Quantification of biometric growth and litterfall dynamics of four-year-old *Dendrocalamus stocksii* at differential spacing regime in humid tropics of central Kerala, India

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ABSTRACT: *Dendrocalamus stocksii (solid bamboo), a wild bamboo species native to the central Western Ghats of India, holds significant commercial value. Despite being a prioritized species, its productivity performance is still relatively unexplored compared to other bamboo species. Therefore, a praxis-oriented field study was undertaken in the humid tropics of Kerala to evaluate the biometric growth performance, leaf area index (LAI), and litterfall dynamics of four-year-old D. stocksii at differential spacing regime (8 × 8 m, 8 × 6 m, 8 × 4 m). Results revealed that all these attributes were manifested by planting spacings, highlighting the importance of regulating planting spacing/density for optimizing the growth and productivity of D. stocksii. With increase in spacing from 8 × 4m (closest) to 8 × 8m (widest), most growth parameters (culm diameter, girth, crown width, culms/clump) increased, except for culm height and internodal length. Litterfall followed a seasonal bimodal pattern with a major peak in the dry months (Mid-January to Mid-February) and a minor peak in Mid-May to Mid-June. Highest litterfall was observed in closest spacing (10.10 Mg ha^{-1}), while lowest at widest spacing (7.86 Mg ha^{-1}). LAI also followed similar trend. However, management objectives can play a central role in determining the optimal bamboo spacing for farmers. Moreover, its abundant litterfall has the potential to enhance on-site enrichment and improve soil fertility through leaf litter accumulation, particularly in nutrient-poor, degraded soils. Likewise, D. stocksii- compact clump circumference, thornless, easily manageable- is also advisable as a promising bamboo species, in the context of sustainable and resilient multitier agroforestry systems to diversify economic returns and promote the overall usefulness of the species across humid tropics of central Kerala and the Western Ghats.*

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1. INTRODUCTION

Bamboo, a tall arborescent grass, belongs to subfamily Bambusoideae of the family Poaceae. They are distinguished from other woody trees by their fast-growing woody culms, infrequent flowering, intricate branching patterns, and robust rhizome systems. Bamboos play a crucial role in rural communities, contributing to their economy, biodiversity conservation, controlling erosion, riverbank protection, carbon sequestration, and overall forest health. Globally, there are approximately 1662 bamboo species belonging to 121 genera, widely distributed in tropical, sub-tropical, and temperate regions (Canavan et al., 2017). These species currently occupy an area of 35 million hectares, and their range is projected to expand under various climate change scenarios (Jin *et al.,* 2012; Zhang *et al.,* 2022). With 136 species, India ranks second in diversity of bamboo in the world (after China), of these, 125 are native and 11 are introduced, found in 15 million hectares of forest and non-forest areas (ISFR, 2021).

Bamboo offers significant potential for poverty alleviation, environmental conservation, and advancing the Sustainable Development Goals (SDGs), particularly 7/17 (Kaushal *et al.*, 2020). Recognized for its versatility and economic value, bamboo has earned various monikers such as 'Green Gold,' 'Timber of the 21st Century,' 'Friend of the People,' 'Cradle to Coffin Timber,' 'Poor Man's Timber,' and 'Wonder Plant of the 21st Century'. These appellations highlight bamboo's multifaceted potential in various sectors. Recent amendment in Indian Forest Act of 1927, bamboo declassified from 'tree' to 'grass' and removed restrictions on the felling and interstate transportation of bamboo grown in non-forest areas, which opened new avenues to utilize its potential. By promoting bamboo cultivation and trade, these reforms aim to generate new income for farmers and expand India's green cover. Add on to this, National Bamboo Mission (NBM) has prioritized 18 commercial bamboo species for plantation in the farmer's fields across the country for doubling the farmer's income.

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Furthermore, Pan *et al.* (2023) highlighted bamboo's potential as a Nature-Based Solution (NbS) for mitigating climate change, emphasizing its significance as a key component of future climate strategies worldwide.

Bamboos, known for their rapid growth, can produce significantly more biomass than other fast-growing woody trees within a short cultivation cycle. Studies have reported that bamboo can store and sequester carbon at impressive rates, ranging from 30 to 145 t ha^{-1} and 1.3 to 24 t $ha^{-1}year^{-1}$ respectively (Dwivedi *et al.,* 2019). Bamboo's carbon sequestration capacity can significantly surpass the global average for forest vegetation (86 t ha^{-1}). However, effective management practices are crucial to maximize this potential.

Bamboos are grown as pure block plantations to complex agroforestry systems such as home gardens (Tewari *et al.,* 2015; Kittur *et al.*, 2016; Rane *et al.,* 2016). Integrating bamboo in agroforestry systems facilitates ecological benefits and environmental protection to the intercrops. Alongside due to high biomass accumulation and abundant litter fall bamboos help in nutrient enrichment and improving the soil physical, chemical and biological properties of site (Dev *et al.,* 2020; Kaushal *et al.,* 2020).

Litterfall is critical link between the tree canopy and the underlying soil, providing nutrients accumulated from plant biomass and regulates forest productivity and tree growth. It serves as a transient sink as well as "slow-release nutrient source", ensuring a long-term nutrient contribution to the soil **(**Jamaludheen and Kumar, 1999**).** The pace at which litter falls and decomposes, regulates energy flow, primary production, organic matter accumulation and nutrient cycling in forest ecosystems. Litterfall rates are influenced by various factors, including tree basal area, species composition, stand age, density/spacing, temporal variations, site characteristics, level of maturity of stand and tree management practices. Additionally, the breakdown of litter is regulated by interactions among litter quality, soil biota, and climatic conditions (Kumar, 2008; Tripathi *et al.,* 2006).

Yet, another crucial factor, Leaf area index (LAI)-leaf area per unit ground area- a measure that controls the functioning and primary production of forest ecosystem (Moser *et al.* 2007). Litterfall can be used as a proxy for estimating Leaf Area Index (LAI) (Moser *et al.,* 2007). Studies also reported that LAI is closely related to influence the biometric growth and seasonal foliage dynamics, and density plays crucial factor in it (Bura and Ding, 2020).

Dendrocalamus stocksii, a wild bamboo species native to the Central Western Ghats of India, naturally distributed in the regions of Kerala, Karnataka, Goa and Maharashtra (Rane *et al.,* 2018). Also known locally as mesh, manga, or marihal bamboo, the species has been synonymized under various names, including *Oxytenanthera stocksii* (Munro), *Gigantochloa stocksii* (Munro) T.Q. Nguyen, and *Pseudoxytenanthera stocksii* (Munro) Naithani. The species is characterized by its mid-sized, non-thorny, and sympodial (pachymorph) nature, with non-prominent nodes and a favorable culm wall thickness to diameter (cw/cd) ratio. It has loosely spaced, mostly solid, erect culms ranging from 30-55 mm in diameter, making it easy to manage and highly flexible for harvesting. Because of its ecological and economic significance, species has been domesticated in major traditional agroforestry system (TAFS) like in farm boundaries, block plantation, homestead (Viswanath *et al.,* 2018). Due to its diverse use and significant commercial value, NBM has prioritized this species for large scale cultivation in Peninsular India. While other well-known bamboo species *viz., D. strictus, B. bamboos, B. vulgaris, D. brandisii, B. balcooa, B. tulda*, *etc.* (Kittur *et al.,* 2016; Dev *et al.,* 2020; Kaushal *et al.,* 2021; Amani *et al.,* 2022) have been extensively studied for their productivity and litterfall dynamics, *D. stocksii* remains relatively unexplored. As a result, despite its potential, *D. stocksii* remains restricted to limited areas and has not garnered the same level of attention as other species.

With this backdrop, a praxis-oriented field study was undertaken in the humid tropics of Kerala to evaluate the growth performance and litterfall dynamics of four-year-old *D. stocksii* under varying spacing regimes. The main objectives were to: (a) examine the effect of planting spacing/density on biometric growth, (b) analyze the interaction of spacing and monthly variations on litterfall, and (c) assess the influence of spacing on the LAI of *D. stocksii*, which will highlight the importance of regulating spacing on growth and productivity of *D. stocksii*-a valuable bamboo species of Western Ghats.

2. MATERIALS AND METHODS

The present experiment was conducted in Vellanikara, Trissur, Kerala during 2021-2022 (10° 32′ 59″ N latitude and 76° 16′ 07″ E longitudes with an altitude of 34.15 m above mean sea level). Experiments were carried out in an established four-year-old (2018) block plantation of *D. stocksii* over an area of 1.32 hectares. The experiment was laid out in Randomized block design involving three spacing (8 × 8m, 8 × 6m, 8 × 4m) treatments of bamboo with the corresponding densities of 312, 208, and 156 clumps ha^{-1} and each treatment replicated eight times. Agrometeorological data for the study area, spanning from June 2021 to October 2022, were obtained from the Agrometeorological Observatory at Kerala Agricultural University. Vellanikkara experiences a tropical warm humid climate, with an average mean annual rainfall of 3020 mm, most of which is received during the South-West monsoon (June to September). The mean maximum temperature ranges from 23.5 °C (August) to 36.1 °C (April) while the mean minimum temperature ranges from 22.6 °C (December) to 25.1 °C (April), whereas February to April are the hottest months. The experiment site's soil is an Ultisol composed of Typic Plinthustult, Vellanikkara series midland laterite, Ustic moisture regimes (dry season, February to May), with low in fertility whereas the soil depth was 45-50 cm with rocky and grabbles soil having Isohyperthermic temperature regimes.

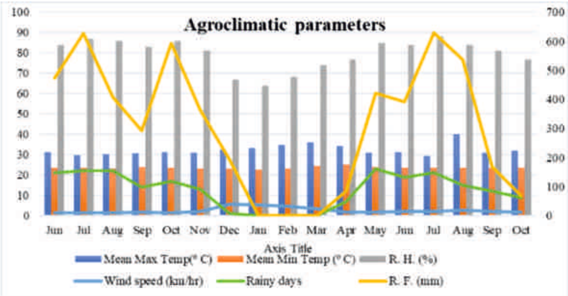

Figure 1. Agroclimatic data during the study period (June 2021- October 2022) at Vellanikara, Trissur, Keral

Bamboo biometric attributes

To assess the growth attributes, total height (leading culm) in all the plots was measured by using the Forestry pro (Nikon) and recorded in meters (m). Ten culms per clump were selected for biometric attributes measurements like internodal length and culm diameter. Culm diameter at the 5^{th} internode was measured using a digital calliper, in two perpendicular directions and average recorded in millimetres (mm). Internodal length was determined by measuring the length of the 5th internode on each culm using a tailor tape and recording it in centimetres (cm). The total number of internodes of the leading culms was counted till the utmost visibility from selected clumps and average was recorded. Crown width was measured by projecting the crown onto the ground in two perpendicular directions (north-south and east-west) and recording the mean value in meters (m). Clump circumference was measured at breast height (1.37 m) using a tailor tape and recorded in meters (m). Finally, the total number of culms $clump^{-1}$ was counted for selected clumps and recorded.

Stand Leaf area index (LAI)

LAI was measured using a LAI 2000 plant canopy analyzer (LI-COR Inc., Lincoln, Nebraska, USA) at a height of 1.5 meters above ground. To obtain accurate LAI measurements, the LAI 2000 unit was first calibrated by taking a reading of sky brightness outside the plot in open conditions. Then, ten random locations within each plot were sampled to measure light transmission beneath the canopy. To ensure consistent measurements, the unit was always oriented in the same direction both inside and outside the stand. To avoid direct sunlight reaching the sensor, measurements were taken during periods of low solar elevation, such as just after sunrise or just before sunset. A 90-degree view restrictor was used to prevent direct sunlight and the observer from obstructing the sensor.

Litter fall production

Installation of bamboo litter traps:

Litter collection was conducted using specially designed circular litter traps, following the methodology outlined by Hughes *et al.* (1987). Each trap consisted of four 210 cm long galvanized (2-3 mm) iron wires, arranged in a tripod configuration. A circular hoop, measuring 55 cm in diameter, was created using the remaining wire and secured horizontally to the tripod. A plastic grain bag with a tapered bottom was placed inside the hoop, forming a litter trap with a collection area of 0.25 m^2 (50 cm × 50 cm) and a depth of 30 cm. Three such traps were installed in each plot, totalling 24 traps across the eight replicates. The traps were positioned 1 meter away from the bamboo clumps and 50 cm above the ground level.

Sampling and weighing:

Litter was collected monthly from each trap for a period of 12 months, spanning from November 2021 to October 2022. The collected litter samples were transported to the laboratory and oven-dried at 70°C until they reached a constant weight (approximately 72 hours). Once cooled, the dry litter samples were weighed to the nearest milligram.

Statistical analysis

Bamboo biometric growth attributes were analysed by single factor -spacing- Randomized Block Design (RBD) whereas litter fall production was analysed by two factor -spacing + months- Randomized Block Design (RBD). Data were analysed for treatment comparisons at the $p \leq 0.05$ level of significance using statistical software R 3.6.1 version and Microsoft Excel 2010 version.

3. RESULT AND DISCUSSION

Biometric parameters of bamboo at different spacings

The present finding showed that the biometric growth attributes particularly: culm height, number of culms per clump, crown width, and clump circumference (except culm diameter, number of internodes and length) of four-years-old *D. stocksii* plantation were significantly influenced by planting spacing/density (Table 1).

Culm height

The culm height was reduced as the bamboo spacing expands. Culm height was highest at 8 × 4m (8.12 m) and decreased by 10% as the spacing was widened to 8 × 8m (7.27 m). The average annual increment of stand was 0.99, 1.1 and 1.04 m at 8 × 8, 8 × 6 and 8 × 4 m respectively. Height growth patterns in response to varying planting densities are well documented (Kittur *et al.,* 2016; Kar *et al.*, 2019; Rane *et al.*, 2018). Similarly, in this study, spacing manifested rapid height growth at closer spacing, but lower densities encouraged greater crown spread and radial growth. In dense, even-aged plantations, competition for light can actually stimulate height growth. As a strong light demanding species, *D. stocksii* naturally showed taller at closer clump densities. Interestingly, the observed culm height in this study was relatively higher than that reported by Rane *et al.* (2018) for the same species, where height increased as stand spacing decreased from 6x6 m to 3 × 3 m. This trend was also reported for *D. strictus* by Kittur *et al.* (2016) in same geographic location and Dev *et al.* (2020) in central India.

Culm diameter

The culm diameter at the 5th and 6th internodes was statistically insignificant across all spacing treatments. Intriguingly, despite varying spacing, culm diameter remained relatively consistent, likely due to a combination of the plantation's young age and the site's high soil fertility. Radial growth between 5^{th} and 6^{th} internodal diameter was found moderate for *D. stocksii* in the present study which varied from 36.82 mm (8 × 4 m) to 38.08 mm (8 × 8 m) which is comparable to the mean values reported by Rane *et al.,* (2018) from the Western Ghats. Patil and Mutanal (2017) on their study at Karnataka, reported higher culm diameter for *D. stocksii* at wider spacing (4 × 5m), compared to closer spacing (4 × 2m). Similar trend was also reported by Prasath *et al.* (2014) for *B. vulgaris* in the transition from 5 × 5m to 7 × 4m from Tamil Nadu.

In the present study observed that when compared to wider spacing (8 × 8 m), closer spacing (8 × 4 m) clearly demonstrated a reduced growth rate in diameter and crown width. The rapid expansion of the crown driven by the wide spacing might have triggered the diameter growth at the detriment of the height growth (Jiang *et al.*, 2007). Bahru and Ding (2020), in their study from southwestern China, found that a higher density stand (597 culms ha^{-1}) of *D. brandisii* exhibited a denser canopy and larger leaf area, leading to a substantial reduction in culm diameter compared to a lower density stand (532 culms ha^{-1}).

Internodal length and number

Internodal length is a key growth characteristic that significantly impacts the commercial value of bamboo. In the present study, internodal length and numbers were observed non-significant across all spacing treatments. Interestingly, at spacing (8 × 4 m), we found that taller culms had longer internodes but fewer nodes, suggesting a direct relation between height and internodal length and an inverse relation between height and node number. The opposite trend was observed at wider spacing (8 × 8 m). Internodal length in bamboo can vary significantly depending on soil and climatic conditions, even within the same species. For instance, *D. stocksii* in our study exhibited substantially longer internodes at all spacing regimes

Table 1. Biometric performance of 4-year-old *Dendrocalamus stocksii* stand under differential spacing regime in Kerala, India.

Spacings (m)	Culm height (m)	Culm Diameter (mm)	Number of culms/clump	Internodal length (cm)	Number of internodes	Crown width (m)	Clump circumference (m)
8 × 8	7.27 ± 0.21b	38.08 ± 1.55	58.00 ± 1.58a	29.97 ± 0.34	31.33 ± 0.96	8.48 ± 0.34a	4.06 ± 0.20a
8 × 6	7.51 ± 0.21b	37.18 ± 0.81	48.83 ± 1.64b	31.51 ± 0.76	30.58 ± 0.51	8.00 ± 0.21a	3.80 ± 0.17a
8 × 4	8.12 ± 0.09a	36.82 ± 0.85	41.33 ± 1.93c	31.60 ± 0.59	29.58 ± 1.00	6.58 ± 0.45b	3.49 ± 0.16b
CD0.05	0.516	NS	4.714	NS	NS	1.009	0.419

(± values are standard error of the mean; values followed by the same superscript in a column do not differ significantly ($p< 0.05$); NS: Non-significant) compared to previous reports from the Himalayas (26.6 cm) (Kaushal *et al.,* 2021). Previous studies from Kerala, reported significant correlations between height and number of nodes (r = 0.480) and internodal length and number of internodes (r = 0.435) (Jijeesh, 2013). However, in our study it was not much notable, may be due relatively young age, site specific factor or difference in growth rate.

Number of culms per clump

The culm number per clump is a key determinant of bamboo growth and productivity. To optimize bamboo production, regulating spacing essential for clumps with an ideal number of culms and desirable culm dimensions. In this study, regardless of the non-significant variations in culm diameter, the number of culms per clump was significantly influenced by spacing treatments, showing a decreasing trend as spacing decreased. The highest count of culms/culms was at widest spacing (58.00) and this count drastically declined by 41.46 % at closest spacing. On a hectare basis: 9048, 10,156 and 12,792 number of culms per hectare was recorded under 8 × 8, 8 × 6 and 8 × 4 m bamboo spacings respectively. The increased number of culms in wider spacing could be attributed to reduced crown competition and more available above-ground space for culm growth. Kittur *et al.* (2016) found that as spacing increased from 4 × 4 m to 12 × 12 m, the number of culms also increased from 46.66 to 130. Compared to Kittur *et al.* (2016), the number of culms per clump was lower in this study, possibly because of the younger age and different species. Notably, Rane *et al.* (2018) and Patil and Mutanal (2017) reported significantly lower culms per hectare than ours for *D. stocksii* in the Konkan region and Dharwad, Karnataka respectively, suggesting that agro-climatic conditions play a key role in the growth and productivity of bamboo.

Crown width

The crown width was statistically significant ($p < 0.05$) among the spacing treatments. In the present study, it was observed that with increase in spacings, crown expanded 28.89 % more at 8 × 8m spacing compared to 8 × 4 m (6.58 m). The average crown width varies depending on the age of the plantation and the level of competition the tree undergoes. It is typical to expect a broader crown in widely spaced trees. This trend was also reported from Kerala, were crown width with increases as spacing increased from 4 × 4 to 12 × 12 m for *D. strictus* (Kittur *et al.*, 2016). Kar *et al.* (2019) in their study reported a decrease in height and increase in diameter of tree along with increasing crown spread as moving from closer (8 × 1 m) to wider (8 × 4 m) spacing for *Grewia optiva* stand.

The crown width of bamboo plays a critical role in manifesting PAR (Photosynthetically Active Radiation) and LAI (Leaf Area Index), which in turn affects understorey productivity in agroforestry systems (Kittur *et al.,* 2016). A wider crown increases shade, reducing PAR transmission to the understorey, while a narrower crown allows more light penetration. Achieving an optimal shade level is essential for maximizing understorey crop yield without suppressing growth. In intercropping systems, maintaining the right balance of shade ensures that understorey crops receive sufficient light for photosynthesis while benefiting from the microclimate created by the bamboo canopy. Understory productivity may benefit from the increased PAR availability in wider stands. To mitigate the effects of overshading, canopy management techniques such as harvesting or pruning can help improve light penetration and stimulate understory growth and productivity.

Clump circumference

Clump circumference showed a consistent increase as increase in the spacings. The maximum clump circumference was observed for widest spacing (4.06 m) and there was reduction of 16.33% in closest spacing (3.49 m). It can be linked as number of culms per clump increases, the average clump cover also increased. The average annual rate of increment was highest in 8 × 4m spacing (1.09 m) and lowest was in 8 × 8m spacing, declined to 0.89 m. A similar pattern of spatial expansion was observed when spacing increased from 4 × 4 to 12 × 12 m in, as reported by Kittur *et al.* (2016).

The spatial extent of bamboo clumps is a key consideration when integrating them into agroforestry systems. For agroforestry, bamboos with compact growth and lower clump circumference are always desired. Compared to the widely cultivated *B. bambos* in Kerala, which has reported clump circumference of 10.76 meters (Kumar *et al.,* 2005) and values reported by Amani *et al.* (2021), *D. stocksii* in this study exhibited a more compact and less spreading growth habit. This implies that it would be more suitable for integrating in multitier agroforestry systems, like Kerala's home gardens.

Litterfall dynamics

The impact of planting density (spacing) on litterfall in a four-year-old *D. stocksii* stand is evident in Figure 2. The litterfall rates across spacing and months were very significant ($p<.005$), while interaction effect of spacing × month was insignificant. With increasing spacing, litterfall production declined significantly ($p < 0.05$). Mean annual litter production was ranged from 7.86 Mg ha^{-1}in the widest spacing (8 × 8m: 156 clumps ha^{-1}) to 10.11 Mg ha^{-1}in the closest spacing (8 × 4 m: 320 clumps ha^{-1}). These values were relatively higher than reported by Lubina *et al.,* (2021) in moist semi-arid areas, Karnataka and Kaushal *et al.* (2020, 2021) in the Himalayan foothills for the same species. The increased litter fall may be attributed to favorable climatic conditions and higher soil fertility, which promoted bamboo growth and denser canopies, leading to greater litter production year-round. The highest mean monthly litterfall (841.49 kg ha^{-1}) was observed in the closest spacing, while the lowest (654.74 kg ha^{-1}) was seen in the widest spacing. Leaf litter contributed dominantly to total litterfall (> 90%) across the spacing and seasonal variations (based on visual observation). Compared to wider spacing stand, closer spacing stand may produce more litter due to the presence of a larger number of non-functional crowns associated with them (Kunhamu *et al.,* 2009).

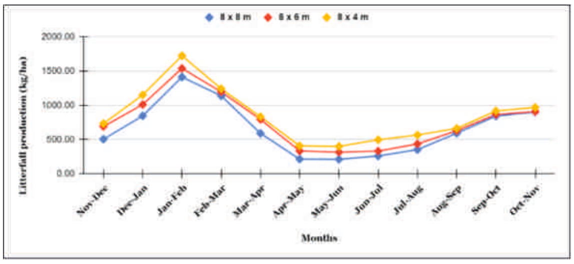

Figure 2. Monthly variations of litterfall production (kg ha^{-1}) of four-year old *D. stocksii* at differential spacing regime in Kerala, India.

Seasonal variations in litterfall followed a bimodal pattern where the major peak observed during dry months (January to February) and a subsidiary minor peak observed from May to June. Seasonal variations in leaf litterfall are well-reported for many tropical species, as evidenced by studies in both natural and planted ecosystems (Jamaludheen and Kumar, 1999; Jijeesh and Seethalkshmi, 2015). Meteorological variables like low relative humidity, high wind speed, mean maximum monthly temperature coupled with lesser rainy days (Fig. 1) in the dry season (January-March) might have led to higher litterfall than in other seasons (Jijeesh and Seethalkshmi, 2015). Additionally, the planting density did not significantly alter the seasonal trend of litterfall, with Nov'2021 to Mar' 2022 accounted for > 55% of the total.

Quantity of litterfall might also be regulated by factors such as LAI, crown spread, and crown structure. Studies reported that compared to low density stand, *D. brandisii* at high density stand with high LAI and compact canopy structure exerted in ample foliar biomass which enhanced higher litter production (Bahru and Ding, 2020). Our finding implies that spacing, biometric and climatic factors had the greatest impact on the quantity and periodic fluctuations of litterfall year-round.

Leaf Area Index (LAI) dynamics

LAI, a species-specific measure of plant, is a critical factor in understanding plant systems. As a fundamental canopy structural parameter, LAI significantly impacts various eco-physiological processes, such as evapotranspiration, rainfall interception, photosynthesis, respiration, and soil organic matter contribution (Yan *et al.,* 2019). From the fig. 3, it is evident that LAI and spacings were inversely related. LAI was highest at 8 × 4m (4.35 m^2 m^{-2}) and declined by 46.90 % as spacing widened to 8x8m. Decreasing trend of LAI with respect to spacing was in order of: 8 × 4 > 8 × 6 > 8 × 8m. Despite lower clump girth and crown width, the higher LAI in closely spaced stands could be attributed to the more number of clumps per unit area (Table 1). The similar trend was also observed by Kittur *et al.,* (2016) for *Dendrocalamus strictus* within the similar ecoclimatic conditions and geographic location of the present study. High density stand (8 × 4 m) had overlapping crowns, led to reduced canopy gaps and consequently higher LAI values and *vice versa*. For instance, Bura and Ding (2020) reported a higher LAI value at high density stand of *D. brandisii*, favoured by largest canopy leaf area (5.63 ± 0.34 m^2) and least canopy spread area (9.92 ±1.73 m^2), while at lower density both factors altered and LAI eventually reduced. For successful integration of *D. stocksii* into agroforestry, regulating spacing will be a critical factor in maintaining the quantitative relationship between planting density, LAI, and understorey PAR transmittance, with the ultimate goal of optimizing understorey production (Kittur *et al.*, 2016, Kumar *et al.*, 2001).

4. CONCLUSION

The present study attempted to explore the biometric growth performance, LAI, and litterfall dynamics of four-year-old *Dendrocalamus stocksii* under differential spacing regimes in the humid climate of Kerala. Observed that as spacing increases from 8x4 to 8x8 m, most biometric growth attributes (culm diameter, crown width, clump circumference and culms clump^{-1}) increased, except for culm height and internodal length. Litterfall- bimodal pattern- was highest in closest spacing (8 × 4 m) than wider spacing (8 × 8 m). Likewise, LAI also followed a similar trend. Our findings revealed that all these attributes

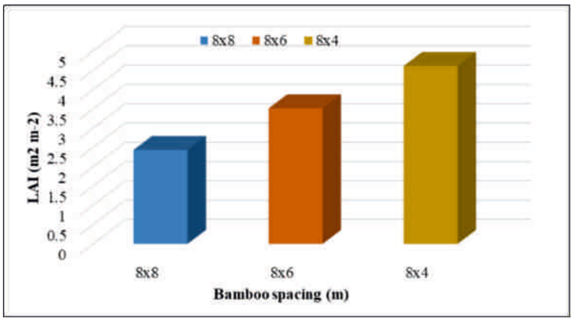

Figure 3. LAI dynamics of four-year-old *D. stocksii* at differential spacing regime in Kerala, India

were manifested by planting spacings, highlighting the importance of regulating planting spacing/density for optimizing the growth and productivity of *D. stocksii* (in terms of culm yield, quality, and economic returns). However, management objectives can play a central role in determining the optimal bamboo spacing for farmers. Moreover, its abundant litterfall has the potential to enhance on-site enrichment and improve soil fertility through leaf litter accumulation, particularly in nutrient-poor, degraded soils. *D. stocksii*, with its compact clump, thornless nature, and ease of management is also advisable as a promising bamboo species, in the context of sustainable and resilient multitier agroforestry systems to diversify economic returns and to promote the overall usefulness of the species across humid tropics of central Kerala and the Western Ghats.

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