Growth response of *Dendrocalamus asper* on elevational variation and intra-clump spacing management

AQMAL NUR JIHAD, BUDIADI♥, WIDIYATNO

Department of Silviculture, Faculty of Forestry, Universitas Gadjah Mada. Jl. Agro No. 1, Bulaksumur, Sleman 55281, Yogyakarta, Indonesia.
Tel.: +62-274-512102, 6491420, Fax.: +62-274-550541, ♥email: budiadi@ugm.ac.id

Abstract. *Growth response of* Dendrocalamus asper *on elevational variation and intra-clump spacing management. 2021. Title. Biodiversitas 22: 3801-3810.* Dendrocalamus asper (Schult. Schult. F.) Backer Ex. K. Heyne is a well-known commodity classified as a non-timber forest product (NTFP) to substitute wood-based products in the future. While bamboo is widely distributed in various habitats, and it could impact growth performance and quality. Nevertheless, the development of bamboo research on the upstream level is quite rare, specifically for clumping bamboo species. Therefore, our study aimed to reveal the performance in elevational variation and to discover the intra-clump spacing and diameter relationship. The elevational variation was divided into three levels, which were lower, middle, and higher levels. Each elevation was established in 9 plots with parameters observed were culm diameter at breast height (DBH), culm height (H), and culm volume (V) of *D. asper*. The intra-clump spacing was used to assess the relationship between the clump density and diameter growth. The research is complemented with in-depth interviews to explore the traditional silvicultural practices of *Dendrocalamus asper* and spatial analysis to generate land surface temperature and soil moisture index. The result showed that there is no effect ($P > 0.05$) of elevational variation to *D. asper* growth and development, while the availability of intra-clump spacing showed a significant result ($P < 0.05$) on the culm DBH of *D, asper*. Furthermore, our result suggests a wider intra-clump spacing (0.4-0.6 m^2) is more recommended than a narrow intra-clump spacing for optimal culm diameter growth. Additionally, bamboo plantation was still less managed and utilized. Therefore, improving the productivity of *D. asper* by maintaining plantation, i.e., fertilizing, managing spacing among clump bamboo, and harvesting to achieve sustainable development of the bamboo plantation is useful.

Keywords: *Dendrocalamus asper,* intra-clump spacing, elevational variation, silviculture of bamboo

INTRODUCTION

Bamboo is an important commodity that is classified as a non-timber forest product referred to as the material of building and industries in the future (Hossain et al. 2015; Kaur et al. 2016). Bamboo can contribute as an income resource of rural communities (Hogarth and Belcher 2013), carbon storage (Li et al. 2016; Liu and Yen 2021), and others ecosystem services (Muñoz-lópez et al. 2021). Globally, bamboo consists of 1,662 bamboo species, while the bamboo plantation was estimated to cover 35 million Ha around the world (Canavan et al. 2016; FAO 2020).

One of the popular bamboo species with various uses in Indonesian community forests is *Dendrocalamus asper*. *Dendrocalamus asper* (Schult. Schult. F.) Backer Ex. K. Heyne can be used as an option for wood-based products (Chaowana 2013). Furthermore, the wide range of bamboo benefits namely, copper absorber, rehabilitation and phytoremediation plant species, nutrient source, biomass sequestration, and to reduce soil erosion and nutrient leaching (Soejono et al. 2013; Nirmala et al. 2014; Chua et al. 2019; Durai and Long 2019; Go et al. 2019; Bian et al. 2020). Thus, the large scale of Bamboo (i.e. *D. asper*) could improve economic, social, and ecosystem services (Hogarth and Belcher 2013; Yuen et al. 2017; Ramakrishnan et al. 2018).

The distribution of *D. asper* ranged from lowland to upland (up to 2000 m asl./meter above sea level)

(Zulkarnaen 2015). Consequently, the variations among environmental factors may affect bamboo's growth, for instance, the emergence of bamboo shoots or culm, internode length, and diameter size (Banik 2015b). Besides, the adjustment of clump at the feasible quality and quantity influenced the growth of bamboo (Durai and Long 2019). Therefore, understanding the vertical and horizontal structure should be embedded in bamboo clump management to achieve effective bamboo sustainability management (Banik 2015b).

However, there is inadequate research intervention regarding the effect of environmental variations on *D. asper* growth and development. Previous studies showed that the study of bamboo was dominated by postharvest research during 1994-2019, i.e., tensile testing, strength properties, bending strength, physical and mechanical properties, several chemical compounds, post-harvest products (Nurhazwani et al. 2016; Srivaro and Jakranod 2016; Kadivar et al. 2019; Suryadi et al. 2019; Widodo et al. 2019). The growth of bamboo was affected by environmental factors i.e., altitude and temperature (Sonboon 2001) and clump density (Mera and Xu 2014). For instance, the growth of moso bamboo (*Phyllostachys edulis*) in elevation 1,400 m asl was higher than 1,000 m asl (Chen et al. 2014). Then, standing culm density would enhance shoot production and the growth of bamboo (Mera and Xu 2014; Bahru et al. 2021).

Additionally, the habitat loss and intensive harvesting of bamboo could potentially place bamboo species on extinction threats (Hakim et al. 2002). Therefore, research on elevational variation and relationship of intra-clump spacing management and traditional silvicultural practices on bamboo growth and development is essential to improve the productivity of bamboo plantations. Our objectives were as follows: (i) revealing the performance of *D. asper* growth among elevational variation and intra-clump spacing and (ii) discovering the relationship between diameter and intra-clump spacing on *D. asper*.

MATERIALS AND METHODS

Study area

The research was conducted at Sleman District, Yogyakarta, Indonesia. The experimental site was established in a random mix planting pattern, whereas the bamboo plantation was relatively dominant in their community plantation. Accordingly, the random mix planting was not associated with specific species, while several valuable species according to community and market perspective were planted by the community, such as *Paraserianthes falcataria*; *Artocarpus altilis*; *Leucaena leucocephala; Cocos nucifera, Gliricidia sepium, Gnetum gnemon*, and other bamboo species.

The research site was located at 110° 33′ 00″ and 110° 13′ 00″ E, 7° 34′ 51″ and 7° 47′ 30″ S. An average of 15 years annual precipitation of the area was up to 2758,47 mm per year (BMKG 2015, unpublished data). According to Sleman District official data (2021, unpublished data) total area of Sleman was 57.482 ha which was divided into 17 sub-districts. Based on topography, the southern side was relatively flat while the higher altitude would be found with the higher steep at northern side due to Mount Merapi. Furthermore, the altitude was vary, ranged from below 100 m asl. and above 1.000 m asl.

The field experiment was established with a randomized complete block design where the main plot was an elevational gradient. Accordingly, the research sites were distributed into three elevations, namely, lower elevation (<499 m asl.), medium elevation (500-999 m asl.), and higher elevation (>1,000 m asl.).

Procedures

Biometric data totaling 27 plots (9 plots per elevation, 1-2 clump per plot, and 227 culms on average) were collected to determine the number of parameters such as culm height (H, m), culm diameter at breast height (DBH, cm), culm volume (m^3), and intra-clump spacing (m^2). A total of 27 bamboo clumps were observed with an intra-clump spacing that ranged between 0.0001 m^2 to 0.6 m^2. Measurement of intra-clump spacing approached by calculating of total area of the clump divided by the number of culms. However, these intra-clump spacing variations are non-operational values. To facilitate analysis, we conducted an experiment by classifying it into 3 classes of intra-clump spacing, which were mainly, narrow (<0.19 m^2), intermediate (0.2-0.39 m^2), and wide ($\geq$0.4 m^2). We gathered additional data, such as traditional silvicultural practices and environmental conditions (land surface temperature and soil moisture index) as complementary data. Ecological data was obtained from spatial analysis using Landsat-8 (path 120, row 65), which was acquired on May 20, 2020.
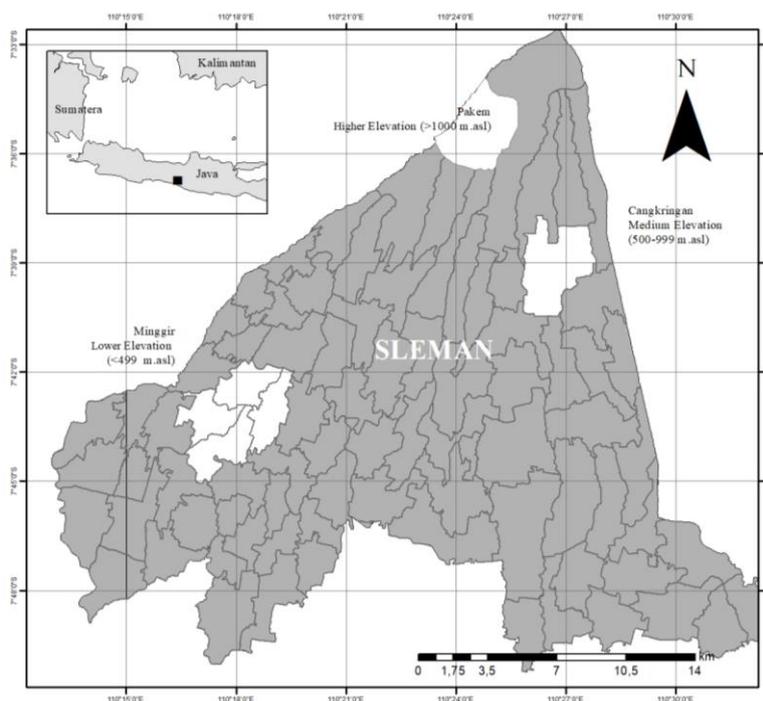

Figure 1. Location of the study area in Sleman District, Yogyakarta, Indonesia

Data analysis

Diameter at breast height (DBH, cm) was the diameter of bamboo measured at 1.3 m, and the culm height (H, m) was measured using Haga altimeter which is a tree height measuring tool based on the angle between altimeter position to the top in a certain length from the object. Meanwhile, the culm volume (V, m³) of each bamboo culm was calculated using the following formula:

$$V_{bamboo} = DBH_{culm}^2 - (DBH_{culm} * 0.7)^2 / 4 * \pi * H_{length} * F_{bamboo} \ldots\ldots (1) \text{ (MoEF and FAO 2007)} \qquad (1)$$

Where: DBH: Diameter(m); π: 3.14; H: height (m); F: correction factor for bamboo (0,8)
Furthermore, the clump basal area was calculated following the formula:

$$BA = \pi * (DBH_{clump}^2) * 0.25 \qquad (2)$$

Where: BA: basal area (m²); π: 3.14; DBH_{clump}: clump diameter (m).

The data were analyzed using SAS v.9.0 software using analysis of variance (ANOVA). Suppose the result indicates that there is no significant effect of elevational variation on growth and development of bamboo clumps. Here the analysis is continued separately, and elevational variation is no longer used as a variable in the second ANOVA analysis stage to test the effect of the available intra-clump spacing classes. The difference between treatments was analyzed using a Duncan Multiple Range Test (DMRT) at a significance level of 5%. Regression analysis was conducted to determine the relationship between intra-clump spacing and culm DBH. Diameter is a critical parameter in assessing the effectiveness of intra-clump spacing in a clump, so that the regression analysis was performed on diameter.

The analysis of supporting data related to environmental data, both temperature, and soil moisture, was carried out with the spatial analysis of Landsat-8, which was equipped with a thermal sensor. The land surface temperature and soil moisture index data obtained were used as materials for correlating analysis on the three variables, namely height, diameter, and volume. The channel bases used in image processing include channel 4, channel 5, channel 10, and channel 11. Soil moisture index (SMI) data was based on the relationship between land surface temperature (LST) and the normalized vegetation index (NDVI). The number of equations in the analysis refers to Potic et al. (2017) cited by Tajudin et al. (2021), as follows:

$$SMI: (LST_{max} - LST) / (LST_{max} - LST_{min}) \qquad (3)$$

Where LST is land surface temperature, while maximum LST and minimum LST were obtained from NDVI data through this formula:

$$LST_{max} = a_1 * NDVI + b_1 \qquad (4)$$
$$LST_{min} = a_2 * NDVI + b_2 \qquad (5)$$

Where a_1, a_2, b_1, dan b_2 are empirical parameters. There are two required parameters, namely, LST and NDVI. And LST was obtained from the following equation:

$$LST = Tb / (1 + (\lambda * Tb / c2) * \ln (e)) \qquad (6)$$

Tb is satellite brightness temperature, λ is the wavelength of emitted radiance, $c2 = 1.4388 * 10^{-2 \text{ m}}$ K and e = emissivity (typically 0.95). Tb was obtained from the following equation:

$$Tb = (K2 / Ln (K1 * e / L + 1)) \qquad (7)$$

The values of K and L were constants obtained from sensors and conversion calculations for each metadata file Landsat 8. Meanwhile, to obtain NDVI data was obtained through the following equation:

$$NDVI = (NIR - Red) / (NIR + red) \qquad (8)$$

Where the NIR and Red values are derived from channels 4 and 5, SMI data obtained would range from 0 to 1, which can be interpreted as 0 for areas with low humidity and 1 for areas with high humidity and tend to be wet.

The status of traditional bamboo silvicultural practices

In this study, traditional silvicultural practices refer to how the community manages or treats the *D. asper* clumps. Traditional bamboo management can be grouped into several aspects: land preparation, planting, maintenance, pest control, and harvesting (Irawan et al. 2019).

Traditional silvicultural practices were obtained through in-depth interviews with 15 key-informant persons, dominated by bamboo clump owners. Key-informant person criteria include (i) full enculturation, (ii) involvement, (iii) availability of time, (iv) neutrality, and (v) readiness to provide information (Spradley 2007).

Inteview on traditional silviculture encompasses the stages of traditional bamboo management by the owners. The results of in-depth interviews were analyzed through several stages such as data reduction, thematic connection, and data interpretation (Seidman 2015).

Overall, in-depth interview was conducted to create narrative (Bariyah 2020), thus the qualitative analysis synthesizes the complete figure of traditional silvicultural practices of *D. asper* applied by the community based on the results of interviews. Furthermore, the output of the qualitative analysis found that the traditional *D. asper* clump management cycle was a closed cycle.

RESULTS AND DISCUSSION

The effect of elevational variation and intra-clump spacing to *D. asper* growth

Spatial analysis from Landsat-8 showed that research sites have different environmental conditions. The higher temperature was found on the southern side, which has a lower elevation, while the SMI shows the highest value on the northern side. This significant difference was shown in

Figures 2 and 3, either temperature ($P < 0.05$) or SMI ($P < 0.05$) due to the difference in altitude. The temperatures in the lower, medium, and higher elevations were 21.39°C, 20.22°C, and 18.51°C, respectively, while the SMI in the low, medium, and highlands is 0.21, 0.26, and 0.34.

Our result elucidated that the elevational variation of bamboo's site plantation does not affect the culm height, culm diameter, and volume per individual of *D. asper* culm diameter ($P > 0.05$, Table 1). The culm height of *D. asper* in the lower, medium, and higher elevation was 17.28 ±

0.99 m, 16.38 ± 2.53 m, 15.42 ± 3.7 m, respectively (Figure 4.A). A similar pattern was shown on the culm diameter and culm volume, as follows, DBH of *D. asper* in the lower, medium, and higher elevation was 13.92 ± 1.39 cm, 13.8 ± 1.65 cm, and 12.4 ± 3.92 cm, respectively (Figure 4.B). Meanwhile, the average culm volume per individual of *D. asper* in the lower, medium, and higher elevation was 0.124 ± 0.02 m³, 0.106 ± 0.03 m³, and 0.102 ± 0.06 m³, respectively (Figure 4.C).
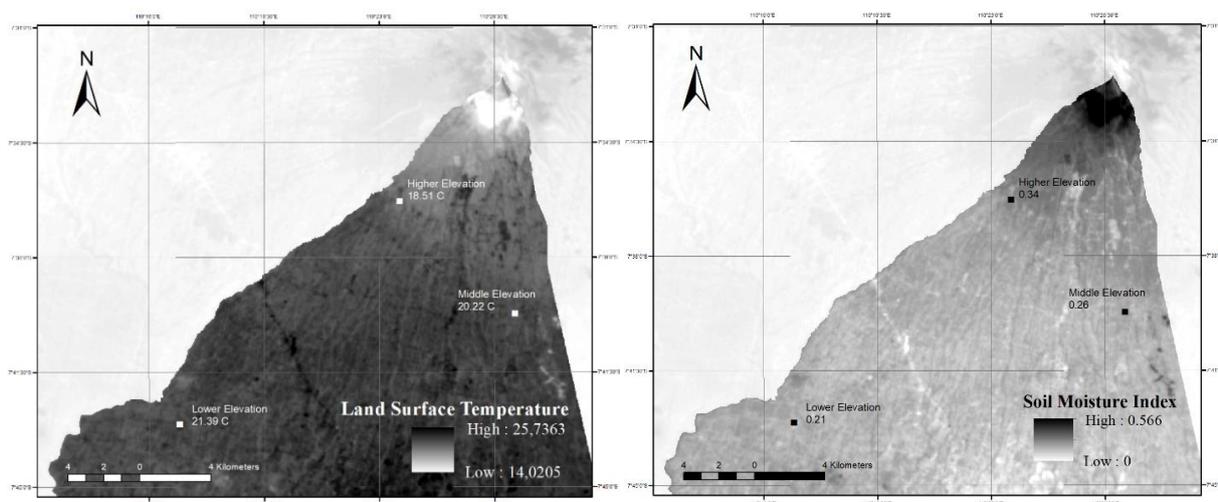

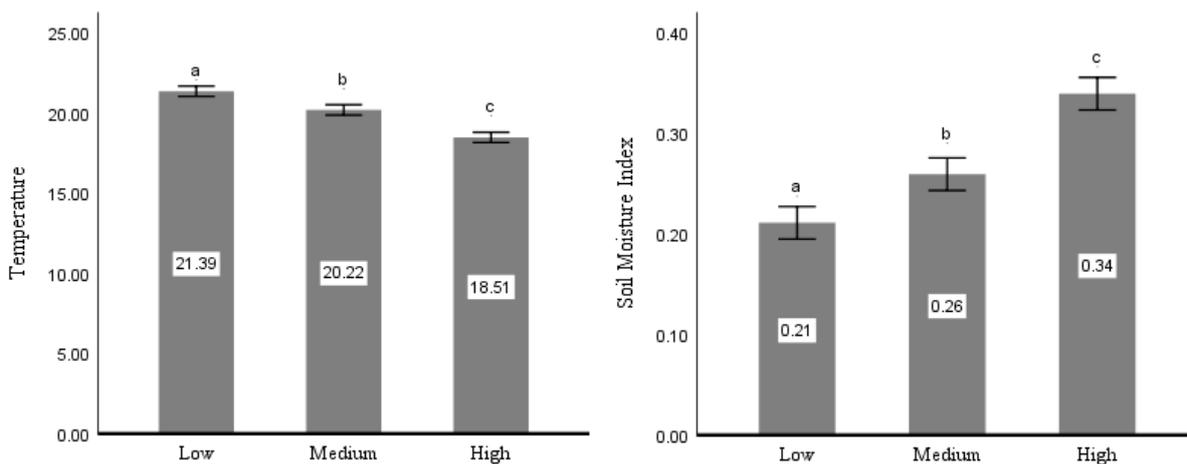**Figure 2.** Land Surface Temperature (LST) and Soil Moisture Index (SMI) at Sleman District generated by Landsat 8.

Figure 3. The average temperature and soil moisture index based on elevational variation

Table 1. Influence of elevation on *Dendrocalamus asper* growth

Source	df	Mean square			F value		
		Height	DBH	Vol	Height	DBH	Vol
Replication	7	13.44	9.33	0.0028	3.52	1.74	1.89
Elevation	2	6.95	6.27	0.0007	1.82ns	1.17ns	0.49ns

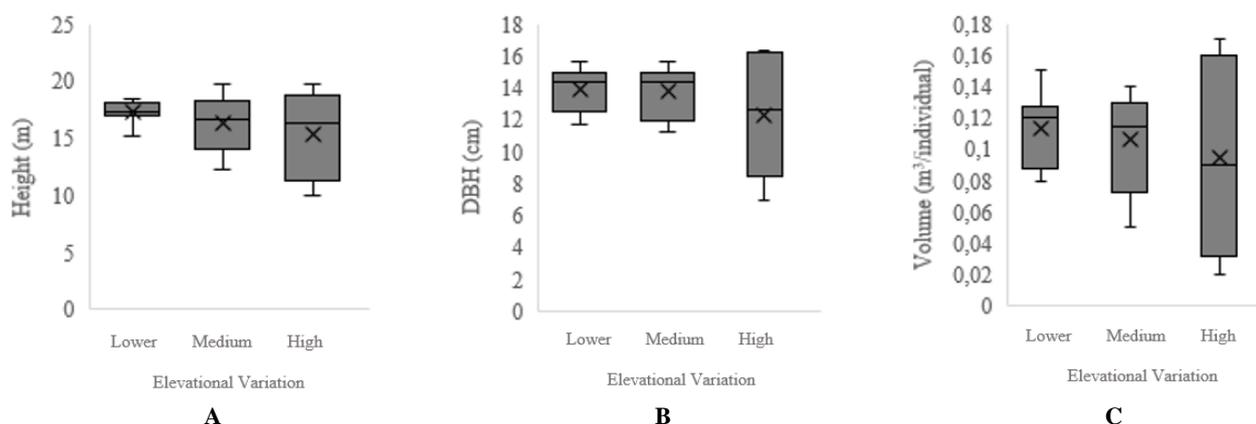Note: ns: no significant difference among treatments at tα 0.05

Figure 4. The average A. culm height, B. culm diameter (DBH), and C. culm volume of *Dendrocalamus asper* culms in elevational variation.

Table 2. Correlation analysis between environmental factors and *Dendrocalamus asper* growth

Variables	Pearson correlation		
	Height	Diameter	Volume
Land Surface Temperature	0.107ns	0.154ns	0.314ns
Soil Moisture Index	0.107ns	0.15ns	0.3ns

Note: ns: no significant difference among treatments at tα 0.05

Our result showed that *D. asper* in the lower elevation has a greater average than higher elevation due to a various standard deviation value at higher elevation, in height, culm diameter, and volume parameters. The culm height ranges from 10 m to 20 m, while the diameter ranges from 8 cm-17 cm. As a consequence, the volume was also affected due to the formulation consisting of these two parameters. In contrast, lower and medium elevations showed a narrow standard deviation on the bamboo's culm height, culm diameter, and culm volume. It suggested that optimal growth of *D. asper* was in elevation below 999 m asl. temperatures above 20°C.

Furthermore, temperature, rainfall, and soil properties could influence the distribution and growth of bamboo (Mera and Xu 2014; Xie et al. 2019). Nonetheless, our research showed no correlation between LST and SMI to height, diameter, and volume of *D. asper* (Table 2). It was due to that the distribution of *D. asper* is quite wide range distribution and can grow at various sites with different environmental factors (Table 1). Our result strengthens that the elevational variation is still providing good growth of *D. asper*, which is still acceptable for the future development of the bamboo plantations. The result is quite different from previous research, which stated that the high temperature could stimulate growth and low temperature would inhibit the growth (Banik 2016). Several research proved that elevational variation would affect bamboo growth and the lower elevation provide a greater growth rate on *Yushania alpina* (Hoek et al. 2019) and *Chusquea* (Clark et al. 2015). In addition, according to various species of bamboo, each species has a favorable environmental requirement, such as *Chimonobambusa utilis* which is optimum on 1.500-2.000 m asl. (Li et al. 2014).

Intra-clump spacing-diameter relationship

Additionally, due to the insignificant result of the first analysis, elevation is no longer used as a variable. Consequently, we conduct ANOVA separately to examine the effect of intra-clump spacing to bamboo growth as complementary data for regression analysis. Figure 5 depicts the diameter distribution that can be grouped into three clusters written with Zone I to III notations. In Zone I, it can be seen that the diameter distribution is clustered with a relatively lower diameter. Zone II and Zone III have a larger diameter; however, the polynomial trend line shows an increasing value and reaches a peak of 0.41 m^2-0.6 m^2 and then decreases. The three clusters should be the basis for determining silvicultural practices applied in community practices.

The diameter class for *D. asper* was based on market standards. The sizes of the diameter range from grade 1 to 4 were 0-9.99 cm, 10-13.99 cm, 14-16.99 cm, and more than 17 cm, respectively. Grade 1 is often referred to as apus (*Gigantochloa apus*) grade, while grade 4 is also mentioned as a super grade (Marzuni 2020, pers.com.). In Figure 6, it can be seen that a wider intra-clump spacing has a relatively larger diameter performance. It can be shown that the intermediate and wide spaces were dominated by diameter class 3 accounted for 53% and 68%, respectively. However, the polynomial regression shows that the average diameter increase in class 3 is in the 0.3-0.6 m^2 intra-clump spacing and decreases after reaching an intra-clump spacing of more than 0.6 m^2. These results indicate that the optimal point for diameter development of *D. asper* is estimated at nearly 0.4 m^2 intra-clump spacing or Zone II (Figure 5).

Furthermore, based on Figure 5 we compose several suggestions on each cluster as follows. Zone I, as a representation of the narrow intra-clump spacing requires (i) thinning to increase intra-clump spacing availability, (ii) improving soil quality with organic matters, and (iii) promoting qualified *D. asper* shoot or natural regeneration. Zone II which is the desired clusters should tend and manage the *D. asper* clump harvesting to achieve sustainability. Zone 3, despite having sufficient intra-clump spacing, requires management for effective bamboo clump

management, by limiting clump expansion or creating new clump that is potentially more valuable than a single clump that is too wide.

ANOVA analysis of intra-clump spacing variation resulting significantly in diameter growth ($P < 0.05$, Figure 7.A), however, the Intra-clump spacing variation didn't affect the height and volume of bamboo ($P > 0.05$, Figure 7.B, C). The narrow intra-clump spacing has a lower value of diameter and volume, vice versa. The diameter of *D. asper* on narrow to wide, was 9.75±1.91 cm, 13.41 ± 1.38 cm, and 15.4 ± 0.85 cm. Following that, the height and volume of *D. asper* were not significant. The culm height on narrow to wide value was 16.30 ± 2.99 m, 16.64 ± 0.75 m, and 15.35 ± 4.03 m, respectively. Its similar pattern is shown on culm volume as follows, 0.1 ± 0.04 m^3, 0.11 ± 0.02 m^3, and 0.09 ± 0.06 m^{3,} respectively.
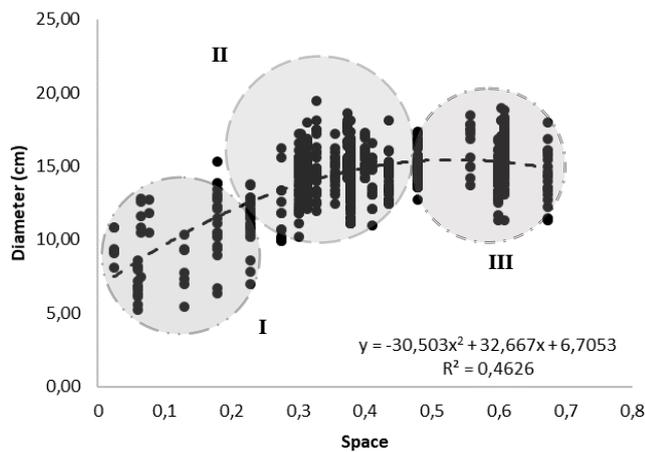
On the scope of intra-clump spacing, according to Bahru and Ding (2020), clump density has implications for several parameters, such as bamboo shoot production to the diameter size of *D. brandisii*. Furthermore, the growing space within clumps influences the growth and yield (Raveendran et al. 2010; Mera and Xu 2014). A bigger diameter emerges due to resource availability and competition among the culms (Banik 2015a). In addition, there was positive correlation between culm diameter and culm height on *Phyllotachy pubescens* (Yen 2016). Intra-clump density was one of bamboo stand structure parameters which varies across clumping bamboo species. Yet, intra-clump density is necessary for optimum and sustainable yield through retaining a reasonable number of the clump (Durai and Long 2019).
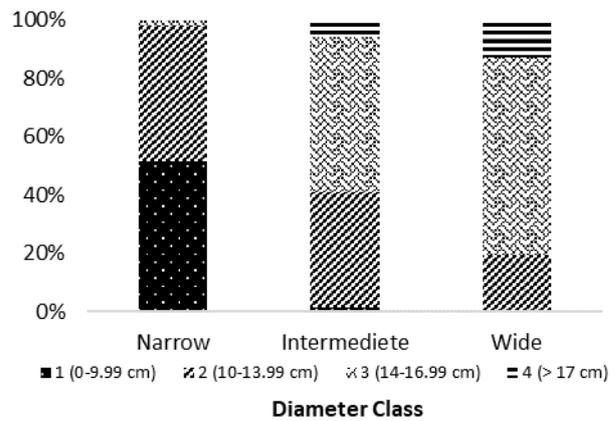

Figure 5. Diameter distribution based on intra-clump spacing within research sites.

$$y = -30{,}503x^2 + 32{,}667x + 6{,}7053$$
$$R^2 = 0{,}4626$$

Figure 6. Proportion of culm diameter class in each intra-clump spacing variation
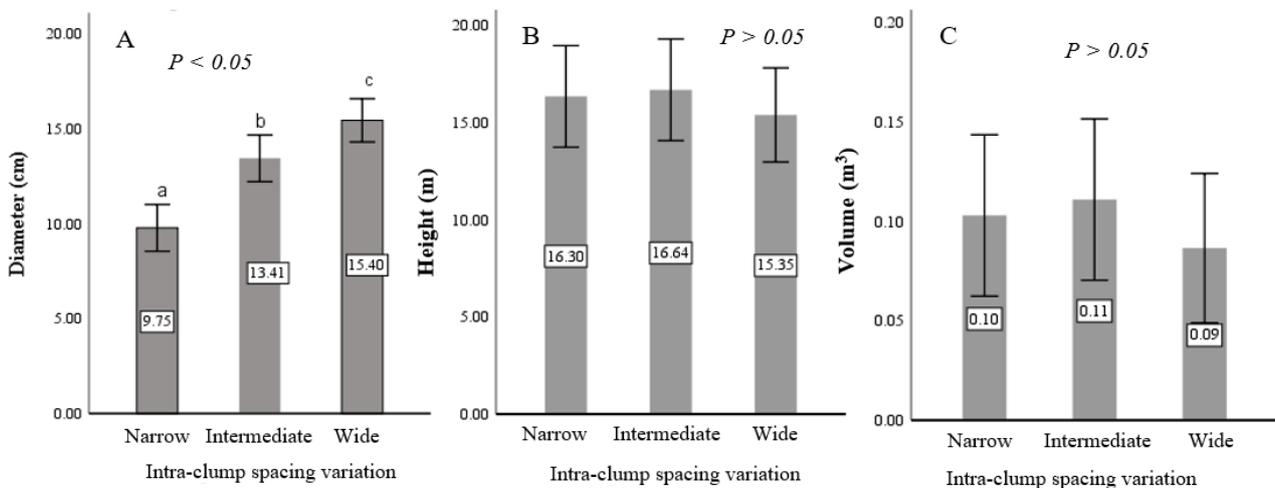

Figure 7. A. The average height, B. Diameter, and C. Volume of *Dendrocalamus asper* culms in intra-clump spacing variation

Our result stimulates the need for the application of silviculture to *D. asper* in Indonesia. According to Banik (2015a) silvicultural knowledge is essential to production and sustainability. Through silviculture, the clump will be managed sustainably and could achieve higher production of bamboo. The silviculture of bamboo positively has affect, for instance, increases the culm recruitment, alleviates the mortality of young shoot, and raises the diameter and height trend (Mulatu and Fetene 2013). Meanwhile, space availability needs an adjustment due to the implication of overcutting or clear-cutting methods that issue a problem (Virtucio and Tomboc (1994) cited in Bahru and Ding 2020). Higher harvesting intensity affects culm recruitment in *D. hamiltonii* (Banik 2016; Darabant et al. 2016; Bahru and Ding 2020). Although the harvesting treatment would provide more space for new shoots, the emergence of new culm did not occur due to the absence of mother culm. Furthermore, the low number of mothers culm due to higher harvesting intensity causes a reduced nutrient supply to the young generation (Virtucio and Tomboc (1994) cited in Bahru and Ding 2020). It suggested that an intensification of bamboo plantation level should be maintained to increase the bamboo quality, although the intensive management provides both positive and negative impacts on soil properties, such as (i) stimulating root development, growth, and biomass; and (ii) decreasing soil nutrient (Ni et al. 2021).

The implication to silviculture and conservation purposes of bamboo in Java

Management of *D. asper* clumps in community forest considered as a traditional treatment. In-depth interview results explained that the traditional silvicultural practices form closed-cycle, which was distinguished into two stages (Figure 8). The first phase would occur in 0-5 years, and the second would resume the next year until reach the regenerative period. The letter notation in the closed-cycle in the second phase shows a number of activities in one year carried out by the community, such as clump maintenance, selection of young shoots or culms to be harvested and retained. In this cycle, the community can obtain vegetative material for regeneration through vegetative propagation, while generative propagation is carried out when the bamboo reaches the regenerative phase.

The two phases have different treatment emphases based on the main activity on the *D. asper* clump. The first phase tends to emphasize the management of individuals or culms, while the second phase leads to the management of the clump. This is due to the small number of clumps in the first five years of growth of *D. asper*. The treatments in the first phase included (i) fertilization before planting, (ii) pruning of the first generation of culm, and (iii) cutting of small branches. On the other hand, in the first phase, no harvesting was carried out, and the priority was on the emergence of new shoots.
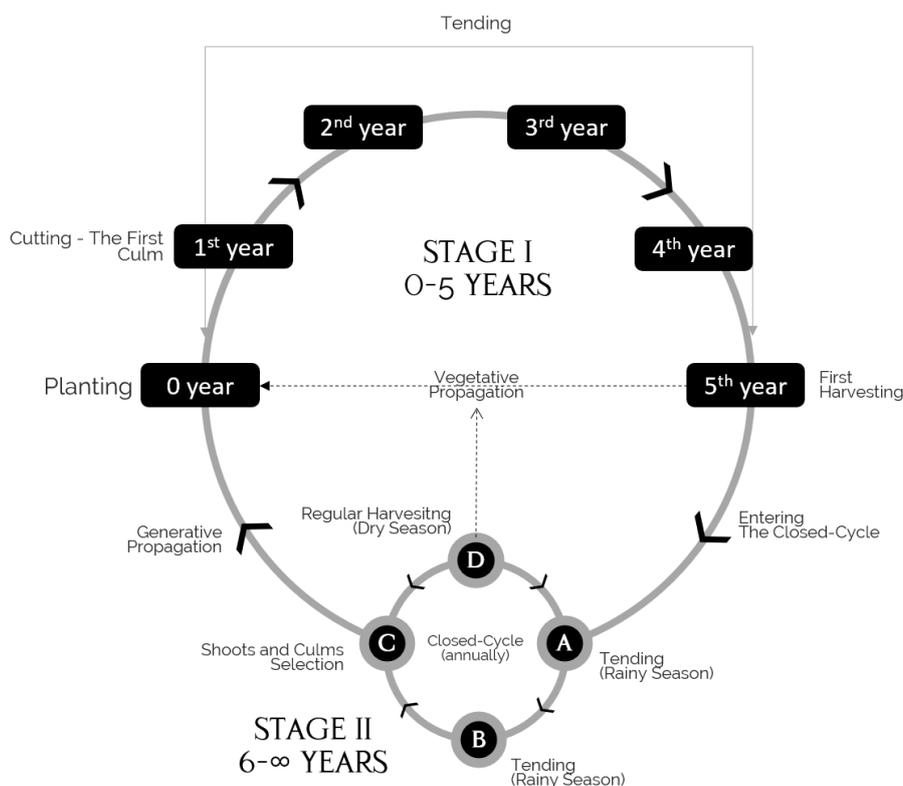

Figure 8. *Dendrocalamus asper* rotation system at the community forest, Sleman District, Indonesia

After the clump reaches 5 years old, the *D. asper* begins harvesting period and entering the second stage which is closed-cycle. Several treatments were aimed at clump maintenance and harvest regulation to obtain sustainable bamboo clump management. Key treatments in the second stage included clump maintenance such as (i) clump cleaning, (ii) selective harvesting of culms and shoots, and (iii) relocation of litterfall into the clump. Those are important because young culms and litterfall have a contribution in provisioning the nutrients and maintain the rhizome system, which could positively affect shoot production and growth (Banik 2015b; Toledo-Bruno et al. 2017). Meanwhile, during regeneration, the community considers vegetative propagation due to long period of generative phase.

Traditional bamboo management is playing important role to achieve sustainability of production. According to our result, Sleman community with their local knowledge has tended to proper bamboo management which has closed-cycle in clump management. Whilst, Indonesia has a diverse local knowledge of bamboo either bamboo management or utilization that very important in further bamboo development for instance, age determination in order to seasonal and phenological indicators (Partasasmita et al. 2017); bamboo management in the mixed garden by Naga communities that include seedling propagation, land preparation, planting, maintenance, pest control, and harvesting (Irawan et al. 2019); *Palembahan* concept (human and environment relation) on bamboo forest management (Yeny et al. 2016). In addition, the traditional practices by community need attention either in relation to overcutting on harvesting system which would threaten the ecosystem (Das et al. 2016) or supporting policy that could provide more opportunities in the future.

The development of bamboo that goes comprehensively will have positive implications in supporting land restoration, the rejuvenation of the national economy, and combating climate change (Choudhury et al. 2012; Dwivedi et al. 2019; Ferreira et al. 2020; Singh et al. 2020). Bamboo-based agroforestry is an agroforestry system that is still rarely practiced, yet promising system and increase in trend by combining several commodities (Banik 2015a; Kittur et al. 2016; Hani 2020). The silviculture of bamboo also has a role in the conservation purposes, such as maintaining more culm to increase the function of erosion control function (Durai and Long 2019). The huge benefit from bamboo plantation would impact the awareness of the community, as the result, we could avoid bamboo extinction due to human population. On the other hand, we could also control bamboo expansion due to ecological risks that potentially emerged (Buziquia et al. 2019; Xu et al. 2020).

In conclusion, the elevational variation, soil temperature, and humidity had no effect on the growth of *D. asper*, whereas intra-clump spacing would affect the diameter growth of *D. asper*. Thus, increasing the productivity of bamboo plantations could be managed by increasing the intra-clump spacing of bamboo in a clump ranged 0.3-0.4 m^2 and maintaining bamboo clump, i.e., harvesting and adjusting the intra-clump spacing of

bamboo regeneration. The findings in this study are necessary to improve the traditional silvicultural practices of *D. asper* to achieve sustainability of bamboo plantations. Further research on *D. asper* and other sympodial bamboo is also necessary to enriching database for future decision support.

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