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# BASELINE STUDY FOR ASSESSING POTENTIAL FOR IMPROVEMENT OF PRODUCTIVITY OF BAMBOO

## (FINAL TECHNICAL REPORT OF THE PROJECT KFRI RP 712.3/2015)

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## Abstract of Project Proposal

| | |
|---|---|
| **Code** | **KFRI RP 712.3/2015** |
| **Title** | **Baseline Study for Assessing Potential for Improvement of Productivity of Bamboo** |
| **Objectives** | a) To characterize culm physical properties in different species of bamboo planed in Kerala<br>B) The assess culm biomass and biomass accumulation potential of different species bamboo planted in Kerala. |
| **Project period** | September 2015- September 2016 |
| **Funded by** | National Bamboo Mission under its Project `Bamboo Technical Support Group – KFRI' |
| **Scientific personnel** | U.M. Chandrashekara<br>V.P. Raveendran |

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# BASELINE STUDY FOR ASSESSING POTENTIAL FOR IMPROVEMENT OF PRODUCTIVITY OF BAMBOO

## A. Abstract

In the rapidly changing socio-economic and marketing opportunities, both at the regional and national level, cultivation of different species of bamboo is gaining importance. The National Bamboo Mission has initiated programmes to increase the area under bamboo plantations in government and private lands outside forests to supplement farm income and contribute towards resilience to climate change as well as availability of quality raw material requirement of industries. As part of a NBM funded programme, the Kerala Forest Research Institute undertook a project to promote cultivation of 14 species of bamboo (*Bambusa balcooa* Roxb., *Bambusa bambos* (L.) Voss, *Bambusa nutans* Wall. ex Munro, *Bambusa tulda* Roxb., *Bambusa vulgaris cv. wamin* McClure, *Bambusa vulgaris* Schrad. ex Wendl., *Bambusa wamin* E.G.Camus, *Dendrocalamus asper* (Schult.) Backer, *Dendrocalamus hamiltonii* Nees & Arn. ex Munro, *Dendrocalamus longispathus* (Kurz) Kurz, *Dendrocalamus sikkimensis* Gamble ex Oliv., *Dendrocalamus strictus* (Roxb.) Nees, *Gigantochloa rostrata* K.M.Wong and *Thyrsostachys oliveri* Gamble), prioritized by the NBM as commercially important species, in the State of Kerala. Since these species were planted in the same geographic region and clumps are of same age (5-year old), a study was undertaken on their culm characteristics and biomass production potential. The total number of culms per clump in different species varied between 5 and 32 and with lowest number in *D. strictus* and highest in *B. bambos*. The mean culm diameter was high in *B. bambos* (8.0 cm). Culm wall thickness and culm weight in different species did not correlate significantly. Partitioning of culm biomass among stem, branches and leaf components in different bamboo species indicated a common pattern with 67%, 23% and 10% of total culm weight distributed among stem, branches and leaves respectively. This observation may be useful to estimate the total culm biomass, once the weight of any one of the three components is known. Regression equations between culm diameter and weight of each culm component, and also between $d^2h$ (culm diameter$^2$ x culm height) and weight of

each culm component were developed. In ten out of fourteen species studied there exists significant correlation between biomass of three components (stem, branch, leaf) and dbh or $((dbh)^2$ x h. However, in *B. balcooa, B. nutans, B. tulda, D. strictus,* correlation between leaf biomass and independent variable (dbh or $((dbh)^2$ x h ) was weak. The estimated total biomass in 5-year old bamboo farms of different species varied from 10.6 t $ha^{-1}$ (*D. sikkimensis*) to 95.7 t $ha^{-1}$ (*B.bambos*). The annual biomass production was also comparatively high in *B. bambos* (19.8 t $ha^{-1}$ $yr^{-1}$) and low in *D. longispathus* (2.5 t $ha^{-1}$ $yr^{-1}$).Thus attempts may be made in the State to promote different species of bamboo considering farmers' requirement, marketing opportunities, and requirement of bamboo-based micro and macro industries. At the same time package of practice to enhance their biomass production potential need to be evolved.

## B. Introduction

Biomass is the total quantity of organic matter per unit area present in an ecosystem at a given time and may relate to a particular species or, a group of species of a community as a whole. The biomass accumulated in a given unit period (generally, one year period) represents the productivity. Productivity is one of the most important functional attributes of an ecosystem and this provides basic energy and matter for all the other biotic components of the ecosystem (Billore and Mall, 1977). Importance is given for assessing plant productivity in an ecosystem as it provides basic energy and matter for all the other biotic components of the ecosystem. At the same, productive potential of a species or a community is also an indication of their contribution to overall organic matter production in a given a given ecosystem.

In the tropics, it is estimated that the energy generated from sunlight per hectare per year is equivalent to that generated by 2,000 tonnes of dry biomass. In addition, the tree community has the potential to generate 200 dry tonnes of biomass per hectare per annum through photosynthesis and this is equivalent to 10 per cent energy yield from sunlight. However, available literature indicates that that maximum productivity in tree community with the fast growing abilities could reach 20 tonnes per hectare per annum. On the other hand, studies have shown that with the right genetic material, growing condition and management, bamboo can yield up 80 dry tonnes per hectare per annum. Apart from its ability to produce biomass at a faster rate and contribute significantly for carbon sequestration, bamboo has the ability to a serve as the viable substitute for timber and tropical hardwoods (Nath et al., 2015). Thus, bamboo has gained global importance as a major biomass resource, as a traditional source of energy and other multiple uses with high growth rates, and as a prominent bioresources which is having the ability to provide a number of potential ecosystem services including carbon sequestration (Zhang et al., 2014). In a rapidly changing scenario of socio-economic and marketing opportunities, bamboo is being elevated from the "poor man's timber", to the status of the "timber of the 21st century" (http://agricoop.nic.in/bamboo/bamboomission.html). It may be mentioned here that one of the objectives of the National Bamboo Mission is to increase the area under bamboo plantation in non- forest Government and private lands to supplement farm income and contribute towards resilience to climate change as well as availability of quality raw material requirement of industries. Similarly, the Kerala Forest Research Institute has recognized the fact that the scope of bamboo plantation has to go beyond forest jurisdiction to non-forest lands in order to develop a strong bamboo resource base and strengthen economy related to bamboo in the State of Kerala. Thus, the Institute has initiated several activities for lending support to stakeholders by providing both propagules and technical guidance for cultivating and managing bamboos. For instance, during the year 2010-11, as part of different research and extension projects a total of 14 species of bamboo, prioritized by the National Bamboo Mission as commercially important species were planted in the State (Chandrashekara and Raveendran, 2018) and all these species are included in this study. Since these species are planted in the same geographic region, the knowledge generated on the growth and biomass production potential is important for sustainable commercial utilization of these species. At the same time, some of the previous studies (Shanmughavel and Francis, 1996; Isagi et al., 1997; Yen et al., 2010; Yen and Lee, 2011; Jijeesh, 2013) indicated considerably high level of biomass accumulation in a short period in some bamboos species, such as *Bambusa balcooa, Bambusa bambos, Phyllostachys pubescens and Phyllostachys makinoi.* These studies also highlighted the fact that comparative assessment of different species of bamboos for physical and biomass production and accumulation properties of culms in clumps of same age are very important not only for understanding the performance of a set of selected species growing in a give geographic region, but also for making a better prediction of the future yield.

The present study was undertaken to make a comparative assessment of culm biomass and biomass accumulation potential of different species in Kerala. The regression models developed using data generated from this baseline study on culm diameter, culm height and culm weight will be helpful for yield estimation of a stand without harvesting culms.

## C. Methodology

For the present study, 5-6 year old clumps of 14 bamboo species were selected. The list of bamboo species and farm locations are provided in Table 1.

Table 1. The list of bamboo species selected for the Study and farm location details.

| Species | Location of the Plantation | Latitude | Longitude |
|---|---|---|---|
| *Bambusa balcooa* Roxb. | Pattambi | 10°48'40.58"N | 76°11'13.58"E |
| *Bambusa bambos* (L.) Voss | Akathethara | 10°48'03.26"N | 76°39'03.91"E |
| Bambusa nutans Wall. ex Munro | Thrikangode | 10°45'58.67"N | 76°21'07.89"E |
| *Bambusa tulda* Roxb. | Desamangalam | 10°24'34.39"N | 76°19'11.35"E |
| *Bambusa vulgaris cv. wamin* McClure | Mupliyar | 10°24'37.61"N | 76°19'57.47"E |
| *Bambusa vulgaris* Schrad. ex Wendl. | Desamangalam | 10°24'34.86"N | 76°19'11.76"E |
| *Bambusa wamin* E.G.Camus | Thalikulam | 10°25'54.95"N | 76°04'38.65"E |
| *Dendrocalamus asper* (Schult.) Backer | Kodanad | 10°11'42.31"N | 76°31'40.25"E |
| *Dendrocalamus hamiltonii* Nees & Arn. ex Munro | Pattambi | 10°48'41.28"N | 76°11'21.30"E |
| *Dendrocalamus longispathus* (Kurz) Kurz | Kallar | 10°02'45.18"N | 76°57'35.82"E |
| *Dendrocalamus sikkimensis* Gamble ex Oliv. | Neriyamangalam | 10°03'04.70"N | 76°51'16.08"E |
| *Dendrocalamus strictus* (Roxb.) Nees | Keezhumad | 10°06'31.45"N | 76°23'20.49"E |
| *Gigantochloa rostrata* K.M.Wong | Pattambi | 10°48'40.58"N | 76°11'13.58"E |
| *Thyrsostachys oliveri* Gamble | Chundampatta | 10°54'24.63"N | 76°12'49.71"E |

The planting stock of *B. balcooa, B. nutans, B. vulgaris, B.vulgaris* cv. *wamin, B. wamin* and *D. longispathus* were rooted cutting raised at nurseries in KFRI. On the other hand, seeds of B.

bambos, B. tulda, D. sikkimensis and D. strictus collected from the bambusetum of KFRI were used to raise seedlings and planting in above mentioned farms. The planting stock of D. hamiltonii and D. rostrata were seedlings raised using seeds collected from Himachal Pradesh and Pune respectively.

For a given species, 45 clumps were randomly selected and counted the total number of culms in each clump separately. Altogether, 250 culms per species were selected for recording the culm physical properties, such as, height, girth at the height of 1.37 m from the ground and number of internodes. For estimating the total biomass of each species, forty-five culms per species, covering different sizes, were selected randomly. Later, culm height and girth of each culm was measured. Removed the leaves and branches from each culm and fresh weight was recorded separately. The sub samples of both leaves and stem were brought to the laboratory. The culm wall thickness was measured at the height of 1.37 m from the ground. The culm (stem) was divided into three parts: bottom, middle, and top, and fresh weight was recorded separately using a digital scale and sub samples; 200 gm from the 2nd internodes of the bottom, middle and top parts, were taken from each culm. Similarly, 100 gm of branch and 100 gm of leaves per culm were also taken from the field. All samples were dried in an electric oven at $85^0$ C until constant weight was reached.

Simple regression equations were developed, between culm diameter and weight of each culm component, such as foliage, branches and stem (culm without branches and foliage). Similarly, simple regression equations were developed, between $d^2h$ (culm diameter$^2$ x culm height) and weight of each culm component, such as foliage, branches and stem (culm without branches and foliage). Using the weight of all culms in a given clump was estimated and based on the number of clumps in an unit area culm stand biomass in per hectare basis was estimated. In each selected clump, number of 1-year old culms were counted and using the regression equation developed the total biomass of all 1-year old culms in the clump was estimated to represent annual biomass accumulation.

Statistical analyses were performed using Microsoft Excel (version 2010) and SPSS (version 12). Tukey's test was used to identify significant differences between means (at 5% level of significance) of total biomass and annual production of biomass in 5-year old clumps of different bamboo species. Descriptive statistical analysis was performed for different parameters.

## D. Results and Discussion

### D1. Clump and culm characteristics of different species of bamboo

1. ***Bambusa balcooa*** Roxb.

*Bambusa balcooa*, indigenous to the North-Eastern India is being cultivated in different parts of the Country. This species is known as the best and strongest species for building purposes and much used for scaffolding. Culms of *B. balcooa* are also preferred for making agarbathi sticks and in bamboo wood chip industry.

The present study conducted in a 5-year old plantation of *B. balcooa* showed that the number of culms per clump ranged from 7 to 11 with a mean of 9 and low value for the coefficient of variation (17%) (Table 2). In these clumps, culm height ranged from 5.12 m to 7.58 m with a mean 6.74 m. Number of internodes per culm ranged from 23 to 29 with a mean of 27. Culm diameter at 1.37 m above the ground level ranged from 2.52 cm to 4.76 cm with a mean of 3.68 cm. The ratio between wall thickness and culm diameter ranged from 0.293 to 0.322 with a mean of 0.302. The coefficient of variation (CV) is an index of the overall variation or heterogeneity of a given variable. The calculated CV (i.e., the ratio of the standard deviation to the mean value times 100) indicated a comparatively high variability within the datasets of culm wall thickness (CV=36.9%) than those obtained for other culm properties (Table 2).

Table 2. Clumps size, culm characteristics and biomass allocation in different components of culms in *B.balcooa*. Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 9 | 1.5 | 7 | 11 | 17 |
| Culm height (m) (N= 250 culms) | 6.74 | 0.62 | 5.12 | 7.58 | 9.20 |
| Number of internodes per culm (N= 250 culms) | 27 | 1.39 | 23 | 29 | 5.15 |
| Culm diameter (cm) (N= 250 culms) | 3.68 | 0.50 | 2.52 | 4.76 | 13.68 |
| Culm wall thickness (cm) (N= 45 culms) | 1.11 | 0.41 | 0.78 | 1.34 | 36.90 |

It was found that dbh and $\{(dbh)^2 \times h\}]$ positively and significantly correlated with component (stem. branch and total culm) dry weight. The linear association between the independent variables [dbh or $\{(dbh)^2 \times h\}]$ and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass and branch biomass indicated that the independent variable(s) (dbh or $\{(dbh)^2 \times h\}$) and component dry weight had a significant relationship (P<0.01) (Table 3). All the three components (stem. branch and total culm) showed $R^2$ between 0.973 and 0.989, showing positive relationship between biomass and dbh or $((dbh)^2 \times h\}$. The fitted regression lines are shown in Figure 1 and 2. However, in the case of leaf, correlation between biomass and independent variable was weak (P- value= 0.565 and 0.583; $r^2$ = 0.088 and 0.0.084). This suggests that the leaf being a short durability component in the culm will have poor correlation with independent variables.

Table 3. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in cm$^2$) x culm height (h: in m)} of *B. balcooa*.

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.893 (d) - 0.929* | 0.924 |
| | DW (Stem) = *0.013 ($d^2h$) + 1.078** | 0.928 |
| Branch | DW (Branch) = 0.297(d) - 0.270* | 0.924 |
| | DW (Stem) = *0.004 ($d^2h$) + 0.396** | 0.931 |
| Total culm | DW (Culm) = 1.211(d) - 0.941* | 0.919 |
| | DW (Culm) = *0.018 ($d^2h$) + 1.78** | 0.922 |

*, Significant at p < .01.

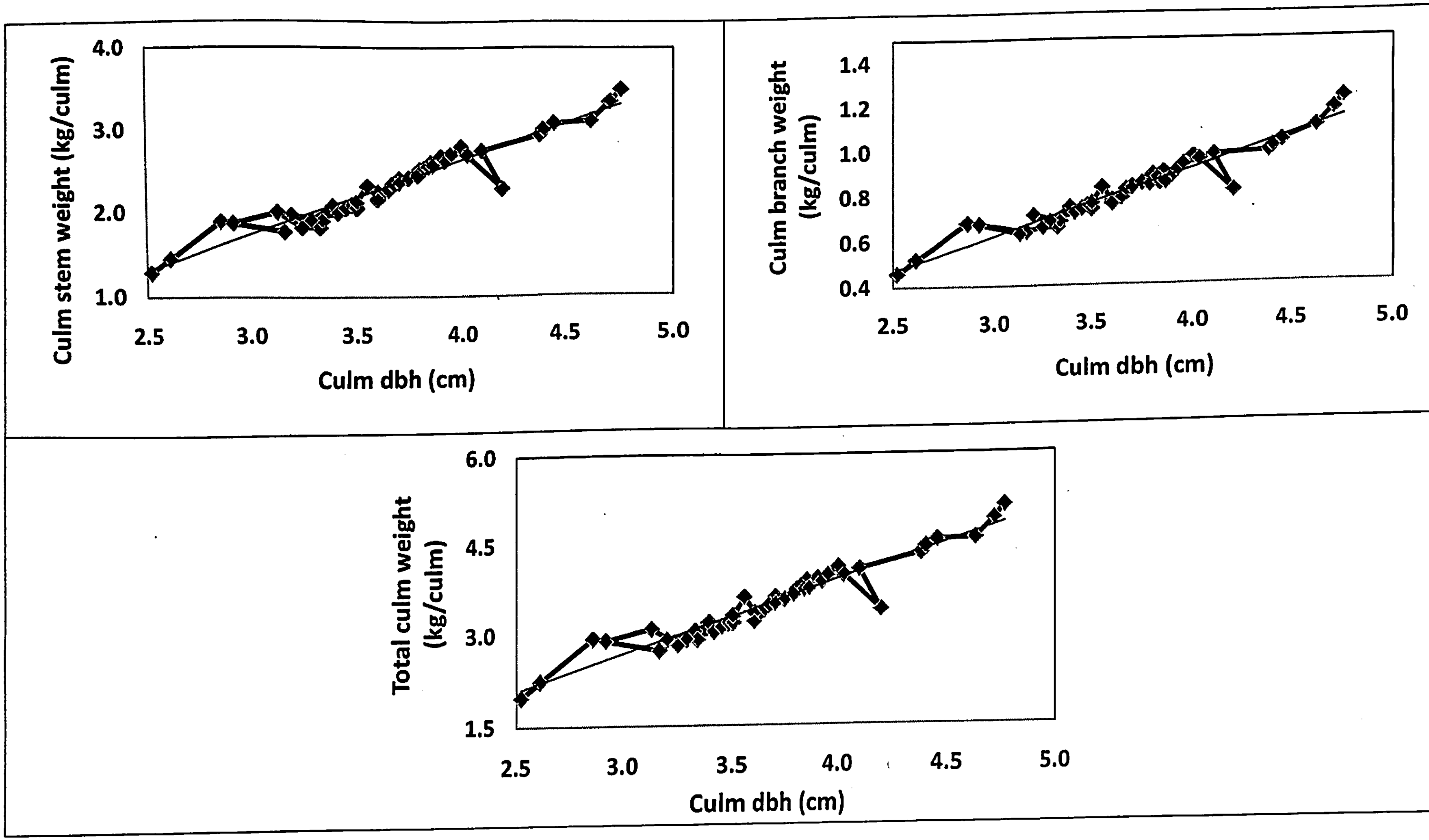



Figure 1. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *B. balcooa*

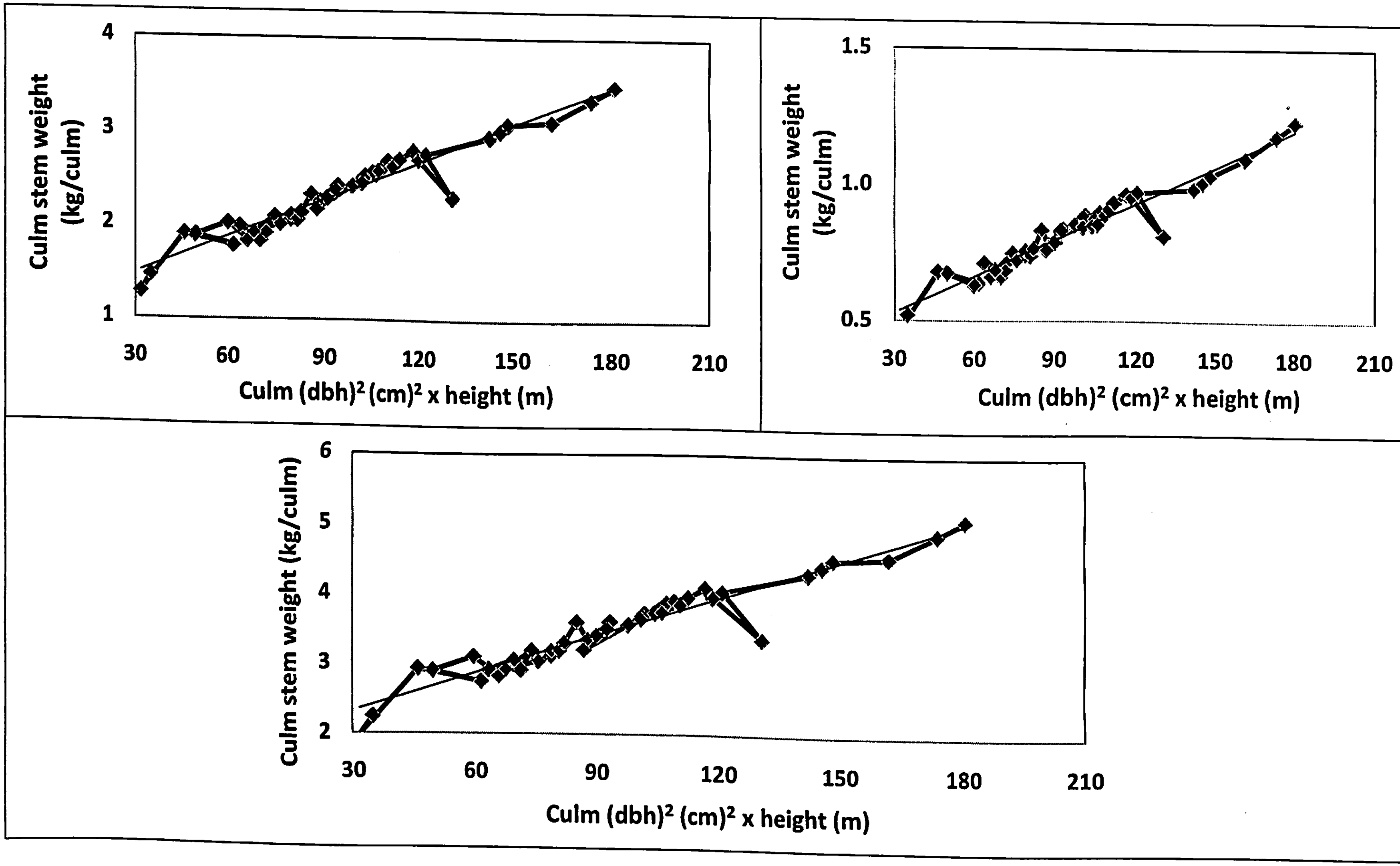



Figure 2. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *B. balcooa*. Culm dbh in cm and height in m.

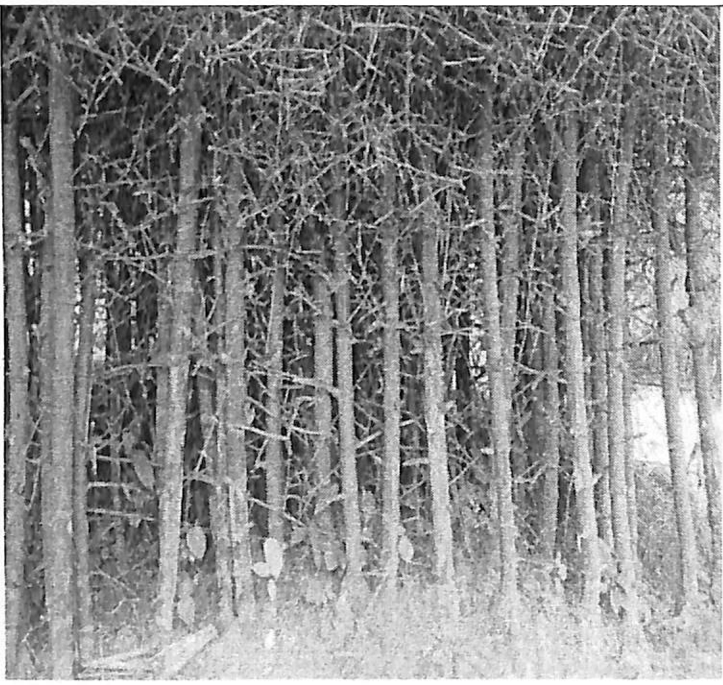
Oven dry weight of the entire culm ranged from 1.98 kg to 5.10 kg with a mean of 3.52 kg (Table 4). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 1.28 kg and 3.49 kg (mean: 2.36 kg per culm). While the branch oven dry weight ranged from 0.46 kg per culm to 1.23 kg per culm (mean: 0.82 kg per culm), the leaf weight ranged from 0.24 to 0.55 kg per culm (mean: 0.33 kg per culm). In all these cases, the CV was less than 20%. The ratio between stem, branches and leaf components of a culm of *B. balcooa* is 0.68: 0.23:0.09.

Table 4. Biomass allocation in different components of culms in *Bambusa balcooa.* Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 3.52 | 0.64 | 1.98 | 5.10 | 18.10 |
| Stem oven dry weight (kg/culm) | 2.36 | 0.47 | 1.28 | 3.49 | 19.83 |
| Branch oven dry weight (kg/culm) | 0.82 | 0.16 | 0.46 | 1.23 | 18.90 |
| Leaf oven dry weight (kg/culm) | 0.33 | 0.06 | 0.24 | 0.55 | 16.92 |

2. ***Bambusa bambos*** (L.) Voss

This bamboo, native to South-East Asia, is widely introduced and cultivated throughout the tropics for its multiple uses. Important use of this bamboo is as a raw material for pulp, paper and panel products. Other uses include scaffoldings, rafters, thatching and roofing, basket making, bows and arrows, furniture, floating timber and rafting, cooking utensils and fencing. Shoots and seeds are edible.



The present study conducted in a 5-year old plantation of *B. bambos* showed that the number of culms per clump ranged from 21 to 41 with a mean value of 32 and variability within the datasets of clump size is minimum (CV=11.3%) (Table 5). In these clumps, culm height ranged from 11.30 m to 16.72 m with a mean 14.89 m. Number of internodes per culm ranged from 51 to 88 with a mean of 68. Culm diameter at 1.37 m above the ground level ranged from 5.48 cm to 11.1 cm with a mean of 8.14 cm. The ratio between wall thickness and culm diameter ranged from 0.387 to 0.401 with a mean of 0.344. The calculated coefficient of variation (CV) indicated a comparatively high variability within the datasets of culm wall thickness (CV=25.71 %) than those obtained for other culm properties (Table 5).

Table 5. Clumps size and culm characteristics in different components of culms in *B. bambos.* Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 32 | 3.60 | 21 | 41 | 11.25 |
| Culm height (m) (N= 250 culms) | 14.89 | 1.36 | 11.30 | 16.72 | 9.13 |
| Number of internodes per culm (N= 250 culms) | 68 | 2.71 | 51 | 88 | 3.99 |
| Culm diameter (cm) (N= 250 culms) | 8.14 | 1.12 | 5.48 | 11.10 | 14.95 |
| Culm wall thickness (cm) (N= 45 culms) | 2.8 | 0.72 | 2.2 | 4.3 | 25.71 |

A positive and significant correlation between dbh dry weight of different culm components (stem. Branch, leaf and total culm) was recorded. Similarly, correlation between $\{(dbh)^2 \times h\}]$ with dry weight of each culm component was also positive and significant. The linear association between the independent variables [dbh or $\{(dbh)^2 \times h\}]$ and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or $\{(dbh)^2 \times h\}$) and component dry weight had a significant relationship ($P<0.01$) (Table 6). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.915 and 0.982, showing positive relationship between biomass and dbh or $((dbh)^2 \times h\}$. The fitted regression lines are shown in Figure 3 and 4.

Table 6. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in $cm^2$) x culm height (h: in m)} of *Bambusa bambos.*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.831 (d) – 1.593* | 0.976 |
| | DW (Stem) = *0.002 ($d^2h$) + 2.348** | 0.970 |
| Branch | DW (Branch) = 0.270 (d) - 0.438* | 0.967 |
| | DW (Stem) = *0.001 ($d^2h$) + 0.837** | 0.978 |
| Leaf | DW (Branch) = 0.145(d) - 0.419* | 0.930 |
| | DW (Stem) = *0.001 ($d^2h$) + 0.273** | 0.915 |
| Total culm | DW (Culm) = 1.246 (d) – 2.448* | 0.982 |
| | DW (Culm) = *0.004 ($d^2h$) + 3.460** | 0.978 |

*, Significant at $p < .01$

Oven dry weight of the entire culm ranged from 4.58 kg to 11.32 kg with a mean of 7.70 kg (Table 7). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 3.07 kg and 7.00 kg (mean: 5.17 kg per culm). While the branch oven dry weight ranged from 1.12 kg per culm to 2.61 kg per culm (mean: 1.76 kg per culm), the leaf weight ranged from 0.39 to 1.11 kg per culm (mean: 0.76 kg per culm). Except in leaf component, other components have less variability within the datasets of their dry weight (Table 7). The ratio between stem, branches and leaf components of a culm of *Bambusa bambos* is 0.67: 0.23:0.10.

Table 7. Biomass allocation in different components of culms in *Bambusa bambos*. Age of the clump= 5 years. N= 45 culms

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 7.70 | 1.37 | 4.58 | 11.32 | 17.79 |
| Stem oven dry weight (kg/culm) | 5.17 | 0.94 | 3.07 | 7.00 | 18.11 |
| Branch oven dry weight (kg/culm) | 1.76 | 0.31 | 1.12 | 2.61 | 17.34 |
| Leaf oven dry weight (kg/culm) | 0.76 | 0.17 | 0.39 | 1.11 | 22.67 |

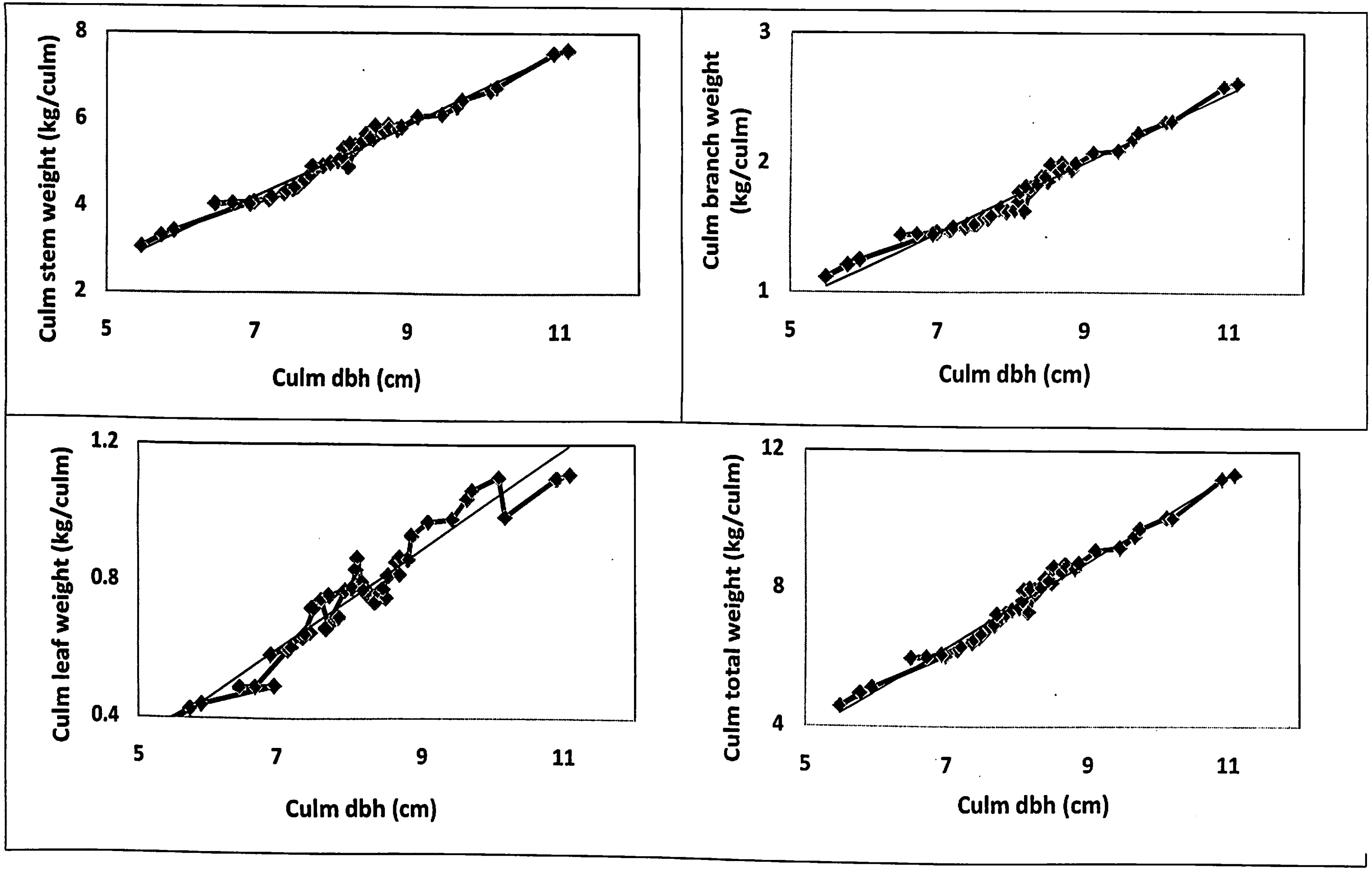



Figure 3. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *Bambusa bambos*

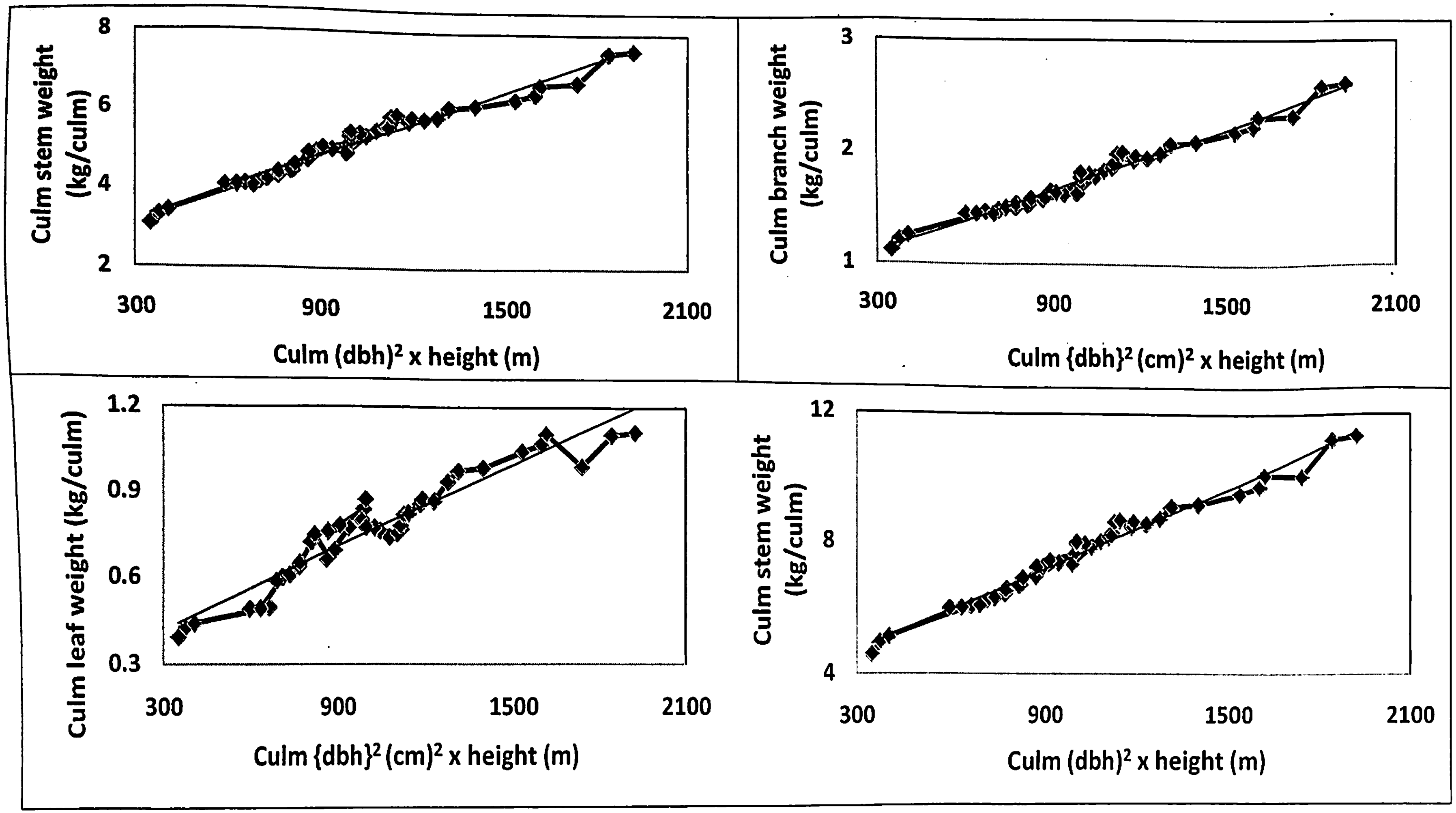



Figure 4. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *Bambusa bambos*. Culm dbh in cm and height in m.

3. *Bambusa nutans* Wall. ex Munro

| | |
|---|---|
| Bambusa nutans is a medium sized graceful loosely clumped bamboo. This is one of the important bamboo species commonly used in Indian paper industry. The culm is good, strong, straight and used locally for various purposes, mainly as poles. Being a graceful bamboo, *B.nutans* is also growing as an ornamental plant. |  |

In the 5-year old plantation of *B. nutans,* 4 to 9 culms per clump (Mean = 6 culms) were recorded having variability within the datasets of clump size is 15% (Table 8). In these clumps, culm height ranged from 8.4 m to 12.43 m with a mean 11.07 m. Number of internodes per culm ranged from 37 to 52 with a mean of 42. Culm diameter at 1.37 m above the ground level ranged from 4.28 cm to 7.72 cm with a mean of 6.09 cm. The calculated coefficient of variation (CV) indicated a less variability (>15%) within the datasets of each of the above mentioned parameters (Table 8).

Table 8. Clumps size and culm characteristics in different components of culms in *B. nutans.* Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 6 | 0.9 | 4 | 9 | 15.00 |
| Culm height (m) (N= 250 culms) | 11.07 | 1.01 | 8.40 | 12.43 | 9.12 |
| Number of internodes per culm (N= 250 culms) | 42 | 3.72 | 37 | 52 | 8.86 |
| Culm diameter (cm) (N= 250 culms) | 6.09 | 0.78 | 4.28 | 7.72 | 12.79 |

Culm dbh and dry weight of stem, branch and total culm showed a positive and significant correlation between each other. Similarly, correlation between {(dbh)$^2$ x h}] with dry weight of stem, branch and total culm was also positive and significant. The linear association between the independent variables [dbh or {(dbh)$^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass and branch biomass indicated that the independent variable(s) (dbh or {(dbh)$^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 9). All these three components (stem, branch and total culm) showed $R^2$ between 0.883 and 0.925, showing positive relationship between biomass and dbh or ((dbh)$^2$ x h}. The fitted regression lines are shown in Figure 5 and 6. However, in the case of leaf, correlation between biomass and independent variable was weak (P- value= 0.552 and 0.505; $r^2$ = 0.091 and 0.102). This suggests that the leaf being a short durability component in the culm will have poor correlation with independent variables.

Table 9. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in cm$^2$) x culm height (h: in m)} of *B. nutans.*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.927 (d) – 1.735* | 0.894 |
| | DW (Stem) = *0.005 ($d^2h$) + 1.696** | 0.925 |
| Branch | DW (Branch) = 0.387(d) - 0.930* | 0.883 |
| | DW (Stem) = *0.002 ($d^2h$) + 0.498** | 0.889 |
| *Total culm* | DW (Culm) = 1.328(d) – 2.298* | 0.890 |
| | DW (Culm) = *0.007 ($d^2h$) + 2.601** | 0.899 |

***, Significant at p < .01**

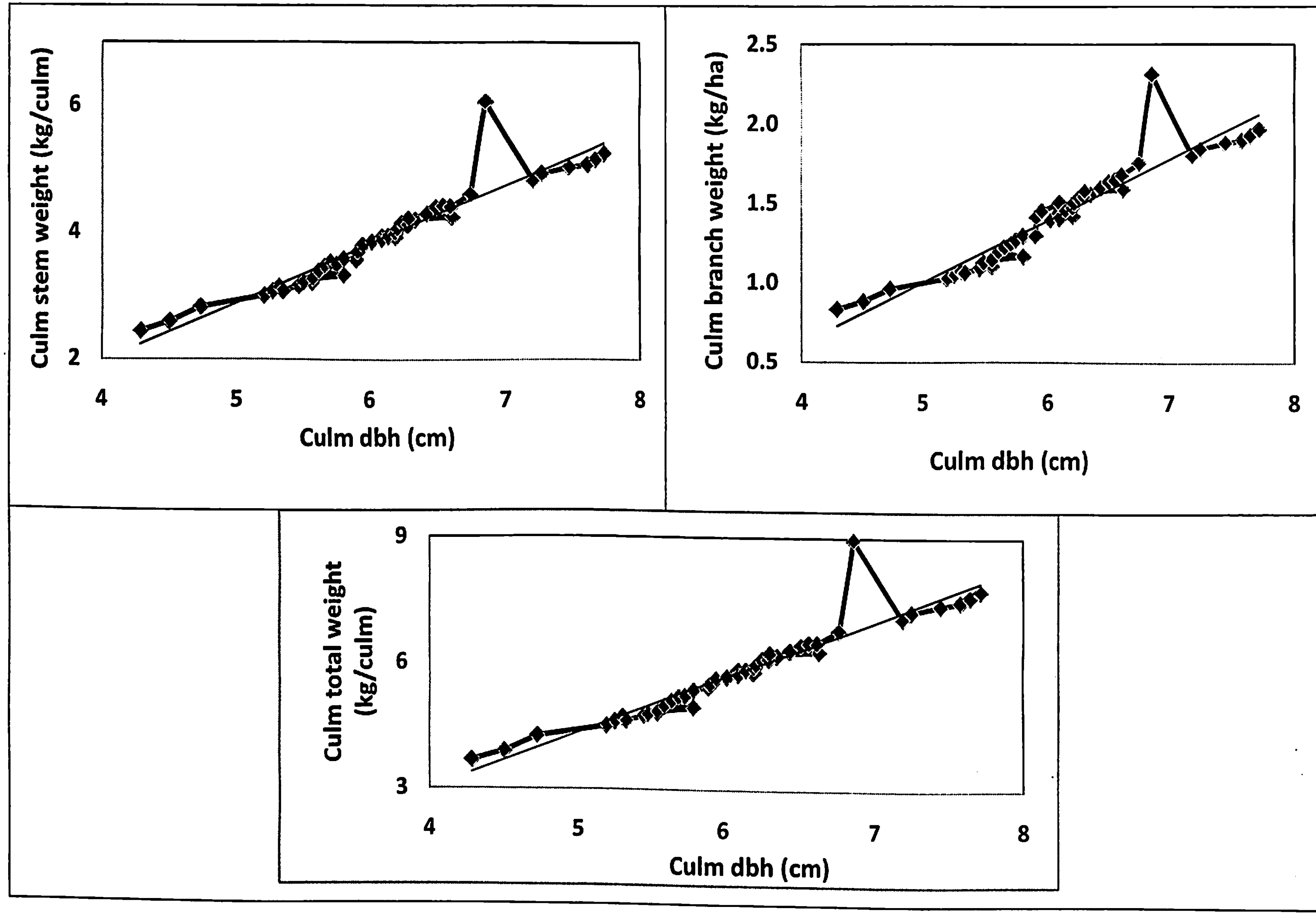



Figure 5 . Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *B. nutans*

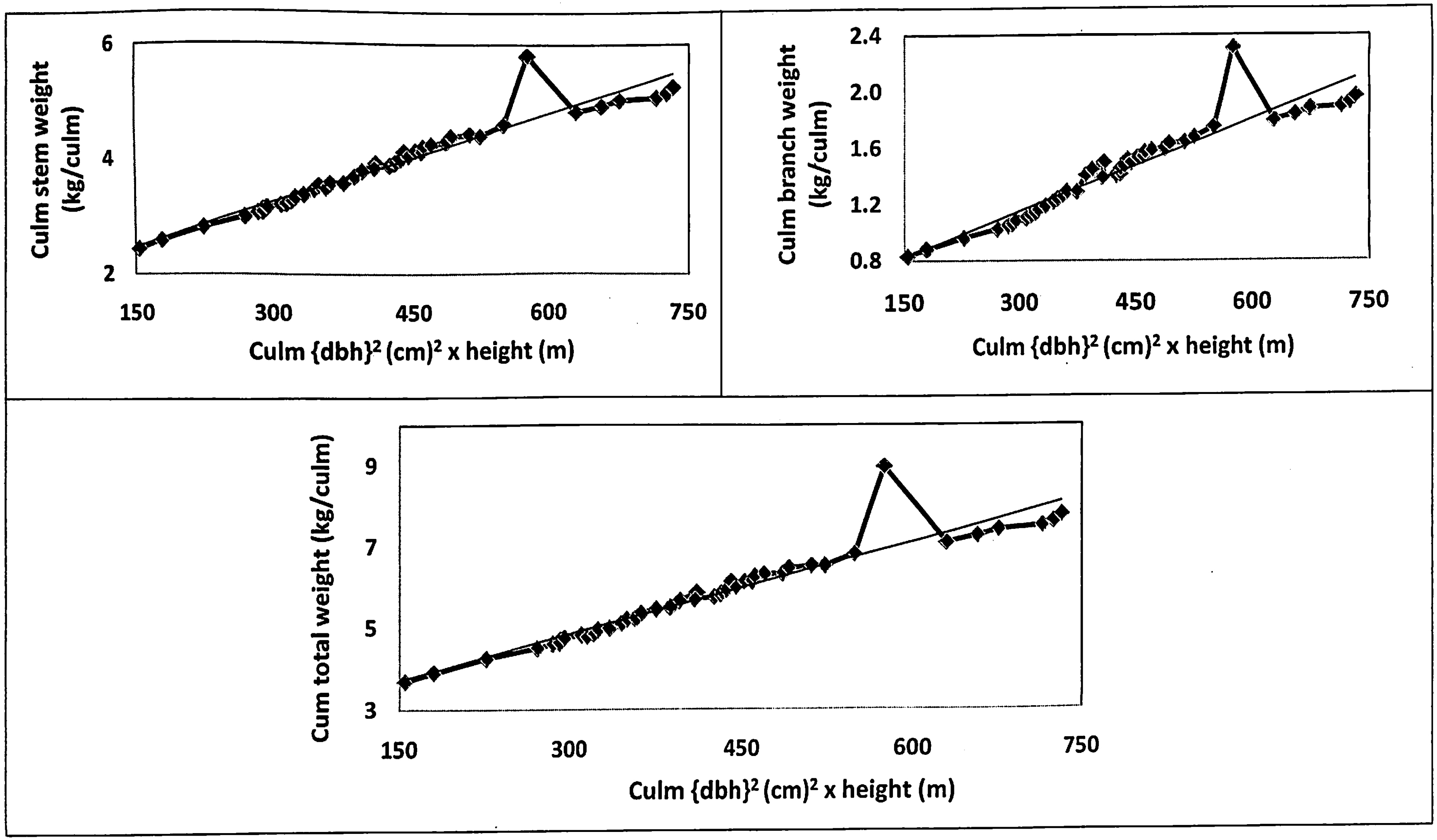



Figure 6. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *B.nutans*. Culm dbh in cm and height in m.

Oven dry weight of the entire culm ranged from 3.68 kg to 8.95 kg with a mean of 5.80 kg (Table 10). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 2.44 kg and 6.07 kg (mean: 3.91 kg per culm). While the branch oven dry weight ranged from 0.83 kg per culm to 2.31 kg per culm (mean: 1.43 kg per culm), the leaf weight ranged from 0.38 to 0.57 kg per culm (mean: 0.46 kg per culm). Except branch component, other components have less variability within the datasets of their dry weight (Table 10). The ratio between stem, branches and leaf components of a culm of *B. nutans* is 0.67: 0.25:0.08.

Table 10. Biomass allocation in different components of culms in *B. nutans.* Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 5.80 | 1.10 | 3.68 | 8.95 | 18.92 |
| Stem oven dry weight | 3.91 | 0.76 | 2.44 | 6.07 | 19.53 |
| Branch oven dry weight (kg/culm) | 1.43 | 0.32 | 0.83 | 2.31 | 22.47 |
| Leaf oven dry weight (kg/culm) | 0.46 | 0.04 | 0.38 | 0.57 | 8.44 |

## 4. ***Bambusa tulda*** Roxb.

*Bambusa tulda* is a tufted, gregarious bamboo found in the states of Assam, Bihar, Meghalaya, Mizoram, Nagaland and Tripura and cultivated in Arunachal Pradesh, Uttar Pradesh, Karnataka and Bengal. This is one the five quick-growing species of bamboos preferred for raising plantations in India. It can be used as reinforcement in cement concrete. The succulent shoots are rich in phytosterols and the fermented shoots can be used for production of sterol drugs.

In the 5-year old plantation of *B. tulda,* 18 to 34 culms per clump (Mean = 26 culms) were recorded having variability within the datasets of clump size is 27% (Table 11). In these clumps, culm height ranged from 8.12 m to 12.02 m with a mean 10.7 m. Number of internodes per culm ranged from 39 to 47 with a mean of 44. Culm diameter at 1.37 m above the ground level ranged from 4.14 cm to 7.60 cm with a mean of 5.91 cm. The calculated coefficient of variation (CV) indicated a less variability (>15%) within the datasets of culm height, number of internodes per culm and culm diameter (Table 11).

Table 11. Clumps size and culm characteristics in different components of culms in *B. tulda.* Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 26 | 7 | 18 | 34 | 26.9 |
| Culm height (m) (N= 250 culms) | 10.70 | 0.98 | 8.12 | 12.02 | 9.2 |
| Number of internodes per culm (N= 250 culms) | 44 | 3.16 | 39 | 47 | 7.2 |
| Culm diameter (cm) (N= 250 culms) | 5.91 | 0.73 | 4.14 | 7.60 | 12.4 |
| Culm wall thickness (cm) (N= 45 culms) | 1.32 | 0.12 | 1.17 | 1.43 | 9.1 |

A positive and significant correlation between culm dbh and dry weight of stem, branch and total culm was recorded (Table 12). Similarly, correlation between {$(dbh)^2$ x h}] with dry weight of stem, branch and total culm was also positive and significant. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass and branch biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 8). All these three components (stem, branch and total culm) showed $R^2$ between 0.893 and 0.987, showing positive relationship between biomass and dbh or ($(dbh)^2$ x h}. The fitted regression lines are shown in Figure 7 and 8. However, in the case of leaf, correlation between biomass and independent variable was weak (the result is not significant at $p < 0.01$ or $p < 0.05$). This suggests that even in this species, the leaf being a short durability component in the culm will have poor correlation with independent variables.

Table 12. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in $cm^2$) x culm height (h: in m)} of *B. tulda.*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.68 (d) – 0.656* | 0.921 |
| | DW (Stem) = *0.004 ($d^2h$) + 1.831** | 0.954 |
| Branch | DW (Branch) = 0.208(d) - 0.052* | 0.893 |
| | DW (Stem) = *0.001* ($d^2h$) *+ 0.702** | 0.942 |
| Total culm | DW (Culm) = 0.892(d) – 0.206* | 0.936 |
| | DW (Culm) = *0.005 ($d^2h$) + 3.021** | 0.987 |

*, Significant at $p < .01$

Oven dry weight of the entire culm ranged from 3.56 kg to 6.60 kg with a mean of 5.07 kg (Table 7). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 2.38 kg and 4.41 kg (mean: 3.38 kg per culm). While the branch oven dry weight ranged from 0.81 kg per culm to 1.51 kg per culm (mean: 1.18 kg per culm), the leaf weight ranged from 0.37 to 0.78 kg per culm (mean: 0.51 kg per culm). Except leaf component, other components have less variability within the datasets of their dry weight (Table 7). The ratio between stem, branches and leaf components of a culm of *B.tulda* is 0.67: 0.23:0.10.

Table 13. Biomass allocation in different components of culms in *B.tulda.* Age of the clump= 5 years. N= 45 culms

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 5.07 | 0.68 | 3.56 | 6.60 | 13.3 |
| Stem oven dry weight (kg/culm) | 3.38 | 0.52 | 2.38 | 4.41 | 15.4 |
| Branch oven dry weight (kg/culm) | 1.18 | 0.16 | 0.81 | 1.51 | 13.7 |
| Leaf oven dry weight (kg/culm) | 0.51 | 0.11 | 0.37 | 0.76 | 21.0 |

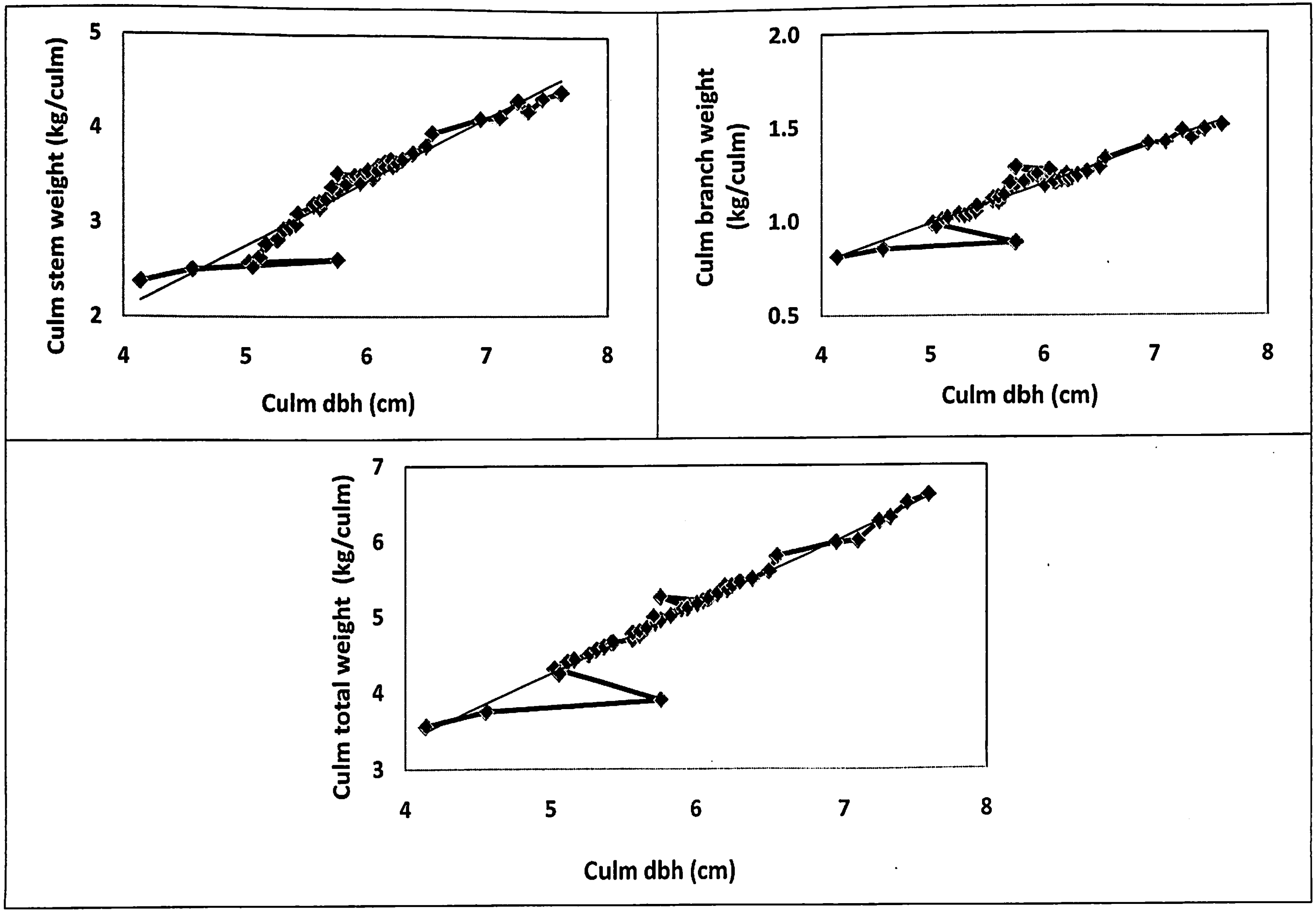



Figure 7. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *B. tulda*

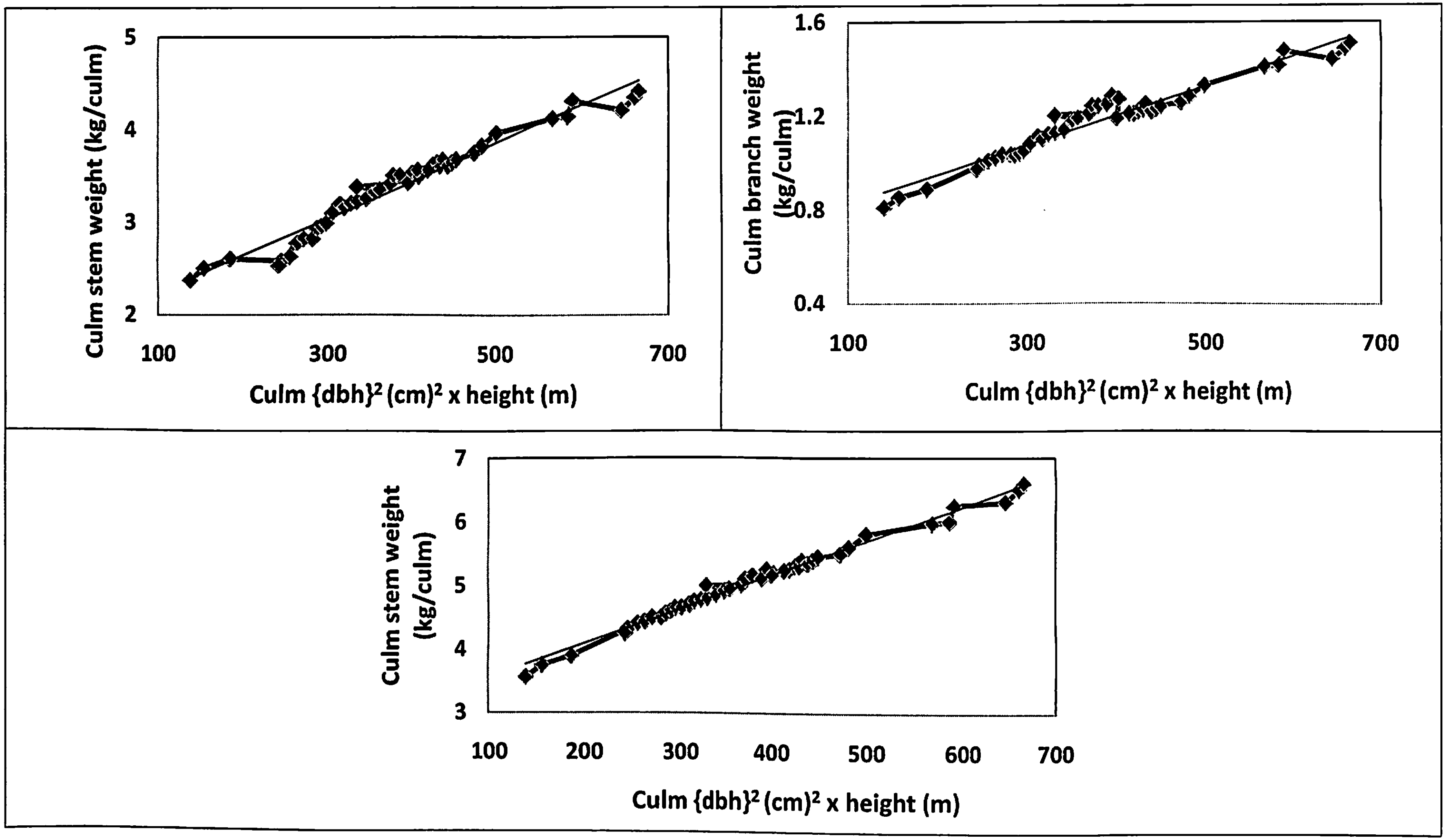



Figure 8. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *B.tulda*. Culm dbh in cm and height in m.

5. ***Bambusa vulgaris*** Schrad. ex Wendl.

| | | |
|---|---|---|
| *Bambusa vulgaris,* popularly known as yellow bamboo is native to Indochina and to the Province of Yunnan in southern China. This is a densely tufted bamboo grows well mostly on river banks, road sides, wastelands, and open ground, generally in the low altitudes. Culms are used for fencing and construction as well as to make furniture, basketry, windbreakers, flutes, fishing rods, tool handles and stakes. *B. vulgaris* is also cultivated as ornamental solitary or as border hedge. |  |  |

In the 5-year old plantation of *B. vulgaris,* 11 to 17 culms per clump (Mean = 13 culms) were recorded having variability within the datasets of clump size is 23% (Table 14). In these clumps, culm height ranged from 6.90 m to 10.21 m with a mean 9.1 m. Number of internodes per culm ranged from 35 to 54 with a mean of 41. Culm diameter at 1.37 m above the ground level ranged from 3.5 cm to 6.7 cm with a mean of 5.0 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.1% to 17.1% within the datasets of culm height, number of internodes per culm and culm diameter (Table 14).

A positive and significant correlation between dbh dry weight of different culm components (stem. branch, leaf and total culm) was recorded. Similarly, correlation between {$(dbh)^2$ x h}] with dry weight of each culm component was also positive and significant. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 15). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.915 and 0.982, showing positive relationship between biomass and dbh or (($(dbh)^2$ x h}. The fitted regression lines are shown in Figure 9 and 10.

Table 14. Clumps size and culm characteristics in different components of culms in *B. vulgaris*. Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 13 | 3 | 11 | 17 | 23.1 |
| Culm height (m) (N= 250 culms) | 9.09 | 0.83 | 6.90 | 10.21 | 9.1 |
| Number of internodes per culm (N= 250 culms) | 41 | 7 | 35 | 54 | 17.1 |
| Culm diameter (cm) (N= 250 culms) | 5.03 | 0.67 | 3.5 | 6.7 | 13.4 |
| Culm wall thickness (cm) (N= 45 culms) | 1.1 | 0.2 | 0.8 | 1.3 | 18.2 |

Table 15. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in $cm^2$) x culm height (h: in m)} of *Bambusa vulgaris*.

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.823 (d) – 1.011* | 0.962 |
| | DW (Stem) = *0.007 ($d^2h$) + 1.445** | 0.960 |
| Branch | DW (Branch) = 0.302 (d) - 0.450* | 0.938 |
| | DW (Stem) = *0.002* ($d^2h$) *+ 0.447** | 0.944 |
| Leaf | DW (Branch) = 0.135(d) - 0.143* | 0.773 |
| | DW (Stem) = *0.001* ($d^2h$) *+ 0.255** | 0.790 |
| Total culm | DW (Culm) = 1.260 (d) – 1.607* | 0.964 |
| | DW (Culm) = *0.010 ($d^2h$) + 2.148** | 0.966 |

*, Significant at p < .01

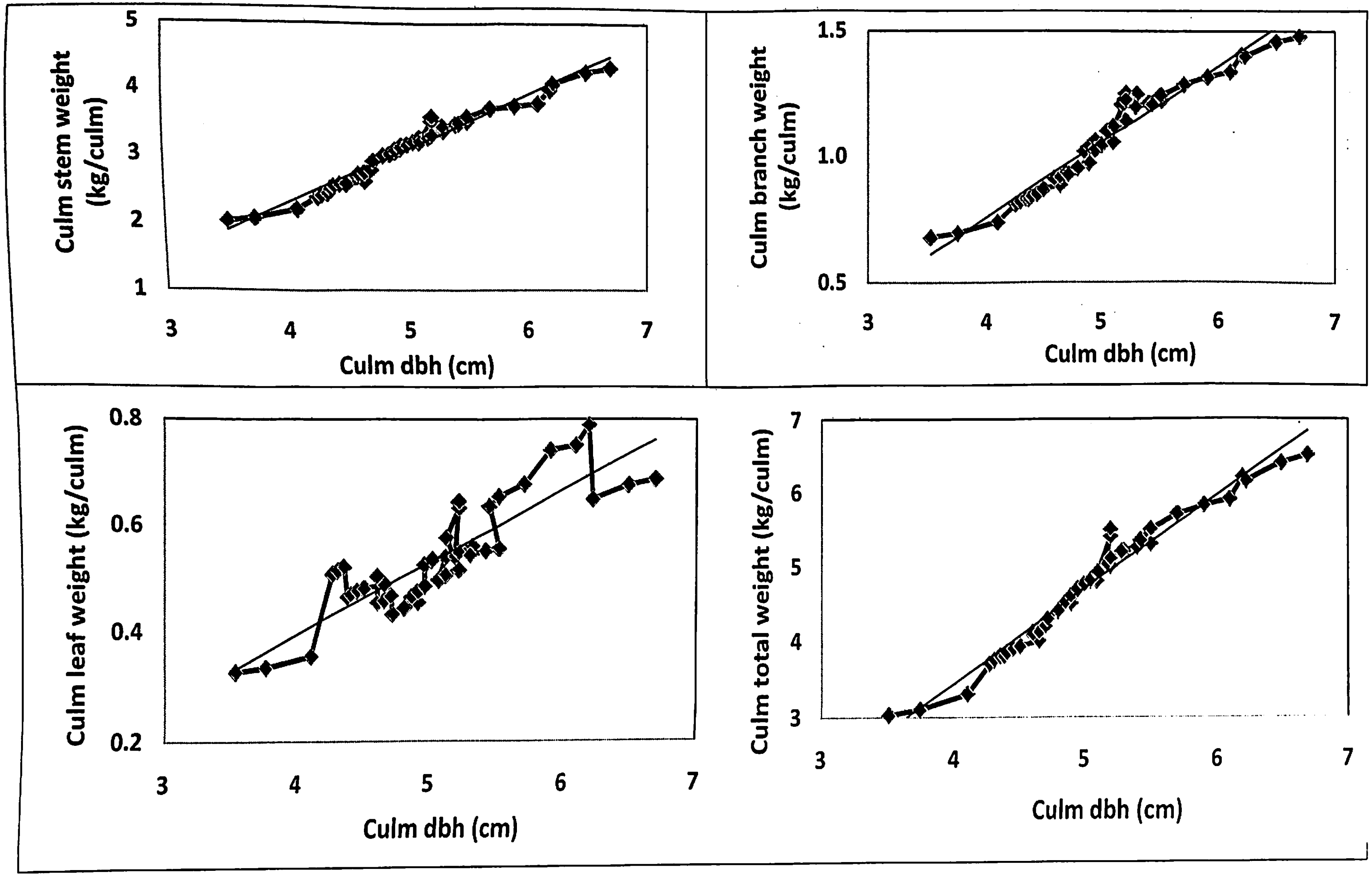



Figure 9. Fitted regression lines of oven dry weight (kg/culm) of stem, branch, leaf and total culm on culm dbh (cm) of *B.vulgaris*.

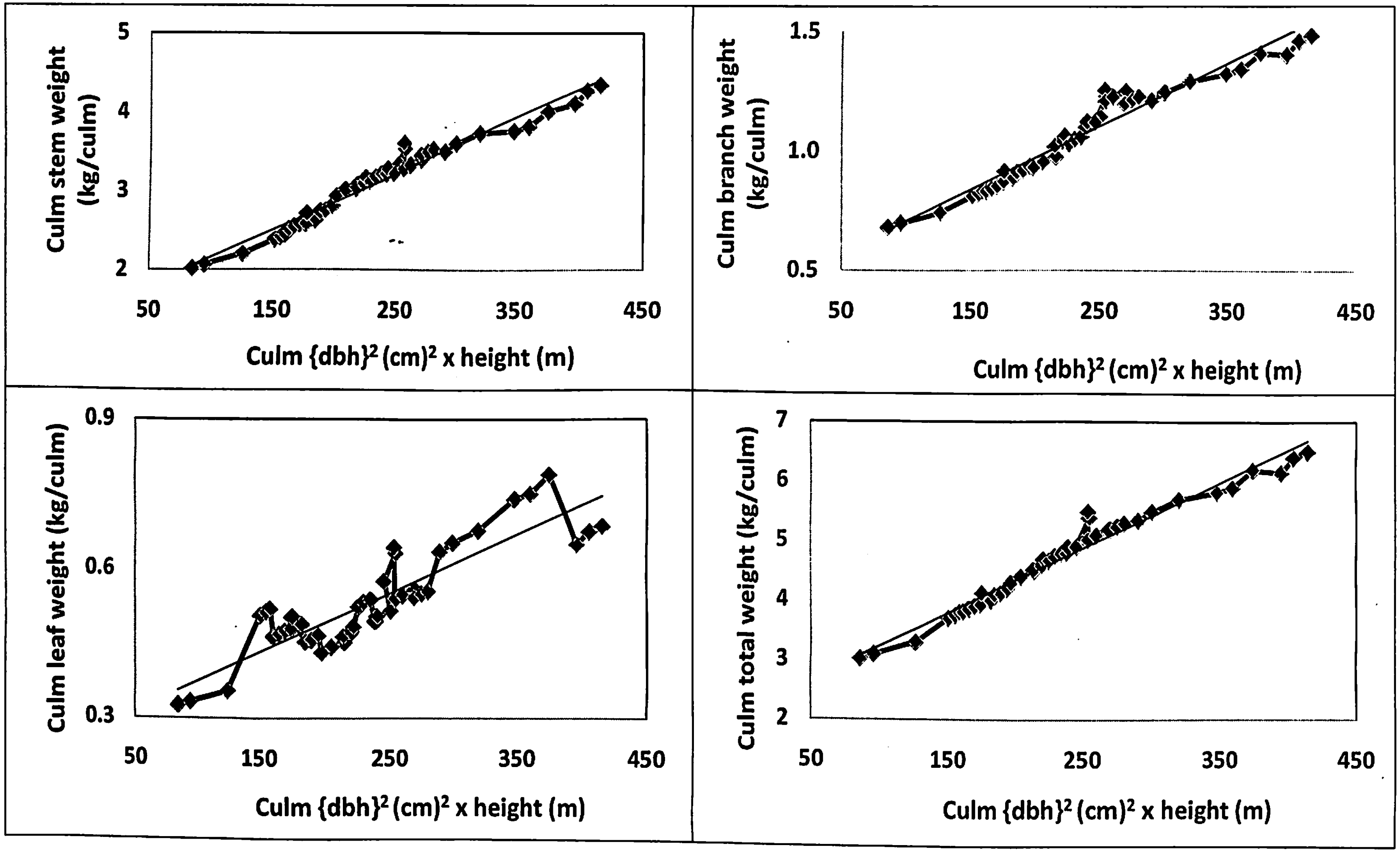



Figure 10. Fitted regression lines of oven dry weight (kg/culm) of stem, branch, leaf and total culm on culm $dbh^2$ x height of *B. vulgaris*. Culm dbh in cm and height in m.

Oven dry weight of the entire culm ranged from 3.03 kg to 6.50 kg with a mean of 4.73 kg (Table 16). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 2.02 kg and 4.33 kg (mean: 3.13 kg per culm). While the branch oven dry weight ranged from 0.68 kg per culm to 1.48 kg per culm (mean: 1.07 kg per culm), the leaf weight ranged from 0.33 to 0.79 kg per culm (mean: 0.54 kg per culm). Variability within the datasets of dry weight of different components ranged between 18.% to 19.6% (Table 16). The ratio between stem, branches and leaf components of a culm of *B. vulgaris* is 0.66: 0.23:0.11.

Table 16. Biomass allocation in different components of culms in *B. vulgaris.* Clump age = 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 4.73 | 0.86 | 3.03 | 6.50 | 18.3 |
| Stem oven dry weight (kg/culm) | 3.13 | 0.56 | 2.02 | 4.33 | 18.0 |
| Branch oven dry weight (kg/culm) | 1.07 | 0.21 | 0.68 | 1.48 | 19.6 |
| Leaf oven dry weight (kg/culm) | 0.54 | 0.10 | 0.33 | 0.79 | 19.3 |

## 6. *Bambusa vulgaris cv. wamin* McClure

*Bambusa vulgaris* cv. *wamin* is a moderate sized bright green bamboo cultivated extensively in many parts of the word. It is used for paper-making, scaffolding, construction, poles, curios and handicrafts in different parts of India. In Malaysia, it is cultivated for its edible shoots. This species is suitable for planting slopes to soil erosion

In the 5-year old plantation of *B. vulgaris cv. wamin,* 12 to 21 culms per clump (Mean = 16 culms) were recorded having variability within the datasets of clump size is 25% (Table 17). In these clumps, culm height ranged from 7.2 m to 10.66 m with a mean 9.48 m. Number of internodes per culm ranged from 21 to 26 with a mean of 23. Culm diameter at 1.37 m above the ground level ranged from 3.7 cm to 7.2 cm with a mean of 5.3 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 13% to 18.9% within the datasets of culm height, number of internodes per culm and culm diameter (Table 17).

Table 17. Clumps size and culm characteristics in different components of culms in *B. vulgaris cv. wamin*. Age of the clump= 5 years

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 16 | 4 | 12 | 21 | 25.0 |
| Culm height (m) (N= 250 culms) | 9.48 | 0.87 | 7.20 | 10.66 | 9.2 |
| Number of internodes per culm (N= 250 culms) | 23 | 3 | 21 | 26 | 13.0 |
| Culm diameter (cm) (N= 250 culms) | 5.26 | 0.73 | 3.7 | 7.2 | 13.8 |

Correlation between dbh and dry weight of different culm components (stem. branch, leaf and total culm) was positive and significant. Similarly, between {$(dbh)^2$ x h}] and dry weight of each culm component a positive and significant correlation was recorded. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 18). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.564 and 0.946, showing positive relationship between biomass and dbh or ($(dbh)^2$ x h}. The fitted regression lines are shown in Figure 11 and 12.

Table 18. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in $cm^2$) x culm height (h: in m)} of *B. vulgaris cv. Wamin.*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.850 (d) – 1.204* | 0.925 |
| | DW (Stem) = *0.006* ($d^2h$) *+ 1.458** | 0.932 |
| Branch | DW (Branch) = 0.295 (d) - 0.422* | 0.890 |
| | DW (Stem) = *0.002* ($d^2h$) *+ 0.500** | 0.904 |
| Leaf | DW (Branch) = 0.104(d) - 0.022* | 0.594 |
| | DW (Stem) = *0.0003* ($d^2h$) *+ 0.355** | 0.564 |
| Total culm | DW (Culm) = 1.250 (d) – 1.605* | 0.943 |
| | DW (Culm) = *0.009* ($d^2h$) *+ 2.314** | 0.946 |

*, Significant at p < .01

Oven dry weight of the entire culm ranged from 3.16 kg to 7.20 kg with a mean of 4.97 kg (Table 19). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 2.09 kg and 4.73 kg (mean: 3.27 kg per culm). While the branch oven dry weight ranged from 0.71 kg per culm to 1.6 kg per culm (mean: 1.13 kg per culm), the leaf weight ranged from 0.36 to 0.84 kg per culm (mean: 0.57 kg per culm). Variability within the datasets of dry weight of different components ranged between 17.3 % and 20.2% (Table 19). The ratio between stem, branches and leaf components of a culm of *B.vulgaris cv. wamin* is 0.66: 0.23:0.11.

Table 19. Clumps size, culm characteristics and biomass allocation in different components of culms in *B. vulgaris cv. wamin.* Age of the clump= 5 years. N= 45 culms

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 4.97 | 0.94 | 3.16 | 7.20 | 18.9 |
| Stem oven dry weight (kg/culm) | 3.27 | 0.64 | 2.09 | 4.73 | 19.7 |
| Branch oven dry weight (kg/culm) | 1.13 | 0.23 | 0.71 | 1.63 | 20.2 |
| Leaf oven dry weight (kg/culm) | 0.57 | 0.10 | 0.36 | 0.84 | 17.3 |

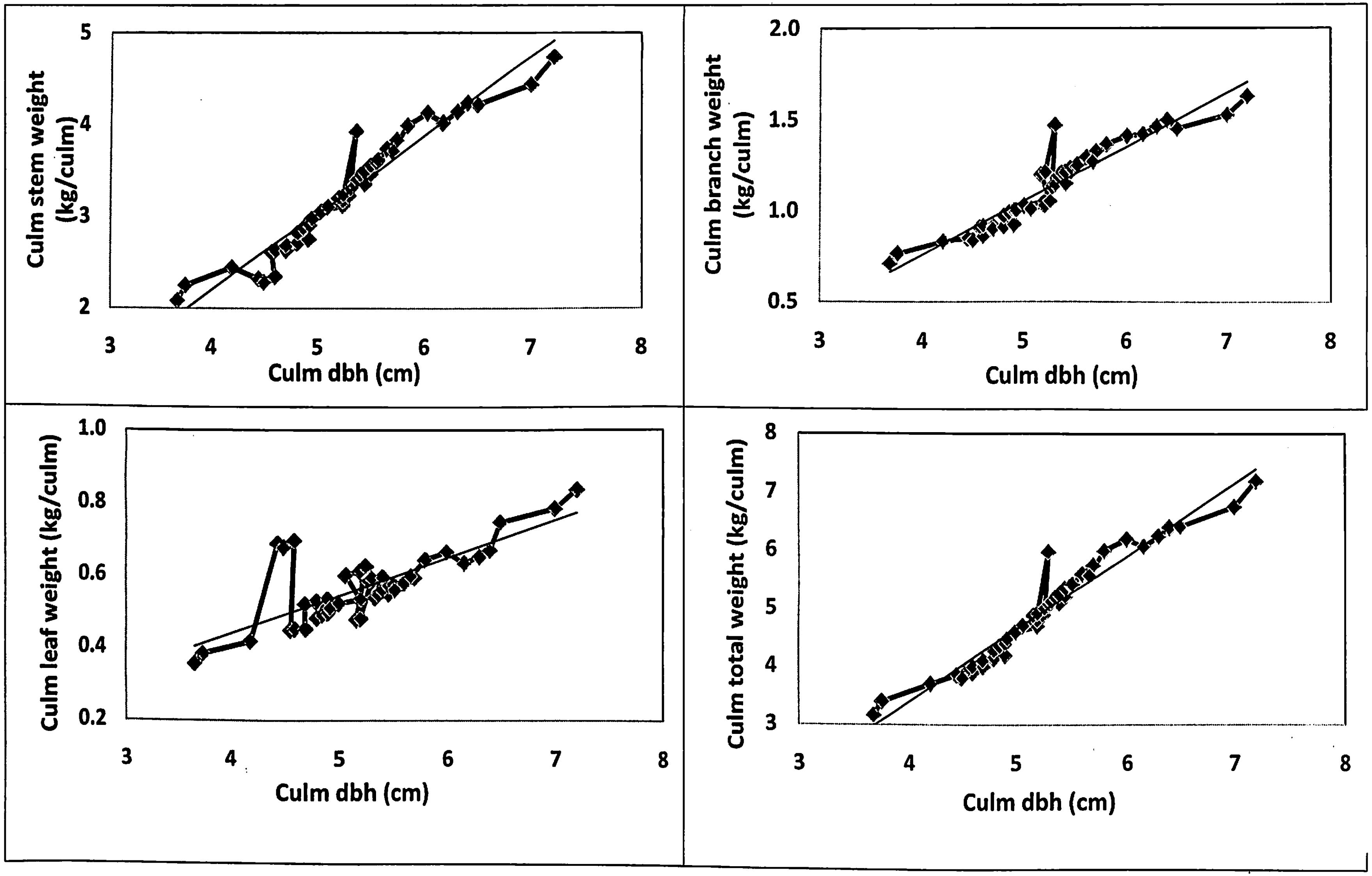



Figure 11. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *B. vulgaris cv. wamin*

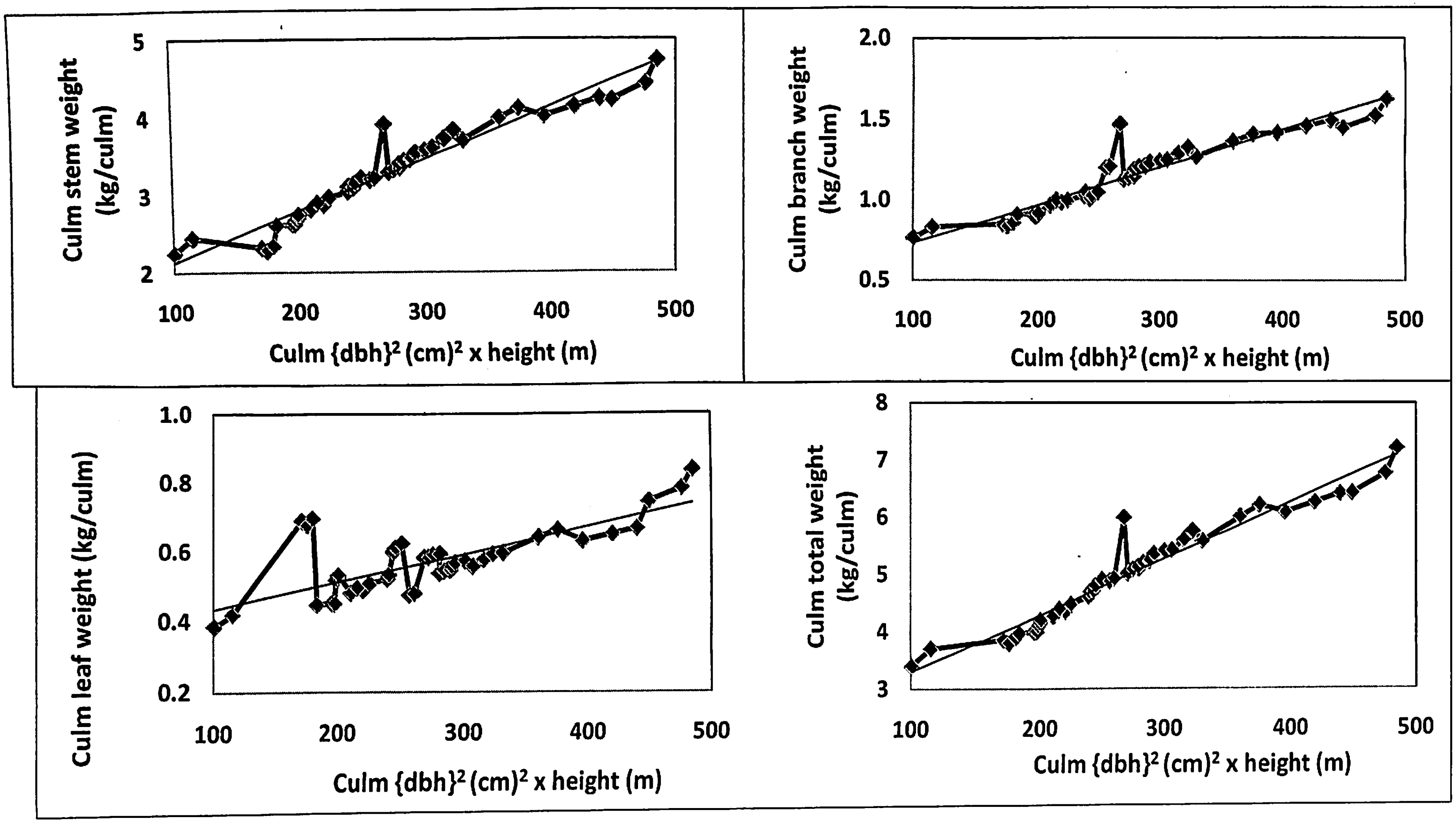



Figure 12. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *B.vulgaris cv. wamin*. Culm dbh in cm and height in m.

7. ***Bambusa wamin*** E.G.Camus

*Bambusa wamin* is a medium-sized graceful bamboo. Culms loosely tufted, usually arching at the top, dark green, shining and glabrous. Lower half portion of the internodes swollen (pitcher shaped). *B. wamin* is grown in many gardens as an ornamental bamboo mainly in the subtropical regions including India. Culms of this species are used for handicrafts.

In the 5-year old plantation of *B. wamin,* 24 to 38 culms per clump (Mean = 31 culms) were recorded having variability within the datasets of clump size is 16% (Table 20). In these clumps, culm height ranged from 6.3 m to 9.32 m with a mean 8.30 m. Number of internodes per culm ranged from 61 to 83 with a mean of 71. Culm diameter at 1.37 m above the ground level ranged from 3.2 cm to 6.6 cm with a mean of 4.6 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.2 % to 14.4% within the datasets of culm height, number of internodes per culm and culm diameter (Table 20). However, coefficient of variation (CV) was high for the culm wall thickness (36.4%). The mean ratio between wall thickness and culm diameter was 0.24.

Table 20. Clumps size and culm characteristics in different components of culms in *B. wamin.* Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 31 | 5 | 24 | 38 | 16.1% |
| Culm height (m) (N= 250 culms) | 8.30 | 0.76 | 6.30 | 9.32 | 9.2 |
| Number of internodes per culm (N= 250 culms) | 71 | 8 | 61 | 83 | 11.3 |
| Culm diameter (cm) (N= 250 culms) | 4.62 | 0.67 | 3.21 | 6.60 | 14.4 |
| Culm wall thickness (cm) (N= 45 culms) | 1.1 | 0.4 | 0.6 | 1.3 | 36.4 |

Correlation between dbh and dry weight of different culm components (stem. branch, leaf and total culm) was positive and significant. Similarly, between {(dbh)$^2$ x h}] and dry weight of each culm component a positive and significant correlation was recorded. The linear association between the independent variables [dbh or {(dbh)$^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {(dbh)$^2$ x h}) and component dry weight had a significant relationship (P<0.01) (Table 21). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.918 and 0.979, showing positive relationship between biomass and dbh or ((dbh)$^2$ x h}. The fitted regression lines are shown in Figure 13 and 14.

Table 21. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in cm$^2$) x culm height (h: in m)} of *B. wamin*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.788 (d) – 1.725* | 0.970 |
| | DW (Stem) = *0.008 ($d^2h$) - 1.373** | 0.969 |
| Branch | DW (Branch) = 0.274 (d) - 0.272* | 0.949 |
| | DW (Stem) = *0.003* ($d^2$h) *- 0.458** | 0.954 |
| Leaf | DW (Branch) = 0.134(d) - 0.188* | 0.918 |
| | DW (Stem) = *0.001* ($d^2$h) *+ 0.168** | 0.927 |
| Total culm | DW (Culm) = 1.207 (d) – 1.228* | 0.972 |
| | DW (Culm) = *0.013 ($d^2h$) – 1.978** | 0.979 |

*, Significant at p < .01

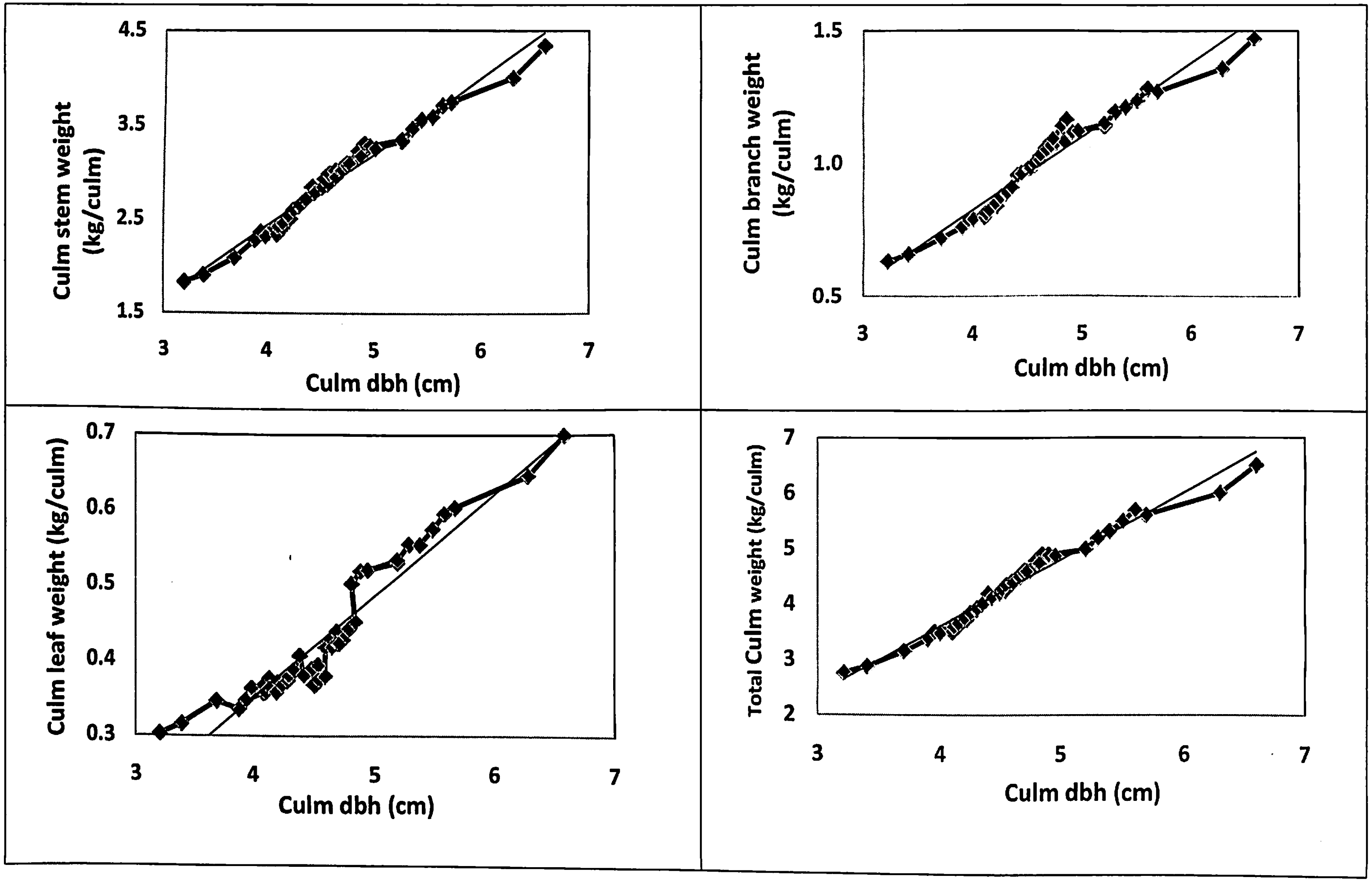



Figure 13. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *B. wamin*

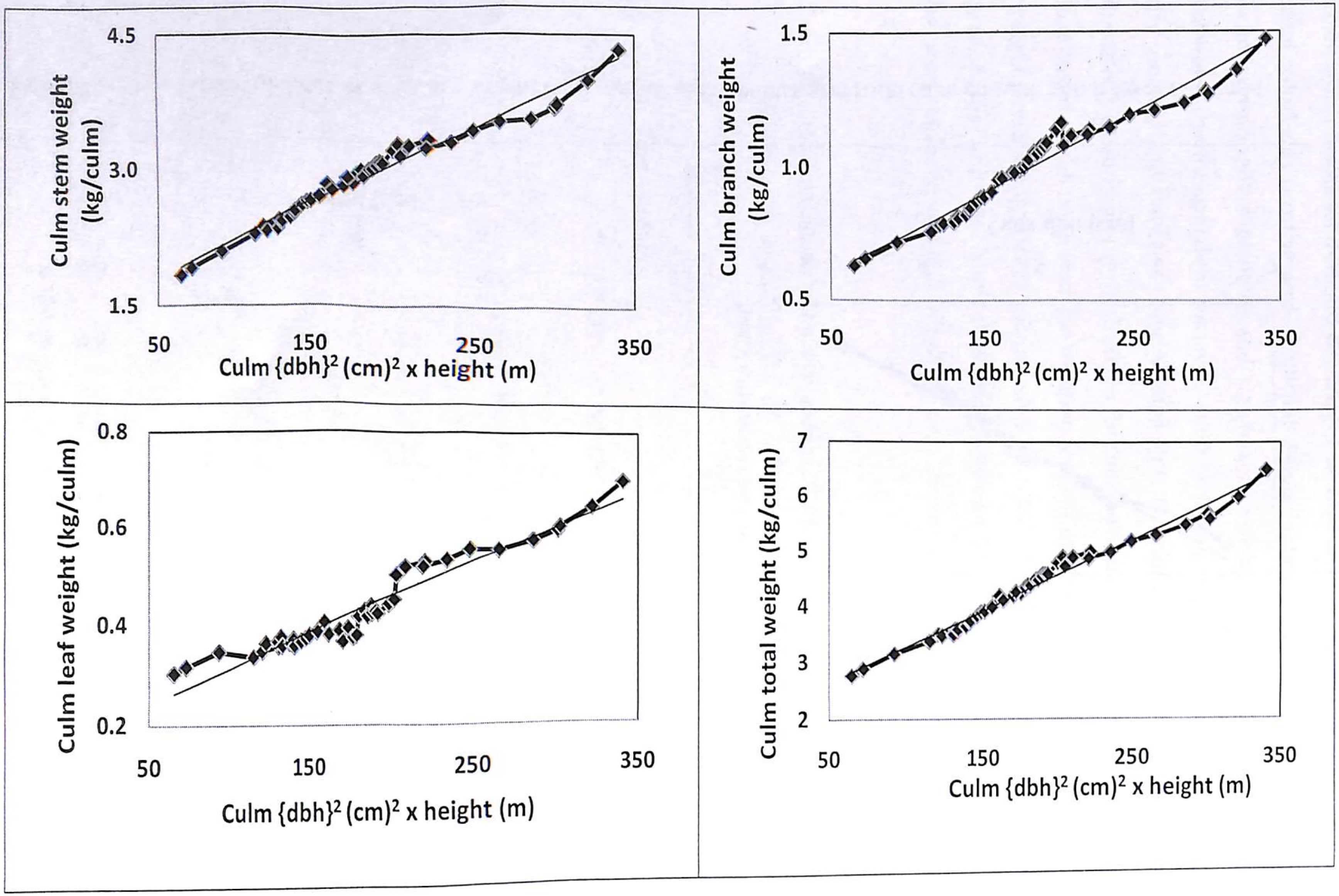



Figure 14. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *B.wamin*.

Culm dbh in cm and height in m.

Oven dry weight of the entire culm ranged from 2.76 kg to 6.50 kg with a mean of 4.35 kg (Table 22). On the hand, the dry weight of the stem (excluding branches and leaves) ranged from 1.83 kg and 4.33 kg (mean: 2.91 kg per culm). While the branch oven dry weight ranged from 0.63 kg per culm to 1.47 kg per culm (mean: 1.00 kg per culm), the leaf weight ranged from 0.30 to 0.70 kg per culm (mean: 0.43 kg per culm). Variability within the datasets of dry weight of different components ranged between 18.3 % and 21.6% (Table 22). The ratio between biomass of stem, branches and leaf components of a culm of *B. wamin* is 0.67: 0.23:0.10.

Table 22. Biomass allocation in different components of culms in *B. wamin.* Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 4.35 | 0.82 | 2.76 | 6.50 | 18.7 |
| Stem oven dry weight (kg/culm) | 2.91 | 0.53 | 1.83 | 4.33 | 18.3 |
| Branch oven dry weight (kg/culm) | 1.00 | 0.19 | 0.63 | 1.47 | 18.8 |
| Leaf oven dry weight (kg/culm) | 0.43 | 0.09 | 0.30 | 0.70 | 21.6 |

***8. Dendrocalamus asper*** **(Schult.) Backer**

*Dendrocalamus asper* is a tall bamboo having culms trumpet-shaped with lowest diameter thicker than from breast height up. Culm internodes of lower culm completely covered with velvety greenish to brown hairs. This species is cultivated throughout tropical Asia, from lowlands up to about 1,500 m altitude for shoot for food, culms for construction, for making chop-sticks and tooth-picks, and for pulp.

Table 24. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {$d^2$ (in $cm^2$) x culm height (h: in m)} of *D.asper*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Stem | DW (Stem) = 0.780 (d) – 1.154* | 0.962 |
| | DW (Stem) = *0.003 ($d^2h$) + 2.160** | 0.970 |
| Branch | DW (Branch) = 0.302 (d) - 0.634* | 0.975 |
| | DW (Stem) = *0.001* ($d^2h$) *+ 0.652** | 0.978 |
| Leaf | DW (Branch) = 0.113(d) - 0.016* | 0.735 |
| | DW (Stem) = *0.001* ($d^2h$) *+ 0.463** | 0.738 |
| Total culm | DW (Culm) = 1.195 (d) – 1.805* | 0.977 |
| | DW (Culm) = *0.005($d^2h$) + 3.277** | 0.984 |

*, Significant at p < .01

Oven dry weight of the entire culm ranged from 4.36 kg to 9.25 kg with a mean of 6.82 kg (Table 25). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.89 kg and 6.04 kg (mean: 4.48 kg per culm). While the branch oven dry weight ranged from 0.92 kg per culm to 2.17 kg per culm (mean: 1.54 kg per culm), the leaf weight ranged from 0.55 to 0.99 kg per culm (mean: 0.79 kg per culm). Variability within the datasets of dry weight of different components ranged between 14.5 % and 18.6% (Table 25). The ratio between biomass of stem, branches and leaf components of a culm of *D. asper* is 0.66: 0.23:0.11.

Table 25. Clumps size, culm characteristics and biomass allocation in different components of culms in *D. asper.* Age of the clump= 5 years, N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 6.82 | 1.16 | 4.36 | 9.25 | 17.0 |
| Stem oven dry weight (kg/culm) | 4.48 | 0.77 | 2.89 | 6.04 | 17.3 |
| Branch oven dry weight (kg/culm) | 1.54 | 0.29 | 0.92 | 2.17 | 18.6 |
| Leaf oven dry weight (kg/culm) | 0.79 | 0.12 | 0.55 | 0.99 | 14.5 |

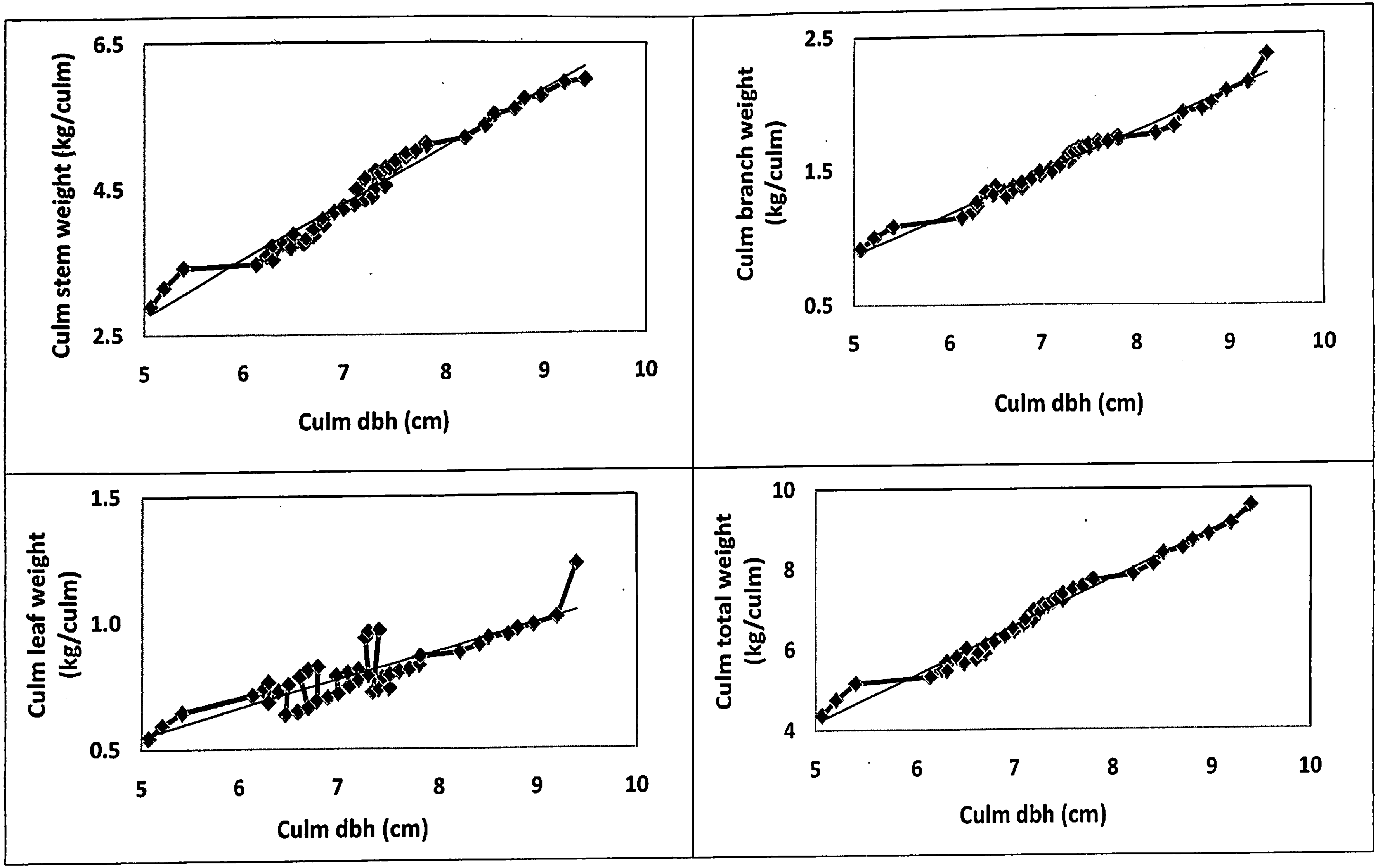



Figure 15. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *D.asper*.

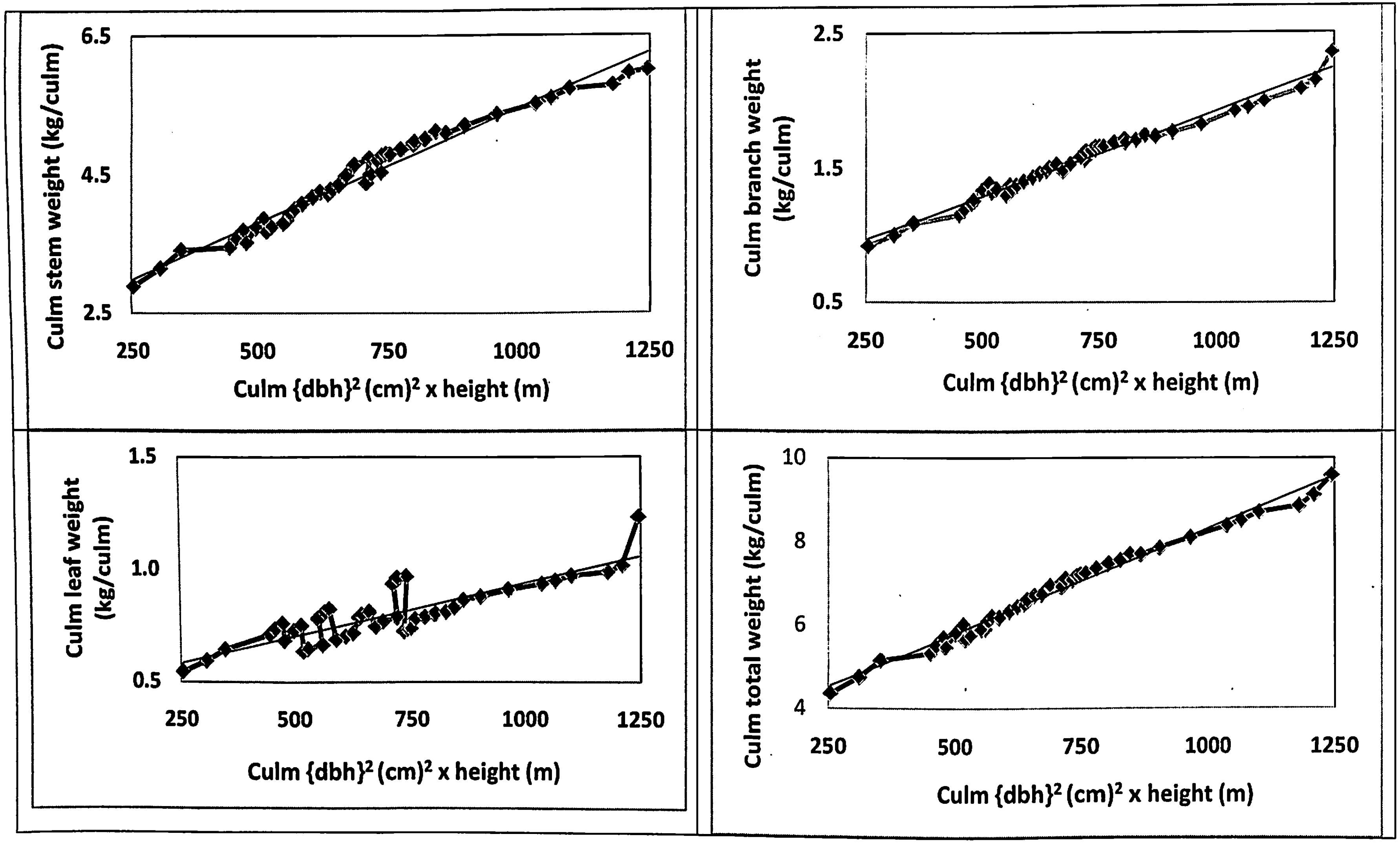



Figure 16. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *D. asper*. Culm dbh in cm and height in m.

9. ***Dendrocalamus hamiltonii*** **Nees & Arn. ex Munro**

*Dendrocalamus hamiltonii* is a large- sized bamboo with young culms grayish-white covered with dense pubescence, Old culms are dull green in colour. In India, this species is distributed in the North-eastern States; but also generally cultivated in other parts of the country. The species is used for construction purposes, basket-making, mats, water and milk vessels, fuel, floats for timber-rafts. The tribals of Arunachal Pradesh use the tender shoot for preparation of 'hiyup', a sour pickle. Recently, it was observed that the skin of this bamboo can be used in cottage industry for binding and caning of chairs.

In the 5-year old plantation of *D.hamiltonii*, 7 to 10 culms per clump (Mean = 8 culms) were recorded having variability within the datasets of clump size is 12.5% (Table 26). In these clumps, culm height ranged from 9.68 m to 14.33 m with a mean 12.75 m. Number of internodes per culm ranged from 35 to 44 with a mean of 39. Culm diameter at 1.37 m above the ground level ranged from 4.9 cm to 9.1 cm with a mean of 7.0 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.2 % to 13.0% within the datasets of culm height, number of internodes per culm, culm diameter and culm wall thickness (Table 26). The mean ratio between wall thickness and culm diameter was 0.1.

Table 26. Clumps size and culm characteristics in different components of culms in *D. hamiltonii.* Age of the clump= 5 years

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 8 | 1 | 7 | 10 | 12.5 |
| Culm height (m) (N= 250 culms) | 12.75 | 1.17 | 9.68 | 14.33 | 9.2 |
| Number of internodes per culm (N= 250 culms) | 39 | 4 | 35 | 44 | 10.3 |
| Culm diameter (cm) (N= 250 culms) | 7.04 | 0.91 | 4.94 | 9.10 | 13.0 |
| Culm wall thickness (cm) (N= 45 culms) | 0.7 | 0.2 | 0.4 | 0.9 | 9.9 |

Correlation between dbh and dry weight of different culm components (stem. branch, leaf and total culm) was positive and significant. Similarly, between {$(dbh)^2$ x h}] and dry weight of each culm component a positive and significant correlation was recorded. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 27). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.83 and 0.99, showing positive relationship between biomass and dbh or (($dbh)^2$ x h}. The fitted regression lines are shown in Figure 17 and 18.

Table 27. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {$d^2$ (in $cm^2$) x culm height (h: in m)} of *D. hamiltonii*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.332 (d) - 2.176 | 0.990 |
| | DW (culm) = 0.005 ($d^2h$) + 3.069 | 0.976 |
| Stem | DW (stem) = 0.826 (d) – 1.394 | 0.983 |
| | DW (stem) = 0.004 ($d^2h$) + 2.075 | 0.956 |
| Branch | DW (branch) = 0.282 (d) - 0.476 | 0.987 |
| | DW (branch) = 0.001($d^2h$) + 0.703 | 0.977 |
| Leaf | DW (leaf) = 0.144 (d) - 0.306 | 0.899 |
| | DW (leaf) = 0.0006 ($d^2h$) + 0.291 | 0.832 |

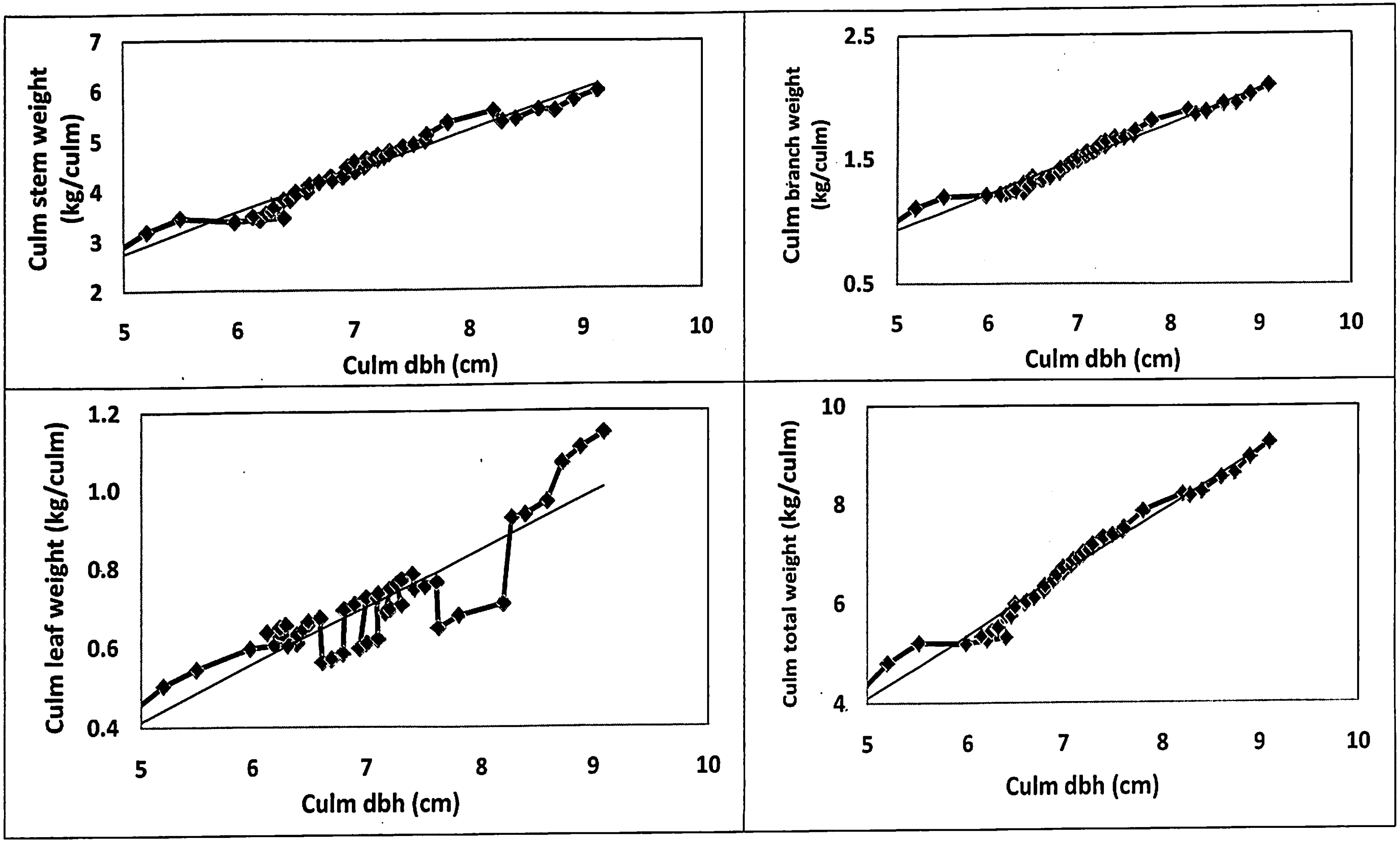



Figure 17. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *D.hamiltonii*

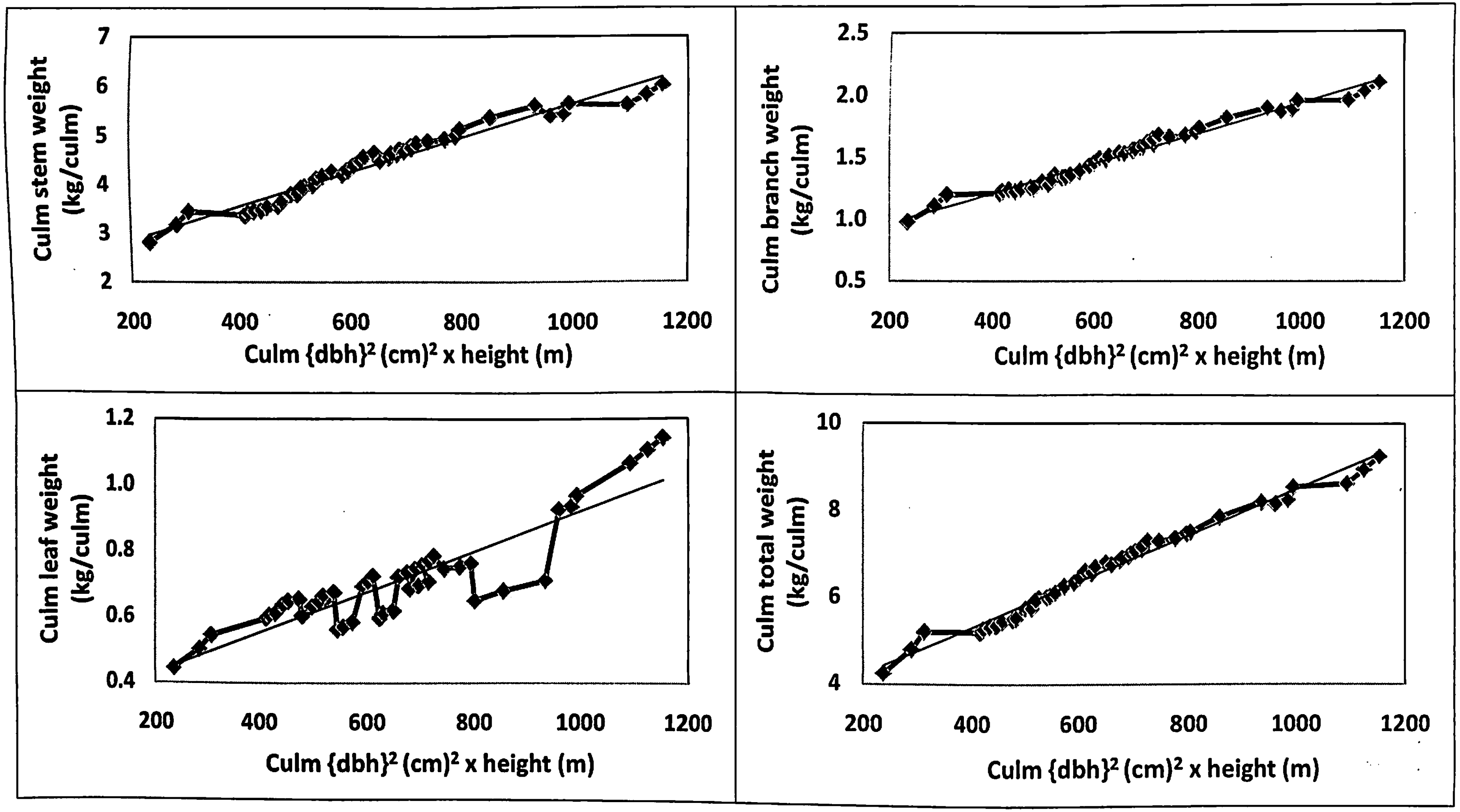



Figure 18. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *D. hamiltonii*. Culm dbh in cm and height in m.

Oven dry weight of the entire culm ranged from 4.25 kg to 9.25 kg with a mean of 6.65 kg (Table 28). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.82 kg and 6.01 kg (mean: 4.43 kg per culm). While the branch oven dry weight ranged from 0.98 kg per culm to 2.09 kg per culm (mean: 1.51 kg per culm), the leaf weight ranged from 0.45 to 1.14 kg per culm (mean: 0.71 kg per culm). Variability within the datasets of dry weight of different components ranged between 17.4 % and 20.9% (Table 28). The ratio between biomass of stem, branches and leaf components of a culm of *D. hamiltonii* is 0.67: 0.23:0.10.

Table 28. Biomass allocation in different components of culms in *D. hamiltonii.* Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 6.65 | 1.16 | 4.25 | 9.25 | 17.4 |
| Stem oven dry weight (kg/culm) | 4.43 | 0.77 | 2.82 | 6.01 | 17.4 |
| Branch oven dry weight (kg/culm) | 1.51 | 0.26 | 0.98 | 2.09 | 17.3 |
| Leaf oven dry weight (kg/culm) | 0.71 | 0.15 | 0.45 | 1.14 | 20.9 |

10. ***Dendrocalamus longispathus (Kurz) Kurz***

*Dendrocalamus longispathus* is a large tufted bamboo with glaucous green young culms and greyish-green mature culms. This species is generally used for the manufacture of paper. It is also used for making basket and containers. *D. longispathus* is found as an ideal material for the manufacture of good quality tooth picks.

In the 5-year old plantation of *D. longispathus, 5* to 9 culms per clump (Mean = 6 culms) were recorded having variability within the datasets of clump size is 33.3% (Table 29). In these clumps, culm height ranged from 7.12 m to 10.54 m with a mean 9.38 m. Number of internodes per culm ranged from 28 to 39 with a mean of 34. Culm diameter at 1.37 m above the ground level ranged from 3.6 cm to 6.6 cm with a mean of 5.2 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.2 % to 25.0% within the datasets of culm height, number of internodes per culm, culm diameter and culm wall thickness; with high value for culm wall thickness (Table 29). The mean ratio between wall thickness and culm diameter was 0.23.

Table 29. Clumps size and culm characteristics in different components of culms in *D. longispathus*. Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 6 | 1 | 5 | 9 | 33.3 |
| Culm height (m) (N= 250 culms) | 9.38 | 1.17 | 7.12 | 10.54 | 12.5 |
| Number of internodes per culm (N= 250 culms) | 34 | 4 | 28 | 39 | 11.8 |
| Culm diameter (cm) (N= 250 culms) | 5.2 | 0.91 | 3.6 | 6.6 | 17.5 |
| Culm wall thickness (cm) (N= 45 culms) | 1.2 | 0.3 | 1.0 | 1.5 | 25.0 |

Correlation between dbh and dry weight of different culm components (stem. branch, leaf and total culm) was positive and significant. Similarly, between {(dbh)$^2$ x h}] and dry weight of each culm component a positive and significant correlation was recorded. The linear association between the independent variables [dbh or {(dbh)$^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {(dbh)$^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 30). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.83 and 0.99, showing positive relationship between biomass and dbh or ((dbh)$^2$ x h}. The fitted regression lines are shown in Figure 19 and 20.

Table 30. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in $cm^2$) x culm height (h: in m)} of *D. longispathus*

| Culm Components | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.291 (d) - 1.802* | 0.971 |
| | DW (culm) = 0.009 (d2h) + 2.318* | 0.970 |
| Stem weight | DW (stem) = 0.862 (d) – 1.202* | 0.972 |
| | DW (stem) = 0.006 (d2h) + 1.548* | 0.970 |
| Branch | DW (branch) = 0.291 (d) - 0.368* | 0.948 |
| | DW (branch) = 0.002(d2h) + 0.544* | 0.939 |
| Leaf | DW (leaf) = 0.137 (d) - 0. 210* | 0.898 |
| | DW (leaf) = 0.001 (d2h) + 0.225* | 0.911 |

*, Significant at p < .01

Oven dry weight of the entire culm ranged from 4.25 kg to 9.25 kg with a mean of 6.65 kg (Table 31). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.82 kg and 6.01 kg (mean: 4.43 kg per culm). While the branch oven dry weight ranged from 0.98 kg per culm to 2.09 kg per culm (mean: 1.51 kg per culm), the leaf weight ranged from 0.45 to 1.14 kg per culm (mean: 0.71 kg per culm). Variability within the datasets of dry weight of different components ranged between 17.4 % and 20.9% (Table 31). The ratio between biomass of stem, branches and leaf components of a culm of *D. longispathus* is 0.67: 0.23:0.10.

Table 31. Biomass allocation in different components of culms in *D. longispathus*. Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 6.65 | 1.16 | 4.25 | 9.25 | 17.4 |
| Stem oven dry weight (kg/culm) | 4.43 | 0.77 | 2.82 | 6.01 | 17.4 |
| Branch oven dry weight (kg/culm) | 1.51 | 0.26 | 0.98 | 2.09 | 17.3 |
| Leaf oven dry weight (kg/culm) | 0.71 | 0.15 | 0.45 | 1.14 | 20.9 |

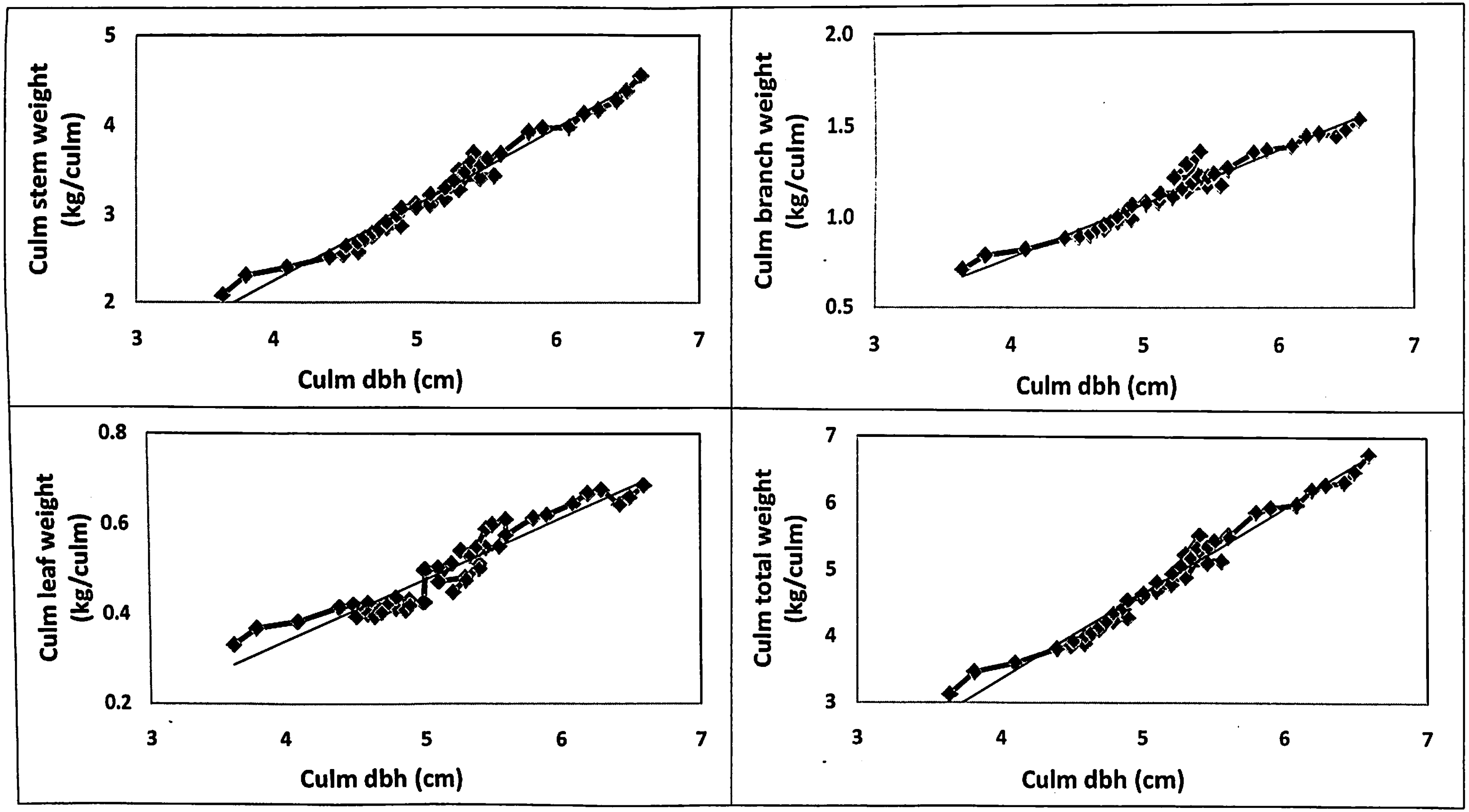



Figure 19. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *D. longispathus*.

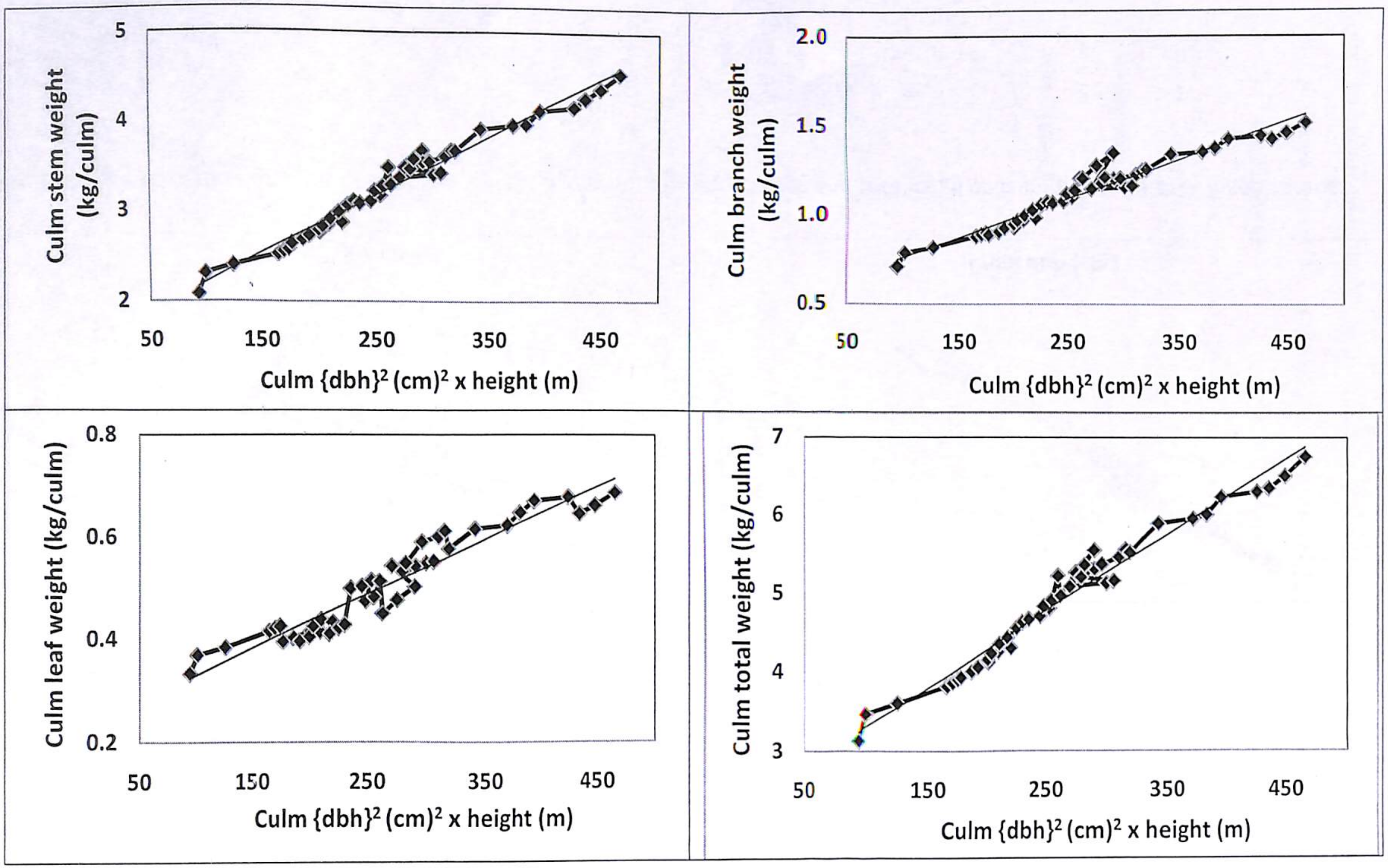



Figure 20. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *D.longispathus*. Culm dbh in cm and height in m.

11. ***Dendrocalamus sikkimensis*** **Gamble ex Oliv.**

| | | |
|---|---|---|
| *Dendrocalamus sikkimensis* is as large bamboo with few culms. Culms are large and dark-green. In Sikkim Himalaya, this is one important species of bamboo preferred by Lepchas and Bhutias for making the 'Chungas' for carrying water and milk. In Sikkim, it is used for fencing, posts, huts, ropes, boxes, water pipes and as animal fodder. It also can be used for pulp and paper |  |  |

In the 5-year old plantation of *D. sikkimensis, 4* to 8 culms per clump (Mean = 5 culms) were recorded having variability within the datasets of clump size is 40% (Table 32). In these clumps, culm height ranged from 8.12 m to 12.02 m with a mean 10.7 m. Number of internodes per culm ranged from 28 to 32 with a mean of 31. Culm diameter at 1.37 m above the ground level ranged from 4.1 cm to 7.6 cm with a mean of 5.9 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 6.5 % to 13.0% within the datasets of culm height, number of internodes per culm and culm diameter (Table 32). However, coefficient of variation (CV) was high for the culm wall thickness (27.3%). The mean ratio between wall thickness and culm diameter was 0.19.

Correlation between dbh and dry weight of different culm components (stem. branch, leaf and total culm) was positive and significant. Similarly, between $\{(dbh)^2 \times h\}]$ and dry weight of each culm component a positive and significant correlation was recorded. The linear association between the independent variables [dbh or $\{(dbh)^2 \times h\}]$ and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {(dbh)$^2$ x h}) and component dry weight had a significant relationship (P<0.01) (Table 33). All the four components (stem, branch, leaf and total culm) showed $R^2$ between 0.54 and 0.98, showing positive relationship between biomass and dbh or ((dbh)$^2$ x h}. The fitted regression lines are shown in Figure 21 and 22.

Table 32. Clumps size and culm characteristics in different components of culms in *D. sikkimensis*. Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 5 | 2 | 4 | 8 | 40.0 |
| Culm height (m) (N= 200 culms) | 10.70 | 0.98 | 8.12 | 12.02 | 9.2 |
| Number of internodes per culm (N= 200 culms) | 31 | 2 | 28 | 32 | 6.5 |
| Culm diameter (cm) (N= 200 culms) | 5.9 | 0.76 | 4.1 | 7.6 | 13.0 |
| Culm wall thickness (cm) (N= 45 culms) | 1.1 | 0.3 | 0.6 | 1.3 | 27.3 |

Table 33. Regression of oven dry weight (DW; in kg) of different components of culm on diameter at breast height (d: in cm) and {d2 (in cm$^2$) x culm height (h: in m)} of *D. sikkimensis.*

| Culm component | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.275 (d) - 1.966* | 0.970 |
| | DW (culm) = 0.007 (d2h) + 2.585* | 0.964 |
| Stem weight | DW (stem) = 0.896 (d) – 1.589* | 0.967 |
| | DW (stem) = 0.001 (d2h) + 0.607* | 0.981 |
| Branch | DW (branch) = 0.284 (d) - 0.407* | 0.975 |
| | DW (branch) = 0.005(d2h) + 1.603* | 0.967 |
| Leaf | DW (leaf) = 0.095 (d) + 0.028 | 0.566 |
| | DW (leaf) = 0.001 (d2h) + 0.372 | 0.539 |

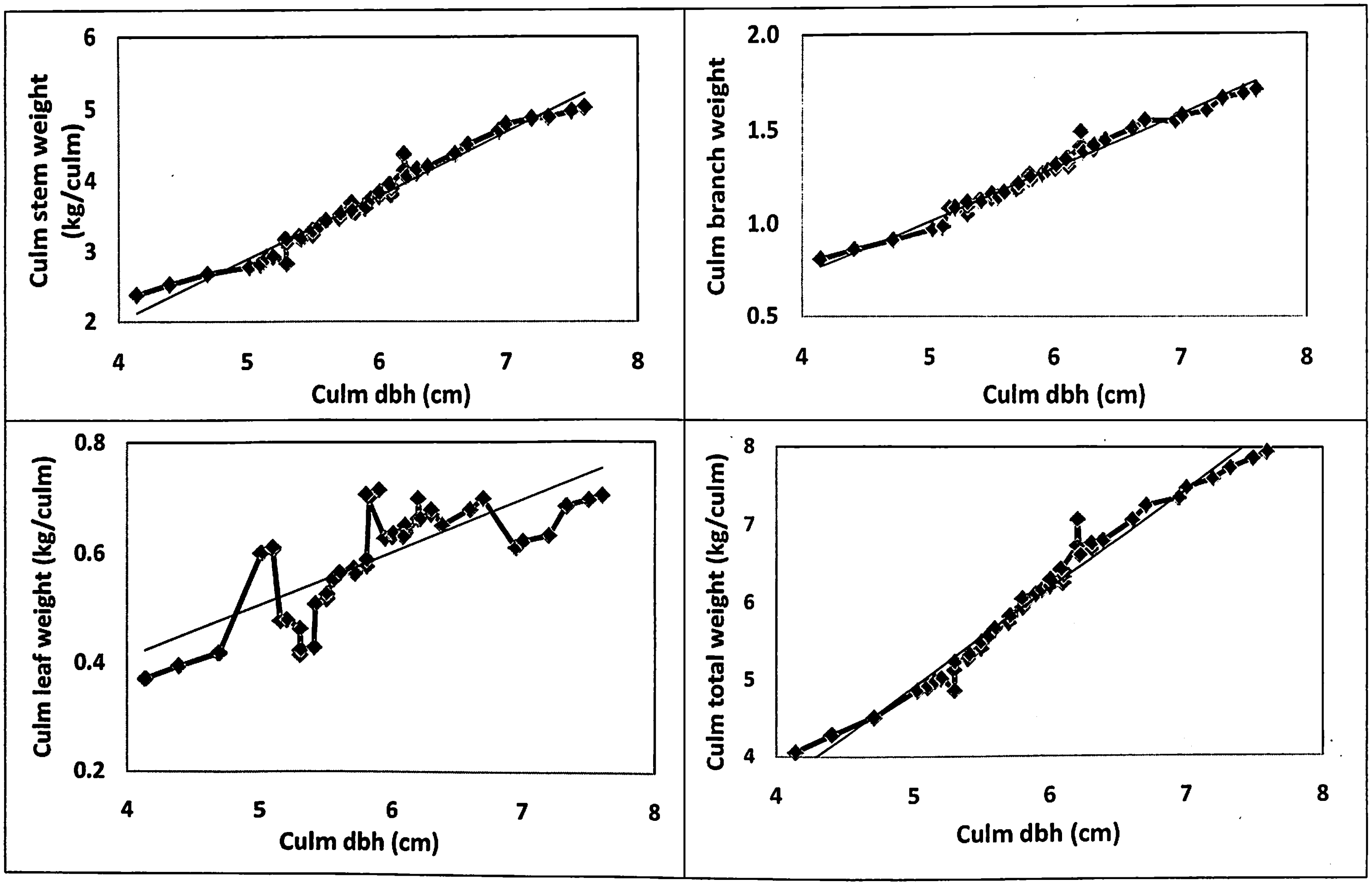



Figure 21. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *D. sikkimensis.*

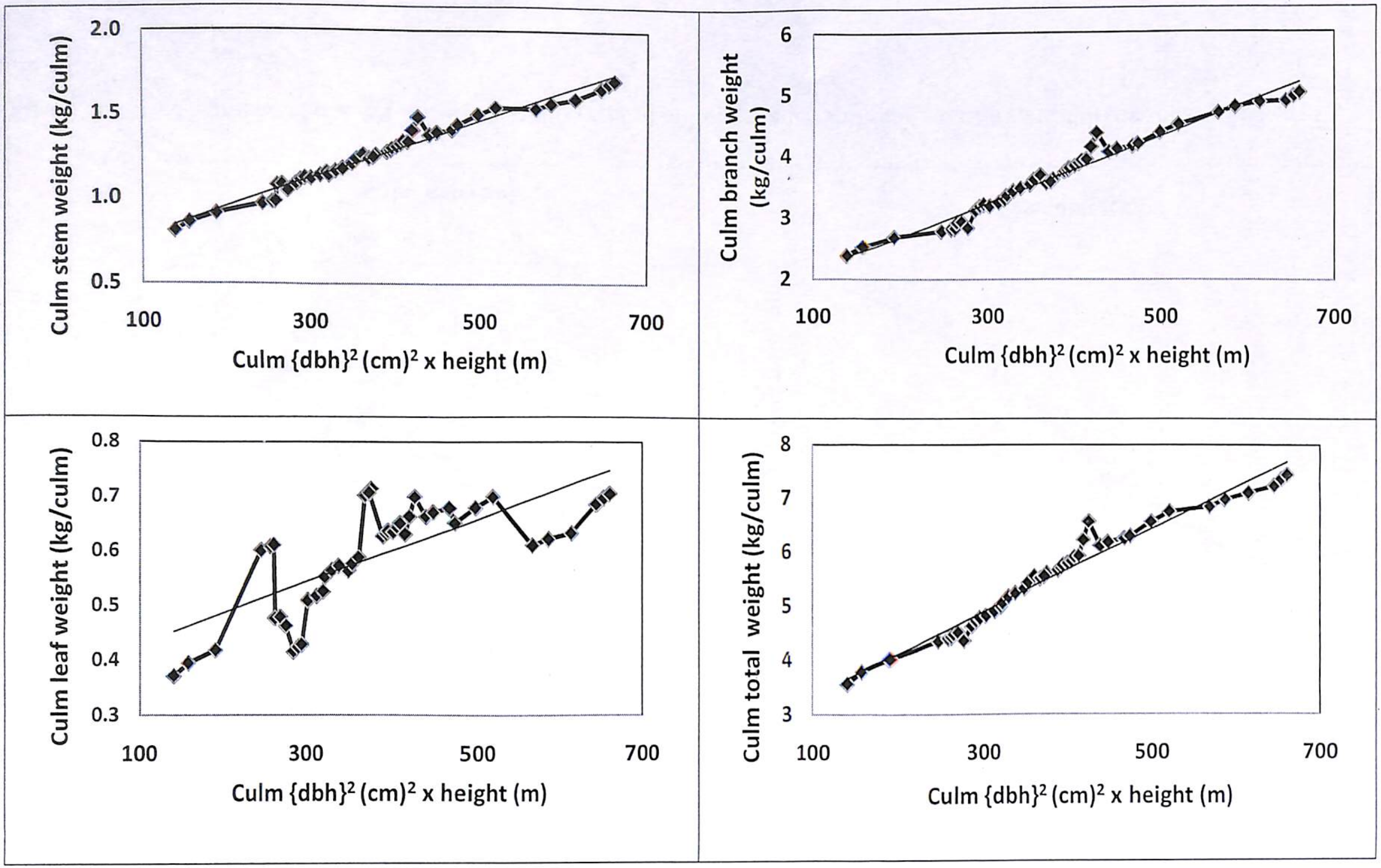



Figure 22. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *D. sikkimensis*. Culm dbh in cm and height in m.

Oven dry weight of the entire culm ranged from 3.56 kg to 7.44 kg with a mean of 5.5 kg (Table 34). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.38 kg and 5.03 kg (mean: 3.70 kg per culm). While the branch oven dry weight ranged from 0.81 kg per culm to 1.71 kg per culm (mean: 1.3 kg per culm), the leaf weight ranged from 0.37 to 0.71 kg per culm (mean: 0.6 kg per culm). Variability within the datasets of dry weight of different components ranged between 16.4 % and 18.9% (Table 34). The ratio between biomass of stem, branches and leaf components of a culm of *Dendrocalamus sikkimensis* is 0.66: 0.24:0.10.

Table 34. Biomass allocation in different components of culms in *D. sikkimensis*. Age of the clump= 5 years. N= 45 culms

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 5.5 | 0.99 | 3.56 | 7.44 | 17.9 |
| Stem oven dry weight (kg/culm) | 3.70 | 0.70 | 2.38 | 5.03 | 18.9 |
| Branch oven dry weight (kg/culm) | 1.3 | 0.22 | 0.81 | 1.71 | 17.4 |
| Leaf oven dry weight (kg/culm) | 0.6 | 0.10 | 0.37 | 0.71 | 16.4 |

12. ***Dendrocalamus strictus* (Roxb.) Nees**

*Dendrocalamus strictus* is a deciduous densely tufted bamboo with thick- walled- culms. This species is found suitable for reclamation of ravine land. It is extensively used as raw material in paper mills and also for a variety of purposes such as construction, agricultural implements, musical instruments, furniture etc. Young shoots are commonly used as food. Decoction of leaves and nodes and siliceous matter is used in the traditional medicine.

In the 5-year old plantation of *D. strictus,* 14 to 22 culms per clump (Mean = 17 culms) were recorded having variability within the datasets of clump size is 23.5% (Table 35). In these clumps, culm height ranged from 9.74 m to 14.42 m with a mean 12.83 m. Number of internodes per culm ranged from 34 to 53 with a mean of 45. Culm diameter at 1.37 m above the ground level ranged from 5.0 cm to 9.1 cm with a mean of 7.1 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 5.1 % to 17.8 % within the datasets of culm height, number of internodes per culm, culm diameter and culm wall thickness (Table 35). The mean ratio between wall thickness and culm diameter was 0.55.

Table 35. Clumps size and culm characteristics in different components of culms in *D. strictus.* Age of the clump= 5 years

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 17 | 4 | 14 | 22 | 23.5 |
| Culm height (m) (N= 200 culms) | 12.83 | 1.18 | 9.74 | 14.42 | 9.2 |
| Number of internodes per culm (N= 200 culms) | 45 | 8 | 34 | 53 | 17.8 |
| Culm diameter (cm) (N= 200 culms) | 7.06 | 0.93 | 4.97 | 9.10 | 13.1 |
| Culm wall thickness (cm) (N= 45 culms) | 3.9 | 0.2 | 3.6 | 4.3 | 5.1 |

It was found that dbh and {$(dbh)^2$ x h}] positively and significantly correlated with component (stem. branch and total culm) dry weight. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass and branch biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship (P<0.01) (Table 36). All the three components (stem. branch and total culm) showed $R^2$ between 0.915 and 0.989, showing positive relationship between biomass and dbh or {$(dbh)^2$ x h}. The fitted regression lines are shown in Figure 23 and 24. However, in the case of leaf, correlation between biomass and independent variable was weak ($R^2$ = 0.081 and 0.0.095). This suggests that the leaf being a short durability component in the culm will have poor correlation with independent variables.

Table 36. Regression of oven dry weight (kg) of different components of culm on diameter at breast height (d: in cm) and {$d^2$ (in $cm^2$) x culm height (h: in m)} of *D. strictus.*

| Culm component | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.413 (d) - 2.190* | 0.989 |
| | DW (culm) = 0.005 (d2h) + 3.088* | 0.979 |
| Stem | DW (stem) = 0.899(d) – 1.793* | 0.929 |
| | DW (stem) = 0.003 (d2h) + 2.023* | 0.915 |
| Branch | DW (branch) = 0.311 (d) - 0.615* | 0.969 |
| | DW (branch) = 0.001(d2h) + 0.703* | 0.936 |

Oven dry weight of the entire culm ranged from 4.27 kg to 9.15 kg with a mean of 6.66 kg (Table 37). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.83 kg and 6.12 kg (mean: 4.56 kg per culm). While the branch oven dry weight ranged from 0.98 kg per culm to 2.17 kg per culm (mean: 1.58 kg per culm), the leaf weight ranged from 0.46 to 0.91 kg per culm (mean: 0.52 kg per culm). Variability within the datasets of dry weight of different components ranged between 17.9% and 37.3% (Table 37), with high value for leaf. The ratio between biomass of stem, branches and leaf components of a culm of *D. strictus* is 0.68: 0.24:0.08.

Table 37. Biomass allocation in different components of culms in *D. strictus.* Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 6.66 | 1.19 | 4.27 | 9.15 | 17.9 |
| Stem oven dry weight (kg/culm) | 4.56 | 0.86 | 2.83 | 6.12 | 19.0 |
| Branch oven dry weight (kg/culm) | 1.58 | 0.30 | 0.98 | 2.17 | 18.7 |
| Leaf oven dry weight (kg/culm) | 0.52 | 0.19 | 0.46 | 0.91 | 37.3 |

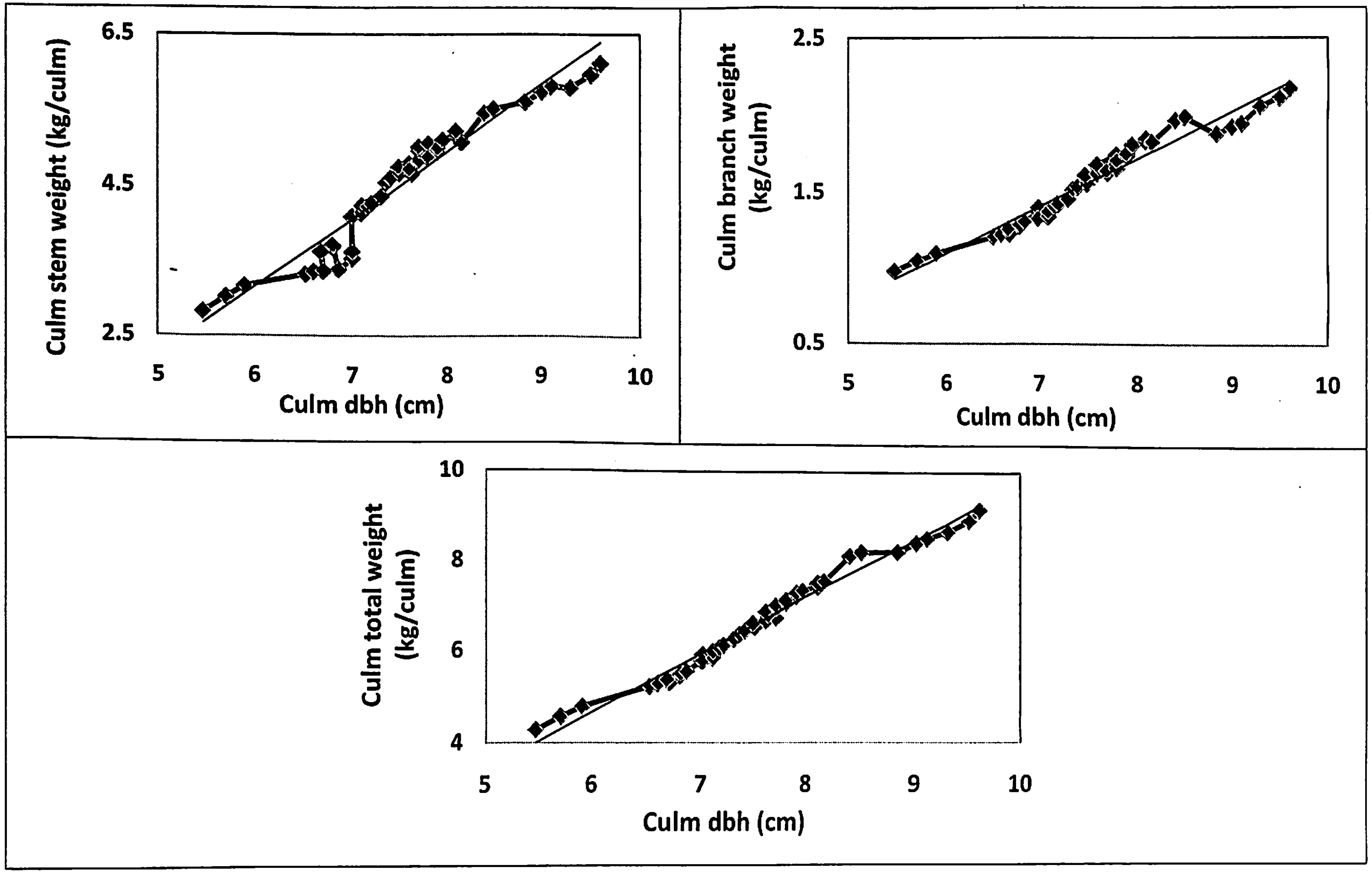



Figure 23. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *D. strictus*.

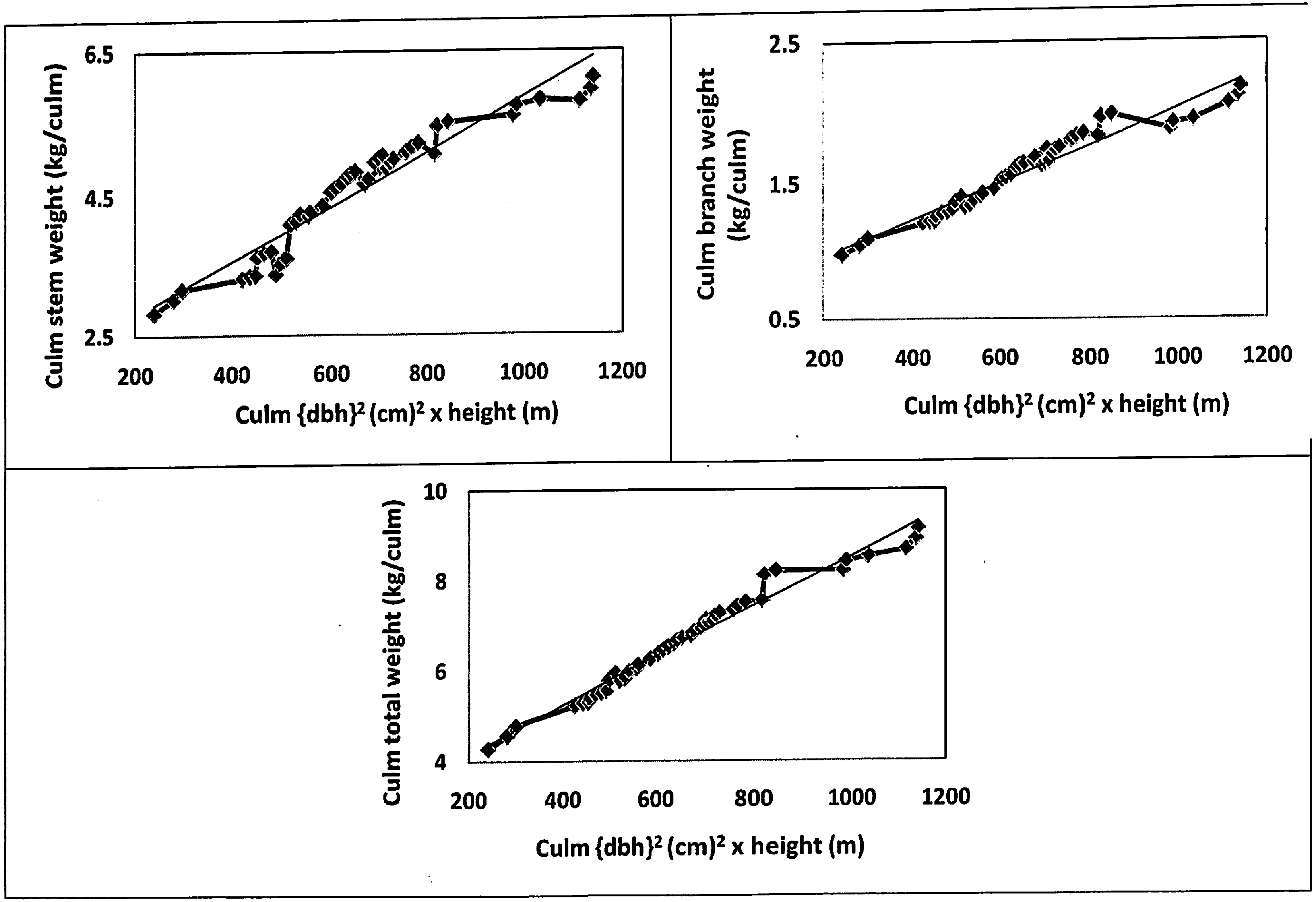



Figure 24. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *D. strictus*. Culm dbh in cm and height in m.

13. ***Gigantochloa rostrata*** **K.M. Wong**

*Gigantochloa rostrata* is a tufted dark-green bamboo with slightly drooping thick-walled culms. It is distributed in Assam, Meghalaya, Tripura, Orissa, Bihar, Madhya Pradesh, Maharashtra and Karnataka. It is also cultivated in different parts of the country. The culms are used for building huts and making baskets. Also used as a raw material for paper industry. In north-eastern states, local people use seeds as food.

In the 5-year old plantation of *G. rostrata,* 15 to 21 culms per clump (Mean = 17 culms) were recorded having variability within the datasets of clump size is 17.6% (Table 38). In these clumps, culm height ranged from 4.2 m to 6.22 m with a mean 5.53 m. Number of internodes per culm ranged from 34 to 24 with a mean of 31. Culm diameter at 1.37 m above the ground level ranged from 2.1 cm to 3.9 cm with a mean of 3.1 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.2 % to 20.0 % within the datasets of culm height, number of internodes per culm, culm diameter and culm wall thickness (Table 38). The mean ratio between wall thickness and culm diameter was 0.16.

It was found that dbh and $\{(dbh)^2 \times h\}]$ positively and significantly correlated with component (stem. branch and total culm) dry weight. The linear association between the independent variables [dbh or $\{(dbh)^2 \times h\}$] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass and branch biomass indicated that the independent variable(s) (dbh or $\{(dbh)^2 \times h\}$) and component dry weight had a significant relationship (P<0.01) (Table 39). All the four components (stem. branch, leaf and total culm) showed $R^2$ between 0.894 and 0.975, showing positive relationship between biomass and dbh or ((dbh)$^2$ x h}. The fitted regression lines are shown in Figure 25 and 26.

Table 38. Clumps size and culm characteristics in different components of culms in *G. rostrata*. Age of the clump= 5 years.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 17 | 3 | 15 | 21 | 17.6 |
| Culm height (m) (N= 250 culms) | 5.53 | 0.51 | 4.20 | 6.22 | 9.2 |
| Number of internodes per culm (N= 250 culms) | 29 | 3 | 24 | 31 | 10.3 |
| Culm diameter (cm) (N= 250 culms) | 3.06 | 0.39 | 2.14 | 3.90 | 12.9 |
| Culm wall thickness (cm) (N= 45 culms) | 0.5 | 0.1 | 0.3 | 0.7 | 20.0 |

Table 39. Regression of oven dry weight (kg) of different components of culm on diameter at breast height (d: in cm) and {$d^2$ (in $cm^2$) x culm height (h: in m)} of *G. rostrata*.

| Component | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.360 (d) – 1.260 | 0.973 |
| | DW (culm) = 0.029 (d2h) + 1.307 | 0.975 |
| Stem | DW (stem) = 0.862 (d) – 0.767 | 0.966 |
| | DW (stem) = 0.018 (d2h) + 0.862 | 0.964 |
| Branch | DW (branch) = 0.309 (d) - 0.280 | 0.969 |
| | DW (branch) = 0.006(d2h) + 0.303 | 0.967 |
| Leaf | DW (leaf) = 0.190 (d) - 0.215 | 0.894 |
| | DW (leaf) = 0.004 (d2h) + 0.140 | 0.921 |

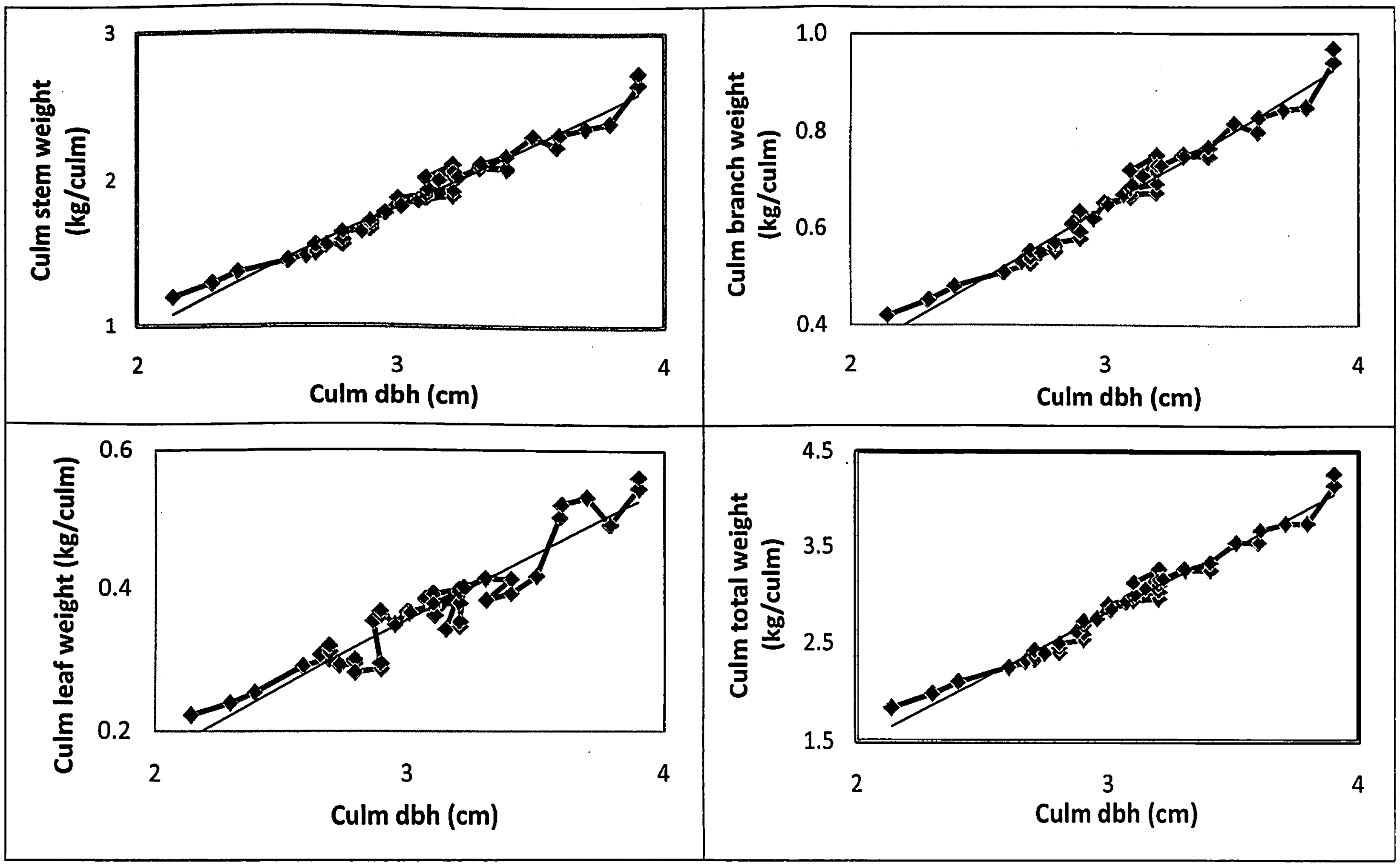



Figure 25. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *G.rostrata*

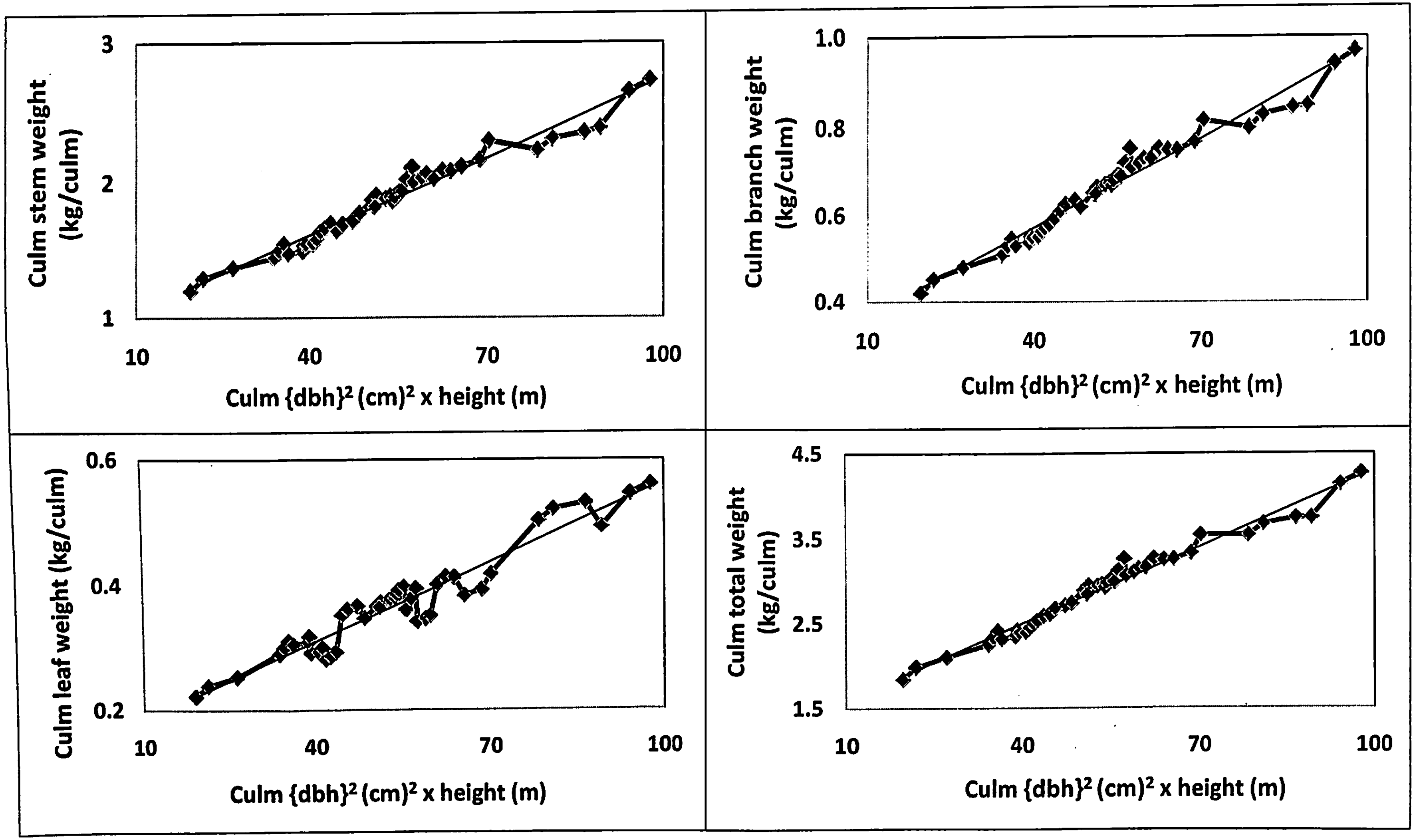



Figure 26. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh$^2$ x height of *G.rostrata*. Culm dbh in cm and height in m.

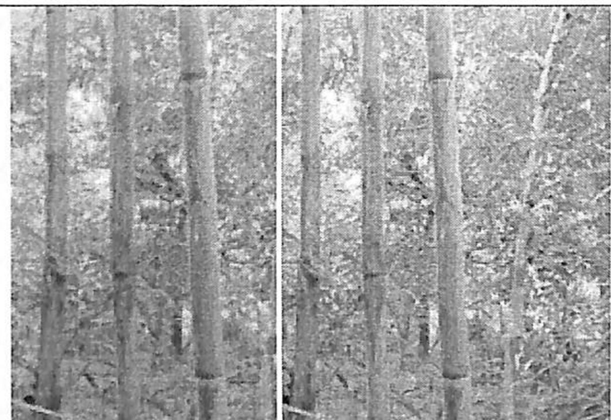
Oven dry weight of the entire culm ranged from 1.84 kg to 4.26 kg with a mean of 2.90 kg (Table 40). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 1.20 kg and 2.73 kg (mean: 1.87 kg per culm). While the branch oven dry weight ranged from 0.42 kg per culm to 0.97 kg per culm (mean: 0.67 kg per culm), the leaf weight ranged from 0.22 to 0.56 kg per culm (mean: 0.37 kg per culm). Variability within the datasets of dry weight of different components ranged between 18.4% and 21.6% (Table 40), with high value for leaf. The ratio between biomass of stem, branches and leaf components of a culm of *G.rostrata* is 0.64: 0.23:0.13.

Table 40. Clumps size, culm characteristics and biomass allocation in different components of culms in *G.rostrata.* Age of the clump= 5 years. N= 45 culms

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 2.90 | 0.54 | 1.84 | 4.26 | 18.7 |
| Stem oven dry weight (kg/culm) | 1.87 | 0.35 | 1.20 | 2.73 | 18.4 |
| Branch oven dry weight (kg/culm | 0.67 | 0.12 | 0.42 | 0.97 | 18.6 |
| Leaf oven dry weight (kg/culm) | 0.37 | 0.08 | 0.22 | 0.56 | 21.6 |

14. ***Thyrsostachys oliveri* Gamble**

*Thyrsostachys oliveri* is a large tufted elegant bamboo. This species is a native of Myanmar and now planted in many parts of India as its culms are in great demand for construction purposes, reinforcement for concrete slabs, poles, basketing and handicrafts. Young shoot is commonly used for edible purposes. This species is used for canning in Thailand for the production of steamed bamboo shoots for export.



In the 5-year old plantation of T. *oliveri,* 11 to 19 culms per clump (Mean = 16 culms) were recorded having variability within the datasets of clump size is 25% (Table 41). In these clumps, culm height ranged from 9.2 m to 13.6 m with a mean 12.1 m. Number of internodes per culm ranged from 37 to 49 with a mean of 46. Culm diameter at 1.37 m above the ground level ranged from 4.7 cm to 8.8 cm with a mean of 6.7 cm. The calculated coefficient of variation (CV) indicated a variability ranging from 9.2 % to 14,3 % within the datasets of culm height, number of internodes per culm, culm diameter and culm wall thickness (Table 41). The mean ratio between wall thickness and culm diameter was 0.11.

Table 41. Clumps size, culm characteristics and biomass allocation in different components of culms in *T. oliveri.* Age of the clump= 5 years

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Number of culms per clump (N= 45 clumps) | 16 | 4 | 11 | 19 | 25 |
| Culm height (m) (N= 200 culms) | 12.12 | 1.11 | 9.20 | 13.62 | 9.2 |
| Number of internodes per culm (N= 200 culms) | 46 | 5 | 37 | 49 | 10.9 |
| Culm diameter (cm) (N= 200 culms) | 6.66 | 0.89 | 4.69 | 8.80 | 13.4 |
| Culm wall thickness (cm) (N= 45 culms) | 0.7 | 0.1 | 0.5 | 0.9 | 14.3 |

It was found that dbh and {$(dbh)^2$ x h}] positively and significantly correlated with component (stem. branch and total culm) dry weight. The linear association between the independent variables [dbh or {$(dbh)^2$ x h}] and dependent variable (component dry weight) was checked using scatter-plot. The normality was checked using Q-Q plots. The linear regression equations obtained for total culm biomass, stem biomass, branch biomass and leaf biomass indicated that the independent variable(s) (dbh or {$(dbh)^2$ x h}) and component dry weight had a significant relationship ($P<0.01$) (Table 42). All the four components (stem. branch, leaf and total culm) showed $R^2$ between 0.568 and 0.982, showing positive relationship between biomass and dbh or ($(dbh)^2$ x h}. The fitted regression lines are shown in Figure 27 and 28.

Table 42. Regression of oven dry weight (kg) of different components of culm on diameter at breast height (d: in cm) and {$d^2$ (in $cm^2$)x culm height (h: in m)} of *T. oliveri*.

| Component | Equation | $R^2$ |
|---|---|---|
| Total culm | DW (culm) = 1.235 (d) – 1.940 | 0.978 |
| | DW (culm) = 0.006 (d2h) + 2.886 | 0.982 |
| Stem | DW (stem) = 0.770 (d) – 1.022 | 0.962 |
| | DW (stem) = 0.003 (d2h) + 2.003 | 0.953 |
| Branch | DW (branch) = 0.278 (d) - 0.412 | 0.915 |
| | DW (branch) = 0.001(d2h) + 0.676 | 0.916 |
| Leaf | DW (leaf) = 0.186 (d) - 0.505 | 0.568 |
| | DW (leaf) = 0.001 (d2h) + 0.206 | 0.606 |

Oven dry weight of the entire culm ranged from 4.05 kg to 8.75 kg with a mean of 6.28 kg (Table 43). On the hand, the dry weight of the stem (excluding branches and leaves) ranged between 2.67 kg and 5.68 kg (mean: 4.11 kg per culm). While the branch oven dry weight ranged from 0.92 kg per culm to 1.96 kg per culm (mean: 1.44 kg per culm), the leaf weight ranged from 0.45 to 1.11 kg per culm (mean: 0.73 kg per culm). Variability within the datasets of dry weight of different components ranged between 17.0% and 30.0% (Table 43), with high value for leaf. The ratio between biomass of stem, branches and leaf components of a culm of is 0.65: 0.23:0.12.

Table 43. Biomass allocation in different components of culms in *T. oliveri*. Age of the clump= 5 years. N= 45 culms.

| Parameter | Mean | SD | Min. | Max. | CV (%) |
|---|---|---|---|---|---|
| Total culm oven dry weight (kg/culm) | 6.28 | 1.11 | 4.04 | 8.75 | 17.7 |
| Stem oven dry weight (kg/culm) | 4.11 | 0.70 | 2.67 | 5.68 | 17.0 |
| Branch oven dry weight (kg/culm) | 1.44 | 0.26 | 0.92 | 1.96 | 18.0 |
| Leaf oven dry weight (kg/culm) | 0.73 | 0.22 | 0.45 | 1.11 | 30.0 |

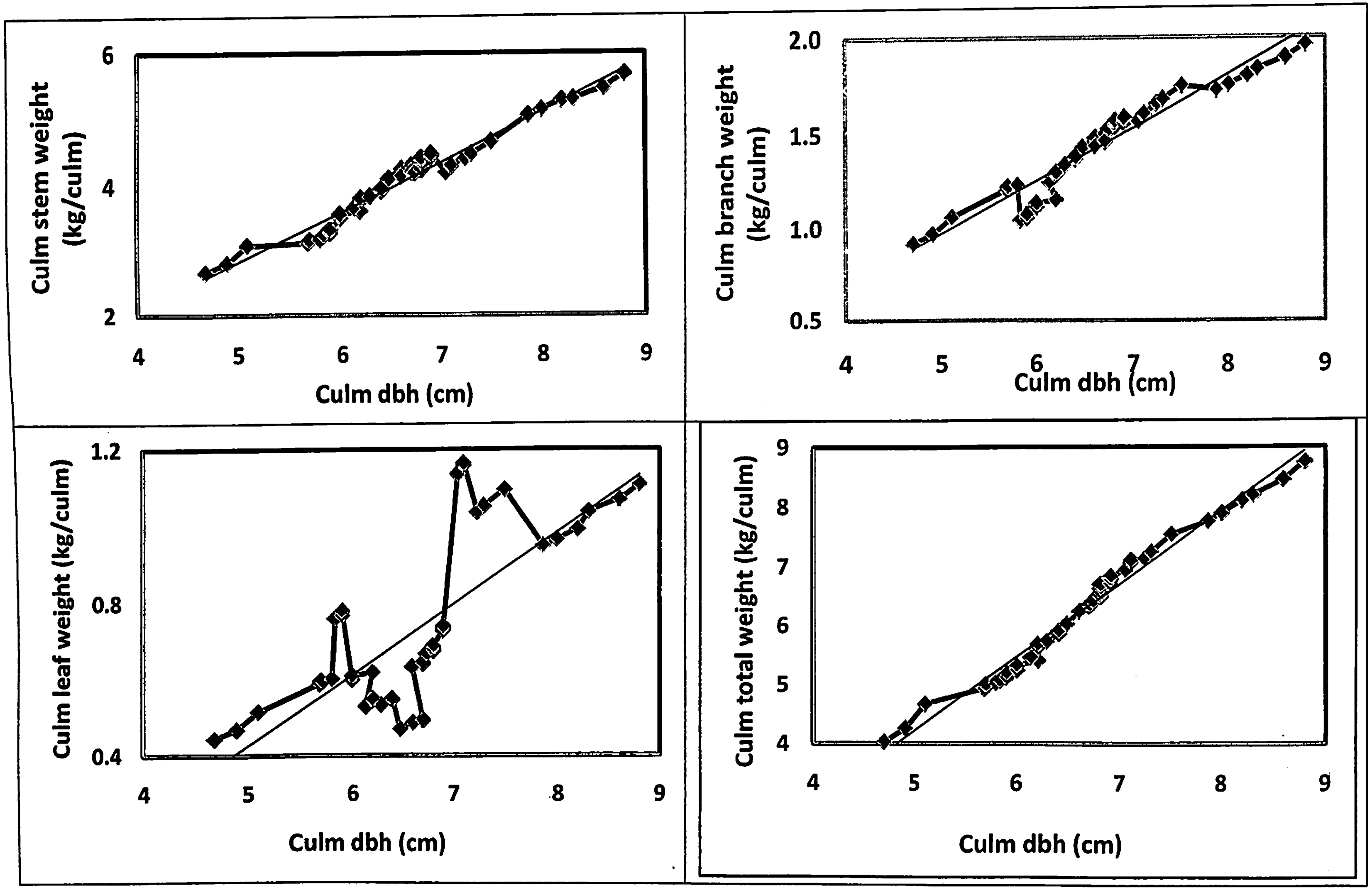



Figure 27. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm dbh (cm) of *T. oliveri*.

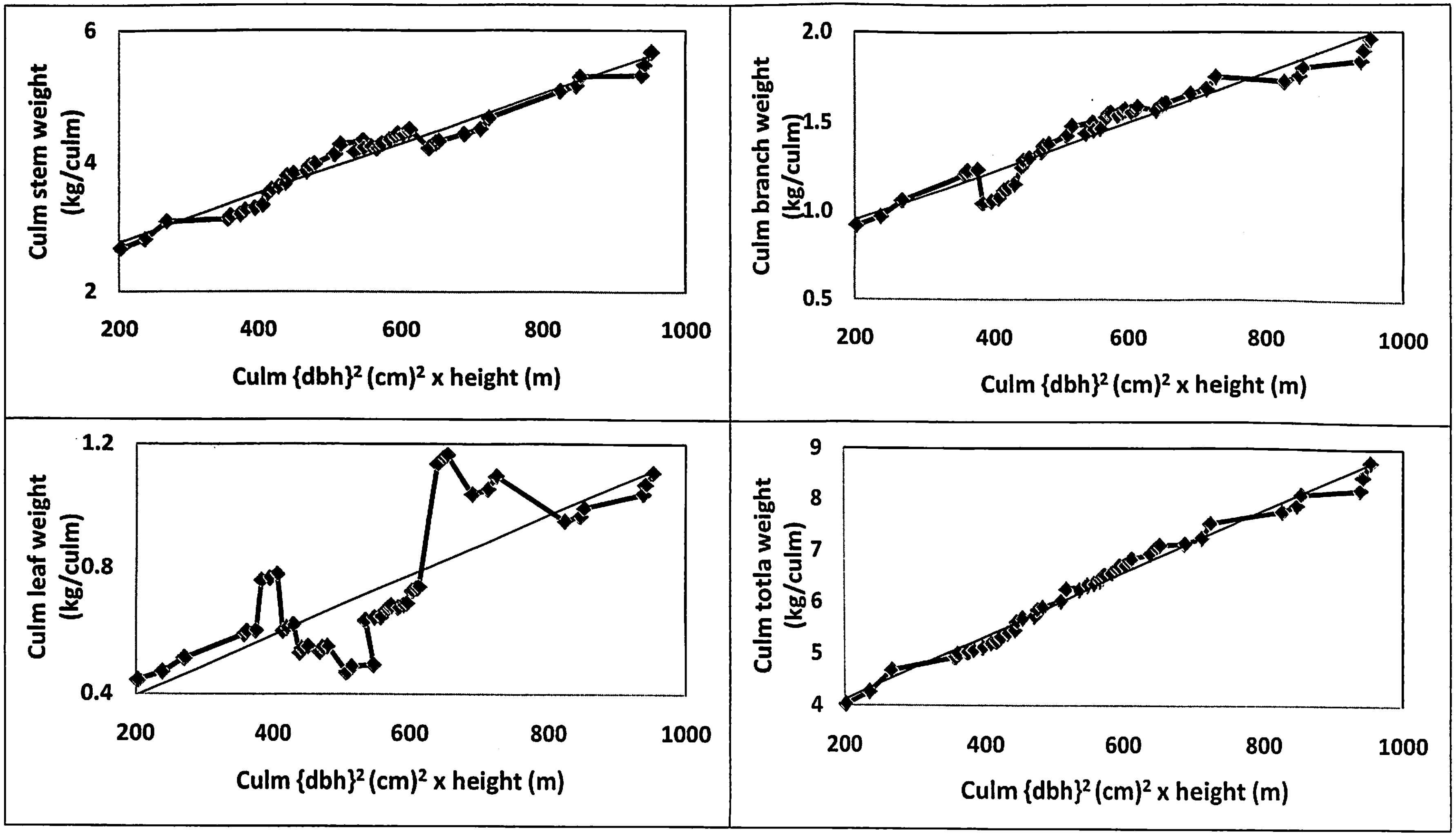



Figure 28. Fitted regression lines of oven dry weight (kg/culm) of stem, branch and total culm on culm $dbh^2$ x height of *T. oliveri*. Culm dbh in cm and height in m.

## D2. Biomass production in different bamboo species

The total biomass of each species was calculated on the basis of total culm weight, number of culms per clump and number clumps per ha. With a spacing of 5 m x 5m, totally 400 clumps can be planted in one hectare area. Thus, the estimated total biomass in 5-year old bamboo farms of different species in the State can vary from 10.6 t/ha to 95.7 t/ha, with highest being in *B. bambos* and lowest in *D. sikkimensis* (Table 44).

In the present study, total biomass of 1- year old culms in a farm of a given bamboo species was used to estimate the annual biomass production potential. Thus, the estimated annual biomass production in 5-year old bamboo farms of different species in the State ranged from 2.5 t $ha^{-1}$ $yr^{-1}$ to 19.8 t $ha^{-1}$ $yr^{-1}$, with highest mean value for *B. bambos* and lowest for *D. longispathus* (Table 44).

Table 44. Total biomass (t $ha^{-1}$) and annual aboveground biomass production (t $ha^{-1}$ $yr^{-1}$) in 5-year old clumps of different bamboo species. Values are mean ± SD. In a row, values with same alphabet in the superscript are not significantly different at 5% level.

| Species | Aboveground biomass (t $ha^{-1}$) | Annual production of aboveground biomass (t $ha^{-1}$ $yr^{-1}$) |
|---|---|---|
| *Bambusa balcooa* | $12.5 \pm 2.3^{a}$ | $2.7 \pm 0.5^{a}$ |
| *Bambusa bambos* | $95.7 \pm 19.0^{j}$ | $19.8 \pm 3.9^{i}$ |
| Bambusa nutans | $13.1 \pm 2.5^{ab}$ | $2.9 \pm 0.6^{ab}$ |
| *Bambusa tulda.* | $62.2 \pm 8.3^{i}$ | $11.4 \pm 1.5^{h}$ |
| *Bambusa vulgaris cv. wamin* | $31.3 \pm 5.9^{ef}$ | $6.3 \pm 1.2^{de}$ |
| *Bambusa vulgaris* | $23.5 \pm 4.3^{de}$ | $4.8 \pm 0.9^{cd}$ |
| *Bambusa wamin* | $55.6 \pm 10.4^{hi}$ | $9.9 \pm 1.9^{g}$ |
| *Dendrocalamus asper* | $17.8 \pm 3.0^{bc}$ | $3.5 \pm 0.6^{ab}$ |
| *Dendrocalamus hamiltonii* | $21.5 \pm 3.7^{cd}$ | $3.4 \pm 0.6^{ab}$ |
| *Dendrocalamus longispathus* | $12.3 \pm 2.2^{a}$ | $2.5 \pm 0.4^{a}$ |
| *Dendrocalamus sikkimensis* | $10.6 \pm 1.9^{a}$ | $2.8 \pm 0.5^{ab}$ |
| *Dendrcalamus strictus* | $43.7 \pm 7.8^{gh}$ | $8.5 \pm 1.5^{fg}$ |
| *Gigantochloa rostrasta* | $19.2 \pm 3.6^{cd}$ | $3.7 \pm 0.7^{bc}$ |
| *Thyrsostachys oliveri* | $38.9 \pm 6.9^{fg}$ | $8.1 \pm 1.4^{ef}$ |

Several important results related to the culm density in the clump and culm characters of different bamboo species have emerged from the present study. For instance, it may be mentioned here that the study plots are distributed within a small geographic area (10°02'N - 10°54'N and 76°04'E- 76°57'E), and here plantations are of same age (5 years) as well as farmers adopted planting and management practices stipulated by the staff of Kerala Forest Research Institute who have handled this Project. However, the total number of culms per clump recorded in different species showed a generally significant difference. Though the annual culm production potential is expected to differ from species to species, the past land-use system and practice, difference in soil physical-chemical properties and difference in microclimate may also contribute significantly for difference in growth and biomass production in different species. Thus, single location studies need to be carried for a systematic comparative assessment of growth performance and biomass production of different species of bamboo.

Analysis of culm characteristics of different species of bamboo from plantations of same age indicated that the mean ratio between wall thickness and culm diameter in *D. asper, D. hamiltonii, D. sikkimensis, G. rostrata* and *T. oliveri* is less than 0.2. One the other hand, the value is between 0.2 and 0.3 in B. nutans, *B. tulda, B. vulagaris, B. vulgaris* cv. *wamin, B. wamin* and *D. longispathus*. It is also estimated that the mean ratio between wall thickness and culm diameter in *B. balcooa* and *B. bambos* is 0.3 and 0.34 respectively with highest value (0.55) in *D. strictus*. However, culm weight and value obtained for mean ratio between wall thickness and culm diameter did not correlate significantly.

In ten out of the fourteen species studied, significant correlation between biomass of three components (stem, branch, leaf) and dbh or $((dbh)^2 \times h$ is observed. However, in species, such as, *B. balcooa, B. nutans, B. tulda* and *D. strictus*, correlation between leaf biomass and independent variable (dbh or $((dbh)^2 \times h$ ) was weak, suggesting that the leaf being a short durability component in the culm may have poor correlation with independent variables at least in some species or at certain period of the year of investigation. Similar, observation was made in *Bambusa* species by Melo and others (2015).

Assessment of partitioning of culm biomass among stem, branches and leaf components in different bamboo species indicated an almost common pattern with 67%, 23% and 10% of total culm weight distributed among stem, branches and leaves respectively. This observation may be useful to estimate the total culm biomass once the weight any one of the three components is known. It is also clear from the present study that the biomass production potential of majority of the species is almost same (Table 44), though significantly less than in species, such as, *B. bambos* and *B. tulda*. Thus, attempts may be made in the State to promote different species of bamboo considering farmers' requirement, marketing opportunities and bamboo-based micro and macro industries. At the same, package of practice to enhance their biomass production potential need to be evolved.

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