, on the other hand, are profitable as shown by the results of profitability indicators.

It is recommended that the properties and quality of young-age ITPS from selected plus/certified seeds be studied to evaluate and provide scientific basis on investing into ITP using the said selected plus/certified seeds, as established by DENR under the program on ITPSs.

ACKNOWLEDGMENT

The authors extend their sincerest thanks and appreciation to the Department of Science and Technology, Grants-in-Aid (DOST, GIA) Program – Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) for providing project funds.

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