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INFLUENCE OF ABIOTIC FACTORS ON GROWTH AND DEVELOPMENT OF GIANT BAMBOO (*DENDROCALAMUS ASPER*) IN BUKIDNON, PHILIPPINES

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The study examines the gross morphology of giant bamboo (*Dendrocalamus asper*) relative to varying elevation, temperature, and relative humidity in five forest areas of Bukidnon province in the Philippines. Results revealed that variations in leaf sizes and the number of nodes and internodes among elevation ranges were not significant. However, the culm length of giant bamboo was significantly higher in the mid-elevation range (644–892 m asl) and lower elevation range (344–447 m asl) compared to culms in higher elevations. In addition, differences in culm diameter and culm thickness were significant showing larger diameter and thicker culms in the mid-elevation range (644–892 m asl) as compared to the higher (1117–1124 m asl) and lower (344–347 m asl) elevation range. The level of phosphorus and nitrogen was the highest in the mid and lower elevation range while potassium level was abundant in the highest elevations. Correlation analysis showed a negative relationship between culm lengths to elevation and relative humidity while mid and top section diameters were negatively correlated to temperature until 892 m asl. Leaf area and leaf width were strongly influenced by phosphorus level. The canonical correspondence analysis showed culm lengths were affected by relative humidity and elevation while the number of nodes and internodes, top and mid-section culm thickness, average diameter and basal section diameters were affected by temperature. Non-metric multidimensional scaling revealed that variation in bamboo morphology occured at the lowest and highest elevation while overall similarity was observed at 600–900 m asl elevation, suggesting an optimal growth for giant bamboo might be within the range.

Keywords: Tropical rain forest, species richness, tropical biodiversity

INTRODUCTION

The numerous use of bamboo is gaining wide acceptance as the best substitute material due to the limited supply and high cost of wood and wood products as a result of unfavorable policies and regulations affecting wood industries in the Philippines (Pulhin and Ramirez 2016). Bamboo is considered among the most important non-timber forest products in the country from its total production and export gain (Razal and Palijon 2009). Various household and light construction applications were produced at a minimal cost using bamboo and hence regarded as poor man's timber. In Bukidnon province, giant bamboo (*Dendrocalamus asper*) is a highly utilised and among the most economically important species of bamboo (Decipulo et al. 2009). Its culms are used as tomato plant stakes, poultry floors, bamboo shoot production, and in furniture industry as engineered bamboo which is gaining more prominence as a replacement for timber. Moreover, the demands of giant bamboo seedlings for forest restoration purposes continuously provide significant contributions in generating livelihood and rural employment in the region (Decipulo et al. 2009). In fact, bamboo was included among the high priority species to be used for the national greening program of the Philippine

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government (Aguinsatan et al. 2019). However, areas solely intended for bamboo plantations are limited because agricultural production is of high priority and constitutes much of the land-use. Generally, sources of culms are seldom in pure stands but from the naturally grown stands, in backyards, from patches to demarcate boundaries of farm lots, in riverbanks, marginal areas, and areas where agriculture is not feasible (Midmore 2009). These natural bamboo stands received no care and maintenance because they are treated as grass and can thrive ubiquitously. Therefore, silvicultural treatments and stand management interventions while observing the species ecophysiology in planting is not a common norm.

Plants alter their development, physiology and life history depending on the environmental conditions (Gratani 2014) and is referred as phenotypic plasticity. It is nearly ubiquitous and occurs in various animals and plants as expressed in their behavior, physiology and morphology. Phenotypic plasticity may be observed as adaptive and non-adaptive responses to the biotic or abiotic environments (Mooney & Agrawal 2008). Hence, environmental factors such as light, temperature, water and soil greatly influence plant growth. The study intended to evaluate the gross morphology of giant bamboo relative to different site conditions. The responses in the morphological structure would provide basic information to determine the influence of the abiotic factors on the growth and development of the plant including their physical and mechanical properties of the material. Optimal bamboo growth and suitability of the site could potentially become a basic guide to identify the ideal sites for growing giant bamboo and improving the productivity of bamboo farms in the area.

MATERIALS AND METHODS

Study site

Five areas in Bukidnon province in Mindanao, Philippines with different elevations were randomly selected as sampling sites (Figure 1). The lowest elevation ranges from 345 to 347 m asl while the highest elevation ranges from 1117 to 1124 m asl (Table 1). The climate condition of the area had no pronounced seasonal variability with dry season during November to April and wet season in the remaining months of the year (Parlucha et al. 2017). Selected bamboo stands were situated in bamboo dominated riparian zones with flat to undulating terrains.

Sample collection and measurements

Samples collected were from the bamboo stands ages from 3–5 years old and located at least 30 meters from any water bodies including in riparian areas. The stands were geotagged to determine their elevation. A total of 9 poles with 3 poles from different clumps per stand aging 4 years old were collected per sampling site. Every bamboo pole collected was subdivided into three sections such as basal, mid and top. The culm length was measured using metric tape while the culm wall thickness was measured using digital caliper. The measurement was replicated 8 times and an average reading was taken for the lower side and upper side of the sectioned culm. The diameters of each section were also measured using tree caliper while the number

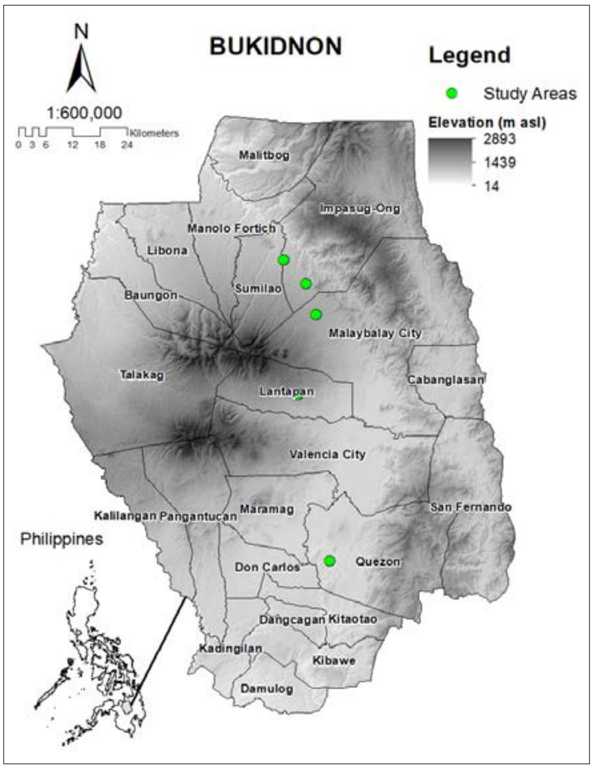

Figure 1 Location of the study area

Table 1 The geographic coordinates and elevations of the sampling sites

Location	Sample	Coordinates	Elevation (m asl)
1	1	7°42'17.0"N 125°04'25.0"E	345
	2	7°42'17.0"N 125°04'25.0"E	344
	3	7°42'17.0"N 125°04'25.0"E	347
2	1	8°18'25.0"N 124°59'03.5"E	651
	2	8°18'25.9"N 124°59'03.5"E	650
	3	8°18'25.9"N 124°59'02.9"E	644
3	1	8°18'25.9"N 124°59'02.9"E	777
	2	8°15'30.3"N 125°01'47.0"E	770
	3	8°15'30.3"N 125°01'47.0"E	765
4	1	8°11'49.1"N 125°02'56.9"E	890
	2	8°11'49.1"N 125°02'56.9"E	890
	3	8°11'49.5"N 125°02'56.2"E	892
5	1	8°02'18.0"N 125°00'46.0"E	1117
	2	8°02'18.0"N 125°00'46.0"E	1120
	3	8°02'18.0"N 125°00'46.0"E	1124

of nodes and internodes for each culm were counted manually.

A data logger was installed in every sampling site and positioned at 5 meters height from the ground within the bamboo stand to measure the daily fluctuations of temperature and relative humidity. Their averages were used to infer the relationship via correlation analysis.

Sample measurements

At least fifty fresh leaves were randomly collected in every bamboo stand from freshly cut bamboo poles. The leaf size indices consisted of length and width were measured using a caliper. The leaf area was determined using the following formula (Cain & De Castro 1959).

$$\text{Leaf area} = 2/3\ LW$$

where,

L = Leaf length measured from the base to the apex
W = Leaf width measured at the edge of the widest portion

Composite leaf samples of every sampling site were collected following standard leaf sampling protocol (Pond et al. 2006). Samples were stored in a sealed container and sent to soil and plant analysis laboratory to determine the nitrogen (N), phosphorus (P) and potassium (K) uptake of each bamboo stand.

Statistical analysis

One-way Analysis of Variance (ANOVA) and Pearson correlation analysis was performed in SPSS package Version 17.0 for Windows. Tukey's Honest Significant Difference (HSD) was used for post-hoc analysis. The Canonical Correspondence Analysis (CCA) and Non-metric Multidimensional Scaling (NMDS) were processed in PAST Software.

RESULTS AND DISCUSSION

Variations in leaf size indices

Leaf size indices of the various study sites were measured and the highest average length in leaves was found in elevations ranging 644–651 m asl and was followed by elevation range 890–892 m asl (Table 2). The lowest average leaf length was observed at elevation range 1117–1124 m asl. The highest leaf width was observed at elevation range 890–892 m asl while the lowest was observed at elevation range 1117–1124 m asl. The biggest leaf area was found in elevation range 890–892 m asl followed by 644–651 m asl range. The lowest average leaf area was observed in elevation range 1117–1124 m asl.

Data collection showed that plants in extremely high elevations had smaller leaf areas (Table 2). The observation supported the findings by Kudo et al. (2018) that bamboo leaf size had decreased at very high elevations. In general, plants in mountainous ecosystems showed a decreasing leaf area from the lowest to the highest elevation due to the variations of light, humidity and nutrient (Poorter 2009). Leaf size and other leaf morphological characteristics generally varied with climatic and edaphic conditions and together with altitude and latitude (Box 2012). Pervious research in the tropics showed that with increasing altitudes, leaf size usually decreased from mesophyllous in the lowland to notophyllous in the upper subalpine regions of Mt. Makiling, Philippines (Brown 1919), in New Guinea (Grubb 1974) and Mt. Kerinci, Indonesia (Ohsawa & Ozaki 1992). The changes in the leaf size from a larger to a smaller size generally followed a gradient from a more favorable habitat to a more stressful environment in the higher altitudes. This pattern was observed not only in large massifs but also in small mountains frequently covered with clouds (Whitmore 1984). Ohsawa (1995) emphasised that the changes in leaf size was also caused by various stress factors other than temperature. Besides environmental conditions, the phytogeographical nature of a locality could influence leaf size zonation.

Variations in culm length, culm diameter, culm thickness, nodes and internodes

Culm length

Data on average culm length revealed highly significant difference between culm lengths at different elevations (Table 2). The culms at the lower to mid-elevation range tend to be longer than the culms in higher elevation. The lower to mid-elevation average culm lengths was 25.33 cm to 29.97 cm while the highest elevation was only 23.67 cm. The culm lengths at elevation range 890–892 m asl did not differ statistically with the 344–347 m asl elevation range. The observation indicated that optimum growth in culms of giant bamboo could reach an elevation up to 900 m asl. The result might conform to the findings by Li et al. (2014) on the *Chimonobambusa utilis* where the culm length in mid-elevations was higher than those at the lower elevations implying that the growth was optimal at relatively mid-elevations of Jinfo Mountains in China. Bamboo situated at a high elevation range (1117–1124 m asl) obtained a lower culm length. A previous report also found that the lower culm lengths were contrasted with more branching and higher culm density

Table 2 Morphological characteristics of giant bamboo across the elevation gradient

Variables	F	Elevation (m asl)				
		344–347	644–651	765–777	890–892	1117–1124
Culm length	25.123***	29.97 ± 0.06^{a}	26.57 ± 0.85^{b}	25.33 ± 0.57^{bc}	29.60 ± 0.53^{a}	23.67 ± 1.76^{c}
Nodes	2.940^{ns}	74.00 ± 1.00	80.00 ± 5.20	78.00 ± 6.66	73.33 ± 2.58	68.00 ± 6.35
Internodes	2.940^{ns}	73.00 ± 1.00	79.00 ± 5.20	77.00 ± 6.66	72.33 ± 2.58	66.66 ± 6.35
Basal section diameter	3.702*	14.20 ± 1.65^{bc}	16.03 ± 1.05^{ab}	15.83 ± 0.76^{ab}	16.83 ± 0.76^{a}	13.57 ± 1.58^{c}
Mid-section diameter	177.905***	4.07 ± 0.70^{d}	9.673 ± 0.58^{c}	9.77 ± 0.67^{c}	15.23 ± 0.25^{a}	11.07 ± 0.11^{b}
Top section diameter	8.611**	2.67 ± 1.04^{c}	6.43 ± 1.40^{ab}	5.23 ± 0.25^{b}	7.95 ± 1.79^{a}	5.83 ± 0.47^{b}
Leaf length	0.624^{ns}	25.07 ± 2.49	26.03 ± 7.96	23.50 ± 1.57	25.87 ± 3.09	20.63 ± 6.27
Leaf width	2.953^{ns}	3.53 ± 0.53	3.47 ± 0.55	3.20 ± 0.36	3.87 ± 0.25	2.60 ± 0.62
Leaf area	1.280^{ns}	59.83 ± 13.45	62.42 ± 9.50	50.62 ± 8.79	67.33 ± 11.8	37.66 ± 17.99
Top section thickness	3.237^{ns}	7.23 ± 0.79	7.57 ± 1.09	8.00 ± 0.30	8.57 ± 0.49	7.15 ± 0.44
Mid-section thickness	4.352*	10.60 ± 0.71^{ab}	8.88 ± 0.75^{b}	12.03 ± 1.06^{a}	11.17 ± 0.33^{a}	10.42 ± 1.38^{ab}
Basal section thickness	7.497**	17.83 ± 0.42^{c}	25.78 ± 3.93^{a}	22.18 ± 1.81^{ab}	23.30 ± 2.76^{a}	18.353 ± 3.26^{bc}

df = 10 in all cases, F = statistic value; ^{ns} = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.0001$
Means with the same letter were not significantly different
Means with superscript a is significantly higher than b, c & d

as a response to severe conditions in higher elevations (Kudo et al. 2018)

Culm diameter, culm thickness, number of nodes and internodes.

The average diameter and culm thickness in the basal section diameters among the five elevation gradients showed significant difference (Table 2). The biggest culm diameter in the basal section was recorded at elevation range 890–892 m asl while the lowest was observed at elevation range 1117–1124 m asl. The thickest culm was found at elevation range 644–651 m asl, while the thinnest was at elevation range 344–347 m asl. A significant difference in culm diameter and culm thickness was also observed for the mid-section as the biggest diameter was recorded at elevation range 890–892 m asl while the smallest diameter was observed at elevation range 344–347 m asl. The thickest culm was observed at elevation range 765–777 m asl while the thinnest was observed at elevation range 1117–1124 m asl. In the top section diameter, results revealed significant difference in the biggest diameter observed at elevation range 890–892 m asl while the smallest diameter was found at elevation range 344–347 m asl. Statistical analysis revealed no significant difference for the top section thickness where the thickest culm was observed at elevation range 890–892 m asl while the thinnest was at elevation range 1117–1124 m asl. Results from the findings implied that the most ideal site for giant bamboo to obtain a larger diameter and thicker culms should be at an elevation range of 600–900 m asl. Giant bamboo in the mid-elevation range tended to have thicker culms and larger diameters compared to those that were planted in low (344–347 m) and high elevation (1117–1124 m). The same observations were also found in Moso bamboo-dominated plantations in Anji and Muchuan provinces in southern China where higher productivity in culms was found in elevations between 500–1000 m asl range (Mertens et al. 2008). The results of this study contradicted the findings from Li et al. (2014) which concluded that the basal diameter of *C. utilis* bamboo was significantly high at higher elevations. However, trait responses of plants to elevational gradients were population-specific (Pfennigwerth et al. 2017). *C. utilis* was dominant species within the altitudinal belt 1300–2200 m while Giant bamboo thrived in the lower-mid elevation range which explained the variation in the response of both species (Li et al. 2014). Bamboo culm with the numerous nodes and internodes was also observed at mid-elevation range 644–651 m asl and at elevation range 765–777 m asl. The lowest number of nodes was observed at the 1117–1124 m asl range. The study results revealed seemingly the reduction of the number of nodes and internodes at a higher elevation but analysis showed reduction no significant difference among the five samples (Table 2). Li et al. (2014) reported a pronounced reduction of nodes and internodes from lower to higher elevations for *C. utilis.* The huge influence of elevation gradient on the morphology of plants was explained by effect of temperature change. The changes were critical to plant growth and development of tissues where they could cause morphological variations such as a decrease in plant size (Jiménez-Noriega et al. 2017). Based on the findings of the study, the reduction was not continuous from the lowest elevation towards the highest. Instead, the reduction was exhibited when the plant exceeded its optimal growth range both in the lower and higher elevation range. Similar to other plants, the sufficient changes in temperature and other abiotic factors such as precipitation, solar radiation and their interactions will determine the productivity of bamboo in a certain region (Li et al. 2020).

Nutrient uptake

The highest nitrogen content was found in the leaf samples collected at elevation range 890–892 m asl while the lowest was content at elevation range 644–651 m asl (Figure 2). High nitrogen content was found in low elevation range 344–347 m asl and the findings did not show a distinct pattern of nitrogen across elevational gradient except for a continuous increase from 644 to 892 m asl. Leaf nitrogen was known to increase with elevational gradient and thus affecting the plant by increasing the photosynthetic capacity and decreasing CO_2 concentrations (Sparks & Ehleringer 1997). Nitrogen concentration in high elevation

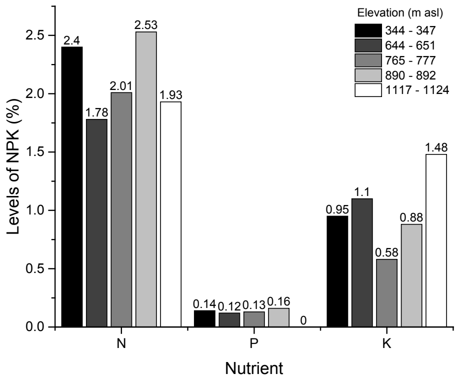

Figure 2 Levels of leaf nitrogen (N), phosphorus (P) and potassium (K) in giant bamboo in various elevation range

areas was a result of high soil nitrogen pools which were accumulated from the reservoir of organic matter slowly decomposing because of the colder temperatures (Bonito et al. 2003).

The highest phosphorus content was obtained from leaf samples in elevation range 890–892 m asl and followed by the samples from elevation range 344–347 m asl (Figure 2). However, there was no significant differences for the values in the elevation range from 344–892 m asl and the samples from elevation range 1117–1124 m asl were found to be below the detection level. Negative correlations of phosphorus and elevation were reported by Liu et al. (2013) across the entire Loess Plateau region of China. Similar observations were reported in Hawaiian montane forest between elevation range 760–1585 m asl (Vitousek et al. 1988), tropical montane forest in Ecuador at 1900–3000 m asl elevation range (Soethe et al. 2008) and in mountain ecosystem of southwestern China at 2032–4235 m asl elevation range (Zhou et al. 2016). The changes in phosphorus content across elevational gradient was similar to nitrogen which was governed by the decreasing decomposition rates of organic matter as temperature decreases in higher elevations and with the influence of vegetation regulating the concentration of phosphorus (Zhou et al. 2016).

The level of potassium was found highest in the samples collected at elevation range 1117–1124 m asl, while the lowest content level was at 765–777 m asl range (Figure 2). However, it did not show any distinctive pattern or relationship with elevation. The same observation was also noted in leaf

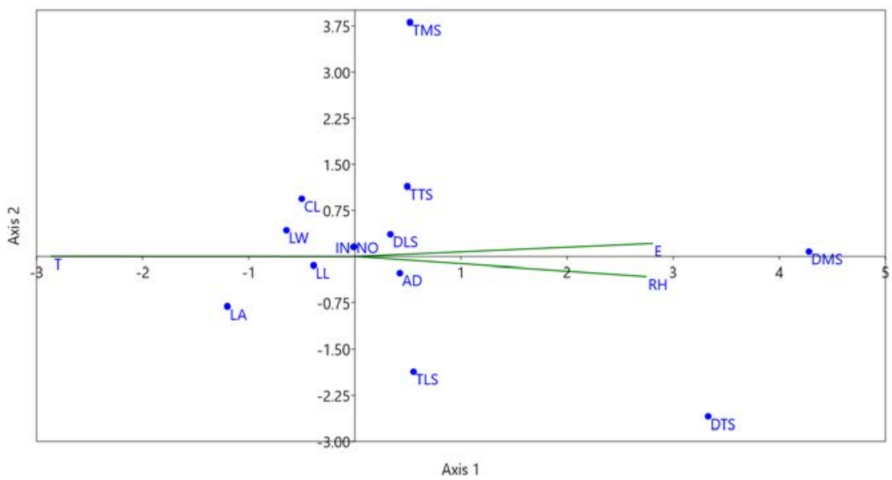

Figure 3 Canonical correspondence analysis of the culm and environmental variables

E = elevation, T = temperature, RH = relative humidity, CL = culm length,
NO = nodes, IN = internodes, DLS = diameter lower section,
DMS = diameter at the mid-section, DTS = diameter at the top section,
LL = leaf length, LW = leaf width, LA = leaf area,
TTS = thickness at the top section, TMS = thickness at the mid-section,
TLS = thickness at lower section, AD = average diameter

potassium concentration of altitudinal gradients in the mountain ecosystem of Beijing which was explained by the non-limiting influence of soil to leaf potassium content (Jian et al. 2009). Potassium is an important nutrient in plants that activates specific enzymes during photosynthesis, in respiration and also facilitates internal regulation by osmotic potential and stomatal control (Salisbury & Ross 1991).

Abiotic effects on plant morphology

The relationship among variables and its effect on the overall morphological attributes of giant bamboo was depicted through canonical correspondence analysis. Results revealed that both humidity and elevation influenced the diameter and thickness while the temperature seemingly affected the number of internodes, leaf attributes and culm thickness of giant bamboo (Figure 3). Phosphorous and nitrogen had direct effects on the leaf width, area and length while potassium seemingly influenced the number of nodes, internodes, top section diameters and average diameter (Figure 4).

Correlation analysis result showed that the factor of elevation and relative humidity were negatively correlated with the culm length (Table 3). Temperature factor on the other hand was directly correlated with culm length. As elevation and relative humidity increased and temperature decreased along the elevation gradient, bamboo culm length tended to decrease. These observations were also observed in the study by Wen et al. (1999) which found that the culm height and diameter of *Bashania spanostachya* decreased with increasing elevation gradient. Moreover, the culm length was positively correlated with nitrogen and phosphorous respectively (Table 3). Nitrogen and phosphorous were macroelements and highly needed by plants in large amounts. The increased level of nitrogen and phosphorous had profound effect on the gross morphology of plants which in this case exhibited in culm lengths of giant bamboo. The study by Shanmughavel et al. (1997) on the phosphorous application to *Bambusa bambos* revealed that high rate of phosphorous and nitrogen supplied to the soil caused bamboo species to increase their ability to store nutrients in their tissues, especially in the culms and the production of wider leaf

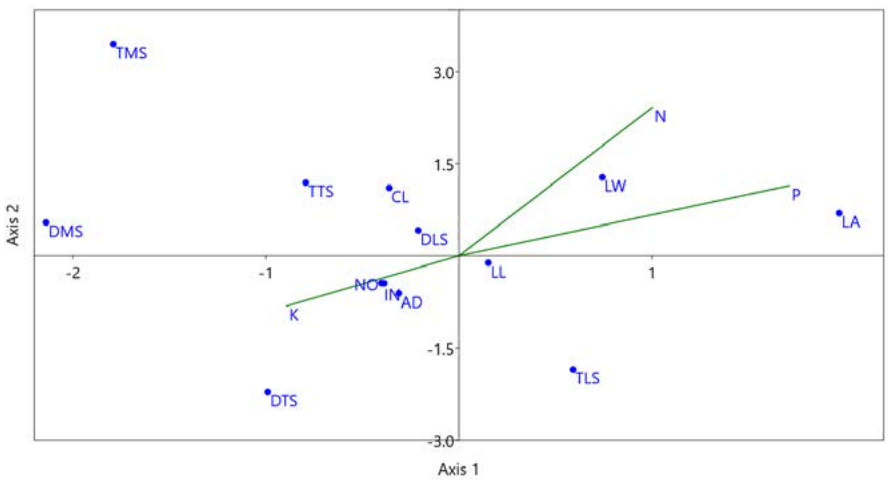

Figure 4 Canonical Correspondence Analysis (CCA) showing the influence of the macroelements to the morphological variations of giant bamboo

N = nitrogen, P = phosphorous, K = potassium, CL = culm length, NO = nodes, IN = internodes, DLS = diameter lower section, DMS = diameter at the mid-section, DTS = diameter at the top section, LL = leaf length, LW = leaf width, LA = leaf area, TTS = thickness at the top section, TMS = thickness at the mid-section, TLS = thickness at the basal section, AD = average diameter

Table 3 Pearson's R correlation matrix and corresponding p-value between morphological attributes of giant bamboo and abiotic factor

Variables	Elev	p-val	Temp	p-val	RH	p-val	N	p-val	P	p-val	K	p-val
Culm length	-0.627*	0.012	0.522*	0.46	-0.646*	0.009	0.782*	0.001	0.759*	0.001	-0.373	0.170
No. of nodes	-0.401	0.139	0.363	0.184	-0.313	0.257	-0.188	0.502	0.492	0.063	-0.462	0.083
No. of internodes	-0.401	0.139	0.363	0.184	-0.313	0.257	-0.188	0.502	0.492	0.063	-0.462	0.083
Basal section diameter	-0.019	0.946	-0.089	0.752	-0.001	0.997	0.152	0.589	0.567*	0.027	-0.480	0.070
Mid section diameter	0.770*	0.001	-0.852*	0.000	0.743*	0.002	0.082	0.771	-0.041	0.885	0.046	0.870
Top section diameter	0.596*	0.019	-0.677*	0.006	0.648*	0.009	-0.052	0.854	0.009	0.975	0.074	0.793
Leaf length	-0.280	0.312	0.237	0.395	-0.233	0.403	0.164	0.558	0.399	0.141	-0.224	0.423
Leaf width	-0.393	0.147	0.306	0.267	-0.379	0.163	0.465	0.081	0.688*	0.005	-0.421	0.118
Leaf area	-0.320	0.245	0.257	0.355	-0.277	0.318	0.296	0.284	0.522*	0.046	-0.281	0.310
Thickness top section	0.139	0.622	-0.272	0.326	0.065	0.818	0.341	0.213	0.478	0.072	-0.470	0.077
Thickness mid section	0.133	0.637	-0.156	0.578	-0.122	0.665	0.372	0.172	0.163	0.561	-0.486	0.066
Thickness lower section	0.033	0.906	-0.151	0.592	0.176	0.530	-0.245	0.379	0.389	0.152	-0.274	0.323
Average diameter	0.004	0.990	-.133	.636	0.119	0.673	-0.260	0.349	0.518*	0.048	-0.485	0.067

* = values were significant at = 0.05 level
Elev = elevation, Temp = temperature, RH = relative humidity, N = nitrogen, P = phosphorus, K = potassium

and bigger leaf area. Similarly, Piouceau et al. (2014) studied the effects of high-nutrient treatment on the seven species of bamboo and found that the increase of phosphorous and nitrogen levels affected the number and length of culms produced whereas the culm diameter was significantly larger than the control. Azmy et al. (2004) reported that the application of phosphorous fertiliser on *Gigantochloa scortechinii* had increased the culm diameter, height and diameter of bamboo and the number of shoots produced.

The elevation and relative humidity were positively correlated with the mid and top section diameters, indicating that an increase in the mid and top section diameters with the increasing elevation and relative humidity (Table 3). On the other hand, temperature showed a negative correlation with mid and top section diameters, suggesting that a decrease in temperature tended to increase the diameter mid and top section. It was important to note that the increase was relatively found only until at 892 m asl and a sudden drop in diameter was observed at 1100 m asl elevation. The observation proposed that the negative correlation was not absolute across elevation gradient and the increase in diameter would not continue beyond its optimal range. The increasing culm dimensions with elevation or altitude gradient were also observed in Moso bamboo propagated in Taiwan resulting in more productive plantations in higher elevations (Chen et al. 2014). However, its productivity was reported to be delimited by elevation as yields of the same bamboo species had decreased beyond 1000 m asl elevation as observed in southern China (Mertens et al. 2008). The morphological change across elevation gradient and higher productivity in mid-elevations could be explained by photosynthetic activity. The

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concentration of non-structural carbohydrate which was the product of photosynthesis was essential to the growth and adaptation of plants (Körner 2003). Abiotic conditions influenced photosynthetic activity and plant nitrogen concentrations thereby regulating non-structural carbohydrate production. The interplay of factors were expressed in the various ways of partitioning assimilates into structural components in plants (Millard et al. 2007, Qi et al. 2020). The assessment of photosynthetic activity of giant bamboo in varying elevations, therefore should be further assessed in future research.

The result of the non-metric multidimensional scaling (Figure 5) further confirmed that the gross morphology of the giant bamboo was affected by temperature and relative humidity as showed by the culms collected from higher elevation (1117–1124 m asl) and lower elevation range (344–347 m asl) and represented by A & E, respectively. The former study site had lower temperatures and high relative humidity contrary to the latter and both site conditions showed extreme dissimilarity against site B, C & D. In the study, the variation in morphology occured at the lowest and highest elevation while overall similarity was observed at the 600–900 m asl elevation range indicated by B, C and D. The findings implied that the optimum growth for giant bamboo could be achieved at 600–900 m asl.

CONCLUSIONS

Results from the experiments confirmed that temperature, relative humidity and elevation had significant effect on the majority of the morphological traits of giant bamboo. There was no significant difference observed on the leaf size indices, eventhough the leaves tended to decrease as elevation increases. However, there was significant difference in terms of culm length, mid-section culm thickness, basal section culm thickness and diameters between the higher and lower elevations but not in nodes and internodes of giant bamboo. The results indicated the most ideal elevation for giant bamboo optimal growth should be at elevations ranging from 600 to 900 m asl and should be considered as the basis in the selecting giant bamboo planting sites.

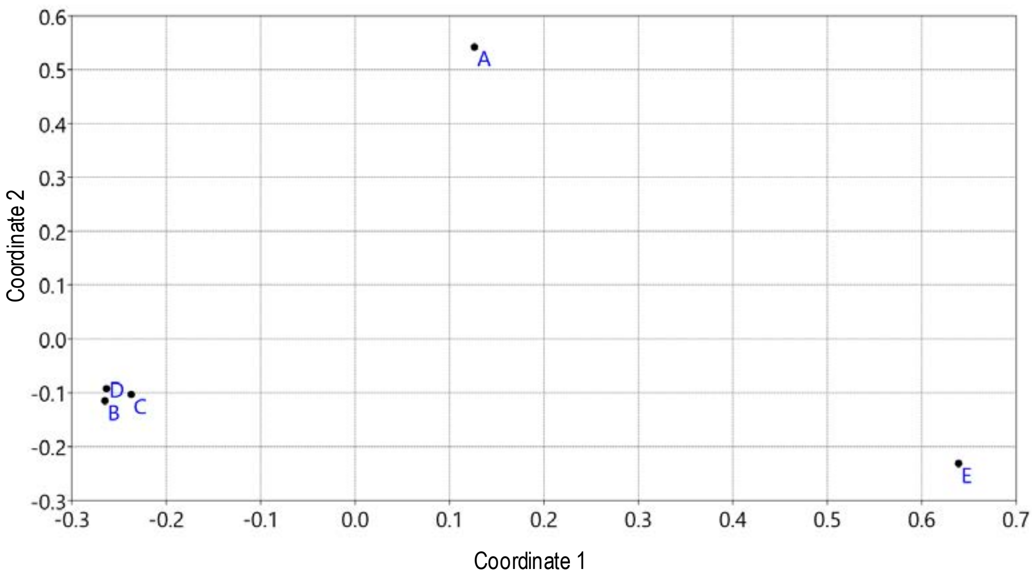

Figure 5 The non-metric multidimensional scaling using Bray-Curtis index to discriminate similarities and differences among the study sites using the environmental variables and culm attributes of giant bamboo

A = 344–347 m asl, B = 644–651 m asl, C = 770–777 m asl, D = 890–892 m asl, E = 1117–1124 m asl

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