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Mechanical attributes of *Gigantochloa levis* and *Dendrocalamus asper* as affected by the application of organic fertilizers

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Abstract: The influence of three organic fertilizers viz., chicken manure, cow dung and rice hull ash, applied at 3, 6 and 12 kg/yr for a period of three years on the mechanical properties of plantation-grown *Gigantochloa levis* Merr. and *Dendrocalamus asper* Heyne. was evaluated. Culm wall thickness, specific gravity, modulus of elasticity (MOE), modulus of rupture (MOR) and maximum crushing strength (MCS) were determined. The mechanical attributes of the culm were affected by the organic fertilizers as compared to the control or unfertilized sample. Some traits were improved while others were reduced. Variation in the response of the culm to the individual fertilizers was not significant. Similarly, impact of the rate of fertilizer application on culm mechanical traits was minimal. Culm wall thickness was inversely associated to the stiffness of the bamboos while specific gravity was directly proportional to it. Thus, mechanical properties of the bamboo culms were affected by the organic fertilizers however, such influence was only minimal.

Keywords: *Gigantochloa levis*, *Dendrocalamus asper*, culm wall thickness, specific gravity, Modulus of elasticity, Modulus of rupture, Maximum crushing strength

INTRODUCTION

Bamboo is a versatile, multifaceted and intrinsically beautiful raw material used in building construction, paper production and in the handicraft industry. It contributes to the livelihood of more than one billion people (Dos Reis Pereira and Faria, 2009) with a current global market share of no less than USD 0.5 billion (Prosperity Initiative, 2008).

Bamboo is a good timber substitute because of its good strength – weight ratio (Brown, 1920). With the prevailing scarcity in timber resources worldwide, bamboo resource has become very popular to producer and consumer countries (Wu and Li, 2009) because of its potential to sustain the ever increasing demand for forest products. Another advantageous trait of bamboo was its fast growth. This is crucial in biomass

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accumulation and offers the opportunity to maintain and increase carbon stocks through carbon sequestration (Agarwal and Purwar, 2009). Thus, the plant is also an important asset in climate change mitigation.

Bamboo plantation should be established to ensure the sustainability of this resource. However, due to drastic changes in the landscape caused by population growth and industrialization, marginal and degraded lands were the only place available for plantation establishment. Silvicultural practices would therefore play an important role in plantation development. Studies pertaining to the impact of different silvicultural practices on bamboo plants abound in literature however, most if not all was restricted to its influence on survival and shoot production (Midmore *et al.,* 1998; Traynor *et al.,* 2009; Zhu *et al.*, 2009; Kleinhenz *et al.*, 2003; Fernandez *et al.,* 2003). This was due the significance of bamboo shoots in the food industry. Moreover, information on the impact of silvicultural treatments particularly the application of inorganic fertilizer on culm properties was limited only to culm diameter and height (Hoanh, 1992).

As a raw material, the influence of fertilizer application on the basic properties of the culm should be clearly understood in order to determine its suitability for a particular end use and maximize its potential as a raw material. In addition, inorganic fertilizers are very costly and could reduce soil productivity when applied for a long period of time (Granstedt and Kjellenberg, 1997) hence, its utilization should be minimized. With this in mind, the study was conducted in order to determine the impact of organic fertilizers viz., chicken manure, cow dung and rice hull ash; and the rate of fertilizer application viz., 3, 6 and 12 kg/year; on the mechanical properties of plantation grown *Gigantochloa levis* and *Dendrocalamus asper*.

METHODOLOGY

Materials

Three year old *Gigantochloa levis* and *Dendrocalamus asper* planted at the University of the Philippines Laguna- Quezon Land Grant, Real Quezon, were used in the study. Age 3 was considered because it was the age in which the culms were already mature in terms of their strength characteristics (Janssen, 2000). Samples were derived from the sixth internode from the base.

Organic fertilizers used were Chicken Manure (CM), Cow Dung (CD) and Rice Hull Ash (RHA). Application rates were 3 kg, 6 kg and 12 kg per year for a period of three years.

Physical properties

At green state, the inner and outer diameters were measured using a vernier caliper.

Similarly, average culm wall thickness for every sample was determined from three measuring points within the culm. Specimens measuring 25 mm x 25 mm x actual thickness were also prepared for specific gravity determination using the gravimetric method. Specific gravity was taken from 10 samples and averaged.

Mechanical properties

a. Static bending

Mechanical testing was conducted following the ASTM standard of 1998 for the standard testing for small clear timber specimen with some modification due to the peculiarities of bamboo culms. Samples were at their green state in order to prevent the influence of varying moisture content on the strength properties of bamboo. A universal testing machine was utilized. The span distance between both ends was based on culm diameter multiplied by14. Load was applied at the center of the culm at a constant rate of 0.003 mm/min. Midspan deflections were measured to the nearest 0.025 mm with a dial gauge. The procedure generated a load-deflection curve where modulus of rupture (MOR) and modulus of elasticity (MOE) were derived using the formulae:

$$MOR = \frac{2.546\ PLdo}{(do^4 - di^4)} \qquad (1)$$

$$MOE = \frac{0.424pL^3}{(do^4 - di^4)E} \qquad (2)$$

Where:

p = load at proportional limit (N)
P = maximum load (N)
L = span (mm)
do = outer diameter (mm)
di = inner diameter (mm); and
E = deflection at proportional limit (mm)

Measurements were replicated thrice and average values were presented.

b. Compression parallel to the grain

Similar to static bending tests, compression tests were conducted at green condition. Specimen length was based on culm wall thickness multiplied by 10. Load was applied at a uniform rate of 0.003 mm/min. Maximum crushing strength (MCS) was computed using the formula:

$$MCS = \frac{1.273P}{(do^2 - di^2)} \quad (3)$$

Where:

P = maximum crushing load (N)
do = outer diameter (mm); and
di = inner diameter

Measurements were replicated thrice and averaged values were presented.

Statistical evaluation

Box and whisker plots were prepared to determine the variation between individual organic fertilizers and its rate of application. Likewise, a 2 x 3 x 3 x 3 factorial design where replications were considered as block, was used to simultaneously evaluate the variation between species and within fertilizer treatments including rate of application. Regression analysis was also conducted in order to detect the factors affecting the mechanical attributes of the bamboo as influenced by the individual organic fertilizers. The statistical analysis considered all the possible sources of variation starting with species, the different fertilizers, the rate of application and interaction between the individual factors.

RESULTS AND DISCUSSION

Properties of the organic fertilizers

Chemical properties of the individual fertilizers were presented in Table 1. Chicken manure and cow dung have neutral pH while rice hull ash was moderately basic (9.20). Cow dung possessed the highest nitrogen content while chicken manure contained the highest potassium (K). Except for the pH level, rice hull ash consistently contained the lowest amount of nutrients.

Physical Properties

The physical properties of the culm *viz*., culm wall thickness, outer and inner diameter and specific gravity were presented in Table 2. Outer diameter of the culm varied

Table 1. Chemical Properties of the different organic fertilizers.

	Fertilizer		
	Chicken Manure	Cow Dung	Rice Hull Ash
pH	7.00	7.30	9.20
N (%)	1.08	1.33	Nil
P (%)	0.84	0.63	0.18
K (%)	1.23	0.89	0.39

Table 2. Physical attributes of the two bamboo species.

Species	Treat-ment	Outside Diameter (Do) mm		Inside Diameter (Di) mm		Culm wall thickness (cm)		Specific Gravity	
	C	33.33	*(6.03)*	17.50	*(4.00)*	7.92	*(1.04)*	0.57	*(0.10)*
	CM3	37.67	*(7.23)*	21.83	*(5.03)*	7.92	*(2.02)*	0.51	*(0.12)*
	CM6	34.00	*(4.36)*	16.67	*(2.84)*	8.67	*(1.01)*	0.59	*(0.15)*
	CM12	34.00	*(1.00)*	15.67	*(1.04)*	9.17	*(0.63)*	0.50	*(0.15)*
Gigantochloa levis	CD3	35.67	*(5.51)*	17.17	*(3.01)*	9.25	*(1.25)*	0.56	*(0.10)*
	CD6	35.67	*(1.15)*	18.50	*(2.29)*	8.58	*(0.80)*	0.66	*(0.22)*
	CD12	32.67	*(6.67)*	18.00	*(6.56)*	7.33	*(1.89)*	0.71	*(0.25)*
	RH3	35.33	*(7.37)*	20.67	*(3.06)*	7.33	*(3.40)*	0.59	*(0.16)*
	RH6	37.33	*(2.52)*	21.17	*(5.35)*	8.08	*(1.42)*	0.60	*(0.17)*
	RH12	43.00	*(9.85)*	21.50	*(2.78)*	10.75	*(3.88)*	0.49	*(0.20)*
	C	42.00	*(13.75)*	17.67	*(6.17)*	12.17	*(3.79)*	0.60	*(0.30)*
	CM3	44.00	*(0.00)*	16.33	*(1.53)*	13.83	*(0.76)*	0.46	*(0.12)*
	CM6	40.33	*(10.12)*	14.67	*(4.25)*	12.83	*(3.02)*	0.61	*(0.16)*
	CM12	40.33	*(5.51)*	15.00	*(3.61)*	12.67	*(1.04)*	0.59	*(0.20)*
Dendrocalamus asper	CD3	36.67	*(8.50)*	11.50	*(5.00)*	12.58	*(1.76)*	0.52	*(0.25)*
	CD6	41.00	*(4.36)*	13.33	*(1.04)*	13.83	*(1.91)*	0.55	*(0.11)*
	CD12	46.33	*(6.51)*	19.50	*(5.27)*	13.42	*(0.72)*	0.50	*(0.10)*
	RH3	47.33	*(8.14)*	20.83	*(3.51)*	13.25	*(2.65)*	0.64	*(0.17)*
	RH6	40.33	*(7.77)*	15.00	*(8.32)*	12.67	*(0.52)*	0.61	*(0.20)*
	RH12	41.00	*(8.66)*	17.00	*(7.81)*	12.00	*(3.91)*	0.62	*(0.23)*

Standard deviation in parentheses, C- control, CM – Chicken manure; CD- Cow dung; RH- Rice hull ash

from 32.67 to 43.00 mm for *Gigantochloa levis* and from 36.67 to 47.33 mm for *Dendrocalamus asper* showing a slightly bigger diameter than the former. Conversely, *D. asper* gave smaller inner diameter (11.50 – 20.83 mm) than *G. levis* (15.57 – 21.83 mm). Culm thickness was typically thicker at the base (Huang *et al.,* 1992). Thinner culm walls were observed in *G. levis* (7.33 – 10.75 mm) as compared to *D. asper* which did not go below 12 mm. Compared to *Dendrocalamus barbatus* of Vietnam (5 -20 mm) (Marsh and Hung, 2009), both *G. levis* and *D. asper* possessed thinner culm wall thickness. Specific gravity did not differ so much between *G. levis* and *D. asper* [p = 0.05]. It ranged from 0.46 to 0.71 which was quite similar to the specific gravity of *Phyllostachys bambusoides* (Lee *et al.,* 1994).

Mechanical Properties

Mechanical properties of the *G. levis* and *D. asper* were depicted in Figure 1. Modulus of elasticity (MOE) (Fig. 1a) ranged from 2.8 – 7.8 GPa which was slightly lower to *Phyllostachys bambusoides* (Lee *et al.,* 1994). *G. levis* was consistently stronger than the control (no treatment). This means that the ability of *G. levis* to retain its shape when loaded was more or less improved by the organic fertilizers. In *D. asper* on the other hand, 5 out of 9 treatments or 55.55% of the population were weaker than the control. It thus showed that there was a big possibility that more than half of the samples would develop irrecoverable deformation when subjected to increasing load.

Modulus of rupture (MOR) (Fig. 1b) ranged from 25 – 65 MPa. In *G. levis,* only 4 treatments gave slightly higher values to the control while the rest were weaker in ultimate strength. In *D. asper*, all the treatments gave higher values than the control. This revealed that the ability of the latter to resist load upon application was better than the former. The implication of this was if the two bamboo species were subjected to the same amount of load, there was a big tendency for *G. levis* to break all of the sudden than *D. asper.*

Maximum crushing strength (MCS) was from 15 – 30 MPa (Fig. 1c). The control of *G. levis* was evidently stronger than all the samples treated with organic fertilizers. *D. asper* gave the exact opposite results. All the treated samples were more resistant to compression load than the control. The three figures clearly showed that the mechanical

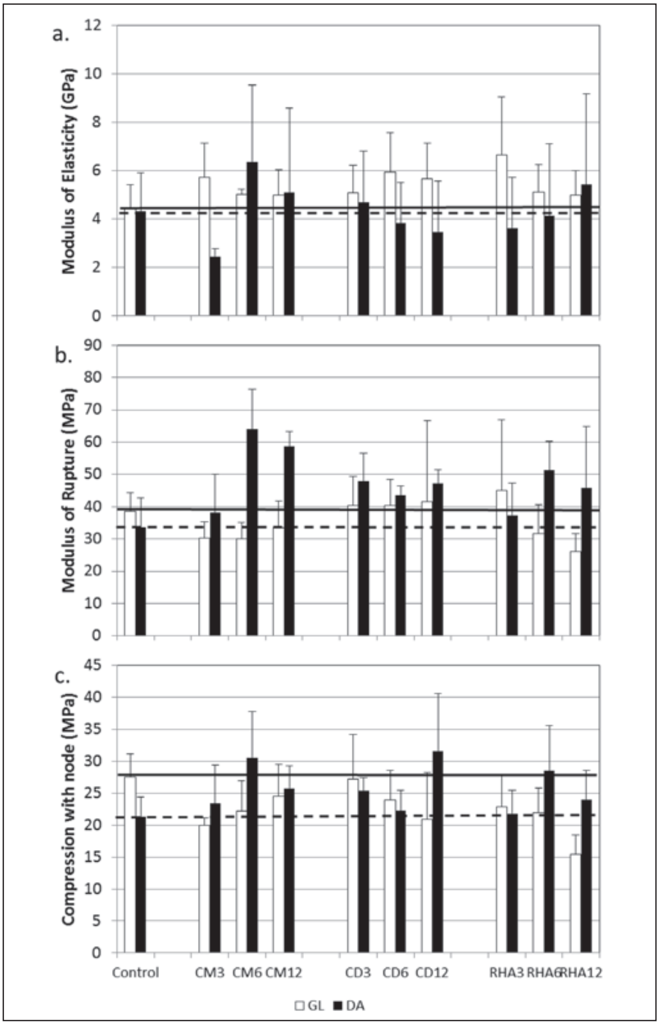

Figure 1. Mechanical properties of plantation-grown *Gigantochloa levis* and *Dendrocalamus asper* treated with organic fertilizers.

attributes of the culm were affected by the organic fertilizers and such response differed between the two species. As compared to the control, some traits were improved while others were reduced.

Factorial Analysis of Variance

The factorial analysis of variance was presented in Table 3. Regardless of MOE, MOR and MCS, variation between species gave the highest F-computed value. This showed that the organic fertilizer influenced the mechanical attributes of the two samples differently. However, among the three, only the variation in MOR was significant at 5%. The impact of the different fertilizers as well as its rate of application was observed to be non- significant. Also, the mechanical attributes were not considerably affected by the interaction between the three parameters combined (p=0.05).

Table 3. Factorial analysis of variance

	F - Computed			F-Tabulated
Sources of Variation	MOE	MOR	MCS	5%
Replicates	0.66ns	1.14ns	0.51ns	3.59
Treatments	0.40ns	1.18ns	0.80ns	2.31
Between species (A)	1.98ns	8.74**	3.55ns	4.45
Between fertilizer (B)	0.02ns	0.29ns	0.65ns	3.59
Between rate of application (C)	0.07ns	0.24ns	0.20ns	3.59
A x B	0.12ns	1.35ns	0.12ns	3.59
A x C	0.47ns	1.38ns	0.91ns	3.59
B x C	0.24ns	0.62ns	0.81ns	2.96
A x B x C	0.62ns	0.57ns	0.77ns	2.96

ns - not significant; ** - significant at 5% level.

Effect of organic fertilizer on mechanical properties

Mechanical properties of bamboos are normally age dependent (Chai and Wang, 1987; Espiloy, 1994) and position (base, middle, top) sensitive (Abd. Latif and Mohd. Zin, 1992). It deteriorates when the culm produces inflorescence (Kitamura, 1975) probably because the plant diverts most of the stored food in its stem to its flowers. The influence of the individual organic fertilizer on the mechanical properties of the samples was shown in Figure 2. The box and whisker plots showed scattering of values in all the traits that were measured. Based on the size of the box, scattering was more pronounced in *D. asper* (II) particularly in the MOE values (A). Taking for example CM of IIA, upper 25 percentile of the values fall within the range of 4.5 – 8 GPa while the lower 25% was from 4.4 – 4.5 GPa, a difference of about 4 GPa. The treatment with the least scattering can also be found in the MOE measurement specifically at CM of *G. levis* (I). Here, the values were between 4.5 – 4.8 GPa or a variation of only about 0.3 GPa. Looking at the median, it could be observed that CD gave a higher average

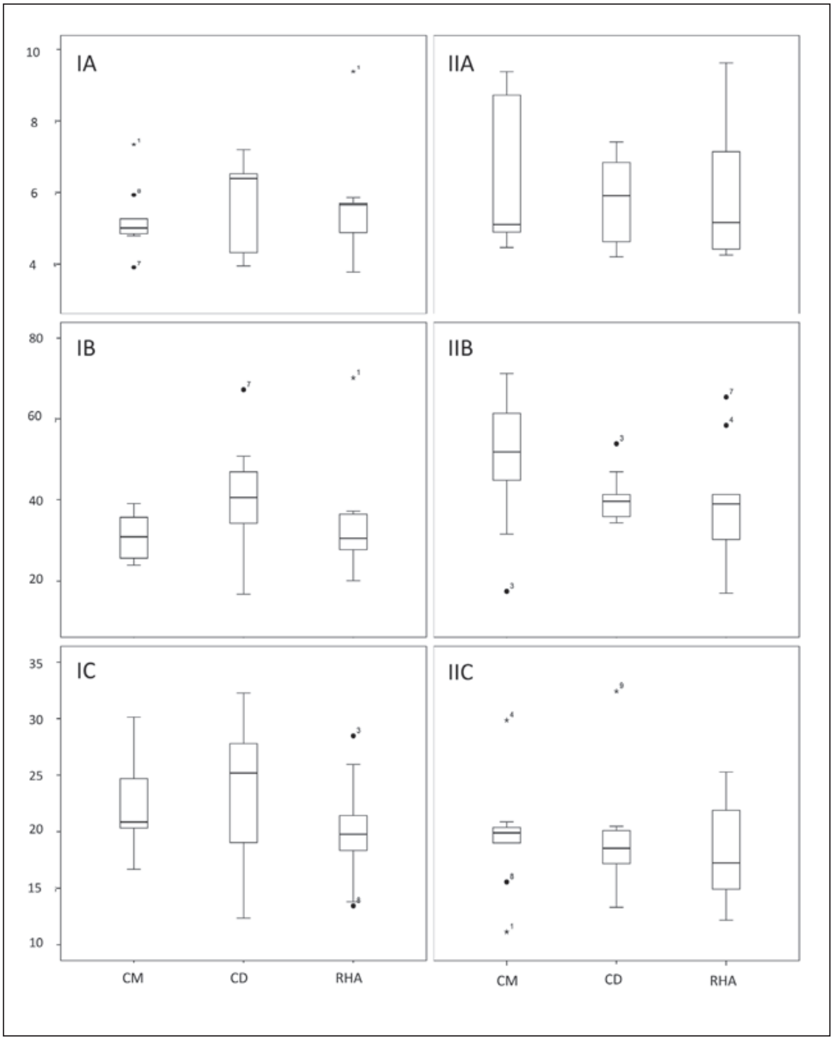

Figure 2. Influence of the organic fertilizer on the mechanical properties of the culms. I = *Gigantochloa levis*; II = *Dendrocalamus asper*; A = modulus of elasticity; B = modulus of rupture; C = maximum crushing strength.

irrespective of the species except in IIB and IIC where CM gave the highest average. However considering the whole area covered by the box, it was noticed that overlapping between boxes occurred. From this, it could be deduced that the variation in mechanical attributes caused by the three organic fertilizers on the two bamboo species was only minimal or was not significant because the box area fell within the range of each other.

Box and whisker plots were also prepared in order to determine the influence of the rate of application on the mechanical attributes of the bamboos (Fig. 3). Variation in values was again evident. The sample with the largest difference was observed in *D.*

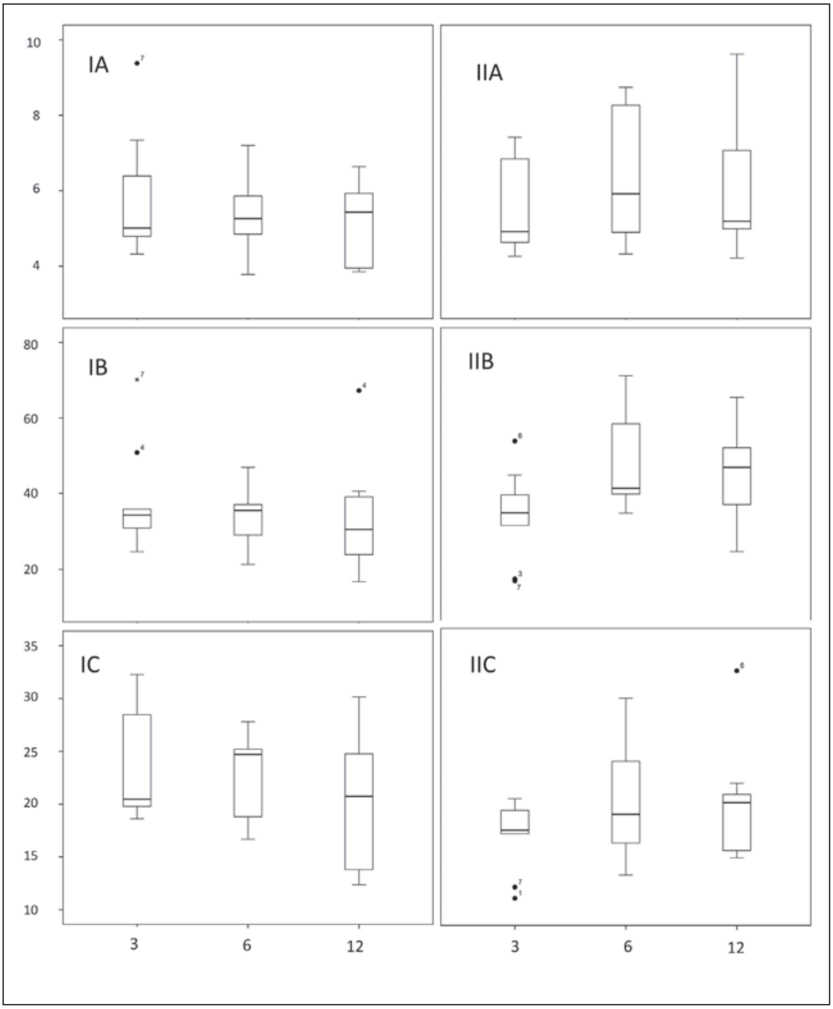

Figure 3. Influence of the rate of fertilizer application on the mechanical properties of the culms. I = *Gigantochloa levis*; II = *Dendrocalamus asper*; A = modulus of elasticity; B = modulus of rupture; C = maximum crushing strength.

asper for MOE values (IIA) while the least variation was in *G. levis* for MOR values (IB). Mean of the values showed that 50% has the tendency to increase with the amount of fertilizer applied where 12 kg/yr gave the highest average, while the other 50% had 6 kg/yr of fertilizer to be the highest. Nonetheless, overlapping of boxes was again noticed hence, the rate of application of fertilizer did not show any significant effect on the mechanical properties of the culm.

Influence of culm wall thickness and specific gravity on the mechanical properties

Culm wall thickness is related to the amount of vascular bundles and thus, influences the mechanical properties of the culm (Abd. Latif and Liese, 2002). It varies depending on its position along the length of the culm (Abd. Latif *et al*., 1993). The relationship between culm wall thickness and the mechanical traits of the two bamboo samples was depicted in Figure 4. The relationship between culm wall thickness and MOE was very strong for both species (Fig. 4a). They were inversely related with each other. These findings were similar to the observation of Abd. Latif and Mohd. Zin (1992) on *Bambusa* species.

Similarly, culm wall thickness was inversely related to the MOR of the samples (Fig. 4b). The two were moderately associated with each other. MOR is a reflection to the maximum load that the sample could carry before breaking. The results revealed that the thicker the culm wall, the lower was its ultimate strength, opposite to the findings of Abd. Latif *et al*. (1993) on *Bambusa blumeana*. Such differences could be attributed to structural variations between the bamboo species used in these two studies.

MCS was also negatively correlated to culm wall thickness (Fig. 4c), although the

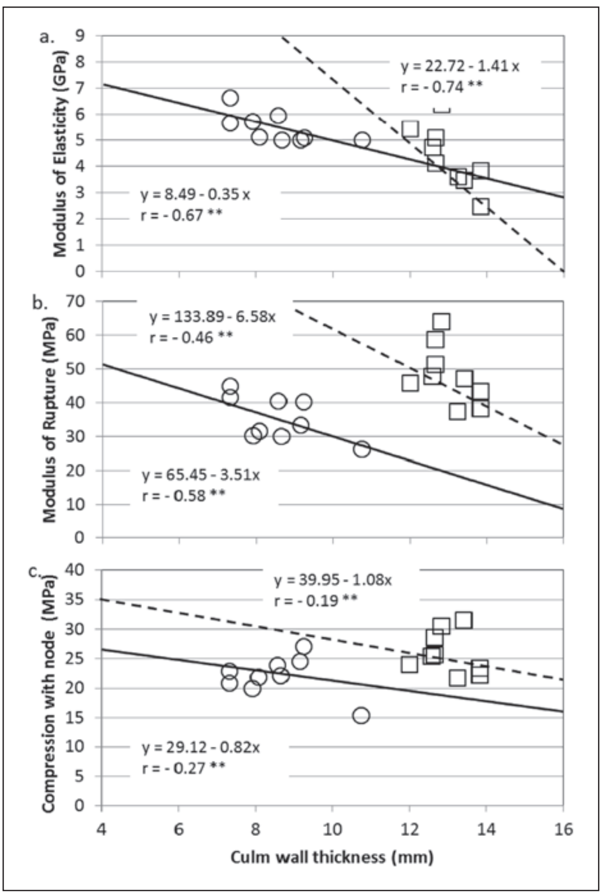

Figure 4. Effect of culm wall thickness on the mechanical properties of the culms. O = *Gigantochloa levis*; • = *Dendrocalamus asper*; ** = significant at 5% level; ns = not significant.

relationship of the two was a little weak (r = - 0.27 for *G. levis* and r = - 0.19 for *D. asper*) as compared to the two previous properties. In compression, the load would be parallel to the grain direction of the bamboos hence more tissues could withstand the increasing load. However just like ordinary columns, bamboo culms were very slender than they were wide, therefore buckling of the material could be expected. Upon application of the load, compressive strains result from the application of forces along the longitudinal direction followed by bending. Initially, strains in the longitudinal direction lead to a series of incomplete failure cause by the buckling of individual vascular bundles followed by the destruction of the embedding parenchyma cells (Spatz *et al*., 1997). In thick-walled culms, together with longitudinal and bending strains, shear strains would also be developed while in thin-walled culms, such strain is negligible (Spatz *et al*., 1995). For this reason, thick-walled culms were weaker in compression than thin-walled stems.

Specific gravity provides an indirect measure of the amount of cell wall substance present in the sample. As such, it provides an indirect gauge of the mechanical stiffness of the material (Haygreen and Bowyer, 1982). Interaction between stiffness and specific gravity of the two bamboo species was presented in Figure 5. Specific gravity

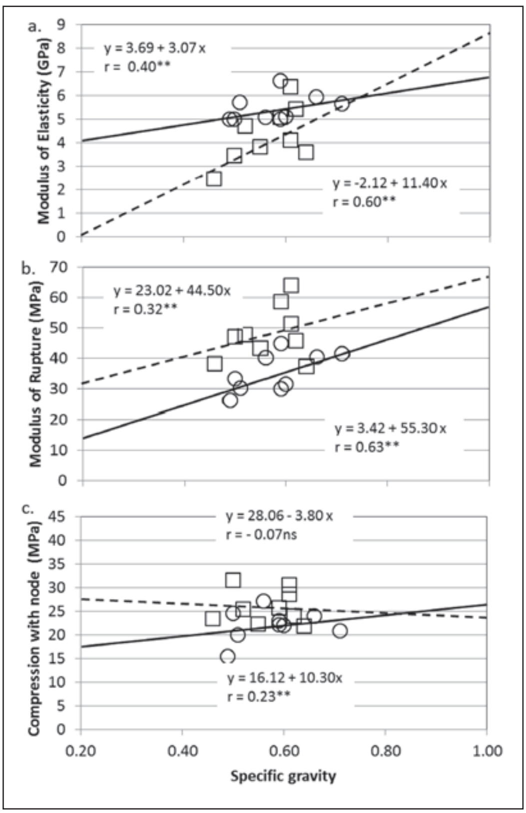

Figure 5. Effect of specific gravity on the mechanical properties of the culms. O = *Gigantochloa levis*; • = *Dendrocalamus asper*; ** = significant at 5% level; ns = not significant.

was positively correlated to all the strength properties measured in the study. This clearly showed the direct impact of specific gravity on the stiffness of bamboo, though its relationship with MCS was only minimal. However, the relationship was not significant. Bamboo culms will fail partially in compression and ultimately either by local buckling or by the splitting along length due to the ovalization of the cross-section (Spatz and Speck, 1994).

CONCLUSION

The mechanical properties of plantation-grown *Gigantochloa levis* and *Dendrocalamus asper*, were minimally affected by the application of organic fertilizers. Culm wall thickness and specific gravity played an important role in the MOE, MOR and MCS of the culms. Wall thickness negatively influenced culm strength while specific gravity was positively correlated to it. This means that the strength properties of the bamboo species were not sensitive to fertilizer application. Bamboo growers can apply cheap organic fertilizers on their bamboo plantations, it would definitely improve plant survival and shoot production without sacrificing the mechanical properties of its culm.

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