Materials and Methods
CHAPTER 3 MATERIALS AND METHODS

The present investigation on litter dynamics and carbon sequestration potential of selected bamboo species of Kerala was conducted during 2010-2012 at Kerala Forest Research Institute, Thrissur, Kerala. The details of the materials and methods used for the study are described in this chapter.

3.1 Selection of bamboo Species

In order to select the bamboo species, extensive field explorations were carried out all over Kerala. The main criteria employed in the selection of the species for investigation were as follows:

- The priority species identified by NMBA for cultivation.
- The natural populations in forest areas were avoided. Those species which are preferred and cultivated by farmers were selected.

Four commercially important bamboo species viz. *Bambusa balcooa* Roxb, *B. bambos* Voss, *Ochlandra travancorica* Benth and *Thyrsostachys oliveri* Gamble were selected (Plates 1-4). *B. balcooa* is a tall clumping bamboo forming distinct tufts, groups or clumps. In general, culms are 20–24 m long, 8 to 15 cm in diameter, thick walled (2–2.5 cm), nodes prominent with white ring above the node and internodes are 30–45 cm long. *B. bambos* is a very densely tufted bamboo, producing large dense clumps of closely packed culms. The culms are strong, green coloured, grows up to 30 m tall and 18-25 cm in diameter. Walls are 3 cm thick at the base. Branching is observed at all the nodes, central dominant branch being produced first, with one or two laterals and branches bear spines. *O. travancorica* is an erect, shrubby, reed-like, gregarious bamboo reaching a height of 2-6 m with an average internode length of 45-60 cm and sometimes up to 150 cm in ideal growing conditions with a diameter of 2.5-5 cm. *T. oliveri* is a moderate sized tropical clumping bamboo with rather small leaves and persistent culm sheaths. Usually, the culms are 15–25 m high, 5 cm in diameter, bright green with whitish silky surface when young, grayish green to light white in colour in maturity, thick walled (2–2.5 cm), internodes 40–60 cm long.
Plate 1. Habit of *Bambusa balcooa* a. A clump  b. Basal part of the clump c. Emerging new shoot d. Young culm covered with culm sheath e. One internode with branches f. Flowering in tissue cultured plants g. Close up of empty glumes
Plate 3. Habit of *Ochlandra travancorica* a. A clump b. Basal part of the clump c. Inflorescence d. Fruits e. New shoot f. Young internode with culm sheath g. Seedlings in the nursery
3.2 Study area

The present investigations were conducted in Thrissur and Palakkad districts of Kerala, India. Kerala state is located in southwestern part of peninsular India and covers an area of 38,863 km², which is approximately 1.18 % of the whole country. It is located in the humid tropics between the latitudes of 8°18’ and 12°48’ N and longitudes of 74°28’ and 77°37’ E. The climate of Kerala is of Tropical Monsoon type with seasonally excessive rainfall and hot summers. The state receives about 380 mm rainfall during summer, about 2150 mm (71 %) during Southwest monsoon and about 500 mm during Northeast monsoon. Three seasons are recognized, summer (January to mid May), South-west monsoon (mid May to August) and North-east monsoon (September to December). The wettest months are June, July and August. The soils of Kerala can be broadly classified as Ultisols (50 per cent by area), Inceptisols (25 per cent), Entisols (20 per cent), and Alfisols (5 per cent) (Nair and Sreedharan, 1986). The topography consists of a hot and wet coastal plain gradually rising in elevation to the high hills and mountains of the Western Ghats.

Palakkad is a centrally located district which lies between latitude 10° 46’ and 10° 59’ and east longitude 76°28’ and 76°39’ (http://www.stateofkerala.in/districts/palakkad.php). The Palakkad district has a humid climate with a very hot season extending from March to June in the Western part of the district whereas it is less humid in the Eastern sector. On an average, Palakkad receives 2348 mm of rainfall annually and the most important rainy season is during South West Monsoon which sets at the second week of June and extends upto September. About 75 per cent of the annual rain is received during the South-west monsoon period. During the period December to May, practically no rain is received. The temperature of the district ranges from 20 to 45°C. The maximum temperature recorded at Palakkad was 43°C. The soil of Palakkad district is mainly of four types, namely, peaty (kari), laterite, forest and black.

Thrissur also is a centrally located district which lies between 10° 0’ and 10° 47’ North latitudes, and 75° 55’ and 76° 54’ East longitudes (http://www.thrissurkerala.com/about}
The climate of Thrissur district is warm humid with mean temperature varying from 30-38°C. The mean annual precipitation is about 2670 mm. Diurnal variation in temperature is very less. The soil is predominantly red loam. The district has a tropical humid climate with an oppressive hot season and plentiful seasonal rainfall. Annual rainfall is about 3000 mm. The hot season from March to May is followed by the South West Monsoon season from June to September. The period from December to February is the North East Monsoon season.

Location of sample plots of each bamboo species is given in the Table 6. Plantations of *B. balcooa, B. bambos* and *O. travancorica* at Vilayannur were established during 2005 as part of the Multilocational Bamboo Species Trial supported by National Mission on Bamboo Applications (Raveendran et al., 2011). The plantation consisted of eight bamboo species viz. *Bambusa balcooa, B. bambos, B. nutans, B. tulda, Dendrocalamus asper, D. hamiltonii, Guadua angustifolia* and *Ochlandra travancorica* in randomized block design (RBD) in three replicates at a spacing of 5 m x 5 m. *Ochlandra travancorica* plantation at Nellikkad, Palakkad was established as part of the clump management trial under the same project. Plantations of *T. oliveri* at Mulayam, Thrissur and Alanellur, Palakkad were established by progressive farmers during 2005. Climate data of the study regions is given in Appendix I 1-2.

Table 6. Location of the sample plots of the selected bamboo species

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Species</th>
<th>Location of sample plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Bambusa balcooa</em></td>
<td>Vilayannur, Palakkad (N 10°37’58.7” and E 76°30’54.2’’)</td>
</tr>
<tr>
<td>2</td>
<td><em>Bambusa bambos</em></td>
<td>Vilayannur, Palakkad (N 10°37’58.7” and E 76°30’54.2’’)</td>
</tr>
<tr>
<td>3</td>
<td><em>Ochlandra travancorica</em></td>
<td>Vilayannur, Palakkad (N 10°37’58.7” and E 76°30’54.2’’)</td>
</tr>
<tr>
<td>4</td>
<td><em>Thrysostachys oliveri</em></td>
<td>Mulayam – Thrissur (N 10°31’21.7” and E 76°17’49.9’’)</td>
</tr>
</tbody>
</table>

The details of planting stock used are given in Table 7. With regards to planting stock, seedlings were available only for *B. bambos* and *O. travancorica*. Although sporadic flowering has been reported rarely, seed setting was not observed so far in *B. balcooa*.
The mother clumps of *T. oliveri* from where all the materials for vegetative propagation was extracted is from a single population appeared to have established from the seedling stock of flowering in 1931 at Dehradun. Flowering or seed set was not observed in the plantation even after 80 years. It is not possible to get the plantations of same genetic age with same type of planting material. Hence available best is taken for the study.

**Table 7.** Type and source of planting material used in plantation establishment of bamboo species

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Species</th>
<th>Planting material</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Bambusa balcooa</em></td>
<td>Rooted Cuttings</td>
<td>Kerala Forest Research Institute, Peechi, Thrissur</td>
</tr>
<tr>
<td>2</td>
<td><em>Bambusa bambos</em></td>
<td>Seedlings</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><em>Ochlandra travancorica</em></td>
<td>Seedlings</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><em>Thrysostachys oliveri</em></td>
<td>Rooted Cuttings</td>
<td>KFRI and Kongad, Palakkad</td>
</tr>
</tbody>
</table>

The management practices adopted at the time of planting and establishment of *B. balcooa, B. bambos* and *O. travancorica* are given in Table 8 and that of *T. oliveri* is given in Table 9. Although an initial dose of fertilizers was given at the time of planting, thereafter, the plantation was managed without any fertilizer application. Irrigation was carried out during summer months for the first two years only.

**Table 8.** Details of management practices adopted for *Bambusa balcooa, B. bambos* and *Ochlandra travancorica*

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Management practice</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spacing</td>
<td>5 x 5 m</td>
</tr>
<tr>
<td>2</td>
<td>Pit size</td>
<td>60 x 60 x 60 cm</td>
</tr>
<tr>
<td>3</td>
<td>Fertilizer</td>
<td>10 kg FYM + 1 kg neem cake + 25 g P + 50 g K/plant during planting</td>
</tr>
<tr>
<td>4</td>
<td>Irrigation</td>
<td>Twice a week during summer months in the first two years</td>
</tr>
<tr>
<td>5</td>
<td>Weeding</td>
<td>Two weeding in the first year and one each in second and third year</td>
</tr>
</tbody>
</table>
Table 9. Details of management practices adopted for *Thyrsostachys oliveri*

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Management practice</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spacing</td>
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<td>Fertilizer</td>
<td>10 kg FYM + 1 kg neem cake per plant</td>
</tr>
<tr>
<td>4</td>
<td>Irrigation</td>
<td>Once in a week during summer months in first two years</td>
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<td>5</td>
<td>Weeding</td>
<td>Two weeding in the first year and one each in second and third year</td>
</tr>
</tbody>
</table>

3.3 Growth, biomass production and carbon sequestration potential

The methods followed in the estimation of growth, biomass production and carbon sequestration potential of bamboo species is discussed in the following sections.

3.3.1 Clump and culm characteristics

Annual observations were recorded on clump and culm growth of bamboo species from sample plots located at Thrissur and Palakkad districts (Table 6). As the plantations of *B. balcooa* and *B. bambos* and *O. travancorica* located at Vilayannur, Palakkad had 16 clumps in each plot for each species; the growth attributes were recorded in the middle four clumps to avoid the border effect. Similarly, the growth observations were carried out in the centrally located four clumps out of 16 clumps of *O. travancorica* at Nellaikkad plantation. *T. oliveri* plantation at Mulayam, Thrissur consisted of 16 clumps and only one sample plot was demarcated and growth attributes were recorded on central four clumps. *T. oliveri* plantation at Alanellur, Palakkad had 60 clumps and 16 clumps each were selected as one plot and the observations were recorded on central four plants.

3.3.1.1 First year assessment

The selected bamboo clumps were tagged and observations were carried out during March-April. Since bamboo culms lack secondary growth (McClure 1966; Simmonds, 1963) culm attributes of current and previous years could be collected from existing clumps. At the time of first observation (March, 2010), after recording the clump attributes, culms within each clump of bamboo species were grouped into first year i.e.
those established at March, 2010, second year (2009) and old culm (established till March, 2008) groups. The growth attributes of entire culms were recorded in different age gradation.

3.3.1.2 Subsequent year’s assessment
Subsequently, in 2011 and 2012 clump attributes were recorded along with the attributes of culms established in respective years. Clump attributes of bamboo species studied included circumference (taken at first node from ground level) and number of culms per clump. Meanwhile, the culm characteristics included height, girth at breast height (GBH), internodal length (between fifth and sixth nodes) and number of nodes per culm. Height of the culm was measured using graduated bamboo poles. GBH was measured with a diameter tape to 0.10 cm in the middle of the internode nearest 1.30 m above the ground. Internodal length was recorded using tape. Observations on culm recruitment (emergence of new culms) were recorded during 2010 to 2012. At the end of each growing season, mortality of culms was observed. Culm recruitment, mortality percentage and survival of culms were observed.

3.3.2 Biomass production
Carbon sequestration potential of the bamboo species was deduced from their biomass accumulation potential. To estimate the biomass accumulation of each bamboo species, three clumps were destructively sampled during April-May, 2011 and 2012. Destructive sampling was carried out in isolated bamboo clumps selected from the sample plots to avoid the interference of roots from nearby clumps (Plate 5).

3.3.2.1 Above ground biomass (AGB)
In order to fell the clumps, the culms were cut at the ground level as close as possible to the first internode. After felling, the branches and leaves were separated culmwise. Fresh weight of the stem was taken immediately and total length, girth, number of internodes and internodal length of the culms were recorded for each culm in a clump. Fresh weight of branch and leaves were recorded and summation of these weights gave the total
Plate 5. Different stages of excavation of bamboo clump a-f. Uprooting the clump e. Culms removed from the base f. Rhizomes separated from root.
Plate 5. g. Rooting profile of Ochlandra travancorica. h. Uprooted clump. i. Rooting profile of Bambusa bambos. j. Weighing the samples.
above ground biomass. In the case of *Bambusa bambos*, the thorns were included in the branch weight. Samples from the base, middle and top (500 g x 5) of the stem were taken for dry weight estimation. Branch and leaf samples were also taken in sealed polythene bags (100 g x 5). The samples were oven dried till constant weight was obtained at 70°C.

### 3.3.2.2 Allometric models

In order to predict the above ground biomass and allocation in culms of bamboo species, six commonly used models were tried in four bamboo species. Among which first three were based on girth at breast height alone and the next three were based on GBH and height of the culms. The six different allometric models were as follows

1. \( Y = a_0 + a_1 \times G \)
2. \( \ln Y = a_0 + a_1 \times G \)
3. \( \ln Y = a_0 + a_1 \times \ln G \)
4. \( Y = a_0 + a_1 \times G + a_2 \times H \)
5. \( \ln Y = a_0 + a_1 \times G + a_2 \times H \)
6. \( \ln Y = a_0 + a_1 \times \ln G + a_2 \times \ln H \)

The dependent variables tried were dry weight of the culm, branch, leaf weight and total culm dry weight. The \( a_0, a_1 \) and \( a_2 \) are parameters to be estimated. \( G \) is girth at breast height, \( H \) is the total height (measured from first node to the tip). \( \ln \) indicates logarithmic transformation.

When the above six models were tried in order to select the best model certain criteria was to be developed. Models are based by their goodness of fit as measured by \( R^2 \), mean of the residuals, root mean square error or standard error of fitted regression. The usual index of fit, i.e. the root mean square error, can only be used to compare models that have the same response or dependent variable (Furnival, 1961). As an alternative, Vanclay (1994) and Philip (1994) suggested the Furnival index as a basis of model comparison (Furnival, 1961). The index adjusts the standard error of the regression in order to facilitate the comparison. The Furnival index (FI) is calculated by multiplying the standard error of the fitted regression (root mean square error) by the geometric
mean and the reciprocal of the derivative of the transformed variable and weighted with
respect to the untransformed variable. The coefficient of determination and Furnival
index values also estimated in different models. Among the six models tried, best fit were
determined by coefficient of determination ($R^2$) and Furnival index.

3.3.2.3 Below ground biomass (BGB)
In order to estimate the BGB, the soil was dug up around the bamboo clumps. The depth
and width of the trench was extended depending on the root spread. The roots and
rhizomes were separated and fresh weight was determined in the field. The
representative samples of 500 g each for different bamboo components were taken to
laboratory in sealed polythene bags. The estimates of the dry weight biomass were
obtained from the fresh weight of various biomass components and their moisture
content that was determined on sub samples.

3.3.3 Carbon content determination
The carbon storage in different bamboo components was determined by the Euro vector
(EA 3000) CHNS Elemental analyser. The samples were ground to fine powder using
Wiely mill. The powdered samples (0.002 g) were taken in tin capsules and the C content
measured using the instrument. The carbon sequestration on per ha basis was calculated
from the clump density biomass equations.

3.3.3.1 Estimation of net carbon content
Total carbon content was computed using the following relations
Total above ground biomass organic carbon = [(Total culm biomass x % carbon in
culms) + (Total leaf biomass x % carbon in leaves) + (Total branch biomass x % of
carbon in branches)]
Total below ground biomass organic carbon = [(Total rhizome biomass x % carbon in
rhizome) + (Total root biomass x % carbon in roots)]
Total biomass organic carbon = Total above ground biomass organic carbon + Total
below ground biomass organic carbon
3.3.3.2 Estimation of soil carbon sequestration
Methods followed in sampling of soil and estimation of organic carbon in the soil is given below.

3.3.3.2.1 Soil sampling
Soil samples were taken from the pits dug up to 60 cm depth at three different levels (0-20, 20-40 and 40-60 cm). A pit was dug up in each plot for each species. The soil samples were collected, labelled and tagged and brought to laboratory for analysis. The samples were air dried and sieved through 2 mm sieve and used for analysis.

3.3.3.2.2 Soil organic carbon
The soil organic carbon (SOC) content was determined using Walkey and Black method (Jackson, 1973). Total soil organic carbon content was estimated using the following formula (Chhabra et al., 2002):

\[ \text{SOC} = \text{Organic carbon content \%} \times \text{bulk density (kg/ m}^3\text{)} \times \text{Thickness of horizon (m)} \]

The total soil carbon storage was expressed on per hectare basis.

3.3.3.2.3 Bulk density
Core samplers were used for determining the bulk density of the soil samples of each soil layer. Undisturbed bulk soil was extracted using these and bagged in plastic bag, sealed and labelled. The samples were transported to laboratory for oven dry weight estimation. The samples were dried at a temperature of 105°C to constant weight.

\[ \text{Bulk density (g/cm}^3\text{)} = \text{(oven dry weight of the soil)} / \text{(volume of the core)} \]

B.D. was expressed in kg/ m³ and further it was expressed as ton ha⁻¹

3.4 Litter dynamics
Procedures followed in studying the dynamics of litterfall and decomposition are narrated below.
3.4.1 Measurement of litterfall

Litterfall in *Bambusa balcooa*, *B. bambos* and *Ochlandra travancorica* was quantified by keeping litter traps at Vilayannur plantation, Palakkad and quantification of litterfall in *T. oliveri* was conducted at Alanellur, Palakkad. The litter production was observed at monthly intervals during June 2010 to May 2011 and it was continued upto June 2012. Litter collections were made using specially designed litter traps made of bamboo basket having diameter of 1 m and a depth of 10 cm hence having a collection area of 0.785 m$^2$ and capacity of 0.079 m$^3$. The litter traps were placed in the centre of each plot. The traps were fixed 25 cm above ground using wooden pegs. There were three litter traps for each bamboo species. The accumulated litter within the traps was carefully removed each month and fresh weights were determined in the field. The representative litter samples were collected from each litter trap and kept dried to constant weight for moisture determination. The dry weight biomass of the litter sample was obtained from the moisture content and expressed on a unit area basis.

3.4.2 Measurement of litter decomposition

Investigation on litter decomposition dynamics of *Bambusa balcooa*, *B. bambos* and *Ochlandra travancorica* were carried out at Vilayannur, Palakkad and that of *T. oliveri* was conducted at Alanellur, Palakkad during June, 2010 to May, 2011.

Litter decomposition was studied by adopting standard litterbag techniques (Bocock and Gilbert, 1957). The freshly fallen/senescent litter of the bamboo species were collected during the peak fall period of each species (February to March). Collected litter samples (500g x 5) were divided into leaves, branches and culm sheaths and the contribution of each component to total litter was recorded. Litter samples were air dried for two weeks and moisture content was determined. The samples of air dried litter were oven dried at 70°C for their dry weights and moisture correction. In order to study the litter decay of bamboo species, the primary litter samples were mixed thoroughly to increase the
homogeneity. Air dried litter samples (25 g for *B. balcooa* and 30 g each for other species) for each species were placed in a nylon litterbag (2 mm mesh; 28 x 23 cm). Only 25 g was filled in the case *B. balcooa*, as the leaves were thick and larger in size compared to other species and to avoid the compaction while packing. Seventy bags of each species were randomly placed in direct contact with soil in each plot on 31, May, 2010 (Plate 6) and a thin layer of soil was added. For each species, five litterbags were recovered at monthly intervals until 95 % of the decomposition occurred in the samples. The residual materials in the litter bags were separated from adhering soil particle using a small brush. Litter samples from each bag were oven dried at 70°C to constant weights to determine dry weight. Monthly mass loss from the decomposing litter was calculated from the difference between the mass remaining in the litterbags in each month. The percentage mass loss at each month can be calculated from the equation

\[
\text{% Mass loss} = \frac{\text{Initial mass} - \text{Final mass}}{\text{Initial mass}} \times 100
\]

Mass loss over time was computed using the negative exponential decay model (Olson, 1963):

\[
\frac{X}{X_0} = e^{-kt}
\]

Where, \(X\) is the weight remaining at time \(t\), \(X_0\) the initial dry weight, \(e\) is the the base of natural logarithm, \(k\) the decay rate constant and \(t\) the time. The \(k\) value was used to calculate turnover time \((1/k)\). The time required for 50 per cent \((t_{50})\) and 99 per cent \((t_{99})\) was calculated as

\[
t_{50} = 0.693/k
\]

\[
t_{99} = 5/k
\]

### 3.4.3 Chemical analysis of litter samples

Five samples of fresh litter and decomposed litter recovered from litter bags sampled for mass loss estimation for each species were chemically analysed. The samples were dried and powdered in Wiley mill. The total carbon was estimated using Euro vector (EA 3000) CHNS Elementar analyser. The nutrients N and P were estimated using Skalar
San++ Auto analyzer. The potassium was estimated using Flame photometer and Ca and Mg was estimated using Atomic Absorption spectrophotometer (Jackson, 1973).

3.4.3.1 Digestion of litter samples
Powdered sample (0.5 g) was taken in a digestion tube and 10 ml of conc. H$_2$SO$_4$ and a pinch of salicylic acid were added. This mixture was kept overnight and digested using block digester (Kel plus) in a digestion chamber by adding 5 ml H$_2$O$_2$ every two hours; at a temperature of 340$^\circ$C till the sample was clear. After the completion of digestion, the digestion tubes were taken from the block and allowed to cool. Each digested sample was transferred to 100 ml standard flask and made up to the mark.

3.4.3.2 Estimation of nitrogen
The samples belonging to different months were analysed for nitrogen in triplicates. Nitrogen content of the digested sample was determined using Skalar San++ autoanalyser.

3.4.3.2.1 Preparation of standards
Ammonium chloride (3.819 g) was dissolved in distilled water and made up to one litre (1000 ppm). Solutions with the concentrations of 0, 25, 50, 75, 100 and 125 ppm were prepared by taking 0.5, 1, 1.5, 2 and 2.5 ml of the stock solution (1000 ppm) and made up to 100 ml with rinsing sampler.

3.4.3.2.2 Procedure
Autoanalyser was switched on half an hour before the analysis for booting; the suction tubes were put into the reagent bottles viz. Potassium sodium citrate, Trisodium citrate, Brij-35 (35 %), Sodium salicylate, Sodium nitroprusside and Rinsing liquid (Sulphuric acid). Samples were kept in the sampler unit. Standards were arranged in the order wash (rinsing liquid), tracer (highest standard), drift (second highest standard) and samples. Drift was placed in between samples in order to minimise the correction.
Washings were carried out automatically. Readings were noted and nitrogen content was calculated.

3.4.3.3 Estimation of Phosphorus
The samples belonging to different months were analysed for P in triplicates.

3.4.3.3.1 Preparation of P standards
Potassium hydrogen phosphate was dried in the oven at 60°C for one hour and after cooling, exactly 0.493 g was dissolved in 1 litre distilled water to make 100 ppm stock solution. From this stock solution 10 ppm solution was prepared by taking the 10 ml of 100 ppm solution and making up to 100 ml. From this 10 ppm solution 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4 an 1.6 ppm were prepared by taking 1, 2, 3, 4, 5, 6, 7 and 8 ml of 10 ppm solution and 5 ml of colouring agent (Barton reagent) to 50 ml standard flasks and made up to 50 ml with distilled water.

3.4.3.3.2 Procedure
Samples were kept in the sampler unit. Standards were arranged in the order wash (rinsing liquid), tracer (highest standard), drift (second highest standard) and samples. Drift was placed in between samples in order to minimise the correction. Washings were carried out automatically. Readings were noted and phosphorus content was calculated.

3.4.3.4 Estimation of potassium, calcium and magnesium
The K, Ca and Mg in the litter samples were determined using the standard procedures (Jackson, 1973). Potassium content of the litter was estimated by Flame Photometer (ELICO) and calcium and magnesium by Atomic Absorption Spectrophotometer (VARIAN).

Nutrient content of the decomposing litter was calculated as (Bockheim et al., 1991).

\[
\% \text{ Nutrient remaining} = \left( \frac{C}{C_0} \right) \times \left( \frac{DM}{DM_0} \right) \times 100
\]

where C is the concentration of the element in litter at the time of sampling; C₀, the concentration of element in the initial litter kept for decomposition; DM, the mass of dry
matter at the time of sampling and DM<sub>0</sub>, the mass of initial dry matter kept for decomposition (Bockheim et al., 1991).

% nutrient released = 100 – % of original nutrient remaining (Giashuddin et al., 1993)

3.5 Statistical analysis

The data were subjected to analysis using the statistical packages SPSS version-17 for windows.

3.5.1 Growth, biomass production and carbon sequestration potential

Variation due to species and age in the clump and culm attributes of bamboos were determined by Two-way analysis of variance with species as one factor and age as the second factor (Jayaraman, 1999). Whereas, variation in clump and culm attributes in each bamboo species due to age was analysed using One-way analysis of variance. Pearson’s bivariate correlation coefficient was determined among the culm attributes of bamboo species like height, girth, number of internodes and internodal length of different age groups (Snedecor and Cochran, 1980). Two-way ANOVA was carried out to find the between plantation variation in clump and culm attributes of O. travancorica and T. oliveri.

Moisture content in the clump biomass components of bamboo species were compared with Two-way analysis of variance with species as the first factor and plant part as the second. The variation in component and total green weight as well as dry weight was determined using Two-way Analysis of variance with species as one factor and age as the second factor. Multiple linear regression equations were tried to predict the above ground green and dry weight of the components connecting height, GBH, number of internodes and internodal length. Six allometric models (both linear and exponential) also were tried to predict the above ground biomass using height and girth (Montgomery and Peck, 1982). Furnival index was used to find the best fit model. Two-way ANOVA was carried out to find the variation in species and component wise carbon
concentration (Furnival, 1961). The carbon accumulation in bamboo species was compared with Three-factor analysis of variance with species, components and age as the factors. Two-way ANOVA was carried out with species as one factor and soil depth as the second to assess the variation in soil carbon content and soil carbon density. Variation in above, below ground biomass and their ratio was compared by One-way analysis of variance.

### 3.5.2 Litter dynamics

Litter production dynamics of bamboos were compared by Two-way Repeated Measures ANOVA with species and age as the factors and month as the repeated factor. Variation in proximate composition of litter mass was analysed using One-way analysis of variance. ANOVA of One-way Repeated Measures was carried out for the differences in mass disappearance of bamboo litter mass due to species and month. Exponential regression equations were fitted in MS-Excel-2007 for the litter decomposition in bamboo species. Species wise variation in initial litter chemistry of litter mass was brought out by One-way analysis of variance. In order to compare the species wise variation in nutrient concentration and percentage nutrient remaining (N, P, K, Ca and Mg) in monthly retrieved litter samples, Two-way analysis of variance was conducted. Least significant difference (lsd) and Duncan’s Multiple Range Test were used to compare the treatment means wherever necessary.