QUANTIFICATION OF SOIL CARBON POOLS AND CARBON SEQUESTRATION RATE AS INFLUENCED BY BAMBOO PLANTATION GROWN ON ENTISOL OF SEMIARID CLIMATE OF MAHARASHTRA

by

Mr. Gaikwad Aniket Sunil

(Reg. No. 2019/091)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

POST GRADUATE INSTITUTE

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The assistance and help received during the course of this investigation have been duly acknowledged.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations		**Description**
@	:	At the rate of
&	:	And
^0C	:	Degree Celsius
$>$	:	Greater than
$<$	:	Less than
=	:	Equal to
Σ	:	Summation
±	:	Plus-minus
%	:	Per cent
$\mu g\ g^{-1}$	:	Micro gram(s) per gram
AAS	:	Atomic Absorption Spectrophotometer
AGB	:	Above ground biomass
BD	:	Bulk density
BGB	:	Below ground biomass
C	:	Carbon
Ca	:	Calcium
$CaCO_3$	:	Calcium carbonate
CD	:	Critical difference
cfu	:	Colonies forming unit
$CHCl_3$	:	Chloroform
cm	:	Centimetre
CO_2	:	Carbon dioxide
Cu	:	Copper
DBH	:	Diameter at breast height
DHA	:	Dehydrogenase enzyme activity
$dS\ m^{-1}$	:	Deci siemen’s per metre
$\mu S\ cm^{-1}$	:	Micro siemen’s per centimetre
DW	:	Distilled water
EC	:	Electrical Conductivity
Ed.	:	Edition
etc.	:	Excetera (and so on)
et al.	:	*Et alia* (and others)
Fe	:	Iron
$FeSO_4(NH_4)_2SO_4.6H_20$	:	Ferrous Ammonium Sulphate
Fig.	:	Figure
FYM	:	Farm yard manure
g	:	Gram(s)
Gt	:	Gigatonnes
H_2O_2	:	Hydrogen peroxide
H_2SO_4	:	Sulfuric acid
H_3PO_4	:	Orthophosphoric acid
ha	:	Hectare(s)
hr	:	Hour(s)
i.e.,	:	*Id est* (that is)
INBAR	:	The International Network for Bamboo and Rattan
IPCC	:	Intergovernmental Panel on Climate Change
ISFR	:	The Indian State of Forest Report
K	:	Potassium

K_2O	:	Potassium oxide
$K_2Cr_2O_7$	:	Potassium dichromate
kg	:	Kilogram(s)
kg ha^{-1}	:	Kilogram per hectare
$KMnO_4$	:	Potassium permanganate
M	:	Molar
m	:	Metre
Max.	:	Maximum
Mg	:	Megagram(s)
mg	:	Milligram(s)
Mg m^{-3}	:	Megagram per cubic metre
Min.	:	Minimum
min.	:	Minute(s)
mL	:	Milliliters(s)
mM	:	Millimolar
Mn	:	Manganese
M.S.	:	Maharashtra
N	:	Nitrogen
N	:	Normality or Normal
Na	:	Sodium
$NaHCO_3$	:	Sodium bicarbonate
$(NaPO_3)_6$	:	Sodium hexametaphosphate
NH_4OAc	:	Ammonium acetate
NS	:	Non-significant
OC	:	Organic carbon
P	:	Phosphorus
P_2O_5	:	Phosphorus pentoxide
Pg	:	Petagram
pH	:	*Puissance de Hydrogen*
PIA	:	Philippine Information Agency
POMC	:	Particulate organic matter carbon
POXC	:	Permanganate oxidizable soil carbon
ppm	:	Parts per million
r	:	Correlation coefficient
RBD	:	Randomized block design
RDF	:	Recommended dose of fertilizer
S	:	Sulphur
SEm $\pm$	:	Standard error of mean
SMBC	:	Soil microbial biomass carbon
SOC	:	Soil organic carbon
SOM	:	Soil organic matter
TC	:	Total carbon
t ha^{-1}	:	Tonnes per hectare
TN	:	Total nitrogen
TOC	:	Total organic carbon
TPF	:	Triphenyl formazon
viz.,	:	*Vide licet*, namely
Vol	:	Volume
WSC	:	Water soluble carbon
wt.	:	Weight
Zn	:	Zinc

ABSTRACT

QUANTIFICATION OF SOIL CARBON POOLS AND CARBON SEQUESTRATION RATE AS INFLUENCED BY BAMBOO PLANTATION GROWN ON ENTISOL OF SEMIARID CLIMATE OF MAHARASHTRA

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A long-term field experiment "Performance of different bamboo species on growth and yield of bamboo" was initiated in the year 2018-19 at National Agricultural Research Project (NARP), Dryland Sub-Centre (Agroforestry), Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar. The same field experiment was selected for conduct of present study entitled, "Quantification of soil carbon pools and carbon sequestration rate as influenced by bamboo plantation grown on entisol of semiarid climate of Maharashtra" during the year 2020-21. The field experiment was laid out in randomized block design comprising three replications and seven treatments of bamboo species *viz., Dendrocalamus brandisii* (T_1), *Bambusa nutans* (T_2), *Bambusa balcooa* (T_3), *Dendrocalamus strictus* (T_4), *Bambusa tulda* (T_5), *Bambusa bamboos* (T_6) and *Dendrocalamus asper* (T_7). The observations pertaining to the effect of different bamboo species on soil properties, growth attributing characters and biomass production, nutrient concentration and uptake, carbon stock and carbon sequestration rate were recorded from the long-term field experiment after 2^{nd} year of plantation.

The soil under the treatment of *Bambusa nutans* recorded highest SOC (8.07 g kg^{-1}) and TOC content (12.9 g kg^{-1}), while lowest qMin ratio (0.63) over rest of bamboo species treatments. Whereas, soil under *Dendrocalamus asper* recorded highest qMic ratio (1.50) as compared to other bamboo species treatments. The soil labile carbon fractions *viz.*, WSC, SMBC and POMC was recorded highest in the soil under *Bambusa tulda* (14.08, 181.7 mg C kg^{-1} and 1.90 g C kg^{-1}, respectively), whereas, soil under the treatment of *Bambusa nutans* recorded highest POXC content (0.666 g C kg^{-1}) over rest of bamboo species.

The total soil bacterial, fungi and actinomycetes population were recorded highest under the treatment of *Bambusa tulda* (11.67 cfu x 10^6 g^{-1} soil, 11.00 cfu x 10^4 g^{-1} soil and 10.67 cfu x 10^5 g^{-1} soil, respectively) the same treatment recorded highest soil dehydrogenase enzyme activity (3.63 µg TPF g^{-1} soil hr^{-1}) over other bamboo species treatments.

The soil under different bamboo species had shown significant changes in soil pH and EC due to plantation of various species of bamboo. Whereas, these bamboo species have shown non-significant changes in the $CaCO_3$ content of soil. The soil under the treatment of *Bambusa tulda* recorded significantly highest soil available nitrogen, phosphorus and potassium content (191.83, 8.37 and 410.33 kg ha^{-1} respectively) as compared to other tested bamboo species and its initial soil level. As compared to control plot, slight reduction in soil bulk density was recorded in the soil under the influence of different bamboo species.

Abstract contd.… **Mr. A. S. Gaikwad**

The treatment, *Bambusa tulda* recorded highest number of culms per clump (59.32), culm density (49413.56 culms ha^{-1}), number of new culms per clump (13.80) and clump girth (712.27 cm) over rest of bamboo species treatments. Whereas, the treatment *Dendrocalamus strictus* recorded highest culm height (6.39 m), basal diameter of culm (8.16 cm), diameter at breast height (7.13 cm), culm girth at 5^{th} internode (16.53 cm) and internodal length (27.51 cm). While the treatment, *Bambusa bamboos* showed its superiority over other bamboo species in the case of number of internodes per culm (28.34) and average culm weight (2.31 kg).

The treatment of *Bambusa nutan* recorded significantly highest aboveground biomass (58.43 t ha^{-1}) while, the treatment of *Bambusa tulda* recorded significantly highest belowground (5.19 t ha^{-1}) and leaf-litter biomass (3.89 t ha^{-1}) as compared to other bamboo species treatments. Whereas, the treatment *Bambusa bamboos* recorded highest biomass per culm (2.31 kg $culm^{-1}$), closely followed by treatment *Dendrocalamus strictus* (2.24 kg $culm^{-1}$) and *Bambusa balcooa* (1.96 kg $culm^{-1}$).

In the average effect of biomass components, the nitrogen concentration was found significantly highest in bamboo leaves (1.51 % N), phosphorus concentration in bamboo branches (0.095 % P), potassium concentration in bamboo branches (0.64 % K) and carbon concentration was found numerically highest in bamboo stem (43.53 % C) biomass component accordingly after 2^{nd} year of bamboo plantation grown on Entisol of semiarid climate.

The treatment, *Bambusa nutans* recorded highest nitrogen uptake (457.83 kg N ha^{-1}) while highest phosphorus and potassium uptake was recorded in treatment *Bambusa tulda* (49.70 kg P ha^{-1} and 409.77 kg K ha^{-1}, respectively).

The total biomass carbon stock in the treatment of *Bambusa nutans* and *Bambusa tulda* of 27.83 t C ha^{-1} and 26.68 t C ha^{-1} was recorded respectively after 2^{nd} year of bamboo plantation. Owing to this results, highest plant carbon sequestration rate was observed in the treatment of *Bambusa nutans* (13.92 t C ha^{-1} yr^{-1}) closely followed by the treatment of *Bambusa tulda* (13.34 t C ha^{-1} yr^{-1}). Whereas, highest soil carbon sequestration rate was found in the soil under the treatment of *Bambusa nutans* (13.40 t C ha^{-1} yr^{-1}) followed by treatments of *Bambusa tulda* (12.41 t C ha^{-1} yr^{-1}) and *Dendrocalamus strictus* (12.23 t C ha^{-1} yr^{-1}). Contrary to this, among the studied bamboo genotypes, *Bambusa nutans* recorded significantly highest carbon sequestration potential, closely followed by *Bambusa tulda* (27.31 and 25.75 t C ha^{-1} yr^{-1}, respectively).

All the soil carbon fractions were found highly correlated with most of the soil properties. The soil available N, P and K shown highest correlation with WSC (0.85), SOC (0.93) and TOC (0.86), respectively after 2^{nd} year of bamboo plantation grown on Entisol of semiarid climate.

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1. INTRODUCTION

Carbon is a key element to sustain soil biological activity, ecosystem productivity, soil biodiversity and quality of environment. Atmospheric carbon enters into terrestrial ecosystem through the natural metabolic process of photosynthesis and is return back to the atmosphere through a variety of processes referred to as respiration. Small imbalance between atmospheric carbon sequestration and emission of carbon into atmosphere may lead to remarkable decadal variations in climate change. In the recent decades, excessive release of carbon into the atmosphere has led to unfavourable consequences on quality of air, water, soil and human life. Atmospheric CO_2 concentration has increased from 280 ppm in preindustrial era to the almost 400 ppm in 2020, with an annual increase of around 2 ppm (3.5 Gt per year). This increase in atmospheric carbon dioxide concentration is the result of anthropogenic perturbation (fossil fuel combustion, deforestation, biomass burning and soil cultivation etc.) of the global carbon cycle that has let two serious concerns about the risks of global warming and possible sea level rise. The late 20^{th} century has been an eyewitness of increase in global surface temperature by 0.80 °C as well as eratic alterations in climate change patterns (IPCC, 2007).

In order to change the existing circumstances of climate change, there has been a concerted global attempt to capture atmospheric carbon. To sequester atmospheric CO_2 into alternative long-term carbon forms, it is critical to identify and quantify viable carbon sinks. Soil is a major sink for carbon and plays a crucial role in carbon sequestration. The top 100 cm of surface soil stores approximately 1500–2400 Pg of organic carbon globally (Ciais *et al*., 2013). Soils contain about 70% of terrestrial organic carbon, thereby below ground processes regulate fluxes to the atmosphere that are approximately 10 times the current anthropogenic CO_2 loading rate (Chapin *et al*., 2002). Soil organic matter is a complex of large and amorphous organic molecules and particles derived from the humification of above ground and below ground litter and incorporated into the soil, represents the largest terrestrial carbon pool being almost 3 times as large as that of the plant biomass (IPCC, 2003a).

Bamboo sometimes called ‘the grass of hope’ (PIA, 2008), is a miracle plant with over 1500 documented uses (Ranjan, 2001). This ‘green gold’ introduces itself as a prime and plentiful resource and commonly known as “poor man’s timber” (Ram *et al.*, 2010). Bamboo a sturdy growing, versatile tall-woody grass, taxonomically belonging to the family Poaceae and sub-family Bambusoideae. According to Ohrnberger (1999) the sub-family Bambusoideae comprises 1575 species of woody and herbaceous bamboo from 87 genera worldwide. Currently Sungkaew *et al.* (2009) has categorized Bambusoideae into three main lineages *viz.*, Arundinarieae (temperate woody bamboos), Bambuseae (tropical woody bamboos) and Olyreae (herbaceous bamboos). Based on morphology, bamboo species are grouped as amphipodial, monopodial and sympodial (Maoyi and Banik, 1996). Bamboos with a single stem (leptomorph) are also called as monopodial bamboos, whereas those with densely clumped (pachymorph) are also known as sympodial bamboos.

Bamboo, a naturally occurring C_3 (Sage and Sultamanis, 2016) plant species native to India, with its rapid growth produces high biomass in a short period of time, exhibits an immense capacity to sequester carbon from the atmosphere and effectively recycle carbon within the system. Bamboos can absorb nearly 12 metric tons of CO_2 per hectare from the air, which is two fold than that of a comparable size forest (Choudhary, 2008). Also the extensive root system of bamboos improves physical, chemical and biological properties of soil, controls soil erosion and is considered suitable for rehabilitation of degraded lands within a short span of time (Sujatha *et al.*, 2008). The plantations of bamboo followed by its periodical harvest makes the bamboo ecosystem highly dynamic from the point of view of its structure and functioning (Tripathi and Singh, 1996).

Bamboo occurs in several bio-climatically defined forest types ranging from Tropical to Sub-alpine zones, covers an area of 14 million hectare globally (Dransfield and Widjaja, 1995). About 80% of the bamboo growing areas are confined to South and South-East Asia (Newman *et al.*, 2007). India is the world largest bamboo reserves, harbouring over 20 genera and 113 species (Naithani, 2008). In terms of bamboo genetic resources, India is the world's 2nd richest country (Tewari et al., 2019). The bamboo area of the country is estimated nearly 15.69 million hectare, with approximately total standing biomass stock of 189 million tonnes (ISFR, 2017).

Biswas (1998) has classified the bamboo in India as per its occurrence in different bio-climatical regions of the country *viz.*, Tropical, Temperate and Sub-alpine and alpine forest. Tropical bamboos are found in moist and dry deciduous, evergreen and semi-evergreen forests and savannas which are both naturally occurring and cultivated. The main species of Tropical bamboos are *Bambusa balcooa, Bambusa bamboos, Bambusa tulda, Bambusa pallida, Bambusa burmanica, Bambusa cacharensis, Bambusa khasiana, Bambusa longispathus, Dendrocalamus patellaris, Dendrocalamus strictus, Dendrocalamus sikkimensis, Dinochloa compactiflora, Gigantochloa hasskarliana, Melocanna baccifera, Schizostachyum dullooa* and *Schizostachyum polymorphum.* Temperate bamboos are confined to elevations ranging from 1500 m to 3000 m. The major species of Temperate bamboos are *Chimonobambusa callosa, Drepanostachyum falcatum, Arundinaria rolloana* and *Phyllostachys bambusoides* etc. Whereas, Sub-alpine and alpine bamboos occur at about $\geq$ 3000 m altitude, very few bamboo species are present in this zone *viz., Pleioblastus simonii, Thamnocalamus aristatus and Arundinaria hirsuta* etc.

In Indian tropical region, the occurrence of extensive landscape transformations from natural forests to degraded landforms is accompanied by changes in soil structure and quality (Tripathi *et al.*, 2008) due to opening up of crown cover, decreased soil organic matter content and reduced efficiency of nutrient and carbon cycling (Tripathi and Singh, 1996). Plantation of tropical bamboo species in this region could be a great resource to manage efficiently in order to sequester significant amount of carbon in the soil and vegetation pool, that may be beneficial for offsetting the carbon emissions.

Bamboos are the tall giant grasses displaying several parts *viz.*, culms, branches, leaves, rhizomes, roots, nodes and buds. The below ground portion of the bamboo is known as rhizome. Bamboo bears two distinct forms of subterranean rhizomes (Liese, 2009), the 'leptomorph type' which grows laterally below the soil surface extending the domain of the plant by enlarging and consolidated its area and the second 'pachymorph type' which grows vertically forming an interconnected rhizome system. Besides, rhizome serves as storehouse of food and nutrients for the growth of bamboos and facilitates rapid growth. The rhizome bears nodes and internodes which vary in length from species to species. The nodes of bamboo rhizome produce extensive root systems through which various small lateral roots spread horizontally. Profuse root growth helps bamboo to exploit water and nutrients from larger soil volume. Stems of bamboo termed as "culm" are the most prominent, easily recognizable and widely used part of bamboo developed from the rhizome. Each culm have distinct and solid nodes, that bears branch bud (primordium) which may later develop into branches and branchlets which bears leaves, flower, fruits and seeds. Buds emerge from the alternate sides of the axes on culm and rhizome of the bamboo. Culm buds are located marginally above the nodes and rhizome buds are seen adjacent to the nodes in the internodal portion. The majority of bamboo species annually produces profuse biomass that falls on the surface soil, which forming a dense carpet of nutrient-rich organic matter.

Bamboo has emerged as one of the potential agricultural crop. The species of bamboo has tremendous capacity to rapidly regenerate after disturbances and has been reported to grow well in degraded areas under conditions of impoverished soil nutrients and water stress (Tripathi and Singh 1994). Bamboo plantation brings in long term soil and environmental benefits, mainly through the fortification characteristics like process of carbon sequestration. Average C storage and sequestration rate in woody bamboos range from 30-121 Mg ha^{-1} and 6-13 Mg ha^{-1} yr^{-1}, respectively. Bamboo in addition to having high biomass carbon storage, also has a high net primary productivity (12–26 Mg ha^{-1} yr^{-1}), making it a standing carbon stock and a living ecosystem that continues to expand, even with regular selective harvesting (Nath *et. al.*, 2015). Through management changes that increase storage capacity within the ecosystem in the short term and transformation of carbon into durable products in the long term (Yiping *et al*., 2010), sustainable management and appropriate utilisation of bamboo resources can increase the amount of carbon sequestered.

Bamboo's ability to provide global environmental services through carbon sequestration is now receiving high levels of interest and is the subject of research. The total carbon stock in bamboos is affected by bamboo species, climate, soil type, altitude variation and management practices. Since the bamboo crop is non-traditional in the Maharashtra, studies on carbon sequestration potential of different bamboo species grown are scare.

In this context, long-term field experiment entitled, Performance of different bamboo species on growth and yield of bamboo, was initiated in the year 2018 at National Agricultural Research Project, M. P. K. V., Rahuri and was laid out in a randomized block design comprising three replications and seven treatments of bamboo *viz.*, *Dendrocalamus brandisii*, *Bambusa nutans*, *Bambusa balcooa*, *Dendrocalamus strictus*, *Bambusa tulda*, *Bambusa bamboos* and *Dendrocalamus asper*. The same long-term field experiment was selected to conduct present investigation in order to quantify soil carbon fractions and carbon sequestration rate as influenced by different bamboo species grown on Entisol of semiarid climate of Maharashtra after the 2^{nd} year of bamboo plantation, with the aims to achieve the following major objectives:

1. To find out the effect of bamboo species on soil carbon fractions in Entisol.
2. To find out the effect of bamboo species on carbon sequestration rate in Entisol.
3. To find out the correlation between soil organic carbon pools and soil properties as influenced by bamboo plantation.

2. REVIEW OF LITERATURE

The available literature pertaining to the effect of different bamboo species on soil carbon content and microbial indices, soil physical, chemical and biological properties, growth attributing characters and biomass production, nutrient concentration and uptake, carbon stock and carbon sequestration rate have been reviewed in this chapter. For the sake of comprehension, the literature on these aspects has been reviewed under the following heads:

2.1 Effect of Different Bamboo Species on Soil Carbon Content and Microbial Indices

2.2 Effect of Different Bamboo Species on Soil Properties

2.3 Effect of Different Bamboo Species on Growth Attributing Characters and Biomass Production

2.4 Effect of Different Bamboo Species on Nutrient Concentration and Nutrient Uptake

2.5 Effect of Different Bamboo Species on Carbon Stock and Carbon Sequestration

2.6 Correlation Study

2.1 Effect of Different Bamboo Species on Soil Carbon Content and Microbial Indices

2.1.1 Potassium Dichromate Oxidizable Carbon (SOC) Content

Noble and Randall (1998) reported that perennial tree species has ability to retain soil organic matter through sufficient production of leaf-litter biomass and below ground biomass (*i.e.* root and rhizome residues). The variation in soil organic carbon content in soil under different species may be attributed to addition of different amounts of leaf-litter biomass and root residues (*i.e*. rhizodeposition) in the soils.

Majumdar *et al.* (2005) studied soil profiles under different bamboo species and observed the higher soil organic carbon content in surface layer in comparison to sub-surface layer under the influence of different bamboo species. High soil organic carbon content in surface soil layer may be attributed due to maximum accumulation of leaf-litter biomass and their higher rate of decomposition in surface soil layer.

Venkatesh *et al*. (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan and reported significant increase in soil organic carbon content under different bamboo species as compared to control. The highest soil organic carbon content was observed in soil under *Dendrocalamus longispathus* (25.3 g kg^{-1}) whereas, lowest increase in soil organic carbon content was found under *Dendrocalamus hamiltonii* (9.9 g kg^{-1}).

Kumari *et al*. (2017) studied effect of various bamboo species on soil properties and growth parameters at Nauni-Solan, HP, India and reported soil organic carbon content found under different bamboo species *viz.*, *Dendrocalamus asper*, *D. hamiltonii*, *Bambusa tulda*, *Phyllostachys aurea, D. strictus*, *Melocanna baccifera* and *P. bambusoides* was recorded as 17.2, 17.0, 15.6, 15.5, 16.9, 15.2 and 15.1 g kg^{-1} SOC, respectively at 0-20 cm soil depth.

2.1.2 Total Soil Organic Carbon (TOC) Content

Xu *et al.* (2008) conducted a research study on soil microbial functional diversity under intensively managed bamboo plantation grown in Southern China with intensively managed fields were annually fertilized @ 350–600, 80–120 and 150–200 kg N, P and K ha^{-1}, respectively and reported total organic carbon content under those managed conventionally (14.98 g C kg^{-1}), intensive management practices for 5-7 years (13.17 g C kg^{-1}) and under intensive management practices for 8-10 years (12.86 g C kg^{-1}).

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in china and reported total soil organic carbon content was recorded to be 15, 20, 29, and 57 g C kg^{-}1, respectively with 1, 5, 10 and 15 years of intensive management. These largely display the fact that the rate of SOM accumulation was much greater than that of output through organic mulching and heavy fertilization from 5 year onwards. Increase in TOC was mainly due to the decomposition of organic residues mulched in winter and secretion of OC from bamboo roots.

2.1.3 Soil Labile Carbon Fractions

2.1.3.1 Water soluble carbon (WSC) content

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in China and reported that water soluble carbon content under *P. praecox* was significantly increased with time under intensive management. The WSC contents in soil under *P. praecox* with 5, 10 and 15 years of intensive management was found to be 132, 147 and 198 % respectively over first year data.

Sharma *et al.* (2014) studied to assess the impact of different land use systems on labile carbon pools and soil organic carbon stocks in the foothill Himalayas and reported water soluble carbon content in soil under each land use system for entire soil depth (50 cm) as in agriculture land, forest land, horticulture land and degraded land were 31.7, 29.2, 26.8 and 31.5 mg kg^{-1} respectively. The WSC content varied widely among different land-use systems and ranged between 12.8 to 100.0, 14.1 to 86.4, 7.9 to 63.5 and 6.9 to 78.0 mg kg^{-1} for agriculture, forest, horticulture and degraded land system, respectively.

2.1.3.2 Soil microbial biomass carbon (SMBC) content

Louise *et al*. (2000) studied management influences on soil microbial communities and their function in botanically diverse hay meadows of northern England and Wales and reported that plant species (productivity and species composition) are fundamental to the soil microbial community in the grasslands.

Dilly *et al*. (2003) studied variation of stabilized, microbial and biologically active C and N in soil and reported that the amount of C in soil microbial biomass carbon mostly accounts for 1 to 5% of the total soil organic carbon and its turnover time is less than a year.

Wang *et al*. (2004) studied microbial biomass carbon, nitrogen and phosphorus in the soil profiles of different vegetation covers established for soil rehabilitation in a red soil region of South-eastern China and reported the levels of soil microbial biomass carbon in five different vegetation covers comprising fallow land, Bamboo plantation, Chinese fir, Citrus plantation and Rice field. The SMBC level in surface and subsurface soil layer under the bamboo species *i.e. Dendrocalamus strictus* was found to be higher over other vegetation covers.

Xu *et al.* (2008) Xu *et al.* (2008) conducted a research study on soil microbial functional diversity under intensively managed bamboo plantation grown in Southern China with intensively managed fields were annually fertilized @ 350–600, 80–120 and 150–200 kg N, P and K ha^{-1}, respectively and reported soil microbial biomass carbon (SMBC) content under those managed conventionally (473.1 mg kg^{-1}), intensive management with short-term practices for 5-7 years (321.6 mg kg^{-1}) and under intensive management with long-term practices for 8-10 years (291.6 mg kg^{-1}). The declined SMBC in the intensively managed bamboo stands may be attributed to the reduction in soil organic matter caused by less input of litter and higher mineralization of soil organic matter, as due to intensive management practices.

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in China and reported that during the initial period of intensive management, SMBC content was significantly increased and thereafter it was drastically decreased with time under intensive management.

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown at Terai region of Uttarakhand (India) and reported that among the different bamboo species highest SMBC was found under *Dendrocalamus strictus* followed by *Bambusa vulgaris* and *Bambusa balcooa*, whereas lowest SMBC content in soil was recorded under *Bambusa nutans*.

Sharma *et al.* (2014) studied to assess the impact of different land use systems on labile carbon pools and soil organic carbon stocks in the foothill of Himalayas and reported the SMBC content was observed in the range of 61.4 to 134.2, 102.5 to 113.3, 64.1 to 110.7 and 67.8 to 86.2 mg kg^{-1} in the surface soil of agriculture, forest, horticulture and degraded lands, respectively.

2.1.3.3 Particulate organic matter carbon (POMC) content

Jenkinson (1990) observed that manure is more resistant to microbial decomposition than plant residues, thus for the same quantity of carbon input, carbon storage could be higher with manure application.

Whalen and Chang (2002) reported that manure application can increases the formation and stabilization of soil macro aggregates and helps in development of particulate organic matter.

Jahan *et al*. (2020) studied effect of land use on organic carbon storage potential of soils and found that cropland recorded lowest POMC, while soils under orchard showed significantly highest POMC content followed by fallow and grassland. The lowest POMC in cropland may be attributed to the rapid decomposition of POM resulted due to intensive cultivation operations, whereas accumulation of tree leaves (dried annual) and aboveground biomass (perennial grasses) addition might be the reason for highest POMC in orchard and fallow land.

2.1.3.4 Permanganate oxidizable soil carbon (POXC) content

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in China and reported that permanganate oxidizable soil carbon content in *P. praecox* stand was significantly increased with time under intensive management due to the mulching of organic residues.

Sharma *et al.* (2014) studied to assess the impact of different land use systems on labile carbon pools and SOC stocks in the foothill Himalayas and reported average POXC content in agriculture, forest, horticulture and degraded lands were found to be 527.5, 867.4, 600.0 and 487.4 mg kg^{-1}, respectively. The POXC content under forest land was 45, 39 and 31 % high as compare to degraded, agriculture and horticulture systems, respectively.

2.1.4 Microbial Indices

Sparling (1992) reported ratios of different carbon fractions to soil TOC and considered the ratio of SMBC to TOC as a most sensitive indicator for changes in SOM quality. A higher value of SMBC to TOC indicates easily available labile carbon pools to sustain large microbial community in the soil. Whereas, comparatively lower values of SMBC to TOC ratio suggests, less substrate carbon may be incorporated into soil microbial biomass, which can be considered as an indication of the decline in labile carbon pools that has occurred in the soil.

Xu *et al.* (2008) studied soil microbial functional diversity under intensively managed bamboo plantations grown in southern China and reported that SMBC to TOC ratio was found high in conventionally managed filed (3.16) as compare to intensive management with short-term practices (2.44) and intensive management with long-term practices (2.27).

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in China and reported that the ratio of SMBC to TOC dramatically decreased under *P. praecox* plantation with 1, 5, 10, and 15 years of intensive management which was recorded to be as 1.79, 1.72, 0.99 and 0.36% respectively, this can be attributed to the possibility that a portion of labile carbon may be respired or leached out by percolating water under intensive management practices.

2.2 Effect of Different Bamboo Species on Soil Properties

2.2.1 Soil Microbial Population

Kirchner *et al*. (1993) reported that variation in microbial count under different bamboo species may be attributed to differences in root intensity, biomass production, characteristics and amount of litter fall, fine-roots turnover and microclimatic environment of microbial community.

Allison *et al*. (2005) studied changes in soil microbial community structure under tall grasses related to tillage management and reported higher microbial counts in no tillage system which may be attributed to least disturbance of surface soil layer.

2.2.1.1 Total soil bacterial population

Hemavathi *et al*. (2006) studied soil enzyme activity and microbial population in different rhizosphere at Southern Transition zone of Karnataka and reported higher soil bacterial population in the rhizosphere soils of *Dendrocalamus strictus*, *Bambusa arundinaceae* and *Bambusa vulgaris* (26.5, 25.3 and 32.8 cfu × 10^4 g^{-1} soil, respectively) than those in adjacent grass rhizosphere (19.7, 19.6 and 17.3 cfu × 10^4 g^{-1} soil, respectively).

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil bacterial population under different bamboo species than those in control plot. Significantly highest soil bacterial count was found under *B. bamboos, D. strictus, B. vulgaris, B. balcooa* and *D. stocksii* (18.2, 14, 11, 9 and 8.4 cfu × 10^6 g^{-1} soil, respectively), whereas lowest soil bacterial count was recorded under *B. nutans* (4.5 cfu × 10^6 g^{-1} soil).

2.2.1.2 Total soil fungi population

Hemavathi *et al*. (2006) studied soil enzyme activity and microbial population in different rhizosphere at Southern Transition zone of Karnataka and reported higher soil fungi population in the rhizosphere soils of *Dendrocalamus strictus*, *Bambusa arundinaceae* and *Bambusa vulgaris* (42.3, 26.7 and 26.7 cfu × 10^3 g^{-1} soil, respectively) than those in adjacent grass rhizosphere (22.1, 15.2 and 17.0 cfu × 10^3 g^{-1} soil, respectively).

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil fungi population under different bamboo species. The fungi population under *D. hamiltonii, B. vulgaris, B. bamboos, B. balcooa, D. strictus* and *B. nutans* were 12.2, 10, 9.9, 9.4, 8.1 and 5.6 cfu × 10^5 g^{-1} soil, respectively.

2.2.1.3 Total soil actinomycetes population

Hemavathi *et al*. (2006) studied soil enzyme activity and microbial population in different rhizosphere at Southern Transition zone of Karnataka and reported that the actinomycetes population in the rhizosphere soils of *D. strictus*, *B. arundinaceae* and *B. vulgaris* were higher (66.1, 42.6 and 31.1 cfu × 10^2 g^{-1} soil, respectively) than those in adjacent grass rhizosphere (23.8, 21.4 and 22.1 cfu × 10^2 g^{-1} soil, respectively).

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil actinomycetes population under *D. hamiltonii, B. vulgaris, B. balcooa, D. strictus, B. bamboos* and *B. Nutans* were 8.4, 7.4, 6.2, 5.9, 5.1 and 5.0 cfu × 10^4 g^{-1} soil, respectively.

2.2.2 Soil Dehydrogenase Enzyme Activity

Perucci *et al*. (1997) studied effect of rotation, nitrogen fertilization and management of crop residues on biochemical properties of soil and reported that the differences in enzymatic activities under the influence of different bamboo species may be attributed due to the variation in microclimate, amount and characteristics of litter fall and root exudates.

Hemavathi *et al*. (2006) studied soil enzyme activity and microbial population in different rhizosphere at Southern Transition zone of Karnataka and reported that the dehydrogenase enzyme activity in the rhizosphere soils of *D. strictus*, *B. arundinaceae* and *B. vulgaris* were higher (825, 851 and 789 µg TPF released g^{-1} soil hr^{-1} respectively) than those in adjacent grass rhizosphere (136, 149 and 133 µg TPF released g^{-1} soil hr^{-1} respectively).

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil dehydrogenase enzyme activity under *B. vulgaris*, *B. balcooa*, *B. nutans*, *D. strictus*, *D. hamiltonii,* B. bamboos and *D. stocksii* were 81.7, 47, 26.5, 25.9, 22.3, 14.3 and 10.9 µg TPF released g^{-1} soil 24 hrs^{-1} respectively.

2.2.3 Soil pH, EC and $CaCO_3$ Content

Singh (2002) studied soils under different bamboo species in Arunachal Pradesh and observed the drastic reduction in soil pH. The change in soil pH with base status of soil under bamboo species may be due to the variation in uptake of Ca and Mg and their replenishment to the soil via leaf litter biomass with different base status and root material decomposition.

Upadhyaya *et al*. (2003) studied physico-chemical properties of soil under the canopy of bamboo species grown in North-eastern part of India and observed that soil under *Bambusa balcooa* was found more acidic than those under *B. palida*. This increase in pH under *B. palida* may be attributed to lower litter production by these species.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region (India) and reported that the soil under *D. longispathus* recorded minimum pH values followed by *D. sikkimensis*. While, soil under *B. nutans* recorded maximum pH value.

Mandal *et al*. (2010) studied soils under natural woodlands and reported reduction in soil pH *i.e*. soil acidification due to rapid and continuous decomposition of organic matter.

Kumari *et al*. (2017) studied effect of various bamboo species on soil nutrients and growth parameters grown in Nauni-Solan, HP, India and observed that bamboo species have no significant influence on soil pH and EC.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil pH values after six years of plantation under the influence of different bamboo species as compared to initial soil pH values. Soil pH was found to be reduced under *B. bamboos* (5.54), *B.*

nutans (5.48), *B. vulgaris* (5.38), *D. hamiltonii* 5.66 *and D. strictus* (5.56). Whereas, increase in soil pH was observed under *B. balcooa* (5.83) and *D. stocksii* (5.81). The soil pH recorded under control plot was 6.25. The reduction in soil pH may be attributed to higher leaf-litter biomass production, whose decomposition may have produced some organic acids, which resulted in slight reduction of soil pH under the influence of different bamboo species.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components grown at Gajwa National Experimental Forest, Jinju of South Korea and reported variation in soil pH and EC between the fertilized and the unfertilized plots. In fertilized plot soil pH was 4.59 and EC 290 µS cm^{-1}, whereas in unfertilized plot soil pH was observed 4.69 and EC 138 µS cm^{-1} at 0-10 cm soil depth.

2.2.4 Soil Available Nutrients Content

Joshi *et al*. (1991) studied nutrient dynamics of a lower Siwalik bamboo forest grown in the Garhwal Himalaya region of India and reported the effects of different bamboo species on soil available nutrients. It was observed that among the nutrients nitrogen and potassium showed significant increase in soils under the influence of different bamboo species suggesting their maximum returns to the residual soil which is followed by phosphorous.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported non-significant differences in soil available nitrogen and phosphorus under the influence of different bamboo species which may be attributed due to variation in accumulated biomass and leaf litter production in different species.

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of two endemic bamboo species of Western Ghats grown in the Nilambur Forest Division of Kerala, India and reported that nutrient concentration and nutrient stock in the soil under bamboo stands showed marked variation with respective soil depth. In *Munrochloa ritchiei* soil nitrogen content was declined with increasing depth of the soil, the soil phosphorus content decreased in order of 0-20 cm > 40-60 cm > 20-40 cm while the soil potassium content decreased in order of 20-40 cm > 40-60 cm > 0-20 cm.

2.2.4.1 Soil available nitrogen content

Singh and Singh (1999) studied biomass net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region of India and reported that the considerable amount of nitrogen was found to be immobilized in soil microbial biomass which may be attributed to higher amount of leaf-litter fall in bamboo plantation as well as the immensity of immobilization was found to be increased with the increasing age of bamboo plantation.

Majumdar *et al*. (2005) studied soil profiles under different bamboo species and reported higher available nitrogen content in surface soil layer (0-20cm) as compared to sub-surface soil layer (>20 cm) under the influence of different bamboo species. Soil available nitrogen content was found higher in surface layer under *B. balcooa* followed by *B. multiplex* and *B. nutans*.

Venkatesh *et al*. (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and reported increased in soil available nitrogen content under the influence of different bamboo species over its control plot. Significantly highest soil available N content was recorded under *Bambusa nutans* (266 kg N ha^{-1}). The effect of different bamboo species on soil available nitrogen content was found to be positive and maximum increase in soil available N was seen under *B. multiplex*, increase in 126 kg N ha^{-1} as compared to control plot.

Xu *et al.* (2008) studied soil microbial functional diversity under intensively managed bamboo plantations grown in China and reported that soil available nitrogen was found to be lower under those managed conventionally (175 mg N kg^{-1}) as compare to intensive management practices for 5-7 years (184 mg N kg^{-1}).

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species in Terai region of Uttarakhand, India and recorded the highest soil available nitrogen in the soil under *D. strictus* followed by *B. balcooa* and *B. nutans* . Whereas, lowest soil available nitrogen was found under *B. vulgaris*.

Kumari *et al*. (2017) studied effect of different bamboo species on soil nutrients and growth parameters grown in Nauni-Solan, Mid hills of HP, India and reported that soil available nitrogen content was significantly influenced by different bamboo species. The soil available nitrogen in soil under *D. asper*, *D. hamiltonii*, *B. tulda*, *P. aurea*, *D. strictus*, *M. baccifera* and under *P. bambusoides* was recorded as 336.2, 334.3, 320.9, 321.1, 332.8, 325.9 and 318.0 kg ha^{-1} nitrogen respectively at 0-20 cm soil depth.

2.2.4.2 Soil available phosphorus content

Patil *et al*. (2004) studied soil profile, organic matter build-up and nutritional status of soil under bamboo based agroforestry system and observed the increase in available phosphorous content in soil under *Dendrocalamus strictus* based agroforestry system in a one year study.

Majumdar *et al*. (2005) studied soil profiles under different bamboo species and reported that soil under the influence of bamboo species recorded higher soil available phosphorus content. The available phosphorus in soil under *B. nutans*, *D. giganteus*, *D. longispathus*, *D. sikkimensis* and *T. wightii* was recorded as 3.2, 4.8, 1.8, 3.7 and 2.07 kg P ha^{-1} respectively.

Xu *et al.* (2008) studied soil microbial functional diversity under intensively managed bamboo plantations grown in China and reported that soil available phosphorous was found to be lower under those managed conventionally (18.95 mg kg^{-1}) as compare to intensive management with short-term practices for 5-7 years (20.15 mg kg^{-1})

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential of four major bamboo species grown in Terai region of Uttarakhand, India and reported highest available phosphorus in soil under *D. strictus* followed by *B. balcooa* and *B. vulgaris.* Whereas, lowest soil available phosphorus content was found under *B. nutans*.

Kumari *et al*. (2017) studied effect of various bamboo species on soil nutrients and growth parameters grown in Nauni-Solan, Mid hills of HP, India and reported that soil available phosphorus content in surface soil was found significantly highest in *D. asper* (46.3 kg P ha^{-1}) followed by *D. strictus* (45.7 kg P ha^{-1}). While, soil under *P. bumbusoides* (40.4 kg P ha^{-1}) recorded lower soil available phosphorus.

Kim *et al*. (2018) studied effect of regular fertilization on nutrient distribution of bamboo components grown at Gajwa National Experimental Forest, Jinju of South Korea and reported significant variation in soil available P content between the fertilized and the unfertilized plots. In fertilized plot soil available phosphorous content was (174 & 132 mg kg^{-1}), whereas in unfertilized plot it was (6.22 & 5.20 mg kg^{-1}) at 0-10 cm & 10-20 cm soil depth, respectively. An increase in available P was generally observed following the fertilizer application because the retentive capacity of P in the soil can be enhanced by addition of phosphatic fertilizer.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported that as compared to initial soil values significant increase in total phosphorus content was observed in soil under *B. balcooa, B. bamboos, B. vulgaris* and *D. hamiltonii* after six years of plantation. Increase in soil P content under bamboo species might be due to their higher rooting intensity and biomass production, which may have resulted in dissolution of inorganic P in soil.

2.2.4.3 Soil available potassium content

Toky and Ramakrishnan (1982) reported that *Dendrocalamus hamiltonii* plays an crucial role in conservation of soil potassium during slash and burn agriculture as observed in NE India, which is attributed to its potential for rapid uptake and accumulation of K in active biomass.

Patil *et al*. (2004) studied soil profile, organic matter build-up and nutritional status of soil under bamboo based agroforestry systems and observed the increase in available potassium content in soil under *Dendrocalamus strictus* based agroforestry system within a one year study.

Venkatesh *et al*. (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and recorded average soil available potassium content in the range of very low to very high in the soil under the influence of different bamboo species. The differential influence of bamboo species on soil available K content may be attributed due to the variation in K uptake by bamboo species and decomposition rate of leaf-litter biomass. The high K content found in the leaves of *D. giganteus* and *D. hookerii* may be responsible for the higher potassium build-up in the soil under these bamboo species.

Xu *et al.* (2008) studied soil microbial functional diversity under intensively managed bamboo plantations grown in China and reported soil available potassium content under those managed conventionally (47.19 mg K kg^{-1}), intensive management with short-term practices (59.15 mg K kg^{-1}) and intensive management with long-term practices (60.38 mg K kg^{-1}).

Tariyal *et al*. (2013) studied plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand, India and reported highest soil available potassium content in soil under *D. strictus* followed by *B. vulgaris* and *B. balcooa*. Whereas, soil under *B. nutans* recorded lowest soil available potassium.

Kumari *et al*. (2017) studied effect of various bamboo species on soil nutrients and growth parameters grown in Nauni-Solan, Mid hills of HP, India and reported that soil available potassium content was significantly influenced under different bamboo species. The soil under *Dendrocalamus asper* recorded significantly highest soil available K content (321.6 kg K ha^{-1}).

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of two endemic bamboo species of Western Ghats grown in the Nilambur Forest Division of Kerala, and reported the K concentration and K stock in the soil under *M. ritchiei* was found to be (0.26% & 6.63 t K ha^{-1}), (0.37% & 9.21 t K ha^{-1}) and (0.28% & 7.13 t K ha^{-1}) respectively at soil depth of 0-20 cm, 20-40 cm and 40-60 cm. Whereas, under *O. setigera* the K conc. and K stock was recorded to be (0.092% & 2.35 t K ha^{-1}), (0.125% & 3.19 t K ha^{-1}) and (0.092 % & 2.35 t K ha^{-1}) respectively at soil depth of 0-20 cm, 20-40 cm and 40-60 cm.

2.2.5 Soil Bulk Density

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported slight reduction in soil bulk density under the influence of bamboo species as compared to control plot. Lowest BD was observed under *D. hamiltonii* and *B. bamboos* (1.42 Mg m^{-3}). Reduction in BD under bamboo species may be attributed to higher fine roots production, turnover of litter fall, amount and quality of leaf-litter, presence of soil fauna and other related biological processes.

2.3 Effect of Different Bamboo Species on Growth Attributing Characters and Biomass Production

2.3.1 Growth Attributing Characters

2.3.1.1 Number of culms per clump

Shanmughavel and Francis (2003) conducted a research study on biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown on red soils with 7- 7.8 pH & 0.2 mScm EC at Bharathiar University Campus, Coimbatore and reported average number of culms per clump was 61 after 13 years of *Dendrocalamus hamiltonii* plantation.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and reported significantly highest number of culms per clump in

D. hamiltonii (32) followed by *M. baccifera* (28.3), *B. Pallida* (27.5), *D. sikkimensis* (26.5), *T.* wightii (26.5), *B. nutans* (25), *D. giganteus* (24), *D. hookerii* (23.5) and *B. balcooa* (23.5). Whereas, lowest was recorded in *D. longispathus* (20.5) followed by *B. multiplex* (21.5).

2.3.1.2 Culm density

Kumar *et al.* (2005) reported culm density in *Bambusa bamboos* plantation found to be 8800 culms ha^{-1} a sympodial type thorny bamboo plantation grown in home gardens of Thrissur.

Kochhar and Singh (2005) studied effect of clump density/spacing on the productivity and nutrient uptake and reported reasonably high culm density of 35000 culms ha^{-1} in sympodial type *Bambusa pallida* plantation.

Lee et al. (2010) estimated biomass production and carbon storage in a fast-growing monopodial type makino bamboo plant based on the diameter distribution model and reported culm density of 21191 culms ha^{-1} in *Phyllostachys makinoi* stand.

Yen and Lee (2011) studied comparison in aboveground carbon sequestration between moso bamboo (*P. heterocycla*) and China fir (*C. lanceolata*) forests based on the allomatric model grown in Taiwan and reported culm density of 7100 culms ha^{-1} in *P. heterocycla* stand.

Quiroga *et al*. (2013) reported culm density of 4500 culms ha^{-1} in *Guadua angustifolia*, a sympodial type bamboo forest grown in Carrasco National Park, Bolivia.

Zhang *et al*. (2014) reported culm density of *Phyllostachys pubescens* stand calculated to be 3968 culms ha^{-1} grown in China using a diameter–age bivariate distribution model.

Sohel *et al.* (2015) studied carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported the average culm density of *B. vulgaris* stand calculated to be 2933 culms ha^{-1}.

Kumari *et al*. (2017) studied effect of age and species on growth characteristics of different bamboo species grown in Nauni-Solan, Mid hills of HP, India and reported that in the average effect of age class, culm density was significantly highest (4781 culms ha^{-1}) in > 3 years old culm in comparison to 1-3 year old (1866 culms ha^{-1}) and 1 year old culm (1409 culms ha^{-1}).

Angom *et al.* (2018) reported the culm density of *Melocanna baccifera* and *Bambusa tulda* found to be 31220 and 21451 culms ha^{-1} respectively. The culm density of *M. baccifera* was found more than *B. tulda,* as *M. baccifera* is monopodial having proficiency to propagate in a larger area, despite the fact that *B. tulda* having lesser density but recorded more aboveground biomass carbon storage than *M. baccifera*. This may be attributed to thick walled culm structure of *B. tulda*, although due to its culm structure the decaying ability was lesser which resulted in decline of SOC stock, whereas *M. baccifera* has thin walled culm structure.

Kim *et al*. (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown in Gajwa National Experimental Forest, Jinju of South Korea and reported that culm density in *P. pubescens* was found lower in the fertilized plots (4633 culms ha^{-1}) than those in unfertilized plots (6833 culms ha^{-1}). The lower culm density in fertilized plot may be attributed to annual edible shoot harvest.

2.3.1.3 Culm height

Shanmughavel and Francis (2003) conducted a research study on biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown on red soils with 7-7.8 pH & 0.2 mScm EC at Bharathiar University Campus, Coimbatore and reported the average culm height of 12.5 m after 13 years of *Dendrocalamus hamiltonii* plantation.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and reported the highest culm height in *B. balcooa* (15 m) followed by *D. giganteus* (14 m), *D. longispathus* (13.7 m), *D. hamiltonii* (12.4 m), *B. nutans* (13 m), *B. pallida* (12 m), *D. hookerii* (11.1 m), *B. multiplex* (10 m), *M. baccifera* (9.8 m) and *D. sikkimensis* (9.7 m). Whereas, lowest culm height was recorded in *T. wightii* (8.1 m).

Sohel *et al.* (2015) conducted a research study on carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported the average culm height of *Bambusa vulgaris* stand was measured to be 21m.

2.3.1.4 Diameter at breast height (DBH)

Shanmughavel and Francis (2003) conducted a research study on biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown on red soils with 7-7.8 pH & 0.2 mScm EC at Bharathiar University Campus, Coimbatore and reported the average diameter at breast height of 2.86 cm in 13 years old clumps of *D. hamiltonii* plantation.

Venkatesh *et al.* (2005) studied soil properties as influenced by some important edible bamboo species grown in the North Eastern Himalayan region of India and observed the effect of different bamboo species on diameter at breast height**.** Significantly highest DBH was observed in *Bambusa balcooa* (6.3 cm). Whereas, lowest DBH was recorded in *T. wightii* (1.4 cm).

Sohel *et al.* (2015) conducted a research study on carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported the average diameter at breast height of *Bambusa vulgaris* stand was measured to be 20.57 cm.

Kim *et al*. (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported that the average diameter at the height of 1.2 m was found almost similar between fertilized (10.8 cm) and unfertilized (10.7 cm) plots. Slight increase of diameter in fertilized plots may be due to increased number of new shoots following fertilizer application.

2.3.1.5 Culm girth

Angom *et al.* (2018) studied aboveground biomass production in *Melocanna baccifera* and *Bambusa tulda* grown at Lengpui, NE India and reported that the culm girth size was found to be between 9.7 to 12.0 cm and 13.0 to 18.0 cm, respectively for *M. baccifera* and *B. tulda*.

2.3.1.6 Basal diameter of culm

Shanmughavel and Francis (2003) conducted a research study on biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown on red soils with 7-7.8 pH & 0.2 mScm EC at Bharathiar University Campus, Coimbatore and reported the average basal diameter of culms was 5.2 cm in 13 years old clumps of *D. hamiltonii* plantation.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and observed the highest basal diameter of culm in *B. balcooa* (8.2 cm) followed by *D. giganteus* (6.1 cm). Whereas, lowest basal diameter of culm was recorded in *B. multiplex* (1.9 cm).

2.3.1.7 Internodal length

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and observed the highest internodal length in *D. hamiltonii* (51.5 cm). Whereas, lowest internodal length was noticed in *B. multiplex* (16.5 cm).

Kumari *et al*. (2017) studied effect of age and species on growth characters of different bamboo species grown in Nauni-Solan, Mid hills of HP, India and reported that in the average effect of age class, culm density was significantly highest (21.24 cm) in > 3 years old culm.

2.3.1.8 Number of internodes per culm

Shanmughavel and Francis (2003) conducted a research study on biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown on red soils with 7-7.8 pH & 0.2 mScm EC at Bharathiar University Campus, Coimbatore and reported the average number of internodes per culm was 41 in 13 years old clumps of *D. hamiltonii* plantation.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and observed the highest average number of internodes per culm in *B. balcooa* (38.6) followed *M. baccifera* (31.6) and *B. multiplex* (31.3). Whereas, lowest number of internodes per culm was noticed in *D. hamiltonii* (22.5).

2.3.1.9 Average culm biomass

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation and reported average culm biomass in 13 years old plantation. The average dry weight leaves, branches, culms and rhizome biomass was 0.81, 8.43, 21.48 and 1.54 kg culm^{-1} respectively. The total culm biomass was recorded as 32.26 kg culm^{-1}.

Nath *et al*. (2009) conducted a study on four year old farmer managed mixed bamboo plantation grown in tropical climate of Barak Valley region of Assam, India and reported average aboveground biomass in 1, 2, 3 and 4 years old *Bambusa cacharensis* plantation was 16.3, 13.03, 7.03 & 4.29 kg clump^{-1} respectively, *B. vulgaris* showed 12.12, 6.88, 3.48 & 3.25 kg clump^{-1} biomass respectively in 1, 2, 3 and 4 years old plantation. Whereas, in *B. balcooa* it was 9.28, 5.17, 5.04 & 2.66 kg clump^{-1} biomass respectively in 1, 2, 3 and 4 years old plantation.

Singnar *et al.* (2017) conducted a study on allometric scaling, biomass accumulation and carbon stock in different aged stands of thin-walled bamboo species grown in Cachar region of Assam, India and reported average aboveground biomass of *Schizostachyum dullooa* 0.99, 1.35, 1.68, 1.49, 1.59 kg clump^{-1} and Melocanna baccifera 1.43, 3.18, 3.2, 4.25 & 3.08 kg clump^{-1}, in 1, 2, 3, 4 and 5 years old bamboo plantation respectively. Whereas, aboveground biomass for *Pseudostachyum polymorphum* grown in Hampur region of Assam, India was 0.66, 1.41, 1.01, 0.93 & 1.08 kg clump^{-1} respectively for 1, 2, 3, 4 and 5 years old bamboo plantation.

2.3.2 Biomass Production

2.3.2.1 Above ground and below ground biomass production

Peddappaiah *et al*. (2001) studied biomass production in an age series of *Bambusa bamboos* plantation and observed that the aboveground portion contributes more towards the total biomass of the clump than the belowground biomass.

Riano *et al*. (2002) studied plant growth and biomass distribution in *Guadua anguistifolia* in relation to ageing grown at Valle del Cauca region of Columbia and reported aboveground biomass in six year old *Guadua anguistifolia* plantation was 54.3 t ha^{-1}.

Castaneda *et al*. (2005) studied carbon accumulation in the aboveground biomass of sympodial type bamboo plantation grown in Mexico and reported the total aboveground biomass production in *Bambusa oldhamii* plantation was 104 t ha^{-1}.

Embaye *et al*. (2005) studied biomass and nutrient distribution in a highland sympodial type bamboo plantation grown at Southwest Ethiopia and reported total aboveground biomass production of 110 t ha^{-1} in *Yushania alpine* plantation.

Kochhar and Singh (2005) studied effect of clump density on the productivity and nutrient uptake in a sympodial type bamboo plantation and reported total aboveground biomass production in *Bambusa pallida* plantation was 319 t ha^{-1}.

Kumar *et al.* (2005) studied aboveground biomass production and nutrient uptake in a sympodial type thorny bamboo plantation grown in Thrissur, Kerala and reported total aboveground biomass production in 20 years old *Bambusa bamboos* stand was 241.7 t ha^{-1}.

Venkatesh *et al.* (2005) studied soil properties as influenced by bamboo species grown in NE Himalayan region of India and recorded highest total standing biomass in *Melocanna baccifera* (50.40 t ha^{-1}) followed by *Bambusa balcooa* (42.1 t ha^{-1}). Whereas, lowest total standing biomass was observed in *Teinostachyum wightii* (2.4 t ha^{-1}).

Dubey *et al*. (2006) studied biomass production and carbon storage at harvest age in superior *Dendrocalamus strictus* plantation grown in dry deciduous forest region of India and reported total aboveground biomass production in 3 and 4 years old *Dendrocalamus strictus* plantation was 182.7 and 207.4 t ha^{-1} respectively.

Das and Chathurvedi (2006) studied culm recruitment, dry matter dynamics and carbon flux and reported total aboveground biomass in 3, 4 and 5 year old *Bambusa bamboos* plantation grown in Eastern India was found to be 170.8, 206.7 and 257.25 t ha^{-1} respectively.

Stokes *et al.* (2007) reported that biomass of belowground components is nearly 5 to 10% of the aboveground culms biomass.

Yen and Lee (2011) reported total aboveground biomass production of 89 t ha^{-1} in *Phyllostachys heterocycla* a monopodial type moso bamboo plantation grown in Taiwan.

Quiroga *et al*. (2013) reported total aboveground biomass production in a sympodial type *Guadua angustifolia* forest grown at Bolivia was 200 t ha^{-1}.

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand, India and reported that the biomass of different culm components was found to be increased with increasing age of plantation. During second year of study, *D. strictus* plantation has the highest value of total biomass (568.08 t ha^{-1}) followed by *B. balcooa* (479.13 t ha^{-1}) and *B. nutans* (354.92 t ha^{-1}). Whereas, lowest biomass was recorded in *B. vulgaris* (164.17 t ha^{-1}). The highest biomass production in *D. strictus* can be attributed to its fast growth and more stem density.

Sohel *et al.* (2015) conducted a research study on carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported total biomass production in *B. vulgaris* was 98 t ha^{-1} which included 80.36 t ha^{-1} biomass of culms, 10.78 t ha^{-1} biomass of branches, 2.94 t ha^{-1} biomass of leaves and 3.92 t ha^{-1} biomass of rhizomes. Biomass content was observed high in culms (82%) than in branches (11%), leaves (3%) and rhizomes (4%) .

Viswanath and Subbanna (2017) reported biomass and net primary productivity of six industrially important bamboo species of 7 years old in Semiarid and Tropical humid region of Peninsular India and observed that the climatic condition are responsible for varying amount of biomass production. The highest total aboveground biomass in tropical humid condition of Koppa, Karnataka was found in *B. balcooa* (206.64 t ha^{-1}) followed by *D. asper* (148.66 t ha^{-1}). Whereas, the highest total aboveground biomass in semiarid condition of Hosakote, Karnataka was recorded in *B. balcooa* (98.94 t ha^{-1}) followed by *D. strictus* (91.50 t ha^{-1}).

Angom *et al.* (2018) studied aboveground biomass production of *Melocanna baccifera* and *Bambusa tulda* grown in Sub-tropical bamboo forest at Lengpui, NE India and reported that out of total aboveground biomass in both the species culm component shared the highest amount 77.90 t ha^{-1} (73%), followed by leaves 16.87 t ha^{-1} (15.8%) and branches 11.91 t ha^{-1} (11.6%) in *M. baccifera* whereas in *B. tulda* culm shared 78.1 t ha^{-1} (80.5%), leaves 9.85 t ha^{-1} (10.1%) and branches 9.04 t ha^{-1} (9.3%). Total aboveground biomass of 106 and 96.99 t ha^{-1} was estimated in *M. baccifera* and *B. tulda* respectively. The ≥ 3 year age class represented the highest amount of standing biomass having 74.1 and 52.2 t ha^{-1} for *M. baccifera* and *B. tulda* respectively.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported that in all the bamboo species, the contribution of fine-root biomass was high in improving soil properties and soil health as compared to coarse-root biomass. The contribution of fine-root biomass in improving soil health in case of *D. stocksii* it was found to be highest (71.60%) followed by *D. hamiltonii* (69.50%), *D. strictus* (68.00%), *B. nutans* (67.90%), *B. bamboos* (67.60%) and *B. vulgaris* 65.70%. Whereas, it was observed lowest in *B. balcooa* (58.70%).

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of *Munrochloa ritchiei* and *Ochlandra setigera* two endemic bamboo species of Western ghats grown in the Nilambur Forest Division of Kerala, India and reported highest total standing biomass stock in *M. ritchiei* (70.6 t ha^{-1}). The highest biomass accumulation was found in aboveground components. The rhizome biomass (30.3 t ha^{-1}) also significantly contributed to the total biomass while the contribution of roots biomass was nearly 2% (1.4 t ha^{-1}) only.

2.3.2.2 Leaf litter biomass production

Muthukumar *et al.* (2000) reported that leaf-litter production increases with increasing age of plantation. It is obseved that leaf-litter biomass prevents soils from harsh impact of falling rain and improves soil health, thus *D. hamiltonii* and *B. bamboos* are considered as an excellent species for reducing soil erosion, improving soil health and checking water loss from soil.

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand, India and recorded litter biomass production for two years and it was found to be highest under *D. strictus* (0.10 & 0.14 t ha^{-1}) followed by *B. balcooa* (0.09 & 0.13 t ha^{-1}) and *B. vulgaris* (0.08 & 0.11 t ha^{-1}). Whereas, lowest litter biomass was recorded under *B. nutans* (0.04 & 0.10 t ha^{-1}). The highest litter biomass under *D. strictus* can be attributed due its large spread canopy.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported that leaf-litter biomass production increases with increasing age of bamboo plantation. After 3 and 4 years of plantation highest leaf litter fall was recorded under *B. vulgaris* (2.94 and 6.04 t ha^{-1}) while lowest litter-fall was observed under *B. nutans* (1.81 and 1.79 t ha^{-1}). Whereas, after 5 years of plantation, leaf-litter fall was found to be increased significantly as it was recorded highest under *Dendrocalamus hamiltonii* (12.4 t ha^{-1}) while lowest was observed under *D. stocksii* (8.1 t ha^{-1}).

2.4 Effect of Different Bamboo Species on Nutrient Concentration and Nutrient Uptake

2.4.1 Nutrient Concentration in Bamboo

2.4.1.1 Nitrogen concentration in bamboo biomass components

Werger *et al.* (2000) reported highest N concentration in the leaves of fertilized plots (2.64 % N) of *Phyllostachys pubescens* stand as compared to leaves of control plot (2.14 % N).

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported N concentration in biomass components of 13 years old *D. hamiltonii* plantation. N concentration in culms, leaves, branches and in rhizome were 0.55, 0.75, 0.60 and 0.40 % respectively.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported nitrogen concentration in root, rhizome and leaves in fertilized plots were 0.52, 0.39 and 1.98 % respectively.

Seethalakshmi *et al*. (2021) reported nitrogen concentration in the range of 0.10 to 0.43% for *Munrochloa ritchiei*. The N concentration observed in culms, leaves, rhizomes and roots of *M. ritchiei* were 0.43, 0.28, 0.19 and 0.10 % respectively. Whereas, N concentration in *Ochlandra setigera* was in the range of 0.12 to 0.67 %. The N concentration observed in culms, leaves, rhizomes and roots of *O. setigera* were 0.67, 0.35, 0.18 and 0.12 % respectively.

2.4.1.2 Phosphorous concentration in bamboo biomass components

Werger *et al.* (2000) studied interactions between shoot age structure, nutrient availability and physiological integration in the monopodial giant bamboo *Phyllostachys pubescens* grown in Southern China and reported phosphorus concentration in *P. pubescens* was found significantly highest in the leaves of fertilized plots (0.148 %) as compared to control plot (0.116 %).

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported P concentration in biomass components of 13 years old *D. hamiltonii* plantation. P concentration in culms, leaves, branches and in rhizome were 0.06, 0.08, 0.07 and 0.05 % respectively.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported phosphorus concentration in root, rhizome and leaves in fertilized plots were 0.069, 0.126 and 0.188 % respectively.

Seethalakshmi *et al*. (2021) reported phosphorous concentration in the range of 0.11 to 0.26 % for *Munrochloa ritchiei*, The P concentration observed in culms, leaves, rhizomes and roots of *M. ritchiei* were 0.13, 0.24, 0.26 and 0.20 % respectively. Whereas, P concentration in *Ochlandra setigera* was in the range of 0.08 to 0.40 %. The P concentration observed in culms, leaves, rhizomes and roots of *O. setigera* were 0.18, 0.24, 0.40 and 0.25 % respectively.

2.4.1.3 Potassium concentration in bamboo biomass components

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported K concentration in biomass components of 13 years old *D. hamiltonii* plantation. K concentration in culms, leaves, branches and in rhizome were 0.75, 0.60, 0.75 and 0.65 % respectively.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported potassium concentration in root and rhizome in fertilized plots were 0.64 and 0.50 % respectively.

Seethalakshmi *et al*. (2021) reported potassium concentration in the range of 0.19 to 0.91 % for *Munrochloa ritchiei*, The K concentration observed in culms, leaves, rhizomes and roots of *M. ritchiei* were 0.70, 0.91, 0.44 and 0.19 % respectively. Whereas, K concentration in *Ochlandra setigera* was in the range of 0.41 to 0.90 %. The K concentration observed in culms, leaves, rhizomes and roots of *O. setigera* were 0.70, 0.74, 0.90 and 0.41 % respectively.

2.4.1.4 Carbon concentration in bamboo biomass components

Nath *et al*. (2009) reported carbon concentration in aboveground biomass of 1, 2, 3 and 4 years old bamboo plantation grown in Tropical climate of Barak Valley region of Assam, India. It was found to be as in *B. cacharensis* (51.23, 48.86, 49.89 & 50.76 %), *B. vulgaris* (51.65, 50.18, 51.73 & 51.34 %) and in *B. balcooa* (52.28, 51.79, 51.86 & 51.98 %) respectively in 1, 2, 3 and 4 years old bamboo plantation.

Tariyal *et al*. (2013) studied for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species in Terai region of Uttarakhand, India and recorded carbon concentration in culm and leaf-litter biomass. It was found to be as in *D. strictus* (48.2 & 28.4%). *B. vulgaris* (44.6 & 32.1%), *B. nutans* (43.7 & 28.6%) and in *B. balcooa* (48.5 & 32.4%) respectively in culm and leaf-litter biomass. Higher C concentration was recorded in culm component of the bamboo as it is observed that in nutrient rich soils major carbon and biomass is allocated in the aboveground components.

Sohel *et al.* (2015) conducted a study on carbon storage in a bamboo plantation grown at Lawachara forest reserve, Bangladesh and reported carbon concentration in oven-dried culm, branches, leaves and rhizome of *Bambusa vulgaris* were 54, 55, 55 and 54 % respectively.

Angom *et al.* (2018) reported carbon concentration in culm components of 1, 2 & 3 years old culm as in *M. baccifera* leaves (41.7, 42.1 & 45 %), branches (50.0, 50.1 & 49 %) and culms (37.6, 33.3 & 37.7 %). Whereas in *B. tulda* leaves (44.2, 45.1 & 43.2 %), branches (51.9, 60.3 & 55.9 %) and culms (52.8, 43 & 59.8 %) respectively. The average carbon content of ≥ 3 year old age class culm was in the sequence of branches (49.7%), leaves (42.9%) and culm (36.2%) for *M. baccifera* and for *B. tulda* branches (56%), culm (51.8%) and leaves (44.1%) respectively.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported carbon concentration in aboveground bamboo components *viz.*, culms, branches and leaves were 45.6, 46.1 and 43.9 % respectively. Whereas, C concentration in belowground bamboo components viz., roots and rhizomes were 42.9 and 45.0 % respectively

2.4.2 Nutrient Uptake in Bamboo

2.4.2.1 Total nitrogen uptake

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported the total nitrogen uptake of 121 kg N ha^{-1}, which distributed as 80, 4.0, 33 and 4.0 kg N ha^{-1} in culm, leaves, branches and rhizome biomass respectively in 13 year old *D. hamiltonii* plantation.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported total aboveground N uptake in fertilized plots of *P. pubescens* was 297.9 kg N ha^{-1} (*i.e.*167, 26.4 and 103.7 kg N ha^{-1} in culms, branches and leaves respectively).

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of two endemic bamboo species of Western Ghats grown in the Nilambur Forest Division of Kerala, India and reported highest total nitrogen uptake in standing biomass stock of *Munrochloa ritchiei* was 196.5 kg N ha^{-1} and was distributed in stem, leaves and rhizomes as 108, 34.3, 52.8 and 1.5 kg N ha^{-1} respectively.

2.4.2.2 Total phosphorus uptake

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported the total phosphorus uptake of 14 kg P ha^{-1} which distributed as 9, 0.48, 4 and 0.55 kg P ha^{-1} in culm, leaves, branches and rhizome biomass respectively in 13 year old *D. hamiltonii* plantation.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported total aboveground P uptake in fertilized plots of *P. pubescens* was 56.8 kg P ha^{-1} (*i.e.* 43.3, 6.4 and 7.2 kg P ha^{-1} in culms, branches and leaves respectively).

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of two endemic bamboo species of Western Ghats grown in the Nilambur Forest Division of Kerala, India and reported highest total phosphorus uptake in standing biomass stock of *Munrochloa ritchiei* was 198.1 kg P ha^{-1} and was distributed in stem, leaves and rhizomes as 94.9, 10.3 and 90.1 kg P ha^{-1} respectively.

2.4.2.3 Total potassium uptake

Shanmughavel and Francis (2003) studied biomass accumulation and nutrient distribution in *Dendrocalamus hamiltonii* plantation grown in the waste lands at Coimbatore and reported the total potassium uptake of 159 kg K ha^{-1} which distributed as 107, 3, 42 and 1 kg K ha^{-1} in culm, leaves, branches and rhizome biomass respectively in 13 year old *D. hamiltonii* plantation.

Rai and Singh (2013) studied effects of bamboo species on soil properties and observed higher potassium uptake by different bamboo species grown in humid Sub-tropics of India.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported total aboveground K uptake in fertilized plots of *P. pubescens* was 591.8 kg K ha^{-1} (*i.e.* 510.4, 29 and 52.4 kg K ha^{-1} in culms, branches and leaves respectively).

Seethalakshmi *et al*. (2021) studied nutrient locking in biomass and soil in the natural populations of two endemic bamboo species of Western Ghats grown in the Nilambur Forest Division of Kerala, India and reported highest total potassium uptake in standing biomass stock of *Munrochloa ritchiei* was 977.6 kg K ha^{-1} and was distributed in stem, leaves and rhizomes as 748, 50.2 and 175.9 kg K ha^{-1} respectively.

2.5 Effect of Different Bamboo Species on Carbon Stock and Carbon Sequestration

2.5.1 Biomass Carbon Stock

Uchimura (1978) conducted a ecological studies on cultivation of tropical bamboo forests grown at Philippines and reported total aboveground biomass carbon stock in *Bambusa blumeana* and *Bambusa vulgaris* was found to be 72 t C ha^{-1} and 53 t C ha^{-1} respectively.

Suzuki (1989) studied biomass and productivity in a sympodial bamboo stand grown at Philippines and reported total aboveground biomass C stock of 73 t C ha^{-1} in *Gigantochloa levis*.

Kamo *et al*. (1993) studied biomass and net production in a monopodial type bamboo plantation grown in Japan and reported total aboveground biomass carbon stock in *Phyllostachys bambusoides was* 68 t C ha^{-1}, whereas biomass carbon sequestration rate was 13 t C ha^{-1} year^{-1}.

Shanmaghavel and Francis (1996) studied aboveground biomass production and nutrient distribution in sympodial type active growing bamboo plantation grown in Tropical region of India and reported total aboveground biomass carbon stock in *Bambusa bamboos* stand found to be 144 t C ha^{-1}, while biomass carbon sequestration rate was 24 t C ha^{-1} Year^{-1}.

Kawahara *et al*. (1997) reported total aboveground biomass carbon stock in a monopodial type bamboo plantation grown in Japan *i.e. Phyllostachys pubescens* stand was 69 t C ha^{-1}, whereas biomass carbon sequestration rate was estimated to 9 t C ha^{-1} year^{-1}. a

Singh and Singh (1999) studied biomass, net primary production and impact of sympodial type bamboo plantation on soil redevelopment grown in dry tropical region of India and reported total aboveground biomass carbon stock in *Dendrocalamus strictus* was 30 t C ha^{-1}, whereas biomass carbon sequestration rate was estimated to 13 t C ha^{-1} year^{-1}.

Castaneda *et al*. (2005) reported total aboveground biomass carbon stock in a monopodial type bamboo plantation grown in Japan *i.e. Bambusa oldhamii* stand was 51.5 t ha^{-1}, whereas biomass carbon sequestration rate was estimated to 16 t C ha^{-1} year^{-1}.

Embaye *et al*. (2005) studied biomass and nutrient distribution in a highland sympodial type bamboo forest grown in Southwest Ethiopia and reported total aboveground biomass carbon stock of 55 t C ha^{-1} in sympodial type alpine bamboo stand.

Kochhar and Singh (2005) studied effect of clump density on productivity and nutrient uptake and reported total aboveground biomass carbon stock in *Bambusa pallida* was 160 t ha^{-1}, whereas biomass carbon sequestration rate was estimated to 13 t C ha^{-1} $year^{-1}$.

Kumar *et al*. (2005) studied aboveground biomass production and nutrient uptake of sympodial type thorny bamboo plantation grown in Tropical climate of Thrissur, Kerala and reported reasonably higher total aboveground biomass carbon stock in *Bambusa bamboos* was 121 t C ha^{-1}, whereas biomass carbon sequestration rate was 6 t C ha^{-1} $year^{-1}$.

Shin *et al.* (2007) studied potential contribution of forestry sector to carbon sequestration and reported carbon stock in different timber species and it was observed that carbon stock accumulated by *Bambusa bamboos* 121 t C ha^{-1}, *Guadua angustifolia* 200 t C ha^{-1}, *B. oldhami* 52 t C ha^{-1} was significantly highest than many fast growing timber species *viz., Acaica auriculiformis, Syzygium grandma, D. Turbinatus* and *S. mahagoni* which accumulated carbon stock of 19.3, 47.07, 8.98 and 28.81 t C ha^{-1} respectively.

Bijaya (2008) studied carbon sequestration potential and uses of *Dendrocalamus strictus* and reported above and below ground biomass carbon stock of 1.66 and 0.8 t C ha^{-1} respectively in *Dendrocalamus strictus* plantation. Whereas, total biomass carbon stock was 2.46 t C ha^{-1}.

Nath *et al*. (2009) conducted a study on above ground standing biomass and carbon storage in four year old farmer managed village mixed bamboo plantation grown in Tropical climate of Barak Valley region of Assam, India and reported total aboveground biomass carbon stock of 61.05 t C ha $^{-1}$ collectively for *Bambusa balcooa, B. vulgaris* and *B. cacharensis* and suggested that bamboo although have short periodicity of culm growth, rapid culm elongation rate, brief clump development period and ability to survive with least management approach, bamboo forests have a significant predicted potential to descend atmospheric carbon dioxide.

Lou *et al.* (2010) reported aboveground carbon stock was in the range between 25 and 32 t C ha^{-1} in 10 year old *Phyllostachys pubescens* stand grown in Sub-tropical climate of China

Lee *et al*. (2010) studied biomass production and carbon storage in a fast-growing monopodial type *Phyllostachys makinoi* plantation and reported total aboveground biomass carbon stock of 50 t C ha^{-1} and biomass carbon sequestration rate of 10 t C ha^{-1} $year^{-1}$.

Yen and Lee (2011) reported total aboveground biomass carbon stock and biomass carbon sequestration rate of 41 t C ha^{-1} and 8 t C ha^{-1} $year^{-1}$ respectively in *Phyllostachys heterocycla* a monopodial type moso bamboo grown in Taiwan.

Purwar and Agarwal (2012) reported aboveground biomass carbon stock in *D. strictus, B. vulgaris* and *B. multiplex* which was found to be 19.5, 5.2 and 2.4 t C ha^{-1} respectively.

Ly *et al.* (2012) studied aboveground carbon fixing capacity and accumulation of SOC stock and reported aboveground biomass carbon stock of 17 t C ha^{-1}, in *Dendrocalamus barbatus* plantation grown in Tropical climate of Northern central upland of Vietnam.

Quiroga *et al*. (2013) reported total aboveground biomass carbon stock in a sympodial type *Guadua angustifolia* forest grown at Carrasco National Park, Bolivia was 100 t C ha^{-1}.

Tariyal *et al*. (2013) conducted a study for two years on plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand, India and at the end of study recorded the highest aboveground, belowground and litter biomass carbon stock in *D. strictus* (217.3, 58.6 & 0.04 t C ha^{-1}) followed by *B. balcooa* (184.38, 49.42 & 0.04 t C ha^{-1}) and *B.nutans* (123.38, 36.61 & 0.03 t C ha^{-1}) respectively.

Zhang *et al*. (2014) estimated biomass and carbon storage in monopodial moso bamboo forest grown in China and reported total aboveground biomass carbon stock and biomass carbon sequestration rate in *Phyllostachys pubescens* was 40 t C ha^{-1} and 7 t C ha^{-1} yr^{-1} respectively.

Sohel *et al.* (2015) studied carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported total biomass carbon stock of 50.44 t C ha^{-1} in *Bambusa vulgaris* plantation.

Tomar et al. (2016) created predictive models for estimation of biomass and carbon stock at Doon valley located in Western Himalayan of India and reported carbon stock in aboveground biomass of 6 & 20 year old *Dendrocalamus strictus* stand was 8.38 & 49.08 t C ha^{-1} respectively.

Singnar *et al*. (2017) conducted a study on allometric scaling, biomass accumulation and carbon storage in different aged stands of thin-walled bamboo species grown in Cachar region of Assam, India and reported carbon stock in aboveground biomass of 1, 2, 3, 4 and 5 year old *Schizostachyum dullooa* bamboo species was 6.1, 5.8, 5.5, 3.6 t C ha^{-1} respectively.

Angom *et al.* (2018) studied on aboveground biomass production of *Melocanna baccifera* and *Bambusa tulda* grown at Lengpui, NE India and reported total carbon stock in aboveground biomass of *B. tulda* and *M. baccifera* was 51.12 and 44.71 t C ha^{-1} respectively. In both the species carbon allocation was found more in culm component.

Kim *et al.* (2018) studied effect of regular fertilization on nutrient distribution of bamboo components in *Phyllostachys pubescens* stand grown at Gajwa National Experimental Forest, South Korea and reported total biomass carbon stock in fertilized plots was 28.76 t C ha^{-1}. Overall significantly high carbon stock was recorded in unfertilized plots (8.23 kg C culm^{-1}) than those in fertilized plots (6.20 kg C culm^{-1}) on culm basis.

2.5.2 Soil Carbon Stock

Tripathi and Singh (1996) studied culm recruitment, dry matter dynamics and carbon flux in recently harvested and mature *Dendrocalamus strictus* bamboo grown in the dry tropics of India and reported soil carbon stock of 53.3 t C ha$^{-1.}$

Bijaya (2008) studied carbon sequestration potential and uses of *Dendrocalamus strictus* in Tropical climate of Nepal and reported reasonably higher soil carbon stock in *Dendrocalamus strictus* plantation which was estimated to be 230 t C ha$^{-1.}$

Ly *et al.* (2012) studied aboveground carbon fixing capacity and accumulation of SOC stock and reported soil carbon stock of 92 t C ha^{-1} in *Dendrocalamus barbatus* plantation grown in Tropical climate of Northern central upland of Vietnam.

Tariyal *et al*. (2013) studied plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand and recorded SOC stock in surface and sub-surface soil under *D. strictus* (68.97 and 144.14 t C ha^{-1}), *B. vulgaris* (58.40 and 111.72 t C ha^{-1}), *B. balcooa* (69.73 and 61.07 t C ha^{-1}) and *B. nutans* (58.07 and 56.50 t C ha^{-1}). The average SOC stock was found highest under *D. strictus* (106.56 t C ha^{-1}) followed by *B. vulgaris* (85.06 t C ha^{-1}) and *B. balcooa* (65.40 t C ha^{-1}). Higher values of SOC stock may be attributed to high amount of leaf litterfall. While high SOC stock in surface soil of *B. balcooa* and *B. nutans* may be due to accumulation of more leaf-litter and fine roots in the upper soil layer which on decomposition releases CO_2 during mineralization of OC and accumulate only resistant products like humus in soil.

Sohel *et al.* (2015) studied carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported SOC stock under *B.* vulgaris plantation which was found to be 24.70 t C ha $^{-1}$.

Kumari *et al*. (2017) studied effect of various bamboo species on soil nutrients and growth parameters grown in Nauni-Solan, Mid hills of HP, India and reported SOC stock at 0-20 and 20-40 cm depth under *D. asper* was 37.7 & 33.6 Mg C ha^{-1} whereas in *B. tulda* it was 36.0 & 31.7 Mg C ha^{-1}. In the average effect of soil depth SOC stock was significantly highest (36.39 Mg C ha^{-1}) in 0-20 cm soil depth in comparison to 20-40 cm (32.25 Mg C ha^{-1}) soil depth.

Angom *et al.* (2018) studied aboveground biomass production of *Melocanna baccifera* and *Bambusa tulda* grown at Lengpui, NE India and reported soil carbon stock upto the depth of 30 cm was estimated to be 53.2 and 38.8 t C ha^{-1} under *M. baccifera* and *B. tulda* respectively. Although the carbon storage in aboveground biomass of *B. tulda* was higher than *M. baccifera*, soil carbon stock was found to be more under *M. baccifera* than *B. tulda*. These results could be due to more decaying ability of culm components attributed to its thin walled culm structure as found in *M. baccifera*. Besides the main contributor to SOM *i.e.* leaf biomass was found more in *M. baccifera* than *B. tulda*.

2.5.3 Total Carbon Stock and Carbon Sequestration

Isagi, (1994) studied carbon stock and cycling in a bamboo stand in Kyoto (Japan) and reported total carbon carbon stock in *Phyllostachys bambusoides* stand which was estimated to be 165.1 t C ha^{-1}, out of which biomass added 73.1 t C ha^{-1} and soil contributed 92 t C ha^{-1} respectively. The total carbon stock of *P. bambusoides* stand (165.1 t C ha^{-1}) was found to be lower than those reported in fir forest (377 t C ha^{-1}), evergreen oak forest (264 t C ha^{-1}) and in a tropical rain forest (365 t C ha^{-1}). The lower carbon stock in the biomass of *P. bambusoides* is attributed due to its shorter life span of culms than those of trunks in forest ecosystems, which generally accumulate a large amount of carbon. Whereas, the soil carbon stock in the *P. bambusoides* stand (92.0 t C ha^{-1}) was found nearly equal or little lower than those estimated in two stands of evergreen oak forest (i.e., 89 and 98 t C ha^{-1}).

Tripathi and Singh (1996) studied culm recruitment, dry matter dynamics and carbon flux in recently harvested and mature bamboo savannas grown in the dry tropics of India and reported total carbon stock of 75.4 t C ha^{-1} in *Dendrocalamus strictus* plantation.

Kawahara *et al*. (1997) studied carbon storage potential of two natural forest bamboo species grown in Sub-tropical climate of Japan and reported aboveground, belowground biomass carbon stock and soil carbon stock as found in *P. bambusoides* (52.30, 20.8 and 92 t C ha^{-1}) and in *P. pubescens* (78.60, 27.51 and 101.2 t C ha $^{-1}$) respectively. Whereas, total carbon stock was summed up to 165.1 and 207.31 t C ha $^{-1}$ respectively in *P. bambusoides* and *P. pubescens***.**

Bijaya (2008) studied carbon sequestration potential and uses of *Dendrocalamus strictus* grown in tropical climate of Nepal and reported total carbon stock of 232.46 t C ha^{-1} in *Dendrocalamus strictus* plantation, out of which soil contributed 230 t C ha^{-1} and biomass added 2.46 t C ha^{-1} respectively to total carbon stock.

INBAR (2009) prepared a fact-sheet of different bamboo species grown in Tropical climate of different part of the world and reported total carbon stock for *Gigantochloa alter* (Indonesia), *Yushamia alpina* (Ethiopia), *Guadua angustifolia* (Colombia), *D. affinis* (China) and *D. strictus* (India) was estimated to be 38, 55, 54, 78 and 37 t C ha^{-1} respectively.

Qi *et al*. (2009) studied effects of different tending measures on carbon density, carbon stock and carbon allocation pattern in *Phyllostachy edulis* forest grown in Sub-tropical climate of Western China and reported total carbon stock of 261.67 t C ha $^{-1}$ in *Phyllostachy edulis* forest.

Tariyal *et al*. (2013) studied plant and soil carbon stock and carbon sequestration potential in four major bamboo species grown in Terai region of Uttarakhand, India and at the end of study recorded highest total carbon stock in *D. strictus* (381.50 t C ha^{-1}) followed by *B. balcooa* (299.24 t C ha^{-1}) and *B. nutans* (217.20 t C ha^{-1}) while the lowest was seen in *B. vulgaris* (160.11t C ha^{-1}). Contrary to this the maximum carbon sequestration potential was observed in *B. balcooa* (99.81 t C ha^{-1} yr $^{-1}$), followed by *B. nutans* (86.92 t C ha^{-1} yr $^{-1}$), *D. strictus* (83.84 t C ha^{-1} yr $^{-1}$) and in *B. vulgaris* (57.77 t C ha^{-1} yr $^{-1}$). It is indicated that total carbon stock depends on net productivity, biomass production, leaf-litter fall, carbon addition from plant into the soil, soil texture and best management practices.

Sohel *et al.* (2015) studied carbon storage in *Bambusa vulgaris* plantation grown at Lawachara forest reserve, Bangladesh and reported total carbon stock of 77.66 t C ha^{-1}, out of which biomass added 52.96 t C ha $^{-1}$ and soil contributed 24.70 t C ha $^{-1}$ respectively to total carbon stock in *B. vulgaris* plantation. The carbon sequestration rate of 15.33 t C ha^{-1} yr^{-1} was recorded in *B.* vulgaris. The carbon sequestration potential of *B.* vulgaris stand was reasonably high as compared to some of the fast growing tree species *viz.*, A. auriculiformis (11 yrs., 10.2 t C ha^{-1} yr^{-1}) and E. camaldulensis (18 yrs., 10.1 t C ha^{-1} yr^{-1}).

2.6 Correlation Study

Youngfu *et al.* (2010) studied influence of organic mulch and fertilization on soil carbon pools under intensively managed *Phyllostachys praecox* plantation grown in southeast china and found that WSC was positively correlated with HWSC (0.91) and POXC (0.99). However, non significant correlation was observed between SMBC and other labile carbon pools. Correlation analysis showed that the WSC was positively correlated with the total soil O-alkyl C content while, soil aromatic C was negatively correlated with HWSC.

Kumari *et al*. (2017) studied effect of various bamboo species on soil nutrients and growth parameters and carried out simple correlation coefficient (r) between growth attributing characters and soil physico-chemical parameters under bamboo plantations grown in Nauni-Solan, Mid hills of HP, India during full growth period on the basis of data collected in field. It was observed that the most of growth attributing characters and soil physico-chemical parameters were positively correlated with each other's. Among the growth and soil nutrients the highest positive correlation coefficient 0.921 was between SOC and culm diameter. While, minimum positive correlation coefficient was 0.003 between culm internodal length and soil pH. Within soil nutrients the maximum positive correlation coefficient was between OC and pH.

3. MATERIAL AND METHODS

A long-term field experiment “Performance of different bamboo species on growth and yield of bamboo” was initiated in the year 2018-19 at National Agricultural Research Project (NARP), Dryland Sub-Centre (Agroforestry), Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) so as to study the growth and yield performance of bamboo species. The same field experiment was selected for conduct of present study entitled, “Quantification of soil carbon pools and carbon sequestration rate as influenced by bamboo plantation grown on Entisol of semiarid climate of Maharashtra” during the year 2020-21. The analytical work as per objectives was carried out in the research laboratory of Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, M. P. K. V., Rahuri. The details regarding long term field experiment, techniques employed and material and methods adopted for the conduct of the present study has been described in this chapter under the following sub-heads:

3.1 Location
3.2 Climate
3.3 Soil of Experimental Site
3.4 Inputs for Field Experiment
3.5 Field Experiment Details
3.6 Observations Recorded
3.7 Sampling
3.8 Methods of Chemical Analysis
3.9 Methods of Soil and Plant Carbon Analysis
3.10 Estimation of Bamboo Biomass
3.11 Computation of Derived Parameters

3.1 Location

3.1.1 Geographical Location

The Mahatma Phule Krishi Vidyapeeth, Rahuri is situated thirty-three kilometres away to the North of Ahmednagar city and fifty kilometres away in the South of Shirdi. Geographically, the Central Campus of Mahatma Phule Krishi Vidyapeeth, Rahuri lies between N 19° 47′ latitude and E 74° 18′ longitude. At the altitude of 657 meter above mean sea level.

3.1.2 Experimental Site

The geographical location of experimental site is N 19° 31′ 996″ to N 19° 32′ 073″ latitude and E 74 ° 63′ 920″ to E 74 ° 64′ 042″ longitude. At the altitude of 608.4 to 616.1 meter above mean sea level. Agro-climatically the experimental site belongs to scarcity zone of Western Maharashtra, comes under hot semiarid region with dry summer and mild winter at an average annual rainfall less than 750 mm. Out of the total annual precipitation about 70% is received during June to September (South-West monsoon), while the remaining precipitation is received in the months of October and November (North-East monsoon).

3.2 Climate

The climatic conditions during crop growth period of different bamboo species for the year 2020-21 are presented in table 3.1.

It was observed that the average maximum and minimum temperature ranged between 27.0 to 38.5 ^{0}C and 13.0 to 25.7 ^{0}C respectively. The total rainfall received was 1345.8 mm in 66 rainy days. The average morning and evening relative humidity ranged between 61.1 to 91.1 % and 19.3 to 66.5 % respectively. The average wind speed ranged between 0.74 - 4.37 km hr^{-1}. The average bright sunshine hours and open pan evaporation ranged between 3.2 to 10.1 hrs and 3.0 to 13.4 mm respectively.

Table 3.1 Meteorological data for the year 2020-21 during crop growth period of different bamboo species (January 2020 to March 2021)

Month	Average Temperature (^{0}C)		Average Relative Humidity (%)		Average Wind Speed (km hr^{-1})	No. of Rainy Days	Total Rainfall (mm)	Average Bright Sunshine Hours (hrs)	Average Open Pan Evaporation (mm)
	Max.	Min.	Morn.	Even.					
Jan-2020	27.0	13.0	82.5	42.7	0.9	00	0.0	7.7	4.7
Feb-2020	30.4	15.1	77.9	33.2	1.4	00	0.0	8.5	5.2
Mar-2020	33.0	16.8	72.0	27.7	1.7	01	23	8.4	6.5
Apr-2020	38.1	21.0	71.9	19.3	1.9	01	4.0	10.0	10.1
May-2020	38.5	25.7	61.1	20.1	4.4	00	0.0	10.1	13.4
Jun-2020	32.3	24.2	86.6	51.9	3.6	14	311.4	5.9	5.3
Jul-2020	31.0	24.2	86.8	61.2	2.8	13	374.0	4.9	4.6
Aug-2020	28.7	23.5	87.0	66.5	3.4	09	136.2	3.2	4.4
Sep-2020	30.4	23.5	91.1	62.4	1.4	14	385.8	4.9	4.0
Oct-2020	30.8	22.5	88.9	52.7	1.3	08	156	6.3	4.8
Nov-2020	29.7	17.3	84.8	39.7	1.2	01	4.2	8.6	5.2
Dec-2020	28.2	14.2	85.8	38.7	1.0	00	0.0	7.6	3.7
Jan-2021	29.0	16.4	86.8	40.3	0.7	01	20.6	7.0	3.0
Feb-2021	29.4	13.8	80.6	29.4	1.2	01	7.20	9.1	3.2
Mar-2021	35.3	17.5	72.2	21.6	1.1	03	23.40	8.8	5.6

3.3 Soil of Experimental Site

The soil of experimental site is grouped under Entisol order and belongs to Rahuri soil series. The experimental soil is sandy clay in texture, slightly alkaline in reaction, normal for Electrical conductivity, low in available nitrogen, very low in available phosphorus and very high in available potassium. The average depth of experimental soil is upto 45 cm. The data on initial physical, chemical and biological properties of soil are presented in table 3.2

Table 3.2 Initial soil properties

Sr. No.	Soil properties	Value
I)	**Physical properties**	
1.	Particle size distribution	
i.	Sand (%)	67.00
ii.	Silt (%)	10.00
iii.	Clay (%)	35.00
2.	Coarse fragments (> 2mm) (%)	20.00
3.	Textural class	Sandy clay
4.	Bulk density (Mg m^{-3})	1.51
II)	**Chemical properties**	
1.	pH (1:2.5)	8.01
2.	Electrical conductivity (EC) (dS m^{-1})	0.21
3.	Calcium carbonate ($CaCO_3$) (%)	3.37
4.	Available nitrogen (kg N ha^{-1} soil)	178.70
5.	Available phosphorus (kg P ha^{-1} soil)	6.10
6.	Available potassium (kg K ha^{-1} soil)	403.20
III)	**Biological properties**	
1.	Dehydrogenase enzyme activity (µg TPF released g^{-1} soil hr^{-1})	2.87
2.	Bacterial count (cfu x 10^6 g^{-1} soil)	5
3.	Fungi count (cfu x 10^4 g^{-1} soil)	4
4.	Actinomyctes count (cfu x 10^5 g^{-1} soil)	4
IV)	**Carbon fractions**	
1.	Soil organic carbon (SOC) (g C kg^{-1} soil)	6.70
2.	Total soil organic carbon (TOC) (g C kg^{-1} soil)	8.15
3.	Water soluble carbon (WSC) (mg C kg^{-1} soil)	9.20
4.	Soil Microbial biomass carbon (SMBC) (mg C kg^{-1} soil)	74.05
5.	Particulate organic matter carbon (POMC) (g C kg^{-1} soil)	1.43
6.	Permanganate oxidizable soil carbon (POXC) (g C kg^{-1} soil)	0.404

3.4 Inputs for Field Experiment

3.4.1 Planting of Bamboo Seedlings

The pits of 45 cm × 45 cm × 45 cm size were made during September, 2018 with a spacing of 4 m × 3 m which accommodate 833 bamboo seedlings per hectare. Bamboo seedlings of selected seven species of uniform size and age were planted during October, 2018.

3.4.2 Chemical Fertilizers

The recommended dose of chemical fertilizers (160:40:200 kg N, P_2O_5 and K_2O ha^{-1}) was applied as split dose through commercial grade urea (46 % N), single superphosphate (16 % P_2O_5) and muriate of potash (60 % K_2O), respectively**.** The data regarding quantity of fertilizer nutrients added through application of chemical fertilizer is presented in table 3.3.

Table 3.3 Quantity of fertilizer nutrients added through chemical fertilizer

Fertilizer nutrient	Quantity of fertilizer nutrients added		Total quantity of fertilizer nutrients added (kg ha^{-1})
	1st year (kg ha^{-1})	2nd year (kg ha^{-1})	
Nitrogen	160	160	320
Phosphorus	40	40	80
Potassium	200	200	400

3.4.3 Organic Manures

Well decomposed farm yard manure was added @ 25 kg clump^{-1} (20.8 t FYM ha^{-1} yr^{-1}) as a source of organic manure. The quantity of nutrient added through application of farm yard manure is presented in table 3.4.

Table 3.4 Quantity of nutrients added through farm yard manure

Parameter	Characterization of farm yard manure added	Quantity of nutrients added		Total quantity of nutrients added (kg ha^{-1} FYM)
		1st year (kg ha^{-1} FYM)	2nd year (kg ha^{-1} FYM)	
Total C	40.00 %	8330.00	8330.00	16660.00
Total N	0.60 %	124.95	124.95	249.90
Total P	0.30 %	62.48	62.48	124.95
Total K	0.70 %	145.78	145.78	291.55
Total S	0.08 %	16.66	16.66	33.32
Calcium (Ca)	2950 mg kg^{-1}	61.43	61.43	122.87
Magnesium (Mg)	2640 mg kg^{-1}	54.98	54.98	109.96
Iron (Fe)	1065 mg kg^{-1}	22.18	22.18	44.36
Manganese (Mn)	24.00 mg kg^{-1}	0.50	0.50	1.00
Zinc (Zn)	43.00 mg kg^{-1}	0.90	0.90	1.79
Copper (Cu)	9.00 mg kg^{-1}	0.19	0.19	0.37

3.5 Field Experiment Details

3.5.1 Experiment Details

The field experiment was laid out in a randomized block design (RBD) comprising seven treatments and three replications. The details are as under:

1. Title : Performance of different bamboo species on growth and yield of bamboo
2. Location : NARP, Dryland Sub Centre (Agroforestry), MPKV, Rahuri
3. Date of plantation : 13.10.2018
4. Plantation : Bamboo
5. Design : Randomized Block Design (RBD)
6. Treatments : Seven (7)
7. Replications : Three (3)
8. Spacing : 4.0 m x 3.0 m
9. Plot size : Gross - 20 m x 15 m
   Net - 12 m x 09 m

3.5.2 Treatment Details

The treatment details *i.e.* seven selected bamboo species are presented in table 3.5.

Table 3.5 Treatment details along with symbols used

Treatment No.	Treatment details (Bamboo species)
T_1	*Dendrocalamus brandisii*
T_2	*Bambusa nutans*
T_3	*Bambusa balcooa*
T_4	*Dendrocalamus strictus*
T_5	*Bambusa tulda*
T_6	*Bambusa bamboos*
T_7	*Dendrocalamus asper*

3.5.3 Experimental Layout

The plan of experimental layout is depicted in Figure 3.1.

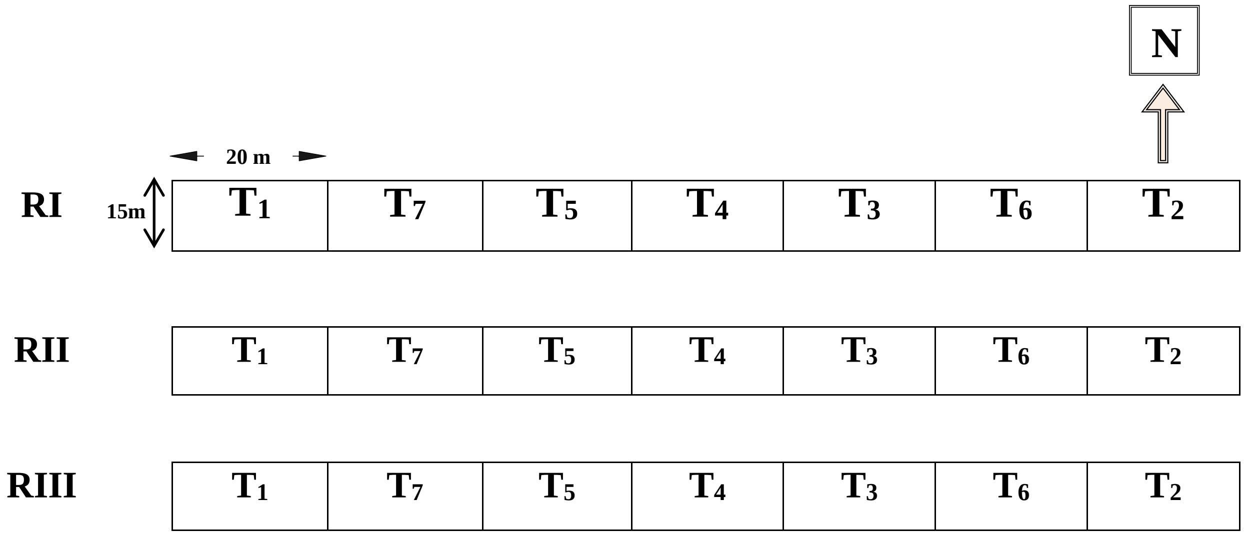

Fig.: 3.1 Plan of experimental layout

3.5.4 Field Operations Carried out in Experimental Field

The schedule of field operations carried out for two years on the selected experimental field during the bamboo crop growth period is presented in table 3.6.

Table 3.6 Schedule of field operations

Sr. No.	Name of operation	Frequency	Date
1.	Planting of bamboo seedlings	1	13.10.2018
2.	Application of manures (1st year)	2	08.10.2018 and 04.06.2019
3.	Application of fertilizer dose (1st year)	2	01.01.2019 and 10.06.2019
4.	Irrigations (1st year)	6	14.10.2018, 24.11.2018, 01.01.2019, 22.02.2019, 04.04.2019 and 10.05.2019
5.	Application of manures (2nd year)	2	26.06.2020 and 09.09.2020
6.	Application of fertilizer dose (2nd year)	2	04.01.2020 and 12.06.2020
7.	Irrigations (2nd year)	6	10.10.2019, 02.12.2019, 04.02.2020, 26.03.2020, 16.05.2020 and 04.10.2020

3.6 Observations Recorded

The details of different observations recorded during the course of investigation are presented in table 3.7

Table 3.7 Observations recorded in the experimental field

Sr. No.	Parameter	Observations recorded
A.	**Plant biometric observation**	
I)	Growth attributing characters	1. Number of culms per clump
		2. Culm density
		3. Number of new culms per clump
		4. Culm height
		5. Basal diameter of culm
		6. Diameter at breast height (DBH)
		7. Culm girth at 5^{th} internodes
		8. Clump girth
		9. Internodal length
		10. Number of internodes per culm
		11. Average culm weight
II)	Biomass estimation	1. Above ground biomass (stem, branches, leaves)
		2. Below ground biomass (roots and rhizome)
		3. Leaf-litter biomass (leaf and leaf sheath)
		4. Total biomass
III)	Bamboo plant carbon estimation	1. Biomass carbon stock
		2. Plant carbon sequestration
B.	**Soil Analysis**	
I)	Soil carbon fractions	**1) Carbon fractions**
		a) Soil organic carbon (SOC)
		b) Total soil organic carbon (TOC)
		c) Water soluble carbon (WSC)
		d) Soil microbial biomass carbon (SMBC)
		e) Particulate organic matter carbon (POMC)
		f) Permanganate oxidizable soil carbon (POXC)
		2) Microbial Indices
		a) Mineralization quotient (SOC/TOC)
		b) Microbial quotient (SMBC/TOC)
		3) Soil carbon stock
		4) Soil carbon sequestration
II)	Biological properties	**1) Microbial analysis**
		Total microbial count (bacteria, fungi, actinomycetes)
		2) Soil enzymes assay
		Soil dehydrogenase enzyme activity
III)	Chemical properties	Soil pH, EC, $CaCO_{3,}$
		Soil available N, P and K
IV)	Physical properties	Particle Size Distribution - Soil Texture
		Bulk density
C.	**Plant Analysis**	
I)	Plant nutrient uptake	Total N, P and K
II)	Plant carbon content	Above and belowground biomass carbon stock
D.	**Manure Analysis**	
I)	Farm Yard Manure	Total N, P, K, C and S., Ca, Mg, Fe, Zn, Cu and Mn

3.7 Sampling

3.7.1 Soil Sampling

Representative composite soil sample was collected from the experimental field upto 0-45 cm soil depth at the time of bamboo seedling plantation during October, 2018 for determining the initial soil properties. The collected soil samples were air-dried, grinded with wooden mortar and pestle to pass through 2 mm sieve and stored in cloth bag for further laboratory analysis.

The composite soil profile samples under selected bamboo species were collected from the experimental field upto 0-45 cm soil depth in the year 2020 during the active growing season. The dry samples were moistened to field capacity, for rejuvenation of microbial activity and kept at 4℃ temperature in plastic bags for few days as to stabilize the microbiological activity and was analysed within the period of two weeks from sampling. Soil profile samples collected under selected bamboo species were analysed for soil chemical, physical, biological properties and carbon fractions. The observations on soil chemical properties (pH, EC, $CaCO_3$, SOC, TOC and available N, P, K) and carbon fractions (POMC and POXC) recorded in the present study (2020-21) were compared with the initial soil test values (2018) to get more reliable results. Whereas, soil physical, biological, biochemical properties and carbon fractions (WSC and SMBC) were compared with control senile soil (*i.e.* soil sample collected from fallow area nearby experimental field which is free from the effect of different bamboo species). The initial soil sample and senile soil sample were used as control for monitoring change in different soil properties as influenced by different bamboo species grown on Entisol of semiarid climate.

3.7.2 Plant Sampling

Bamboo plant samples, aboveground (stem, branches and leaves), belowground (rhizome and roots) and leaf-litter were collected, from the experimental site after the end of active growing season in the month of January, 2021 from randomly selected and identified clumps of different bamboo species. Five representative clumps of each bamboo species were randomly selected and identified with the help of colour paint marking as suggested by Shanmughavel and Francis (2003). The growth attributing observations were recorded on marked clumps.

The uprooted rhizome and rootlets was washed with tap water and removed all adhered soil particles. Thereafter samples were collected and transported to laboratory, air-dried under shade and subsequently oven-dried at 65℃ and grinded with grinding machine to maximum fineness. The processed bamboo plant samples were used for plant analysis

3.8 Methods of Chemical Analysis

Processed soil and bamboo plant samples were analysed by adopting standard methods of analysis for various parameters are presented in table 3.8.

Table 3.8 Standard methods used for analysis of soil, plant and manure samples

SN	Parameter	Method used	Reference
A.	**Soil Analysis**		
i)	**Carbon Fraction**		
1.	Soil organic carbon	Wet oxidation	Nelson and Sommers (1982)
2.	Total soil organic carbon	Dry combustion	Nelson and Sommers (1982)
3.	Water soluble carbon	Water extraction	McGill *et al*., (1986)
4.	Particulate organic carbon	Wet sieving	Camberdella and Elliott (1992)
5.	Soil microbial biomass C	$CHCl_3$ fumigation extraction	Brookes *et al*., (1985)
6.	Permanganate oxidizable C	Permanganate oxidation	Blair *et al.,* (1995)
ii)	**Biological properties**		
1.	Total Microbial count	Serial dilution technique	Halvorsun and Zeiglar (1993)
2.	Dehydrogenase activity	Spectrophotometry	Casida *et al.* (1964)
iii)	**Chemical Properties**		
1.	pH (1: 2.5)	Potentiometry	Jackson (1973)
2.	EC (1: 2.5) (dS m^{-1})	Conductometry	Jackson (1973)
3.	$CaCO_3$ (%)	Acid neutralization	Allison and Moodie (1965)
4.	Available N (kg N ha^{-1})	Alkaline permanganate	Subbiah and Asija (1956)
5.	Available P (kg P ha^{-1})	0.5 *M* $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965)
6.	Available K (kg K ha^{-1})	Neutral *N* NH_4OAc (pH 7.0)	Knudsen *et al.* (1982)
vi)	**Physical properties**		
1.	Soil Texture	International pipette method	Black (1965))
2.	Bulk density	Core sampler	Blake and Hartage (1986)
B.	**Plant Analysis**		
1.	Total N (kg N ha^{-1})	Micro-Kjeldahl (1:1H_2O_2 : H_2SO_4)	Parkinson and Allen (1975)
2.	Total P (kg P ha^{-1})	Vanodomolybdate yellow colour in nitric acid system	Jackson (1973)
3.	Total K (kg K ha^{-1})	Flame photometry	Chapman and Pratt (1961)
4.	Carbon stock (t C ha^{-1})	Dry combustion	Nelson and Sommers (1982)
C.	**Organic Manure Analysis**		
1.	Total C (kg C ha^{-1})	Dry combustion	Nelson and Sommers (1982)
2.	Total N (kg N ha^{-1})	Micro-Kjeldahl	Jackson (1973)
3.	Total P (kg P ha^{-1})	Vanadomolybdate yellow colour in nitric acid system	Jackson (1973)
4.	Total K (kg K ha^{-1})	Flame photometry	Chapman and Pratt (1961)
5.	Ca, Mg, Fe, Mn, Zn, Cu (kg ha^{-1})	Atomic Absorption Spectrophotometry	Zoroski and Burau (1977)

3.9 Methods for Soil and Plant Carbon Analysis

3.9.1 Soil Organic Carbon (SOC)

The determination of SOC in soil is based on the chromic acid wet oxidation method (Nelson and Sommers, 1982). $K_2Cr_2O_7$ in acidic medium is a strong oxidative agent that reacts with reducing substances present in soil. The reaction is assisted by the heat generated when two volumes of conc. H_2SO_4 are mixed with one volume of the $K_2Cr_2O_7$. SOC was determined by taking 1 g of 0.2 mm sieved soil sample in 500 mL conical flask. Add 10 mL 1 *N* $K_2Cr_2O_7$ and 20 mL conc. H_2SO_4, swirl and keep on asbestos sheet for 30 min. Add 2-3 drops of ferroin indicator. Titrate with 0.5 *N* $FeSO_4(NH_4)_2SO_4.6H_20$.

3.9.2 Total Soil Organic Carbon (TOC)

Total soil organic carbon (TOC) content was determined by dry combustion method at high temperatures in a muffle furnace (Nelson and Sommers, 1982). 5 g of 2 mm sieved soil sample in preweight silica crucible, charred in low Bunsen flame and fed inside the muffle furnace having temperature of 600-700 ^{0}C. The sample is combusted at high temperature for 6-8 hours. Carbon content in soil is determined from brick red colour combusted soil sample.

3.9.3 Water Soluble Carbon (WSC)

Water soluble carbon (WSC) in soil was extracted by hot and cold extractions method (McGill *et al.*, 1986). 5 g fresh soil sample in 250 mL conical flask. Add 50 mL DW, keep on a hot plate at 100^{0}C for an hour. Allow to cool and filter through Whatman No.1 filter paper. Collect filtrate in 50 mL vol. flask, make up the volume with hot water. Pipette out 10 mL filtrate in 250 mL conical flask, allow to dry. Add 10 mL 1 *N* $K_2Cr_2O_7$ and 20 mL conc. H_2SO_4 and keep on asbestos sheet for 30 min. Add 200 mL of DW, 10 mL H_3PO_4 (to eliminate interference of ferric ions) and 3 drops of ferroin. Titrate with 0.035 *N* $FeSO_4(NH_4)_2SO_4.6H_20$.

3.9.4 Particulate Organic Matter Carbon (POMC)

POMC was determined by wet sieving method (Camberdella and Elliott, 1992). 10 g of 2 mm sieved soil sample dispersed with 1 % $(NaPO_3)_6$, shake continuously for 18 hrs on reciprocating shaker at 90 rpm. Allow to settle. Soil suspension poured over a 53 µm sieve. Collect and wash the material retained on sieve. Allow to dry at 50^{0}C for 24 hrs in oven. Record the weight. Grind and digest with chromic acid. Titrate with standard FeSO4(NH4)2SO4.6H20.

3.9.5 Soil Microbial Biomass Carbon (SMBC)

Soil microbial biomass carbon (SMBC) was estimated by chloroform fumigation extraction method (Brookes *et al.*, 1985). 10 g of fresh soil sample in seven sets. 1 set for determination of moisture content, 3 sets for fumigation with ethanol-free chloroform for 24 hrs. in vacuum desiccators and 3 sets kept in refrigerator as non-fumigated sample. Remove chloroform from fumigated samples. Both fumigated and non-fumigated samples transfer in 250 mL conical flask. Add 25 mL 0.5 *M* K_2SO_4 and shake for 30 min, filter through Whatman No. 42

filter paper. Pipette out 10 mL filtrate in 500 mL conical flask. Add 5 mL 1 *N* $K_2Cr_2O_7$, 10 mL conc. H_2SO_4 and 5 mL of orthophosphoric acid and keep on hot plate at 100ºC for 30 min. Add 25 mL DW & 3-4 drops of ferroin indicator. Titrate with 0.005 *N* FeSO4(NH4)2SO4.6H20.

SMBC (µg g^{-1} soil) was calculated as Cmic = (Ext. CF - Ext. CNF)/ kEC.

Where, Ext. CF and Ext. CNF are extracted OC in fumigated and non-fumigated soil sample, kEC is a proportionality factor for converting Extractable carbon value to Cmic (45 ± 0.05).

3.9.6 Permanganate Oxidizable Soil Carbon (POXC)

Alkaline permanganate oxidizable soil carbon was analysed by treating the soil samples with 20 m*M* $KMnO_4$ (Blair *et al*., 1995). 3 g of 2 mm sieved soil in centrifugal tube. Add 30 mL of 20 m*M* $KMnO_4$ and shake for 15 min on horizontal shaker. Centrifuge at 2000 rpm for 5 min. 2 mL clear supernatant in 50 mL volumetric flask, make up vol of 50 mL. Record absorbance at 565 nm using spectrophotometer. Record the absorbance of standard KMnO4 solutions (0, 0.5, 1.0, 1.5 and 2.0 mL of 20 m*M* $KMnO_4$) and plot a standard curve for sample measurement.

3.9.7 Methodology Adopted for Carbon Analysis in Bamboos

Estimation of carbon content in bamboo plant samples

The bamboo plant samples were oven dried at 65˚C till constant weight and ground to pass a 30 mesh (0.5 mm) screen. 5 g powdered dry sample in a pre-weight silica crucible, charred in low Bunsen flame and finally ignited by heating the sample at 600˚C for a period of 6 hours in muffle furnace to form ash. The carbon content was calculated from ash using relations as explained by Negi *et al.* (2003*)*

% Carbon content = 100 - [Ash weight (%) + Molecular weight of O_2 in $C_6H_{12}O_6$ (53.3)]

Where,

$$\text{Ash weight (\%)} = \frac{\text{Weight of sample after burning}}{\text{Weight of sample before burning}} \times 100$$

3.10 Estimation of Bamboo Biomass

3.10.1 Estimation of Above Ground Biomass

One representative clump selected from each replication and representative culms are identified for felling. After felling the sample culm was delimbed into leaves, branches and stem components. Total fresh weight of each sample culm component (leaves, branches and stem) was recorded with the help of electronic weighing balance. Then each sample culm component was subdivided into subsamples and weighed for its fresh weight. The subsample were collected and transported to laboratory, oven dried at 65˚C till the constant weight for dry weight estimation.

Average dry weight of each above ground culm component (leaves, branches and stem) were worked out by using following formula and expressed in kg $culm^{-1}$ (Appendix I).

$$\text{Average dry weight} = \frac{\text{Dry wt. of subsample}}{\text{Fresh wt. of subsample}} \times \text{Total fresh wt. of AG culm component}$$

Standing biomass of each above ground clump component (leaves, branches and stem) was calculated by using following formula and expressed in kg clump^{-1} (Appendix II)

Standing biomass = No. of culms per clump × Average dry wt. of AG culm component

Above ground biomass per clump was calculated by summing the standing biomass of each above ground clump component (leaves, branches and stem) and expressed in kg clump^{-1}.

Above ground biomass per hectare was calculated by multiplying above ground biomass per clump with 833 (number of clumps per ha.) and expressed in t ha^{-1} by dividing it with 1000.

3.10.2 Estimation of Below Ground Biomass

After felling the sample culm, the rhizome and roots were extracted and separated carefully. The uprooted rhizome and roots were washed with tap water and removed all adhered soil. The total fresh weight of the below ground culm components (rhizome and roots) was recorded. Then the samples were collected and transported to the laboratory, oven dried at 65˚C till the constant weight was achieved for dry weight estimation.

Average dry weight of each below ground culm component (rhizome and roots) was worked out by using following formula and expressed in kg culm^{-1} (Appendix I).

$$\text{Average dry weight} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Total fresh wt. of BG culm component}$$

Standing biomass of each below ground clump component (rhizome and roots) was calculated by using following formula and expressed in kg clump^{-1} (Appendix II).

Standing biomass = No. of culm per clump × Average dry wt. of BG culm component

Below ground biomass per clump was calculated by summing the standing biomass of each below ground clump component (rhizome and roots) and expressed in kg clump^{-1}.

Below ground biomass per hectare was calculated by multiplying below ground biomass per clump with 833 (number of clumps per ha) and expressed in t ha^{-1} by dividing it with 1000.

3.10.3 Estimation of Leaf Litter Biomass

The litter floor mass (leaf and leaf sheath) was collected twice at 3 months intervals, by placing nylon traps of 1m x 1m sized quadrate mounted on wooden frame randomly at each occasion under each species. The floor leaf-litter mass was weighed accurately. 100 g litter sample from each plot was oven dried at 65˚C for dry weight estimation. Leaf litter biomass was calculated by following same procedure as used for above and below ground biomass estimation.

3.10.4 Estimation of Total Biomass

Total biomass per clump and total biomass per hectare were calculated by summing biomass of above and below ground clump components *viz*., stem, branches, leaves, rhizome and roots including leaf-litter biomass and expressed in kg clump^{-1} and t ha^{-1} respectively.

3.11 Computation of Derived Parameters

3.11.1 Nutrient Uptake

The uptake of macronutrients *viz.*, nitrogen, phosphorous, potassium and carbon were worked out by multiplying total biomass accumulation to respective concentration of N, P, K and C by using the following formulas.

$$\text{Macronutrient uptake (kg N, P, K ha}^{-1}\text{)} = \frac{\text{Total Biomass (kg ha}^{-1}\text{) x Nutrient concentration (\%)}}{100}$$

$$\text{Carbon uptake (t C ha}^{-1}\text{)} = \frac{\text{Total Biomass (t ha}^{-1}\text{) x Carbon concentration (\%)}}{100}$$

3.11.2 Mineralization Quotient (qMin)

qMin = SOC (g C kg^{-1}) / TOC (g C kg^{-1})

3.11.3 Microbial Quotient (qMic)

qMic = SMBC (mg C kg^{-1}) / TOC (mg C kg^{-1})

3.11.4 Total Carbon Content in Above Ground Biomass

Total carbon content in above ground bamboo biomass was estimated by using following formula and expressed in t C ha^{-1}.

Total carbon in above ground bamboo biomass =

[Total stem biomass x % carbon in stem] +

[Total branch biomass x % carbon in branches] +

[Total leaves biomass x % carbon in leaf]

3.11.5 Total Carbon Content in Below Ground Biomass

Total carbon content in below ground bamboo biomass was estimated by using following formula and expressed in t C ha^{-1}.

Total carbon in below ground bamboo biomass =

[Total rhizome biomass x % carbon in rhizome] +

[Total root biomass x % carbon in root]

3.11.6 Total Biomass Carbon Stock

The total carbon storage *i.e.* plant biomass carbon stock was estimated by summing the total carbon content in aboveground and belowground biomass including leaf litter biomass and expressed in terms of t C ha^{-1}.

3.11.7 Carbon Sequestration Rate in Bamboos

Carbon sequestration rate in bamboos was calculated by using following formula and expressed in tonnes carbon per hectare per year (t C ha^{-1} $year^{-1}$).

$$\text{Plant carbon sequestration rate} = \frac{\text{Total biomass carbon stock}}{\text{Age of the plantation}}$$

3.11.8 Soil Carbon Stock Estimation

$$SOC = \sum^{depth=1} SOC_{depth} = \sum^{depth=n} ([SOC] \times BD \times Depth \times (1- C\ Frag) \times 10)_{depth}$$

Where,

SOC = representative SOC content for the soil of interest and forest type, t C ha^{-1}

SOC depth = soil organic carbon content for a constituent soil depth, t C ha^{-1}

[SOC] = SOC content in a given soil mass obtained from lab analysis, g C kg $soil^{-1}$

Bulk density = soil mass per sample volume, tones soil m^{-3} (equivalent to Mg m^{-3})

Depth = soil profile depth or thickness of soil layer, m

Coarse frag = % volume of coarse fragments divide by 100, dimensionless

(IPCC, 2003)

3.11.9 Total Carbon Stock

Total carbon stock (*i.e.,* biomass + soil carbon stock) was estimated by summing the biomass and soil carbon stocks as suggested by Tariyal *et al*. (2013) and expressed in t C ha^{-1}.

3.11.10 Carbon Sequestration Potential in Bamboo Plantation

Carbon sequestration potential in different bamboo species was calculated by using following formula. In this way carbon sequestration potential was obtained in t C ha^{-1} $year^{-1}$.

$$\text{Carbon sequestration potential} = \frac{\text{Total Carbon stock}}{\text{Age of plantation}}$$

3.11.11 Statistical Analysis

The experimental data generated from present study were analysed statistically by applying the technique of "Analysis of variance" *i.e.,* ANOVA table as described by Panse and Sukhatme (1985). Standard error of mean (SEm) and critical difference (CD) was worked out to evaluate differences between treatment means, which were reported in table 4.1 to 4.21.

4. RESULTS AND DISCUSSION

The observations recorded after 2nd year of plantation from long-term field experiment pertaining to the effect of different bamboo species on soil carbon content and microbial indices, soil physical, chemical and biological properties, growth attributing characters and biomass production, nutrient concentration and uptake, carbon stock and carbon sequestration rate have been tabulated, statistically processed and discussed in this chapter under the following heads:

4.1 Effect of Different Bamboo Species on Soil Carbon Content and Microbial Indices

4.2 Effect of Different Bamboo Species on Soil Properties

4.3 Effect of Different Bamboo Species on Growth Attributing Characters and Biomass Production

4.4 Effect of Different Bamboo Species on Nutrient Concentration and Nutrient Uptake

4.5 Effect of Different Bamboo Species on Carbon Stock and Carbon Sequestration

4.6 Correlation Between Soil Organic Carbon Pools and Soil Properties as Influenced by Different Bamboo Species

4.1 Effect of Different Bamboo Species on Soil Carbon Content and Microbial Indices

The soil carbon content (SOC and TOC) and soil labile carbon fractions (WSC, SMBC, POMC and POXC) were significantly influenced by different bamboo species after 2nd year of bamboo plantation grown on Entisol of semiarid climate.

4.1.1 Potassium Dichromate Oxidizable Carbon (SOC) Content

The data on effect of different bamboo species on potassium dichromate oxidizable carbon (SOC) content of Entisol soil in semiarid climate is presented in table 4.1 and fig 1. The soil organic carbon content was significantly influenced by different bamboo species after 2nd year of bamboo plantation.

The soil under the treatment of *Bambusa nutans* recorded significantly highest soil organic carbon content (8.07 g kg^{-1}) over rest of bamboo species. However, the soil organic carbon content under all tested bamboo species were statistically at par with each other after 2nd year of plantation. All the tested bamboo species recorded higher SOC content as compare to its initial soil level (6.70 g kg^{-1}). Similar findings regarding increase in soil organic carbon content over initial soil levels were reported by Venkatesh *et al*. (2005).

The increase in soil organic carbon content under tested bamboo species was ranged from 16.41 to 20.44% over its initial soil level. This increase in soil organic carbon content under the influence of bamboo species may be owed to the ability of bamboos to retain soil organic matter through sufficient production and decomposition of leaf-litter and below ground biomass (*i.e.*, rhizodeposition), which may have helped in slight build-up of soil organic carbon in soil under different bamboo species (Noble and Randall, 1998).

Table 4.1 Effect of different bamboo species on soil carbon content after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	SOC ($g\ C\ kg^{-1}$)	TOC ($g\ C\ kg^{-1}$)
T_1	*Dendrocalamus brandisii*	7.93	10.95
T_2	*Bambusa nutans*	8.07	12.97
T_3	*Bambusa balcooa*	7.80	11.08
T_4	*Dendrocalamus strictus*	7.87	11.52
T_5	*Bambusa tulda*	8.03	12.45
T_6	*Bambusa bamboos*	7.80	10.96
T_7	*Dendrocalamus asper*	7.83	10.80
	General mean	**7.90**	**11.53**
	Initial soil level	**6.70**	**8.15**
	SEm $\pm$	0.13	0.39
	CD at 5 %	0.41	1.21

4.1.2 Total Soil Organic Carbon (TOC) Content

The data on effect of different bamboo species on total soil organic carbon (TOC) content of Entisol soil in semiarid climate is presented in table 4.1 and fig 1. The TOC content of Entisol soil was significantly influenced by different bamboo species after 2^{nd} year of plantation.

The soil under the treatment of *Bambusa nutans* recorded significantly highest TOC content (12.97 g kg^{-1}) which was statistically at par with *Bambusa tulda* (12.45 g kg^{-1}). All the tested bamboo species recorded higher TOC content over its initial soil level (8.15 g kg^{-1}) after 2^{nd} year of bamboo plantation. The increase in TOC content under tested bamboo species varies from 32.51 to 59.14% as compared to its initial level. This increase in TOC content may be due to deposition and decomposition of leaf-litter and fine-root biomass in soil supported by addition of organic manure and mulching effect created by bamboo biomass (Youngfu *et al.*, 2010).

4.1.3 Soil Labile Carbon Fractions

The soil labile carbon fractions were significantly influenced under different bamboo species after 2^{nd} year of plantation grown on Entisol of semiarid climate.

4.1.3.1 Water soluble carbon (WSC) content

The data on effect of different bamboo species on water soluble carbon (WSC) content of Entisol soil in semiarid climate is presented in table 4.2. The WSC content of Entisol soil was significantly influenced by different bamboo species after 2^{nd} year of bamboo plantation.

The soil under the treatment of *Bambusa tulda* recorded significantly highest WSC content (14.08 mg kg^{-1}), which was statistically at par with *B. nutans and D. strictus*. All the tested bamboo species recorded higher WSC content over its initial soil level (9.20 mg kg^{-1}) after 2^{nd} year of plantation. The increase in WSC content under tested bamboo species ranged from 31.73 to 53.04% in comparison to its initial level after 2^{nd} year of plantation grown on Entisol of semiarid climate. Similar results were also reported by Youngfu *et al.* (2010).

This increase in water soluble carbon content might be due root exudation from bamboo plant such as sugars, organic acids, hormones, sloughed root cell and carbon allocated to root associated symbionts, as these substrates provide favourable resources for microbial activities and indirectly results in increased of water soluble carbon content in soil under bamboo species.

Table 4.2 Effect of different bamboo species on soil labile carbon fractions after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil labile carbon fractions			
		WSC ($mg\ C\ kg^{-1}$)	**SMBC ($mg\ C\ kg^{-1}$)**	**POMC ($g\ C\ kg^{-1}$)**	**POXC ($g\ C\ kg^{-1}$)**
T_1	*D. brandisii*	12.31	145.5	1.86	0.656
T_2	*B. nutans*	14.00	167.0	1.88	0.666
T_3	*B. balcooa*	12.12	144.6	1.72	0.652
T_4	*D. strictus*	13.52	166.0	1.74	0.654
T_5	*B. tulda*	14.08	181.7	1.90	0.662
T_6	*B. bamboos*	12.67	158.2	1.70	0.650
T_7	*D. asper*	12.84	161.3	1.76	0.648
	General mean	**13.08**	**160.61**	**1.80**	**0.655**
	Initial / Control	**9.20**	**74.05**	**1.43**	**0.404**
	SEm ±	0.27	2.98	0.03	0.005
	CD at 5 %	0.84	9.14	0.08	0.015

4.1.3.2 Soil microbial biomass carbon (SMBC) content

The data on effect of different bamboo species on soil microbial biomass carbon content of Entisol soil in semiarid climate is presented in table 4.2. The soil under all the tested bamboo species recorded SMBC content in the range of 2.73 to 2.97 % to its soil TOC content (Dilly *et al*., 2003) which was found higher over its control plot`s SMBC content (1.45%).

The soil under the treatment of *Bambusa tulda* recorded significantly highest SMBC content (181.7 mg kg^{-1}) over all the tested bamboo species. The increase in SMBC content under tested bamboo species varies from 95.27 to 145.37 % as compared to its control (74.05 mg kg^{-1}) after 2nd year of bamboo plantation grown on Entisol of semiarid climate. The results are in corroborative with the findings of Youngfu *et al.* (2010).

4.1.3.3 Particulate organic matter carbon (POMC) content

The data on effect of different bamboo species on particulate organic matter carbon (POMC) content of Entisol soil in semiarid climate is presented in table 4.2. The POMC content was significantly influenced under different bamboo species after 2nd year of bamboo plantation.

The soil under the treatment of *Bambusa tulda* recorded significantly highest POMC content (1.90 g kg^{-1}), which was found statistically at par with *B. nutans* and *D. brandisii*. All the tested bamboo species recorded higher POMC content over its initial soil level (1.43 g kg^{-1}). Overall, the increase in POMC content under all tested bamboo species varies from 18.88 to 32.86 % in comparison to its initial soil level after 2nd year of plantation.

This increase in POMC content can be attributed to higher litter biomass production and fibrous root system of bamboo. Similar findings were also reported by Jahan *et al*. (2020). Also, the application of manure increases the formation and stabilization of soil macroaggregates (Whalen and Chang, 2002) and development of particulate organic matter (Kapkiyai *et al.* 1999).

4.1.3.4 Permanganate oxidizable soil carbon (POXC) content

The data on effect of different bamboo species on permanganate oxidizable soil carbon content is presented in table 4.2. The POXC was significantly influenced under bamboo species.

The soil under the treatment of *Bambusa nutans* recorded significantly highest POXC content (0.666 g kg^{-1}), which was statistically at par with all the tested bamboo species except *D. asper* (0.648 g kg^{-1}). The POXC content under tested bamboo species was ranged between 0.648 to 0.666 g kg^{-1} which was significantly highest over its initial soil level (0.404 g kg^{-1}). Overall, the increase in POXC content under tested bamboo species varies from 60.39 to 64.85 % over its initial soil level after 2^{nd} year of plantation grown on Entisol. This increase in soil POXC content under tested bamboo species might be due to the fact that, soil under bamboos remained unaffected by tillage practices and litter fall tends to accumulate, its decomposition contributes to higher permanganate oxidizable soil carbon content in soil.

4.1.4 Microbial Indices

The microbial indices were significantly influenced under different bamboo species after 2^{nd} year of plantation grown on Entisol of semiarid climate

4.1.4.1 Mineralization quotient (SOC/TOC)

The data regarding effect of different bamboo species on mineralization quotient (qMin) is presented in table 4.3. Mineralizable carbon represents performance of OC decomposer in soil. SOC/TOC *i.e.,* qMin ratio is a sensitive indicator for changes in soil organic matter.

The treatment, *Bambusa nutans* recorded significantly lower qMin ratio (0.63), which was statistically at par with treatments *B. tulda* and *D. strictus* (0.65 and 0.69 respectively). All the tested bamboo species showed significantly lower qMin ratio as compared to initial. Lower values of qMin ratio indicate better carbon stabilization in the soil. Overall, the reduction in qMin ratio under tested bamboo species varies from 12.32 to 30.15 % in comparison to its initial soil ratio after 2^{nd} year of plantation. Whereas, comparatively higher qMin ratio (0.82) of initial may be due to lower carbon content in the soil than those recorded under tested bamboo species.

4.1.4.2 Microbial quotient (SMBC/TOC)

The data on effect of different bamboo species on microbial quotient is presented in table 4.3. The microbial quotient (qMic) was significantly influenced under different bamboo species.

The treatment, *Dendrocalamus asper* recorded significantly highest qMic ratio (1.50), which was statistically at par with *D. strictus, B. tulda* and *B. bamboos* (1.47, 1.46 and 1.44 respectively). All the bamboo species treatments showed highest qMic ratio as compared to initial (0.91), indicating that there might be more labile carbon content in the soil. Overall, the increase in qMic ratio due to bamboo species treatments varies from 41.75 to 64.83 % over its initial soil ratio after 2nd year of plantation grown on Entisol of semiarid climate. Whereas, lower value of qMic ratio of initial soil indicate nutritional stress and poor soil quality (Sparling, 1992).

Table 4.3 Effect of different bamboo species on microbial indices after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Mineralization quotient (qMin)	Microbial quotient (qMic)
T_1	*Dendrocalamus brandisii*	0.73	1.33
T_2	*Bambusa nutans*	0.63	1.29
T_3	*Bambusa balcooa*	0.70	1.31
T_4	*Dendrocalamus strictus*	0.69	1.47
T_5	*Bambusa tulda*	0.65	1.46
T_6	*Bambusa bamboos*	0.71	1.44
T_7	*Dendrocalamus asper*	0.73	1.50
	General Mean	**0.69**	**1.40**
	Initial soil ratio	**0.82**	**0.91**
	SE ±	0.02	0.04
	CD at 5 %	0.06	0.12

4.2 Effect of Different Bamboo Species on Soil Properties

4.2.1 Soil Microbial Population

The soil under the treatments of different bamboo species significantly influenced the soil microbial population (*i.e.,* bacteria, fungi and actinomycetes counts) after 2nd year of plantation.

4.2.1.1 Total soil bacterial population

The data regarding effect of different bamboo species on total soil bacterial population of Entisol soil in semiarid climate is presented in table 4.4 and fig 2.

The soil bacterial population under bamboo species treatment varies from 9.33 to 11.67 cfu x 10^6 g^{-1} soil. All the bamboo species treatments recorded higher soil bacterial count over its control plot (6.00 cfu x 10^6 g^{-1} soil). Among the tested bamboo species, the soil under, *B. tulda* recorded highest bacterial count (11.67 cfu x 10^6 g^{-1} soil), however it was at par with other bamboo species. Overall, the increase in soil bacterial count under tested bamboo species varies from 55.5 to 94.5 % as compared to its control plot counts after 2nd year of plantation grown on Entisol of semiarid climate. Similar findings were also reported by Kaushal *et al.* (2020)

The increase in soil bacteria population under bamboo species might be attributed to favourable microclimatic environment created due to mulching of leaf litter, enhancement in soil carbon content, soil available nutrient and moisture content, non-disturbance of soil, root exudates secreted by the bamboo plants in the rhizosphere. Whereas, variation in soil microbial count among bamboo species may be due to differences in root intensity, amount of litter-fall and fine-roots turnover (Kirchner *et al.*, 1993).

Table 4.4 Effect of different bamboo species on soil microbial population after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Total soil microbial population		
		Bacteria (cfu x 10^6 g^{-1} soil)	**Fungi (cfu x 10^4 g^{-1} soil)**	**Actinomycetes (cfu x 10^5 g^{-1} soil)**
T_1	*D. brandisii*	9.67	8.00	9.33
T_2	*B. nutans*	11.33	10.00	10.00
T_3	*B. balcooa*	10.00	9.00	8.33
T_4	*D. strictus*	10.33	8.67	9.33
T_5	*B. tulda*	11.67	11.00	10.67
T_6	*B. bamboos*	9.33	9.67	8.67
T_7	*D. asper*	9.67	9.67	8.33
	General mean	**10.29**	**9.43**	**9.24**
	Control plot	**6.00**	**4.00**	**4.00**
	SEm ±	0.66	0.65	0.55
	CD at 5 %	2.04	1.99	1.69

4.2.1.2 Total soil fungi population

The data regarding effect of different bamboo species on total soil fungi population of Entisol soil in semiarid climate is presented in table 4.4 and fig 2.

The soil under *B. tulda* recorded highest fungi count (11.00 cfu x 10^4 g^{-1} soil), however, it was statistically at par with *B. nutans*, *B. bamboos* and *D. asper* (10.00, 9.67 and 9.67 cfu x 10^4 g^{-1} soil, respectively). All the bamboo species treatments recorded higher soil fungi count as compared to its control plot fungi count (4.00 cfu x 10^4 g^{-1} soil). Overall, the increase in the fungi count under bamboo species varies from 100 to 175 % over its control plot count after 2nd year of bamboo plantation. Similar findings were reported by Hemavathi *et al*. (2006).

The increase in soil fungi population might be attributed to favourable microclimatic environment created due to mulching of leaf litter, enhancement in soil carbon content, soil available nutrient and moisture content, non-disturbance of soil, root exudates secreted by the bamboo plants in the rhizosphere.

4.2.1.3 Total soil actinomycetes population

The data regarding effect of different bamboo species on total soil actinomycetes population of Entisol soil in semiarid climate is presented in table 4.4 and fig 2.

The soil under *B. tulda* recorded highest actinomycetes count (10.67 cfu x 10^5 g^{-1} soil), which was found statistically at par with *B. nutans, D. brandisii* and *D. strictus* (10.00, 9.33 and 9.33 cfu x 10^5 g^{-1} soil, respectively). All the tested bamboo species recorded significantly higher soil actinomycetes count as compared to control plot count. Overall, the increase in the actinomycetes count under bamboo species varies from 108.2 to 166.7 % over its control after 2nd year of bamboo plantation. Similar findings were reported by Hemavathi *et al*. (2006).

The increase in soil actinomycetes population might be attributed to favourable microclimatic environment created due to mulching of leaf litter, enhancement in soil carbon content, soil available nutrient and moisture content, root exudates secreted by the bamboo plants in the rhizosphere. While comparatively lower microbial count in control plots may be due to disturbance of rhizosphere soil created by tillage practices (Allison et al., 2005).

4.2.2 Soil Dehydrogenase Enzyme Activity

The data regarding effect of different bamboo species on soil dehydrogenase enzyme activity after 2nd year of plantation grown on Entisol of semiarid climate is presented in table 4.5 and fig 3. The soil dehydrogenase enzyme activity was significantly influenced under different bamboo species after 2nd year of bamboo plantation grown on Entisol of semiarid climate.

The soil under the treatment of *Bambusa tulda* recorded significantly highest soil dehydrogenase enzyme activity (3.63 µg TPF released g^{-1} soil hr^{-1}), which was statistically at par with *Bambusa nutans* (3.47 µg TPF released g^{-1} soil hr^{-1}). All the tested bamboo species recorded higher soil dehydrogenase enzyme activity over its control (2.87 µg TPF released g^{-1} soil hr^{-1}). Overall, the increase in soil dehydrogenase enzyme activity under the tested bamboo species treatments varies from 9.05 to 26.48 % as compare to its control plot value after 2nd year of plantation grown on Entisol. Similar findings were also reported by Kaushal *et al.* (2020).

The increase in soil dehydrogenase enzyme activity under bamboo species may be attributed to higher organic carbon content in the rhizosphere soil, resulted from accumulation of higher amount of litterfall and root exudates and this carbon is used by soil microbes to carry out metabolism and stimulate microbial growth resulting into higher soil dehydrogenase enzyme activity. Whereas, lower soil dehydrogenase enzyme activity in the control plot might be due to more exposure of surface soil to sunlight, lack of moisture and temperature regulation.

Table 4.5 Effect of different bamboo species on soil dehydrogenase enzyme activity after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil dehydrogenase enzyme activity	
		(µg TPF g^{-1} soil hr^{-1})	(µg TPF g^{-1} soil 24 $hrs.^{-1}$)
T_1	*Dendrocalamus brandisii*	3.23	77.60
T_2	*Bambusa nutans*	3.47	83.20
T_3	*Bambusa balcooa*	3.17	76.00
T_4	*Dendrocalamus strictus*	3.23	77.60
T_5	*Bambusa tulda*	3.63	87.20
T_6	*Bambusa bamboos*	3.13	75.20
T_7	*Dendrocalamus asper*	3.17	76.00
	General mean	**3.29**	**78.97**
	Control plot	**2.87**	**68.80**
	SEm ±	0.12	2.99
	CD at 5 %	0.38	9.08

4.2.3 Soil pH, EC and $CaCO_3$ Content

The data regarding effect of different bamboo species on soil pH, EC and $CaCO_3$ content of Entisol soil under semiarid climatic condition is presented in table 4.6. The soil pH and EC was significantly influenced under different bamboo species after 2nd year of bamboo plantation.

Table 4.6 Effect of different bamboo species on soil chemical properties after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil chemical properties		
		pH (1:2.5)	EC (1:2.5) (dS m^{-1})	$CaCO_3$ (%)
T_1	*Dendrocalamus brandisii*	7.50	0.16	3.60
T_2	*Bambusa nutans*	7.45	0.15	3.56
T_3	*Bambusa balcooa*	7.70	0.19	3.60
T_4	*D. strictus*	7.65	0.18	3.66
T_5	*Bambusa tulda*	7.46	0.15	3.60
T_6	*Bambusa bamboos*	7.95	0.20	3.41
T_7	*Dendrocalamus asper*	7.60	0.17	3.48
	General mean	**7.62**	**0.17**	**3.56**
	Initial soil level	**8.01**	**0.21**	**3.37**
	SEm ±	0.01	0.01	0.10
	CD at 5 %	0.04	0.04	NS

The pH of soil in all the tested bamboo species varies in the range of 7.45 to 7.95 which were significantly lower as compare to its initial soil pH level (8.01). The reduction in soil pH was observed in the range of 0.75 to 7.5 % over its initial soil level after 2nd year of bamboo plantation. Among the tested bamboo species treatments, the highest reduction in soil pH was observed under the treatment of *Bambusa nutans* (7.45) which was found statistically at par with the treatment of *Bambusa tulda* (7.46). Similar findings were reported by Kaushal *et al.* (2020).

The reduction in soil pH under the influence of tested bamboo species might be due to rapid and continuous decomposition of organic matter, which may have produced some organic acids. Also, the root exudation of organic anions from bamboo species such as malate, citrate and oxalate resulted in reduction of soil pH.

The soil under the treatments of *Bambusa nutans* and *Bambusa tulda* recorded lowest soil Electrical conductivity (0.15 dSm^{-1}) which was at par with the treatment of *Dendrocalamus brandisii, Dendrocalamus asper, Dendrocalamus strictus* and *Bambusa balcooa* (0.16, 0.17, 0.18 and 0.19 dS m^{-1} respectively). The soil Electrical conductivity under all the tested bamboo species varies in the range of 0.15 to 0.21 dSm^{-1} which were 4.76 to 28.57 % low as compare to its initial soil level after 2nd year of bamboo plantation grown on Entisol of semiarid climate. Kim *et al*. (2018) also reported reduction in soil EC under the bamboo plantation.

The reduction in soil Electrical conductivity under tested bamboo species treatments might be due to leaching of soluble salts from rhizosphere, which may be attributed to increase in infiltration rate as well as the growth of bamboo species is very fast, hence, there may be very high uptake of soluble salts of calcium, magnesium and potassium from rhizosphere which results in reduction of soil Electrical conductivity.

The $CaCo_3$ content under the different bamboo species were found at par with each other as well as initial soil level after 2nd year of plantation grown on Entisol of semiarid climate.

4.2.4 Soil Available Nutrients Content

The soil available nutrients (N, P and K) were significantly influenced under different bamboo species after 2nd year of plantation grown on Entisol of semiarid climatic condition.

4.2.4.1 Soil available nitrogen content

The data regarding effect of different bamboo species on soil available nitrogen content of Entisol soil in semiarid climate is presented in table 4.7 and fig 4.

The soil under the treatment of *Bambusa tulda* recorded significantly highest soil available nitrogen content (191.83 kg ha^{-1}), which was found statistically at par with all the tested bamboo species treatments. The soil available nitrogen content in all the tested bamboo species varies in the range of 187.47 to 191.83 kg ha^{-1} which was significantly higher as compared to its initial soil available nitrogen content (178.70 kg ha^{-1}). The increase in soil available nitrogen content under tested bamboo species varies from 4.90 to 7.34 % over its initial soil level after 2nd year of plantation grown on Entisol of semiarid climate. Similar findings were also reported by Tariyal *et al*. (2013). This increase in soil available nitrogen content may be due to application of manure and fertilizer nutrients to bamboo, thereby increasing the soil carbon content which improves cation exchange capacity of soil and reduces leaching losses.

4.2.4.2 Soil available phosphorus content

The data regarding effect of different bamboo species on soil available phosphorus content of Entisol soil in semiarid climate is presented in table 4.7 and fig 5.

The soil under the treatment of *Bambusa tulda* recorded significantly highest soil available phosphorus content (8.37 kg ha^{-1}), which was found statistically at par with all the tested bamboo species treatments. The soil available phosphorus content in all the tested bamboo species varies in the range of 8.17 to 8.37 kg ha^{-1} which was significantly higher as compared to its initial soil available phosphorus content (6.10 kg ha^{-1}). The increase in soil available phosphorus content under tested bamboo species varies from 33.93 to 37.21 % over its initial level after 2nd year of plantation grown on Entisol of semiarid climate. Similar findings were also reported by Tariyal *et al*. (2013). The increase in soil available phosphorus content may be due to application of manure and fertilizer nutrients to bamboo. Also, the slight reduction in soil pH and higher rooting intensity in bamboo species helps in dissolution of inorganic phosphorus.

4.2.4.3 Soil available potassium content

The data regarding effect of different bamboo species on soil available potassium content of Entisol soil in semiarid climate is presented in table 4.7 and fig 6.

The soil under the treatment of *Bambusa tulda* recorded significantly highest soil available potassium content (410.33 kg ha^{-1}), which was found to be statistically at par with all the tested bamboo species treatments. The soil available potassium content in all the tested bamboo species varies in the range of 409.33 to 410.33 kg ha^{-1} which was significantly higher as compared to its initial soil available potassium content (403.20 kg ha^{-1}). The increase in soil available potassium content under the tested bamboo species varies from 1.52 to 1.76 % over its initial level after 2nd year of plantation grown on Entisol of semiarid climatic condition. Similar findings were also reported by Kumari *et al*. (2017) and Tariyal *et al*. (2013).

The slight increase in soil available potassium content may be due to application of manure and fertilizer nutrients to bamboo plantation.

Table 4.7 Effect of different bamboo species on soil available nutrients content after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil available nutrients content (kg ha^{-1})		
		Nitrogen (N)	Phosphorus (P)	Potassium (K)
T_1	*Dendrocalamus brandisii*	187.47	8.17	409.60
T_2	*Bambusa nutans*	189.73	8.33	410.07
T_3	*Bambusa balcooa*	187.47	8.17	409.67
T_4	*Dendrocalamus strictus*	189.73	8.17	409.73
T_5	*Bambusa tulda*	191.83	8.37	410.33
T_6	*Bambusa bamboos*	187.83	8.27	409.33
T_7	*Dendrocalamus asper*	189.13	8.30	409.67
	General mean	**189.03**	**8.25**	**409.77**
	Initial soil level	**178.70**	**6.10**	**403.20**
	SEm ±	2.35	0.22	1.23
	CD at 5 %	7.19	0.68	3.78

4.2.5 Soil Bulk Density

The data on effect of different bamboo species on bulk density of Entisol soil in semiarid climate is presented in table 4.8. Soil BD was significantly influenced by tested bamboo species.

Table 4.8 Effect of different bamboo species on soil bulk density after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil bulk density (Mg m^{-3})
T_1	*Dendrocalamus brandisii*	1.50
T_2	*Bambusa nutans*	1.47
T_3	*Bambusa balcooa*	1.50
T_4	*Dendrocalamus strictus*	1.50
T_5	*Bambusa tulda*	1.47
T_6	*Bambusa bamboos*	1.48
T_7	*Dendrocalamus asper*	1.50
	General mean	**1.49**
	Control plot	**1.51**
	SEm ±	0.002
	CD at 5 %	0.007

The soil bulk density under different bamboo species varies between 1.47 to 1.50 Mg m^{-3} as compared to its control (1.51 Mg m^{-3}). The soil under the treatments of *Bambusa nutans* and *Bambusa tulda* showed significantly lower bulk density (1.47 Mg m^{-3}) which was at par with *Bambusa bamboos* (1.48 Mg m^{-3}). Similar results were also reported by Kaushal *et al.* (2020).

The reduction in bulk density may be attributed to the increase in total soil carbon content resulted due to leaf litter deposition and higher fine root system which increases the pore space.

4.3 Effect of Different Bamboo Species on Growth Attributing Characters and Biomass Production

4.3.1 Growth Attributing Characters

The data regarding effect of different bamboo species on growth attributing characters after 2nd year of plantation grown on Entisol of semiarid climate is presented in table 4.9.

4.3.1.1 Number of culms per clump

The treatment, *Bambusa tulda* recorded highest number of culms per clump (59.32) followed by *Bambusa nutans* (44.68) and *Dendrocalamus brandisii* (36.20). Whereas, *Bambusa bamboos* recorded lowest number of culms per clump (10.48) closely followed by *Bambusa balcooa* (13.72) and *Dendrocalamus strictus* (15.24) after 2nd year of bamboo plantation.

4.3.1.2 Culm density (culms ha^{-1})

The treatment, *Bambusa tulda* (49413.56 culms ha^{-1}) recorded highest culm density followed by *Bambusa nutans* (37218.14 culms ha^{-1}). While, lowest culm density was found in *Bambusa bamboos* (8729.34 culms ha^{-1}) followed by *Bambusa balcooa* (11428.76 culms ha^{-1}) and *Dendrocalamus strictus* (12694.92 culms ha^{-1}) after 2nd year of bamboo plantation.

4.3.1.3 Number of new culms per clump

The treatment, *Bambusa tulda* (13.80) recorded highest number of new culms per clump followed by *Bambusa nutans* (12.93) and *Dendrocalamus brandisii* (11.80). Whereas, *Bambusa bamboos* recorded lowest numbers of culms per clump (5.33) closely followed by *Bambusa balcooa* (5.67) and *Dendrocalamus strictus* (5.80) after 2nd year of bamboo plantation.

4.3.1.4 Culm height (m)

The treatment, *Dendrocalamus strictus* (6.39 m) recorded highest culm height followed by *Bambusa balcooa* (6.33 m) and *Bambusa nutans* (6.05 m). While, lowest culm height was recorded in *D. asper* (3.82 m) followed by *D. brandisii* (3.93 m) after 2nd year of plantation.

4.3.1.5 Basal diameter of culm (BDc)

The treatment, *Dendrocalamus strictus* (8.16 cm) recorded highest basal diameter of culm closely followed by *Bambusa bamboos* (7.19 cm) and *Bambusa balcooa* (7.01 cm). While, lowest basal diameter of culm (2.96 cm) was recorded in *Bambusa tulda* followed by *D.brandisii* (3.14 cm) and *D. asper* (3.92 cm), after 2nd year of plantation.

4.3.1.6 Diameter at breast height (DBH)

The treatment, *Dendrocalamus strictus* (7.13 cm) recorded highest diameter at breast height followed by *Bambusa bamboos* (6.38 cm) and *Bambusa balcooa* (6.35 cm). While, lowest DBH (2.51 cm) was recorded in *Bambusa tulda* followed by *Dendrocalamus brandisii* (2.98 cm), *Dendrocalamus asper* (3.38 cm) and *Bambusa nutans* (3.49 cm), after 2nd year of bamboo plantation grown on Entisol of semiarid climate.

4.3.1.7 Culm girth at 5th internode (cm)

The treatment, *Dendrocalamus strictus* (16.53 cm) recorded highest culm girth at 5th internode closely followed by *Bambusa bamboos* (15.99 cm) and *Bambusa balcooa* (14.73 cm). Whereas, *Dendrocalamus brandisii* (6.59 cm) recorded lowest culm girth at 5th internode followed by *Bambusa tulda* (7.00 cm), *Dendrocalamus asper* (7.87 cm) and *Bambusa nutans* (8.34 cm), after 2nd year of plantation grown on Entisol of semiarid climate.

4.3.1.8 Clump girth (cm)

The treatment, *Bambusa tulda* recorded highest clump girth (717.27 cm) followed by *Bambusa nutans* (682.07 cm) and *Dendrocalamus strictus* (638.33 cm). Whereas, *Bambusa balcooa* recorded lowest clump girth (478.47 cm) closely followed by *Dendrocalamus brandisii* (530.93 cm) and *Dendrocalamus asper* (539.73 cm), after 2nd year of plantation.

4.3.1.9 Internodal length (cm)

The treatment, *Dendrocalamus* strictus recorded highest internodal length (27.51 cm) closely followed by *Bambusa* balcooa (25.31 cm) and *Bambusa* nutans (23.03 cm). While, lowest internodal length (16.64 cm) was recorded in *Dendrocalamus* asper followed by *Dendrocalamus* brandisii (17.19 cm) and *Bambusa* tulda (17.94 cm), after 2nd year of plantation.

4.3.1.10 Number of internodes per culm

The treatment, *Bambusa* bamboos recorded highest number of internodes per culm (28.34) followed by *Bambusa nutans* (26.27) and *Bambusa tulda* (26.03). Whereas, *Dendrocalamus brandisii* recorded lowest number of internodes per culm (22.86) closely followed by *Dendrocalamus* asper (22.95) and *Dendrocalamus* strictus (23.22), after 2nd year of plantation grown on Entisol of semiarid climate.

4.3.1.11 Average culm weight (kg)

The treatment, *Bambusa bamboos* recorded highest average culm weight *i.e.,* biomass allocated per culm (2.31 kg) closely followed by *Dendrocalamus* strictus (2.24 kg). While, lowest average culm weight (1.32 kg) was recorded in *Bambusa* tulda followed by *Dendrocalamus brandisii* (1.35 kg) and *Dendrocalamus asper* (1.68 kg).

Table 4.9 Effect of different bamboo species on growth attributing characters after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Growth attributing characters										
		Number of culms per clump	**Culm density (culm ha^{-1})**	**Number of new culms per clump**	**Culm height (m)**	**Basal diameter of culm (cm)**	**Diameter at breast height (cm)**	**Culm girth at 5th internode (cm)**	**Clump girth (cm)**	**Inter-nodal length (cm)**	**Number of Inter-nodes per culm**	**Average Culm weight (kg culm^{-1})**
T_1	*Dendrocalamus brandisii*	36.20	30154.60	11.80	3.93	3.14	2.98	6.59	530.93	17.19	22.86	1.35
T_2	*Bambusa nutans*	44.68	37218.44	12.93	6.05	4.03	3.49	8.34	682.07	23.03	26.27	1.78
T_3	*Bambusa balcooa*	13.72	11428.76	5.67	6.33	7.01	6.35	14.73	478.47	25.31	25.00	1.96
T_4	*Dendrocalamus strictus*	15.24	12694.92	5.80	6.39	8.16	7.13	16.53	638.33	27.51	23.22	2.24
T_5	*Bambusa tulda*	59.32	49413.56	13.80	4.67	2.96	2.51	7.00	717.27	17.94	26.03	1.32
T_6	*Bambusa bamboos*	10.48	8729.84	5.33	5.97	7.19	6.38	15.99	576.80	21.06	28.34	2.31
T_7	*Dendrocalamus asper*	19.68	16393.44	9.27	3.82	3.92	3.38	7.87	539.73	16.64	22.95	1.68
	General mean	**28.47**	**23719.08**	**9.23**	**5.31**	**5.20**	**4.60**	**11.01**	**594.8**	**21.24**	**24.95**	**1.81**
	SEm ±	1.98	820.40	0.58	0.18	0.47	0.44	0.62	34.20	1.23	1.31	0.12
	CD at 5 %	5.99	2468.00	1.80	0.60	1.46	1.35	1.93	105.38	3.73	3.98	0.38

From the data presented in table 4.9 it is clear that tested bamboo species showed significant variation in growth attributing characteristics among themselves after 2nd year of plantation grown on Entisol of semiarid climate.

Growth and developmental characteristics of individual bamboo species rely upon its genetic makeup, climate, genotype and environmental interactions (Kumari *et al*., 2017). As well as above ground biomass and dry matter accumulation increases significantly concomitant with DBH and culm height which in turn contributes its major share to the total biomass (Shanmughavel and Francis, 1996).

4.3.2 Biomass Production

The data regarding effect of different bamboo species on biomass production is presented in table 4.10 and fig 7. The above ground and below ground biomass was significantly influenced by different bamboo species after 2nd year of bamboo plantation grown on Entisol.

Table 4.10 Effect of different bamboo species on biomass production after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Biomass production (t ha^{-1})						Total bamboo biomass (t ha^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	22.22	9.43	3 27	2.02	1.36	2.39	40.69
T_2	*B. nutans*	39.80	14.20	4.43	2.68	1.97	3.06	66.15
T_3	*B. balcooa*	14.06	4.65	1.42	0.81	0.48	1.03	22.45
T_4	*D. strictus*	18.47	5.76	1.57	0.88	0.61	1.09	28.38
T_5	*B. tulda*	38.95	12.91	4.07	3.16	2.03	3.89	65.01
T_6	*B. bamboos*	13.84	3.60	1.10	0.57	0.38	0.71	20.21
T_7	*D. asper*	16.60	5.70	1.89	1.15	0.82	1.31	27.56
	General mean	**23.42**	**8.04**	**2.54**	**1.61**	**1.09**	**1.93**	
	SEm $\pm$	0.74	0.25	0.18	0.10	0.10	0.12	
	CD at 5 %	2.32	0.80	0.57	0.34	0.32	0.38	

Among the tested bamboo species, the treatment, *Bambusa nutans* recorded significantly highest stem biomass (39.80 t ha^{-1}) which was at par with *Bambusa tulda* (38.95 t ha^{-1}), whereas, the treatment, *Bambusa bamboos* recorded lowest stem biomass (13.84 t ha^{-1}). Similar trend was observed in case of leaves biomass, the treatment *Bambusa nutans* recorded significantly highest leaves biomass (4.43 t ha^{-1}). The biomass of branches was found significantly highest in *Bambusa nutans* (14.20 t ha^{-1}) over rest of the tested bamboo species, whereas the lowest stem biomass was recorded in *Bambusa bamboos* (3.60 t ha^{-1}) after 2nd year of bamboo plantation.

For the leaf litter biomass, the treatment of *Bambusa tulda* recorded significantly highest leaf litter biomass (3.89 t ha^{-1}) over all the tested bamboo species, whereas, the treatment of *Bambusa bamboos* recorded lowest leaf litter biomass (0.71 t ha^{-1}) after 2nd year of plantation.

Among the tested bamboo species, *Bambusa tulda* recorded significantly highest rhizome and root biomass (3.16 and 2.03 t ha^{-1} respectively), whereas, the treatment *B. bamboos* recorded lowest rhizome and root biomass (0.57 and 0.38 t ha^{-1} respectively). The treatment, *Bambusa nutans* was found at par with *Bambusa tulda* for the root biomass (1.97 t ha^{-1}).

Overall among the tested bamboo species, *Bambusa nutan* recorded highest aboveground biomass (58.43 t ha^{-1}) followed by *Bambusa tulda* (55.93 t ha^{-1}). Whereas, *Bambusa tulda* recorded highest belowground biomass (5.19 t ha^{-1}) followed by *Bambusa nutans* (4.65 t ha^{-1}). The treatment of *Bambusa nutans* recorded highest total biomass (66.15 t ha^{-1}) which was closely followed by *Bambusa tulda* (65.01 t ha^{-1}) after 2nd year of bamboo plantation.

Considering the average effect of biomass components in all the tested bamboo species, the contribution of stem, branches, leaves, leaf-litter, rhizome and root biomass in total bamboo biomass was 61.62, 20.58, 6.45, 4.74, 3.94 and 2.66 % respectively (Appendix III).

4.4 Effect of Different Bamboo Species on Nutrient Concentration and Nutrient Uptake

4.4.1 Nutrient Concentration in Bamboo

The nutrient concentration in bamboo biomass components was significantly influenced by different bamboo species after 2nd year of plantation grown on Entisol of semiarid climate.

4.4.1.1 Nitrogen concentration in bamboo biomass components

The data on effect of different bamboo species on nitrogen concentration in bamboo biomass components after 2nd year of bamboo plantation is presented in table 4.11.

The nitrogen concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter biomass was ranged between 0.49-0.70, 0.56-0.70, 1.33-1.54, 0.56-0.70, 0.56-0.70 and 0.63-0.84 percent nitrogen respectively after 2nd year of bamboo plantation grown on Entisol.

The treatment of *Dendrocalamus asper* recorded highest N concentration in bamboo leaves and leaf-litter biomass (1.75 and 0.84 % N respectively) over rest of the bamboo species except *D. brandisii* which was at par for the leaves N concentration (1.68 N %). The treatment of *B. tulda* recorded highest N concentration in bamboo branches and roots (0.70 % N each) over other bamboo species. The treatment of *D. brandisii* recorded highest N concentration in bamboo stem and rhizome (0.70 % N each) over the rest of tested bamboo species except *B. balcooa* which recorded same N concentration in bamboo rhizome (0.70 % N).

Considering the mean of all the tested bamboo species, nitrogen concentration in different bamboo biomass components was found in the order of leaves > leaf-litter > rhizome $\simeq$ branches $\simeq$ roots > stem after 2nd year of plantation grown on Entisol of semiarid climate.

Table 4.11 Effect of different bamboo species on N concentration in bamboo biomass components after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Nitrogen concentration in bamboo biomass components (% N)					
		Above ground biomass			Below ground biomass		Leaf litter Biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	0.70	0.63	1.68	0.70	0.56	0.70
T_2	*B. nutans*	0.63	0.63	1.54	0.63	0.56	0.70
T_3	*B. balcooa*	0.56	0.56	1.33	0.70	0.63	0.70
T_4	*D. strictus*	0.49	0.56	1.40	0.63	0.56	0.63
T_5	*B. tulda*	0.56	0.70	1.40	0.63	0.70	0.77
T_6	*B. bamboos*	0.56	0.56	1.47	0.56	0.63	0.77
T_7	*D. asper*	0.56	0.56	1.75	0.63	0.56	0.84
	General mean	**0.58**	**0.60**	**1.51**	**0.64**	**0.60**	**0.73**
	SEm ±	0.010	0.012	0.025	0.012	0.012	0.012
	CD at 5 %	0.020	0.038	0.077	0.038	0.038	0.038

4.4.1.2 Phosphorous concentration in bamboo biomass components

The data on effect of different bamboo species on phosphorus concentration in bamboo biomass components after 2nd year of bamboo plantation is presented in table 4.12.

The phosphorus concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter biomass was ranged between 0.062-0.071, 0.092-0.099, 0.070-0.078, 0.071-0.079, 0.065-0.085 and 0.068-0.079 percent phosphorus respectively after 2nd year of bamboo plantation.

The treatment of *Bambusa balcooa* recorded significantly highest P concentration in bamboo stem, branches, leaves, rhizome and roots (0.071, 0.099, 0.078, 0.079 and 0.085 % P respectively) which was at par with *Bambusa tulda* for stem, branches, leaves and rhizome P concentration (0.072, 0.094, 0.074 and 0.076 % P respectively), *D. strictus* for branches, leaves and rhizome P concentration (0.096, 0.076 and 0.078 % P respectively), *D. brandisii* for stem and branches (0.068 and 0.098 % P respectively) and *D. asper* for branches and leaves (0.094 and 0.075 % P respectively) after 2nd year of bamboo plantation. The treatment of *D. asper* recorded significantly highest P concentration in bamboo leaf litter biomass (0.79 % P) which was at par with *D. strictus* and *B. bamboos* (0.78 and 0.76 % P respectively).

Considering the mean of all the tested bamboo species, phosphorus concentration in different bamboo biomass components was found in the order of branches > rhizome > leaves > leaf-litter > roots > stem after 2nd year of plantation grown on Entisol of semiarid climate.

Table 4.12 Effect of different bamboo species on P concentration in bamboo biomass components after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Phosphorus concentration in bamboo biomass components (% P)					
		Above ground biomass			Below ground biomass		Leaf litter Biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	0.068	0.098	0.070	0.071	0.068	0.073
T_2	*B. nutans*	0.065	0.091	0.071	0.072	0.067	0.072
T_3	*B. balcooa*	0.071	0.099	0.078	0.079	0.085	0.071
T_4	*D. strictus*	0.062	0.096	0.076	0.078	0.074	0.078
T_5	*B. tulda*	0.072	0.094	0.074	0.076	0.072	0.068
T_6	*B. bamboos*	0.067	0.092	0.071	0.075	0.079	0.076
T_7	*D. asper*	0.062	0.094	0.075	0.071	0.065	0.079
	General mean	**0.067**	**0.095**	**0.074**	**0.075**	**0.073**	**0.074**
	SEm ±	0.001	0.002	0.001	0.002	0.001	0.001
	CD at 5 %	0.004	0.006	0.004	0.006	0.004	0.004

4.4.1.3 Potassium concentration in bamboo biomass components

The data on effect of different bamboo species on potassium concentration in bamboo biomass components after 2nd year of bamboo plantation is presented in table 4.13.

The potassium concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 0.48-0.65, 0.49-0.74, 0.42-0.68 0.26-0.38, 0.20-0.28 and 0.34-0.42 percent potassium respectively after 2nd year of bamboo plantation grown on Entisol.

The treatment of *D. asper* recorded significantly highest K concentration in bamboo leaves, rhizome, roots and leaf litter biomass (0.68, 0.38, 0.28 and 0.42 % K respectively) which was at par with *B. balcooa* for leaves K concentration (0.62 % K), *B. nutans* and *D. strictus* for rhizome K concentration (0.34 % K each), *B. nutans, B. balcooa*, *D. strictus* and *B. bamboos* for roots K concentration (0.24,0.26,0.22 and 0.26 % K respectively) and *D. brandisii* and *D. strictus* for leaf litter biomass K concentration (0.42 % K each).

The treatment of *Dendrocalamus brandisii* recorded significantly highest K concentration in bamboo branches (0.74 % K) which was at par with *B. nutans* (0.72 % K). The treatment of *Bambusa tulda* recorded significantly highest K concentration in bamboo stem (0.65 % K) which was at par with *Dendrocalamus brandisii* (0.62 % K).

Considering the mean of all the tested bamboo species, phosphorus concentration in different bamboo biomass components was found in the order of branches > leaves > leaf-litter > stem > rhizome > roots after 2nd year of plantation grown on Entisol of semiarid climate.

Table 4.13 Effect of different bamboo species on K concentration in bamboo biomass components after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Potassium concentration in bamboo biomass components (% K)					
		Above ground biomass			Below ground biomass		Leaf litter Biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	0.62	0.74	0.42	0.26	0.20	0.42
T_2	*B. nutans*	0.56	0.72	0.58	0.34	0.24	0.34
T_3	*B. balcooa*	0.54	0.66	0.62	0.28	0.26	0.36
T_4	*D. strictus*	0.48	0.56	0.58	0.34	0.22	0.42
T_5	*B. tulda*	0.65	0.62	0.46	0.32	0.28	0.36
T_6	*B. bamboos*	0.50	0.52	0.64	0.28	0.26	0.36
T_7	*D. asper*	0.46	0.49	0.68	0.38	0.28	0.42
	General mean	**0.54**	**0.64**	**0.57**	**0.32**	**0.25**	**0.38**
	SEm ±	0.019	0.012	0.025	0.012	0.025	0.019
	CD at 5 %	0.058	0.038	0.077	0.038	0.077	0.058

4.4.1.4 Carbon concentration in bamboo biomass components

The data on effect of different bamboo species on carbon concentration in bamboo biomass components after 2nd year of bamboo plantation is presented in table 4.14.

All the tested bamboo species were at par with each other for carbon content in bamboo stem, branches, leaves, rhizome, roots and leaf litter. The carbon concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 42.70-44.70, 41.30-44.30, 31.50-34.70, 39.50-41.30, 33.30-36.90 and 20.30-27.10 percent C respectively. The treatment of *B. nutans* recorded numerically highest C concentration in bamboo stem, leaves and roots (44.70, 34.70 and 36.90 % C respectively), whereas, *D. strictus*, *B. bamboos* and *D. asper* recorded numerically highest C concentration in bamboo leaf litter biomass, branches and rhizome (27.10, 44.30 and 41.30 % C respectively) after 2nd year of bamboo plantation grown on Entisol.

Considering the mean of all the tested bamboo species, nitrogen concentration in different bamboo biomass components was found in the order of Stem > Branches > Rhizome > Leaves >Roots > Leaf litter biomass after 2nd year of bamboo plantation grown on Entisol.

Table 4.14 Effect of different bamboo species on C concentration in bamboo biomass components after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Carbon concentration in bamboo biomass components (%)					
		Above ground biomass			Below ground biomass		Leaf litter Biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	42.90	41.50	34.10	39.50	35.90	25.70
T_2	*B. nutans*	44.70	41.90	34.70	40.90	36.90	23.90
T_3	*B. balcooa*	42.70	41.30	34.10	40.50	36.70	23.50
T_4	*D. strictus*	43.70	42.50	33.70	39.90	34.70	27.10
T_5	*B. tulda*	43.70	43.30	33.10	39.70	33.50	20.30
T_6	*B. bamboos*	43.90	44.30	33.50	39.70	36.60	22.70
T_7	*D. asper*	43.10	44.10	31.50	41.30	33.30	24.70
	General mean	**43.53**	**42.70**	**33.53**	**40.21**	**35.37**	**23.99**
	SEm ±	3.08	2.46	3.08	3.08	3.08	3.08
	CD at 5 %	9.24	7.40	9.24	9.24	9.24	9.24

4.4.2 Nutrient Uptake in Bamboo

The nutrient uptake (N, P and K) of bamboo was significantly influenced by different bamboo species after 2nd year of bamboo plantation grown on Entisol of semiarid climate.

4.4.2.1 Total nitrogen uptake

The data on effect of different bamboo species on total nitrogen uptake of bamboo after 2nd year of plantation grown on Entisol of semiarid climate is presented in table 4.15 and fig 8.

The total nitrogen uptake of bamboo of different species was varied between 124.96 to 457.83 kg N ha^{-1}. The highest nitrogen uptake was recorded in *B. nutans* (457.83 kg N ha^{-1}) followed by B. tulda (429.47 kg N ha^{-1}), whereas lowest nitrogen uptake was recorded in *B. bamboos* (124.96 kg N ha^{-1}). The total nitrogen uptake of bamboo stem and leaves was significantly highest in *B. nutans* (250.74 and 68.29 kg N ha^{-1} respectively), whereas the total nitrogen uptake of bamboo branches, rhizome and roots were higher in *B. tulda* (90.40, 19.92 and 14.18 kg N ha^{-1} respectively). The total nitrogen uptake of leaf litter biomass was found significantly highest in *B. tulda* (29.93 kg N ha^{-1}), whereas lowest nitrogen uptake of leaf litter biomass was recorded in *B. bamboos* (5.50 kg N ha^{-1}). The higher nitrogen uptake in *B. nutans* and *B. tulda* after may be attributed to their fast growth and high biomass production capacity.

Considering the average value of nitrogen uptake of the all tested bamboo species, stem, branches, leaves, rhizomes, roots and leaf-litter biomass contributed 54.61, 18.91, 14.92, 3.85, 2.41 and 5.29 percent respectively of total N uptake of bamboo (Appendix VIII) after 2nd year.

Table 4.15 Effect of different bamboo species on total nitrogen uptake after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Total nitrogen uptake (kg N ha^{-1})						Total N uptake (kg N ha^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	155.56	59.42	54.93	14.14	7.60	16.72	**308.36**
T_2	*B. nutans*	250.74	89.48	68.29	16.88	11.05	21.39	**457.83**
T_3	*B. balcooa*	78.76	26.04	18.88	5.68	3.02	7.20	**139.58**
T_4	*D. strictus*	90.51	32.25	21.93	5.52	3.41	6.89	**160.51**
T_5	*B. tulda*	218.12	90.40	56.92	19.92	14.18	29.93	**429.47**
T_6	*B. bamboos*	77.57	20.17	16.22	3.18	2.36	5.50	**124.96**
T_7	*D. asper*	92.95	31.90	33.09	7.23	4.59	11.00	**180.76**
	General mean	**137.44**	**49.95**	**38.61**	**10.36**	**6.60**	**14.09**	
	SEm $\pm$	1.91	0.79	0.20	0.21	0.30	1.23	
	CD at 5 %	5.95	2.47	0.64	0.68	0.96	3.84	

4.4.2.2 Total phosphorus uptake

The data on effect of different bamboo species on total phosphorus uptake of bamboo after 2nd year of bamboo plantation grown on Entisol is presented in table 4.16 and fig 9.

Table 4.16 Effect of different bamboo species on total phosphorus uptake after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Total phosphorus uptake (kg P ha^{-1})						Total P uptake (kg P ha^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	15.11	9.24	2.29	1.43	0.92	1.74	**30.74**
T_2	*B. nutans*	25.87	12.92	3.15	1.93	1.32	2.20	**47.39**
T_3	*B. balcooa*	9.99	4.60	1.11	0.64	0.41	0.73	**17.48**
T_4	*D. strictus*	11.45	5.53	1.19	0.68	0.45	0.85	**20.16**
T_5	*B. tulda*	28.04	12.14	3.01	2.40	1.46	2.64	**49.70**
T_6	*B. bamboos*	9.28	3.31	0.78	0.43	0.30	0.54	**14.64**
T_7	*D. asper*	10.29	5.35	1.42	0.81	0.53	1.03	**19.45**
	General mean	**15.72**	**7.59**	**1.85**	**1.19**	**0.77**	**1.39**	
	SEm $\pm$	1.20	1.23	0.12	0.11	0.14	0.12	
	CD at 5 %	3.76	3.84	0.37	0.34	0.43	0.39	

The total phosphorus uptake of bamboo of different species was varied between 14.64 to 49.70 kg P ha^{-1}. The highest phosphorus uptake was recorded in *Bambusa tulda* (49.70 kg P ha^{-1}) followed by *Bambusa nutans* (47.39 kg P ha^{-1}), whereas lowest phosphorus uptake was recorded in *Bambusa bamboos* (14.64 kg P ha^{-1}).

The total P uptake of bamboo branches and leaves was significantly highest in *B. nutans* (12.92 and 3.15 kg P ha^{-1} respectively), whereas the total P uptake of bamboo stem, rhizome, roots and leaf litter were higher in *B. tulda* (28.04, 2.40, 1.46 and 2.64 kg P ha^{-1} respectively).

The high P uptake in *B. nutans* and *B. tulda* after 2nd year of plantation is attributed their fast growing and high biomass production capacity on Entisol under semiarid climatic condition.

Considering the average value of phosphorus uptake of the all tested bamboo species, stem, branches, leaves, rhizomes, roots and leaf-litter contributed 55.78, 26.52, 6.43, 3.93, 2.58 and 4.71 percent respectively of total P uptake of bamboo (Appendix X) after 2nd year.

4.4.2.3 Total potassium uptake

The data on effect of different bamboo species on total potassiujm uptake of bamboo after 2nd year of bamboo plantation grown on Entisol is presented in table 4.17 and fig 10.

The total potassium uptake of bamboo of different species was varied between 100.15 to 409.77 kg K ha^{-1}. The highest K uptake was recorded in *Bambusa tulda* (409.77 kg K ha^{-1}) followed by *Bambusa nutans* (375.09 kg K ha^{-1}), whereas lowest potassium uptake was recorded in *Bambusa bamboos* (100.15 kg K ha^{-1}).

The total potassium uptake of bamboo stem, branches, rhizome, roots and leaf litter was significantly highest in *B. nutans* (253.17, 105.90, 12.33, 5.67 and 13.99 kg K ha^{-1} respectively), whereas the total potassium uptake of bamboo leaves were higher in B. nutans (25.72 kg K ha^{-1}).

The high K uptake in *B. tulda* and *B. nutans* after 2nd year of plantation is attributed their fast growing and high biomass production capacity on Entisol under semiarid climatic condition.

Considering the average value of potassium uptake of the all tested bamboo species, stem, branches, leaves, rhizomes, roots and leaf-litter contributes 61.82, 24.41, 6.84, 2.37, 1.22 and 6.84 percent respectively of total K uptake of bamboo (Appendix XII) after 2nd year.

Table 4.17 Effect of different bamboo species on total potassium uptake after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Total potassium uptake (kg K ha^{-1})						Total K uptake (kg K ha^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	137.78	69.80	13.73	5.25	2.71	10.03	**239.30**
T_2	*B. nutans*	222.88	102.26	25.72	9.11	4.73	10.39	**375.09**
T_3	*B. balcooa*	75.95	30.69	8.80	2.27	1.25	3.70	**122.66**
T_4	*D. strictus*	88.67	32.25	9.08	2.98	1.34	4.59	**138.91**
T_5	*B. tulda*	253.17	105.90	18.70	12.33	5.67	13.99	**409.77**
T_6	*B. bamboos*	69.22	18.73	7.06	1.59	0.98	2.57	**100.15**
T_7	*D. asper*	76.35	27.91	12.86	4.36	2.30	5.50	**129.28**
	General mean	**132.00**	**55.36**	**13.71**	**5.41**	**2.71**	**7.25**	
	SEm ±	3.02	3.08	1.85	0.54	0.12	0.21	
	CD at 5 %	9.41	9.61	5.76	1.69	0.38	0.68	

4.5 Effect of Different Bamboo Species on Carbon Stock and Carbon Sequestration

The carbon stock and carbon sequestration rate after 2nd year of bamboo plantation grown on Entisol of semiarid climate were significantly influenced by different bamboo species.

4.5.1 Biomass Carbon Stock and Plant Carbon Sequestration Rate

The data regarding effect of different bamboo species on plant biomass carbon stock and plant carbon sequestration rate after 2nd year of bamboo plantation grown on Entisol of semiarid climate are presented in table 4.18 and fig 11.

Among the tested bamboo species, *Bambusa nutan* recorded highest total biomass carbon stock and plant carbon sequestration rate (27.83 t C ha^{-1} and 13.92 t C ha^{-1} yr^{-1} respectively) which was closely followed by *B.tulda* (26.68 t C ha^{-1} and 13.34 t C ha^{-1} yr^{-1}) after 2nd year of plantation grown on Entisol of semiarid climate. Whereas, *B. bamboos* recorded lowest total biomass carbon stock and plant carbon sequestration rate (8.57 t C ha^{-1} and 4.258 t C ha^{-1} $yr^{-1)}$.

The above ground carbon stock was found highest in *Bambusa nutans* (17.79, 5.95 and 1.54 t C ha^{-1} in stem, branches and leaves respectively). Whereas, belowground carbon stock was found higher in *Bambusa tulda* (1.26 and 0.68 t C ha^{-1} in rhizome and roots respectively).

Considering average of all the tested bamboo species, the contribution of stem, branches, leaves, leaf-litter, rhizome and root component in total plant biomass carbon stock was 64.73, 21.21, 5.23, 2.73, 3.84 and 2.27 percent respectively after 2nd year (Appendix VI).

Table 4.18 Effect of different bamboo species on plant biomass carbon stock and plant carbon sequestration rate after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Plant biomass carbon stock (t C ha^{-1})						Total bio. C stock (t ha^{-1})	Plant C Seq/yr. (t ha^{-1})
		Above ground biomass			Below ground biomass		Leaf litter bio.		
		Stem	Branches	Leaf	Rhizome	Root			
T_1	*D.brandisii*	9.53	3.91	1.11	0.80	0.49	0.61	**16.46**	**8.23**
T_2	*B.nutans*	17.79	5.95	1.54	1.10	0.73	0.73	**27.83**	**13.92**
T_3	*B.balcooa*	6.01	1.92	0.48	0.33	0.18	0.24	**9.16**	**4.58**
T_4	*D.strictus*	8.07	2.45	0.53	0.35	0.21	0.30	**11.90**	**5.95**
T_5	*B.tulda*	17.02	5.59	1.35	1.26	0.68	0.79	**26.68**	**13.34**
T_6	*B.bamboos*	6.08	1.60	0.37	0.23	0.14	0.16	**8.57**	**4.28**
T_7	*D.asper*	7.15	2.51	0.60	0.47	0.27	0.32	**11.33**	**5.67**
	General mean	**10.24**	**3.42**	**0.85**	**0.65**	**0.38**	**0.45**	**15.99**	**8.00**
	SEm ±	0.61	0.22	0.08	0.06	0.03	0.04		
	CD at 5 %	1.92	0.68	0.25	0.19	0.10	0.14		

4.5.2 Soil Carbon Stock and Soil Carbon Sequestration Rate

The data regarding effect of different bamboo species on soil carbon stock and soil carbon sequestration rate after 2nd year of bamboo plantation grown on Entisol of semiarid climate are presented in table 4.19 and fig 11.

Among the tested bamboo species, the soil under *Bambusa nutan* recorded highest total soil carbon stock (26.79 t C ha^{-1}) and soil carbon sequestration rate (13.40 t C ha^{-1} yr^{-1}) which was closely followed by *Bambusa tulda* (24.82 t C ha^{-1} and 12.41 t C ha^{-1} yr^{-1} respectively) and

Dendrocalamus strictus (24.47 t C ha^{-1} and 12.23 t C ha^{-1} yr^{-1} respectively) in Entisol after 2nd year of bamboo plantation under semiarid climate. Whereas, *B. bamboos* recorded lowest total soil carbon stock and carbon sequestration rate (15.34 t C ha^{-1} and 7.67 t C ha^{-1} yr^{-1} respectively).

The soil under *Bambusa nutans* recorded significantly highest soil organic carbon stock (24.36 t C ha^{-1}) in Entisol of semiarid climate. Whereas, soil under *Dendrocalamus strictus* recorded significantly highest soil inorganic carbon stock (6.45 t C ha^{-1}) which was at par with *Bambusa balcooa* and *Dendrocalamus brandisii* (5.04 and 4.75 t C ha^{-1} respectively).

The treatment with high SOC stock has shown comparatively low SIC stock. This is because of the higher leaf-litter and root biomass production which ultimately increases the total carbon content in soil which reflects in soil organic carbon stock and the decomposition of leaf litter produce some organic acids which reduces soil pH and dissolve inorganic form of carbon thereby reduces calcium carbonate which ultimately reflects in the soil inorganic carbon stock.

Table 4.19 Effect of different bamboo species on soil carbon stock and soil carbon sequestration rate after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Soil organic carbon stock (t C ha^{-1})	Soil inorganic carbon stock (t C ha^{-1})	Total soil carbon stock (SOC+SIC) (t C ha^{-1})	Soil carbon sequestration rate (t C ha^{-1}yr^{-1})
T_1	*Dendrocalamus brandisii*	14.76	4.75	19.50	**9.75**
T_2	*Bambusa nutans*	24.36	2.43	26.79	**13.40**
T_3	*Bambusa balcooa*	15.56	5.04	20.60	**10.30**
T_4	*Dendrocalamus strictus*	18.01	6.45	24.47	**12.23**
T_5	*Bambusa tulda*	21.63	3.19	24.82	**12.41**
T_6	*Bambusa bamboos*	14.16	1.18	15.34	**7.67**
T_7	*Dendrocalamus asper*	14.08	2.14	16.22	**8.11**
	General mean	**17.51**	**3.60**	**21.11**	**10.55**
	SEm ±	0.63	0.68		
	CD at 5 %	1.93	2.08		

4.5.3 Total Carbon Stock and Bamboo Carbon Sequestration Rate

The data regarding effect of different bamboo species on total carbon stock and carbon sequestration rate after 2nd year of plantation grown on Entisol of semiarid climate is presented in table 4.20 and fig 12. The total carbon stock and carbon sequestration rate was significantly influenced by tested bamboo species grown on Entisol under semiarid climatic condition.

Among the tested bamboo species, the treatment of *Bambusa nutans* recorded higher total carbon stock (59.63 t C ha^{-1}) and carbon sequestration rate (27.31 t C ha^{-1} yr^{-1}), followed by *Bambusa tulda* (51.50 t C ha^{-1} and 25.75 t C ha^{-1} yr^{-1} respectively). Whereas, the lowest total carbon stock and carbon sequestration rate was recorded in *Bambusa bamboos* (23.91 t C ha^{-1} and 11.95 t C ha^{-1} yr^{-1}, respectively).

Table 4.20 Effect of different bamboo species on total carbon stock and carbon sequestration rate after 2nd year of plantation grown on Entisol of semiarid climate

Tr. No.	Treatment	Total biomass carbon stock (t C ha^{-1})	Total soil carbon stock (t C ha^{-1})	Total carbon stock (Plant + Soil) (t C ha^{-1})	Bamboo carbon sequestration rate (t C $ha^{-1}year^{-1}$)
T_1	*D. brandisii*	16.46	19.50	**35.96**	**17.98**
T_2	*B. nutans*	27.83	26.79	**59.63**	**27.31**
T_3	*B. balcooa*	9.16	20.60	**29.76**	**14.88**
T_4	*D. strictus*	11.90	24.47	**36.37**	**18.19**
T_5	*B. tulda*	26.68	24.82	**51.50**	**25.75**
T_6	*B. bamboos*	8.57	15.34	**23.91**	**11.95**
T_7	*D. asper*	11.33	16.22	**27.55**	**13.78**

4.11 Correlation Between Soil Organic Carbon Pools and Soil Properties as Influenced by Different Bamboo Species after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The correlation between soil organic carbon pools and soil properties as influenced by tested bamboo species is presented in table 4.21 and fig 13 and 14.

The soil available N, P and K content has highly significant positive correlation with WSC, SOC and TOC. Among the different carbon fractions Water Soluble Carbon fraction (WSC) has shown the highest positive correlation for soil available nutrients. This might be associated with high microbial activity in high carbon content soil which is resulted in increased rate of nutrient transformation from unavailable to available form. The dehydrogenase enzyme activity has highly significant positive correlation with soil microbial population. As the dehydrogenase enzyme is an intracellular enzyme the significant positive correlation was observed between the dehydrogenase enzyme activity and soil microbial population and carbon fractions. The negative correlation was found between soil pH, EC and all other soil properties respectively. As the pH decreases, carbon content and carbon fractions content and nutrient availability increase. The significant reduction in pH was observed in the bamboo species which ultimately reflects in the increase in soil quality parameters.

Table 4.21 Correlation between soil organic carbon pools and soil properties as influenced by different bamboo species after 2nd year of plantation grown on Entisol of semiarid climate

Parameters	TOC	SOC	WSC	SMBC	POXC	POMC	DHG	Bacteria	Fungi	Actin.	pH	EC	Avail. N	Avail. P
SOC	0.85**													
WSC	0.94**	0.88**												
SMBC	0.86**	0.86**	0.94**											
POXC	0.78*	0.87**	0.84**	0.93**										
POMC	0.82**	0.81**	0.84**	0.86**	0.84**									
DHG	0.69*	0.70*	0.75*	0.58	0.72*									
Bacteria	0.80**	0.76**	0.81**	0.82**	0.71*	0.77*	0.66*							
Fungi	0.88**	0.88**	0.91**	0.88**	0.81**	0.76*	0.74*	0.72*						
Actin.	0.81**	0.84**	0.87**	0.88**	0.89**	0.86**	0.76*	0.81**	0.81**					
pH	-0.53	-0.52	-0.57	-0.62*	-0.63*	-0.76*	-0.50	-0.63*	-0.42	-0.66*				
EC	-0.17	-0.08	-0.25	-0.33	-0.35	-0.38	-0.26	-0.29	-0.12	-0.42	0.72*			
Avail. N	0.77*	0.81**	0.85**	0.75*	0.69*	0.67*	0.74*	0.76*	0.75*	0.79*	-0.41	-0.05		
Avail. P	0.87**	0.93**	0.88**	0.87**	0.88**	0.78*	0.63*	0.79*	0.89**	0.80**	-0.43	-0.07	0.81**	
Avail, K	0.86**	0.85**	0.82**	0.70*	0.66*	0.64*	0.61*	0.62*	0.84**	0.66*	-0.25	0.11	0.79*	0.91**

**** Significant Correlation at 0.01 level; * Significant Correlation at 0.05 level.**

SOC (Soil organic carbon); TOC (Total organic carbon); WSC (Water soluble carbon); SMBC (Soil microbial biomass carbon); POXC (Permanganate oxidizable soil carbon); POMC (Particulate organic matter carbon); DHG (Dehydrogenase enzyme activity); Bacteria (Bacterial count); Fungi (Fungi count); Actin. (Actinomycetes count); pH (negative logarithm of hydrogen ion activity); EC (Electrical Conductivity); Avail. N (Soil available nitrogen); Avail. P (Soil available phosphorus); Avail. K (Soil available potassium).

5. SUMMARY AND CONCLUSION

A long-term field experiment "Performance of different bamboo species on growth and yield of bamboo" was initiated in the year 2018-19 at NARP, M. P. K. V., Rahuri. The same field experiment was selected for "Quantification of soil carbon pools and carbon sequestration rate as influenced by bamboo plantation grown on Entisol of semiarid climate of Maharashtra" during the year 2020-21. The field experiment was laid out in randomized block design comprising three replications and seven treatments of bamboo *viz., Dendrocalamus brandisii* (T_1), *Bambusa nutans* (T_2), *Bambusa balcooa* (T_3), *Dendrocalamus strictus* (T_4), *Bambusa tulda* (T_5), *Bambusa bamboos* (T_6) and *Dendrocalamus asper* (T_7). The observations were recorded from the long-term field experiment pertaining to the effect of different bamboo species on soil properties, growth characters and biomass production, nutrient concentration and uptake, carbon stock and carbon sequestration rate after 2nd year of plantation grown on Entisol of semiarid climate. The salient findings of the present investigation have been summarized as below.

5.1 Effect of Different Bamboo Species on Soil Carbon Content and Microbial Indices after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The increase in SOC and TOC content in the different bamboo species was ranged from 16.41 to 20.44 % and 32.51 to 59.14 % over its initial level after 2nd year of plantation. Among the tested bamboo species, *Bambusa nutans* recorded significantly highest SOC (8.07 g kg^{-1}) and TOC content (12.97 g kg^{-1}) as compare to initial level (6.70 and 8.15 g kg^{-1} respectively).

The increase in WSC, SMBC, POMC and POXC were 31.73 to 53.04 %, 95.27 to 145.37 %, 18.88 to 32.86 % and 60.39 to 64.85%, respectively over its initial level after 2nd year of bamboo plantation grown on Entisol. The WSC, SMBC, POMC carbon content was significantly highest in *Bambusa tulda* (14.08 mg kg$^{-1,}$ 181.7 mg kg^{-1}, 1.90 g kg^{-}1, respectively) whereas, the POXC content was significantly highest in *B. nutans* (0.666 g kg^{-1}). The bamboo species, Bambusa *nutans* recorded significantly lowest qMin ratio (0.63) whereas, *Denderocalamus asper* recorded significantly highest qMic ratio (1.50) after 2nd year of bamboo plantation.

5.2 Effect of Different Bamboo Species on Soil Microbial Population after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

All the tested bamboo species recorded significantly highest soil microbial count over its control plot after 2nd year of bamboo plantation grown on Entisol of semiarid climate.

Among the tested bamboo species, the treatment of *B. tulda* recorded highest bacteria, fungi and actinomycetes count (11.67 cfu x 10^6 g^{-1} soil, 11.00 cfu x 10^4 g^{-1} soil and 10.67 cfu x 10^5 g^{-1} soil, respectively). The increase in the bacteria, fungi and actinomycetes count in bamboo species varies from 55.5 to 94.5 %, 100 to 175 % and 108.2 to 166.7%, respectively in comparison to its control plot value after 2nd year of plantation grown on Entisol.

5.3 Effect of Different Bamboo Species on Soil Dehydrogenase Enzyme Activity after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The increase in the soil dehydrogenase enzyme activity under the tested bamboo species varies from 9.05 to 26.48% as compare to its control plot value after 2nd year of plantation grown on Entisol of semiarid climatic condition. The treatment of *Bambusa tulda* recorded significantly highest soil dehydrogenase enzyme activity (3.63 µg TPF released g^{-1} soil hr^{-1}), which was found statistically at par with *Bambusa nutans* (3.47 µg TPF released g^{-1} soil hr^{-1}).

5.4 Effect of Different Bamboo Species on Soil Chemical Properties after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The pH of the soil in all the tested bamboo species varies in the range of 7.45 to 7.95 which were significantly lower as compare to its initial pH value (8.01). The significantly highest reduction in soil pH was observed in the treatment of *Bambusa nutans* (7.45) which was statistically at par with treatment of *Bambusa tulda* (7.46).

The EC of the soil in all the tested bamboo species varies in the range of 0.15 to 0.21 dSm^{-1} which were 4.76 to 28.57 percent low as compare to its initial level after 2nd year of plantation grown on Entisol of semiarid climatic condition. The treatment of *Bambusa nutans* and *Bambusa tulda* recorded significantly lowest soil EC (0.15 dSm^{-1} each). The $CaCo_3$ content in the different bamboo species were found at par with each other after 2nd year of plantation grown on Entisol of semiarid climatic condition.

5.5 Effect of Different Bamboo Species on Soil Bulk Density after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The increase in soil available nitrogen, phosphorus and potassium content under the bamboo species varies from 4.90 to 7.34 %, 33.93 to 37.21 % and 1.52 to 1.76 % respectively in comparison to its initial level after 2nd year of plantation grown on Entisol of semiarid climatic condition. The soil under the treatment of *Bambusa tulda* recorded significantly highest available nitrogen, phosphorus and potassium (191.83 kg N ha^{-1}, 8.37 kg P ha^{-1} and 410.33 kg K ha^{-1} respectively) content.

5.6 Effect of Different Bamboo Species on Growth Attributing Characters after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The treatment of *Bambusa tulda* recorded highest number of culms per clump (59.32), culm density (49413.56 culms ha^{-1}), number of new culms per clump (13.80) and clump girth (712.27 cm) whereas, bamboo species *Dendrocalamus strictus* recorded highest culm height (6.39 m), basal diameter of culm (8.16 cm), Diameter at breast height (7.13 cm), culm girth at 5th internode (16.53 cm) and internodal length (27.51 cm). The treatment of *Bambusa* bamboos recorded highest number of internodes per culm (28.34) and average culm weight (2.31 kg) after 2nd year of plantation grown on Entisol of semiarid climate.

5.7 Effect of Different Bamboo Species on Biomass Production after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

Among the tested bamboo species after 2nd year of plantation grown on Entisol of semiarid climatic condition, the treatment of *Bambusa nutan* recorded highest aboveground biomass (58.43 t ha^{-1}) which was followed by *Bambusa tulda* (55.93 t ha^{-1}). Whereas, the treatment of *B*ambusa *tulda* recorded highest belowground biomass (5.19 t ha^{-1}) which was followed by *Bambusa nutans* (4.65 t ha^{-1}). The treatment of *Bambusa nutans* recorded highest total biomass (66.15 t ha^{-1}) which was closely followed by *Bambusa tulda* (65.01 t ha^{-1}).The contribution of stem, branches, leaves, leaf-litter, rhizome and root biomass in total biomass component was 61.62, 20.58, 6.45, 4.74, 3.94 and 2.66 percent respectively.

5.8 Effect of Different Bamboo Species on Nutrient Concentration in Bamboo Biomass after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The nitrogen concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 0.49-0.70, 0.56-0.70, 1.33-1.54, 0.56-0.70, 0.56-0.70 and 0.63-0.84 % N respectively. The phosphorus concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 0.062-0.071, 0.092-0.099, 0.070-0.078, 0.071-0.079, 0.065-0.085 and 0.068-0.079 % P respectively. The potassium concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 0.48-0.65, 0.49-0.74, 0.42-0.68 0.26-0.38, 0.20-0.28 and 0.34-0.42 % K respectively after 2nd year of bamboo plantation.

The carbon concentration in bamboo stem, branches, leaves, rhizome, roots and leaf litter was ranged between 42.70-44.70, 41.30-44.30, 31.50-34.70, 39.50-41.30, 33.30-36.90 and 20.30-27.10 % C respectively after 2nd year of bamboo plantation.

5.9 Effect of Different Bamboo Species on Nutrient Uptake after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The highest nitrogen uptake was recorded in *Bambusa nutans* (457.83 kg N ha^{-1}) followed by *Bambusa tulda* (429.47 kg N ha^{-1}). The total N uptake of bamboo was distributed as 54.61, 18.91, 14.92, 3.85, 2.41 and 5.29 percent N respectively in bamboo stem, branches, leaves, rhizomes, roots and leaf-litter biomass, respectively.

The highest phosphorus uptake was recorded in *Bambusa tulda* (49.70 kg P ha^{-1}) followed by *Bambusa nutans* (47.39 kg P ha^{-1}). The total P uptake of bamboo was distributed as 55.78, 26.52, 6.43, 3.93, 2.58 and 4.71 percent P respectively in bamboo stem, branches, leaves, rhizomes, roots and leaf-litter biomass, respectively.

The highest potassium uptake was recorded in *Bambusa tulda* (409.77 kg K ha^{-1}) followed by *Bambusa nutans* (375.09 kg K ha^{-1}). The total K uptake of bamboo was distributed as 61.82, 24.41, 6.84, 2.37, 1.22 and 6.84 percent K respectively in bamboo stem, branches, leaves, rhizomes, roots and leaf-litter biomass, respectively.

5.10 Effect of Different Bamboo Species on Carbon Stock and Carbon Sequestration Rate after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The treatment of *B.nutan* recorded highest total biomass carbon stock and plant carbon sequestration rate (27.83 t C ha^{-1} and 13.92 t C ha^{-1} yr^{-1} respectively) which was closely followed by *B. tulda* (26.68 t C ha^{-1} and 13.34 t C ha^{-1} yr^{-1} respectively) after 2nd year of plantation.

The soil under treatment of *B.nutan* recorded highest total soil carbon stock and carbon sequestration rate (26.79 t C ha^{-1} and 13.40 t C ha^{-1} yr^{-1} respectively) which was closely followed by *B.tulda* (24.82 t C ha^{-1} and 12.41 t C ha^{-1} yr^{-1} respectively) after 2nd year of plantation.

The treatment of *B.nutans* recorded highest total carbon stock and carbon sequestration rate (59.63 t C ha^{-1} and 27.31 t C ha^{-1} $year^{-1}$ respectively), followed by *B. tulda* (51.50 t C ha^{-1} and 25.75 t C ha^{-1} yr^{-1} respectively) after 2nd year of bamboo plantation.

5.11 Correlation Between Soil Organic Carbon pools and Soil properties as Influenced by Different Bamboo Species after 2nd Year of Plantation Grown on Entisol of Semiarid Climate

The Soil available N, P and K content has highly significant positive correlation with WSC, SOC and TOC respectively. Among the different carbon fractions WSC has shown the highest positive correlation for soil available nutrients.

5.12 Conclusions

The following conclusions are drawn on the basis of results summarized as earlier.

- The soil organic carbon content and carbon fractions (WSC, SMBC, POMC and POXC) are found significantly highest than the initial level. All the tested bamboo species are statistically at par for soil carbon content and carbon fractions after 2nd year of plantation.
- The soil carbon sequestration rate in different bamboo species range between 7.67 to 13.40 t C ha^{-1} yr^{-1}, whereas plant carbon sequestration rate in different bamboo species range between 4.28 to 13.92 t C ha^{-1} yr^{-1}. Among the studied genotypes, Bambusa nutans recorded highest carbon sequestration rate (27.31 t C ha^{-1} yr^{-1}) closely followed by Bambusa tulda (25.75 t C ha^{-1} yr^{-1}) after 2nd year of bamboo plantation.
- All the soil carbon fractions were found highly correlated with most of the soil properties. The soil available N, P and K shown highest correlation with WSC, SOC and TOC, respectively after 2nd year of bamboo plantation grown on Entisol of semiarid climate.
- The studies on quantification of carbon sequestration potential by different species of bamboo after 2nd year of plantation on Entisol under semiarid climatic condition has revealed that *Dendrocalamus strictus* and *Bambusa tulda* species of bamboo are suitable for soil carbon sequestration in surface and subsurface soil layer, respectively. Whereas, *Bambusa nutans* and *Bambusa tulda* species of bamboo showed the highest potential to sequester atmospheric CO_2 into soil and biomass.

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7. APPENDICES

Appendix I : Biomass (*i.e.* average dry weight) of individual culm component

Tr. No.	Treatment	Average dry weight (kg culm^{-1})						Total biomass (kg culm^{-1})
		Above ground components			Below ground components		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	0.736	0.312	0.108	0.067	0.045	0.079	1.349
T_2	*B. nutans*	1.069	0.381	0.119	0.072	0.053	0.082	1.777
T_3	*B. balcooa*	1.230	0.406	0.124	0.071	0.042	0.089	1.965
T_4	*D. strictus*	1.455	0.453	0.123	0.069	0.048	0.086	2.235
T_5	*B. tulda*	0.788	0.261	0.082	0.064	0.041	0.078	1.316
T_6	*B. bamboos*	1.585	0.412	0.126	0.065	0.043	0.081	2.315
T_7	*D. asper*	1.012	0.347	0.115	0.070	0.050	0.079	1.675
	General mean	**1.126**	**0.368**	**0.114**	**0.068**	**0.046**	**0.083**	
	SEm ±	0.001	0.001	0.001	0.001	0.001	0.001	
	CD at 5 %	0.002	0.002	0.002	0.002	0.002	0.002	

Appendix II : Standing biomass of individual clump component

Tr. No.	Treatment	Standing biomass (kg clump^{-1})						Total Biomass (kg clump^{-1})
		Above ground Biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	26.68	11.32	3.92	2.43	1.63	2.87	48.85
T_2	*B. nutans*	47.78	17.05	5.32	3.22	2.37	3.67	79.41
T_3	*B. balcooa*	16.88	5.58	1.70	0.97	0.58	1.23	26.95
T_4	*D. strictus*	22.18	6.91	1.88	1.05	0.73	1.31	34.06
T_5	*B. tulda*	46.76	15.50	4.88	3.80	2.43	4.67	78.04
T_6	*B. bamboos*	16.62	4.32	1.32	0.68	0.45	0.86	24.26
T_7	*D. asper*	19.23	6.84	1.27	1.38	0.98	1.57	32.97
	General mean	**28.12**	**9.65**	**3.04**	**1.93**	**1.31**	**2.31**	
	SEm ±	0.11	0.20	0.19	0.20	0.20	0.19	
	CD at 5 %	0.34	0.61	0.60	0.61	0.61	0.60	

Appendix III : Average contribution of individual culm component to total biomass

Tr. No.	Treatment	Contribution of individual culm component to total biomass (%)					
		Above ground biomass			Below ground biomass		Leaf litter biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	54.61	23.18	8.04	4.96	3.34	5.87
T_2	*B. nutans*	60.17	21.47	6.70	4.05	2.98	4.63
T_3	*B. balcooa*	62.62	20.71	6.32	3.61	2.14	4.59
T_4	*D. strictus*	65.09	20.30	5.53	3.10	2.15	3.84
T_5	*B. tulda*	59.92	19.86	6.26	4.86	3.12	5.98
T_6	*B. bamboos*	68.49	17.82	5.44	2.82	1.88	3.51
T_7	*D. asper*	60.45	20.76	6.88	4.19	2.99	4.77
	General mean	**61.62**	**20.58**	**6.45**	**3.94**	**2.66**	**4.74**
	SEm ±	2.20	0.80	0.59	0.32	0.32	0.42
	CD at 5 %	6.79	2.46	1.82	0.99	1.00	1.30

Appendix IV : Bamboo biomass carbon stock on culm basis

Tr. No.	Treatment	Bamboo biomass carbon stock (g C culm^{-1})						Total biomass C stock (g C culm^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	316.07	129.71	36.86	26.51	16.33	20.27	545.76
T_2	*B. nutans*	478.00	159.87	41.37	29.52	19.59	19.62	447.97
T_3	*B. balcooa*	525.74	168.01	42.12	28.83	15.64	21.05	801.38
T_4	*D. strictus*	635.75	192.92	41.69	27.56	16.58	23.54	938.03
T_5	*B. tulda*	344.45	113.14	27.29	25.47	13.75	15.98	540.08
T_6	*B. bamboos*	696.36	183.12	42.37	26.17	15.94	18.41	982.36
T_7	*D. asper*	436.23	153.15	36.51	28.75	16.53	19.59	690.77
	General mean	**490.37**	**157.13**	**38.32**	**27.54**	**16.34**	**19.78**	
	SEm $\pm$	42.69	13.04	4.94	4.28	2.20	2.35	
	CD at 5 %	131.52	40.17	15.23	13.17	6.77	7.23	

Appendix V : Bamboo biomass carbon stock on clump basis

Tr. No.	Treatment	Bamboo biomass carbon stock (kg C clump^{-1})						Total biomass C stock (kg clump^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	11.44	4.70	1.33	0.96	0.59	0.73	19.76
T_2	*B. nutans*	21.36	7.14	1.85	1.32	0.88	0.88	33.42
T_3	*B. balcooa*	7.21	2.31	0.58	0.40	0.21	0.29	10.99
T_4	*D. strictus*	9.69	2.94	0.64	0.42	0.25	0.36	14.30
T_5	*B. tulda*	20.43	6.71	1.62	1.51	0.82	0.95	32.04
T_6	*B. bamboos*	7.30	1.92	0.44	0.27	0.17	0.19	10.30
T_7	*D. asper*	8.59	3.01	0.72	0.57	0.33	0.39	13.59
	General mean	**12.29**	**4.10**	**1.03**	**0.78**	**0.46**	**0.54**	
	SEm $\pm$	0.74	0.27	0.10	0.07	0.04	0.06	
	CD at 5 %	2.28	0.82	0.30	0.23	0.13	0.17	

Appendix VI : Avg. contribution of individual culm component to total biomass C stock

Tr. No.	Treatment	Contribution of culm component to total biomass C stock (%)					
		Above ground biomass			Below ground biomass		Leaf litter biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	57.90	23.76	6.75	4.86	2.99	3.71
T_2	*B. nutans*	63.91	21.38	5.53	3.95	2.62	2.62
T_3	*B. balcooa*	65.62	20.97	5.26	3.60	1.95	2.63
T_4	*D. strictus*	67.79	20.57	4.44	2.94	1.77	2.51
T_5	*B. tulda*	63.79	20.95	5.05	4.72	2.55	2.96
T_6	*B. bamboos*	70.96	18.66	4.32	2.67	1.62	1.88
T_7	*D. asper*	63.11	22.16	5.28	4.16	2.39	2.83
	General mean	**64.73**	**21.21**	**5.23**	**3.84**	**2.27**	**2.73**
	SEm $\pm$	5.10	1.63	0.64	0.51	0.28	0.30
	CD at 5 %	15.71	5.04	1.97	1.56	0.86	0.92

Appendix VII : Total nitrogen uptake in bamboo biomass component on culm basis

Tr. No.	Treatment	Total nitrogen uptake (g N culm^{-1})						Total N uptake (g N culm^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	5.16	1.97	1.82	0.47	0.25	0.55	10.23
T_2	*B. nutans*	6.74	2.40	1.83	0.45	0.30	0.57	12.30
T_3	*B. balcooa*	6.89	2.28	1.65	0.50	0.26	0.63	12.21
T_4	*D. strictus*	7.13	2.54	1.73	0.43	0.27	0.54	12.64
T_5	*B. tulda*	4.41	1.83	1.15	0.40	0.29	0.61	8.69
T_6	*B. bamboos*	8.88	2.31	1.86	0.36	0.27	0.63	14.31
T_7	*D. asper*	5.67	1.95	2.02	0.44	0.28	0.67	11.03
	General mean	**6.41**	**2.18**	**1.72**	**0.44**	**0.27**	**0.60**	
	SEm ±	0.28	0.03	0.04	0.03	0.02	0.08	
	CD at 5 %	0.87	0.11	0.12	0.09	0.05	0.26	

Appendix VIll : Average contribution of individual culm component to total N uptake

Tr. No.	Treatment	Contribution of individual culm component to total N uptake (%)					
		Above ground biomass			Below ground biomass		Leaf litter biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	50.45	19.27	17.81	4.59	2.46	5.42
T_2	*B. nutans*	54.77	19.54	14.92	3.69	2.41	4.67
T_3	*B. balcooa*	56.43	18.65	13.53	4.07	2.16	5.16
T_4	*D. strictus*	56.39	20.09	13.66	3.44	2.12	4.29
T_5	*B. tulda*	50.79	21.05	13.25	4.64	3.30	6.97
T_6	*B. bamboos*	62.04	16.14	12.98	2.54	1.89	4.40
T_7	*D. asper*	51.42	17.65	18.31	4.00	2.54	6.09
	General mean	**54.61**	**18.91**	**14.92**	**3.85**	**2.41**	**5.29**
	SEm ±	2.12	0.24	0.26	0.23	0.13	0.67
	CD at 5 %	6.52	0.75	0.80	0.70	0.40	2.05

Appendix IX : Total phosphorus uptake in bamboo biomass component on culm basis

Tr. No.	Treatment	Total phosphorus uptake (g P culm^{-1})						Total P uptake (g P culm^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	0.501	0.306	0.076	0.047	0.031	0.058	1.02
T_2	*B. nutans*	0.695	0.347	0.085	0.052	0.035	0.059	1.27
T_3	*B. balcooa*	0.874	0.402	0.097	0.056	0.036	0.064	1.53
T_4	*D. strictus*	0.902	0.436	0.094	0.054	0.035	0.067	1.59
T_5	*B. tulda*	0.567	0.246	0.061	0.049	0.029	0.053	1.01
T_6	*B. bamboos*	1.063	0.379	0.089	0.049	0.034	0.062	1.68
T_7	*D. asper*	0.628	0.326	0.087	0.047	0.032	0.063	1.18
	General mean	**0.747**	**0.349**	**0.084**	**0.051**	**0.033**	**0.061**	
	SEm ±	0.086	0.085	0.008	0.007	0.009	0.008	
	CD at 5 %	0.264	0.262	0.026	0.022	0.027	0.025	

Appendix X : Average contribution of individual culm component to total P uptake

Tr. No.	Treatment	Contribution of individual culm component to total P uptake (%)					
		Above ground biomass			Below ground biomass		Leaf litter biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	49.15	30.05	7.45	4.65	2.99	5.66
T_2	*B. nutans*	54.58	27.26	6.65	4.07	2.79	4.64
T_3	*B. balcooa*	57.17	26.32	6.35	3.66	2.35	4.18
T_4	*D. strictus*	56.80	27.43	5.90	3.37	2.23	4.22
T_5	*B. tulda*	56.42	24.43	6.06	4.83	2.93	5.31
T_6	*B. bamboos*	63.40	22.61	5.33	2.94	2.05	3.69
T_7	*D. asper*	52.92	27.51	7.30	3.99	2.73	5.30
	General mean	**55.78**	**26.52**	**6.43**	**3.93**	**2.58**	**4.71**
	SEm ±	5.76	5.71	0.57	0.51	0.59	0.58
	CD at 5 %	17.76	17.59	1.76	1.58	1.82	1.78

Appendix XI : Total potassium uptake in bamboo biomass component on culm basis

Tr. No.	Treatment	Total potassium uptake (g K culm^{-1})						Total K uptake (g K culm^{-1})
		Above ground biomass			Below ground biomass		Leaf litter biomass	
		Stem	Branches	Leaves	Rhizome	Roots		
T_1	*D. brandisii*	4.57	2.31	0.46	0.17	0.090	0.33	7.94
T_2	*B. nutans*	5.99	2.75	0.69	0 24	0.127	0.28	10.08
T_3	*B. balcooa*	6.65	2.69	0.77	0.20	0.109	0.32	10.73
T_4	*D. strictus*	6.98	2.54	0.72	0.23	0.106	0.36	10.94
T_5	*B. tulda*	5.12	2.14	0.38	0.25	0.115	0.28	8.29
T_6	*B. bamboos*	7.93	2 15	0.81	0.18	0.112	0.29	11.47
T_7	*D. asper*	4.66	1.70	0.78	0.27	0.140	0.34	7.89
	General mean	**5.99**	**2.33**	**0.66**	**0.22**	**0.114**	**0.32**	
	SEm ±	0.21	0.21	0.13	0.02	0.009	0.01	
	CD at 5 %	0.66	0.66	0.39	0.06	0.028	0.04	

Appendix XII : Average contribution of individual culm component to total K uptake

Tr. No.	Treatment	Contribution of individual culm component to total K uptake (%)					
		Above ground biomass			Below ground biomass		Leaf litter biomass
		Stem	Branches	Leaves	Rhizome	Roots	
T_1	*D. brandisii*	57.57	29.17	5.74	2.19	1.13	4.19
T_2	*B. nutans*	59.42	27.31	6.86	2.43	1.26	2.77
T_3	*B. balcooa*	61.92	25.02	7.17	1.85	1.02	3.02
T_4	*D. strictus*	63.83	23.22	6.54	2.15	0.96	3.30
T_5	*B. tulda*	61.78	25.84	4.56	3.01	1.38	3.41
T_6	*B. bamboos*	69.12	18.70	7.05	1.59	0.98	2.57
T_7	*D. asper*	59.06	21.59	9.95	3.37	1.78	4.25
	General mean	**61.82**	**24.41**	**6.84**	**2.37**	**1.22**	**3.36**
	SEm ±	2.06	2.07	1.23	0.21	0.08	0.12
	CD at 5 %	6.35	6.37	3.79	0.65	0.25	0.38

8. VITAE

Mr. GAIKWAD ANIKET SUNIL

MASTER OF SCIENCE (AGRICULTURE)

IN

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

2021

Title of thesis		:	Quantification of soil carbon pools and carbon sequestration rate as influenced by bamboo plantation grown on Entisol of semiarid climate of Maharashtra
Major field		:	Soil Science and Agricultural Chemistry
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Educational	**Bachelor Degree Obtained**	:	B.Sc. (Agriculture) - 2019 R. C. S. M., College of Agriculture, Kolhapur
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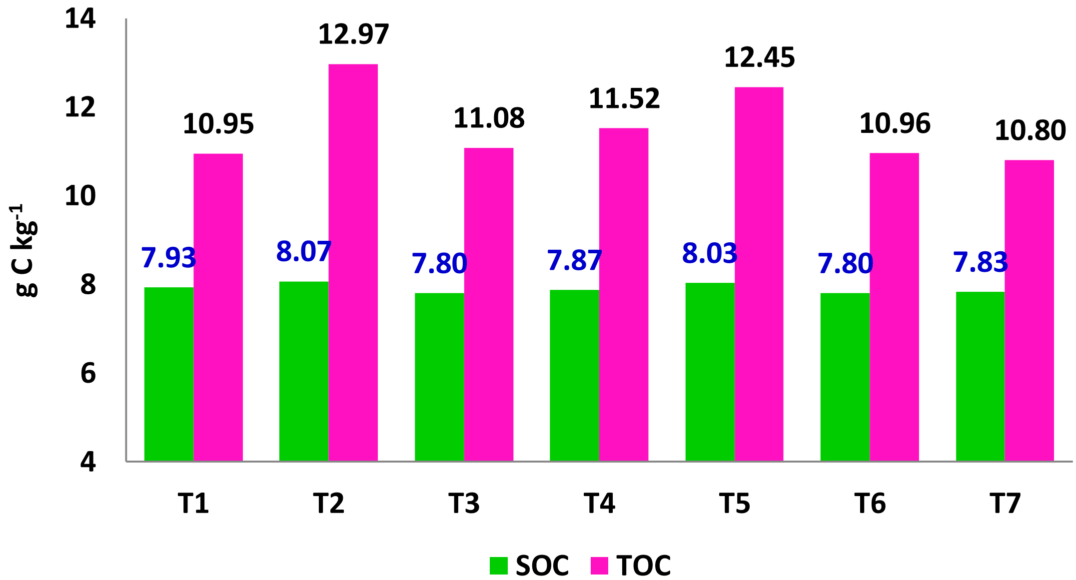

Fig 1: Effect of different bamboo species on soil carbon content

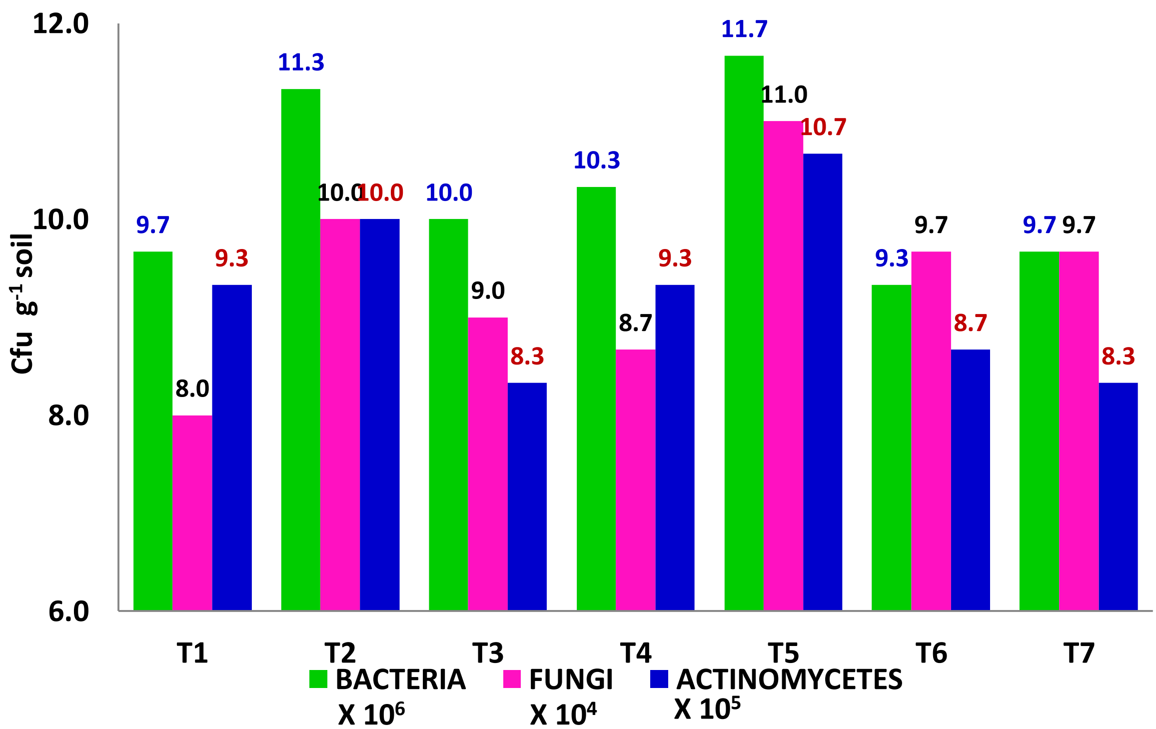

Fig 2: Effect of different bamboo species on soil microbial population

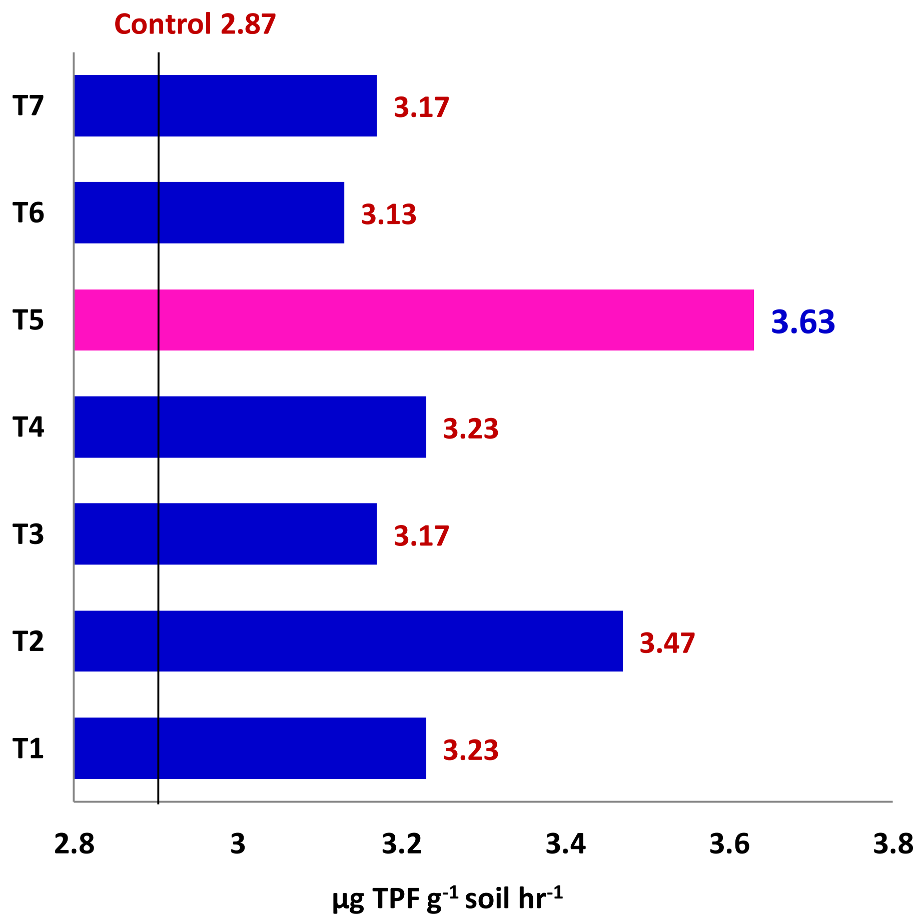

Fig 3: Effect of different bamboo species on dehydrogenase enzyme activity

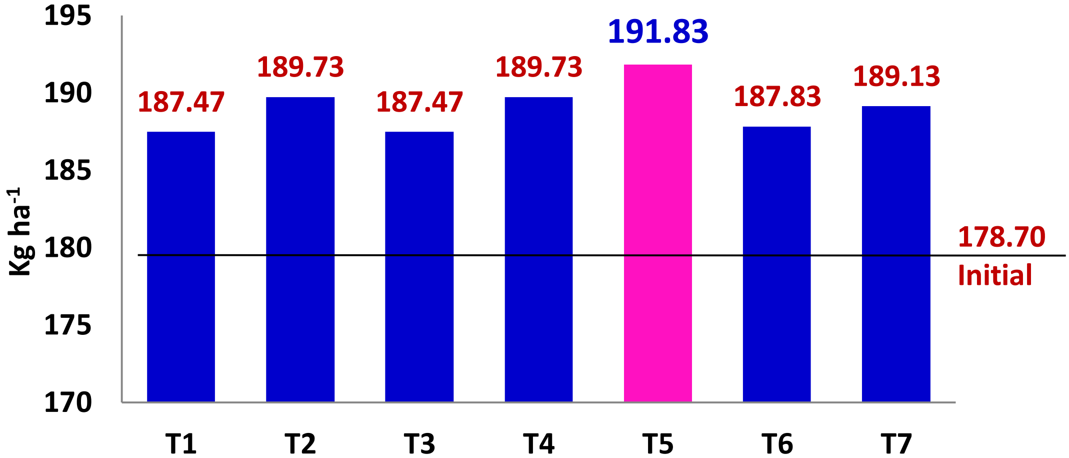

Fig 4: Effect of different bamboo species on soil available nitrogen content

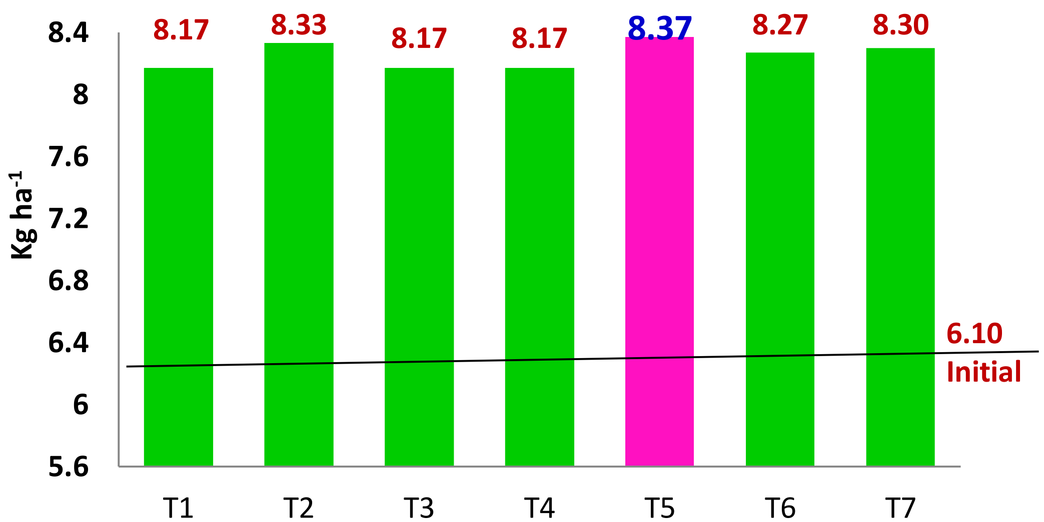

Fig 5: Effect of different bamboo species on soil available phosphorus content

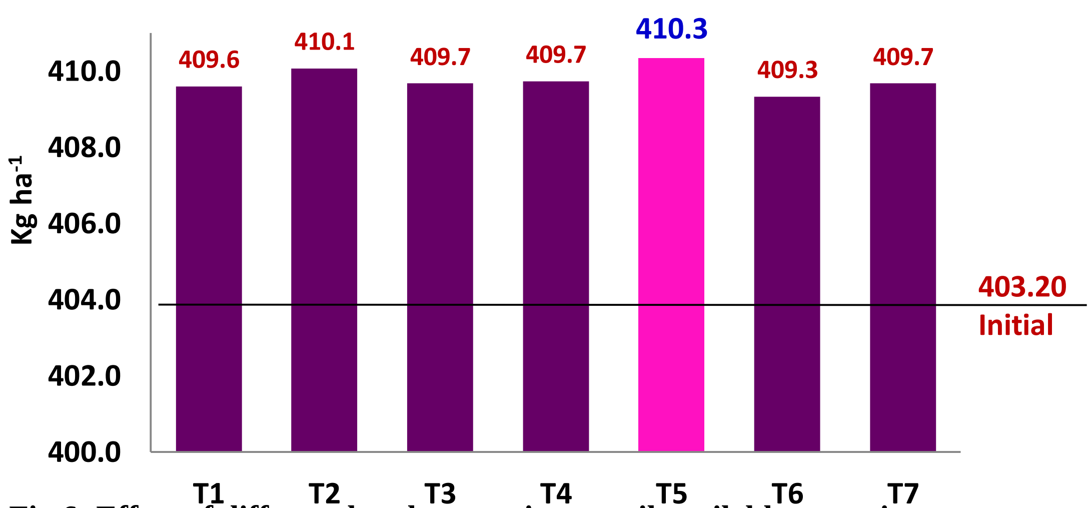

Fig 6: Effect of different bamboo species on soil available potassium content

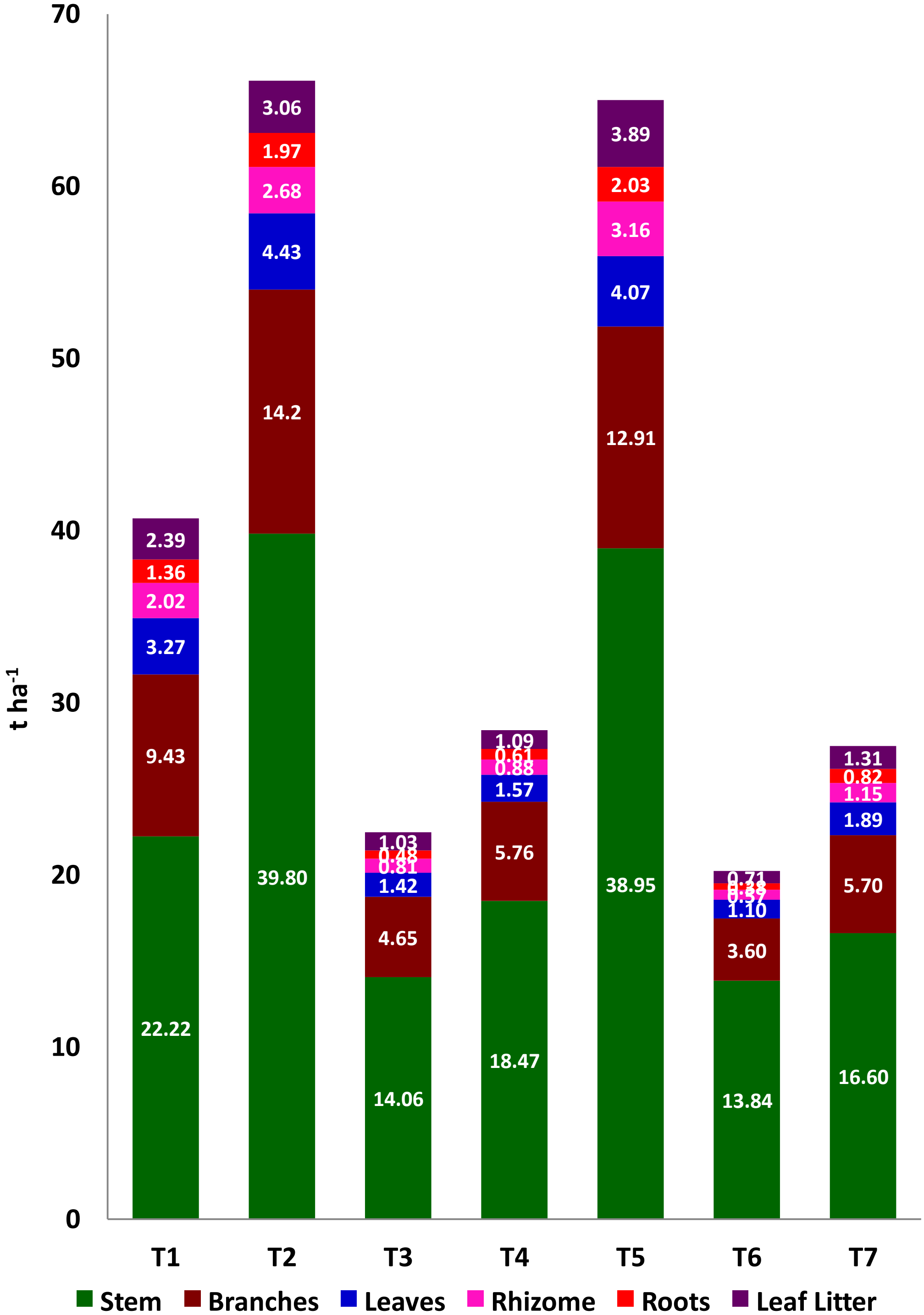

Fig 7 : Effect of different bamboo species on biomass production

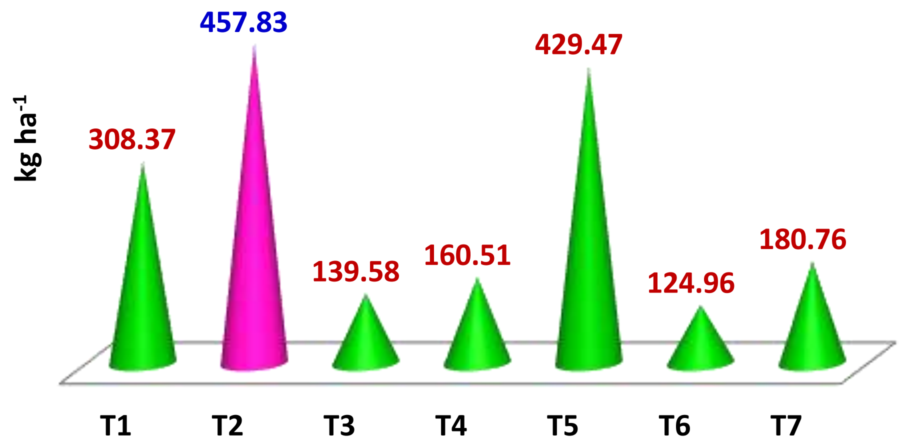

Fig 8 : Effect of different bamboo species on total nitrogen uptake

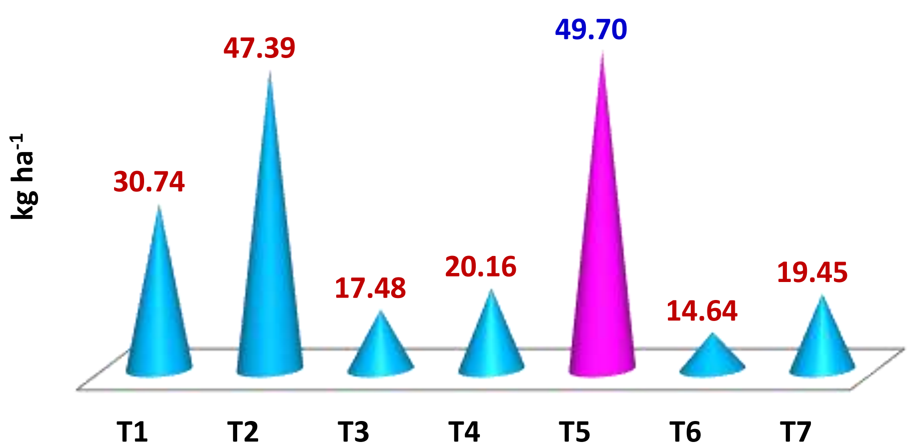

Fig 9 : Effect of different bamboo species on total phosphorus uptake

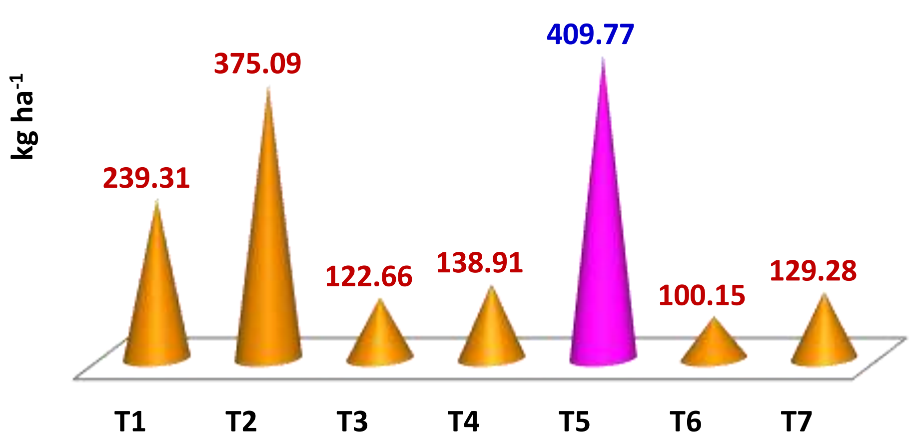

Fig 10 : Effect of different bamboo species on total potassium uptake

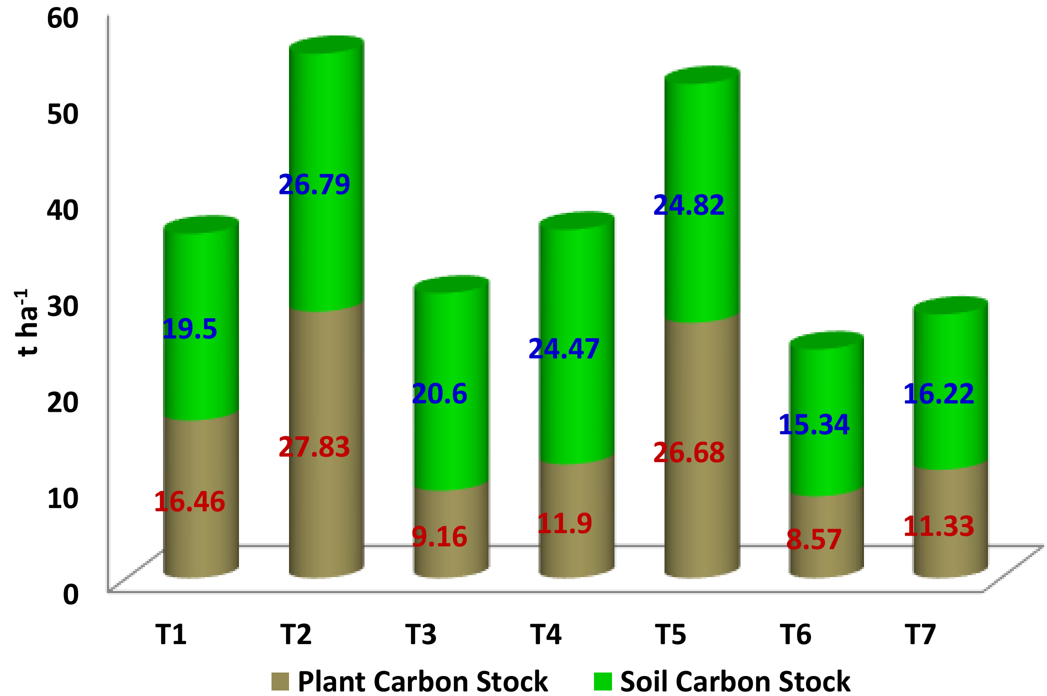

Fig 11 : Effect of different bamboo species on soil and plant carbon stock

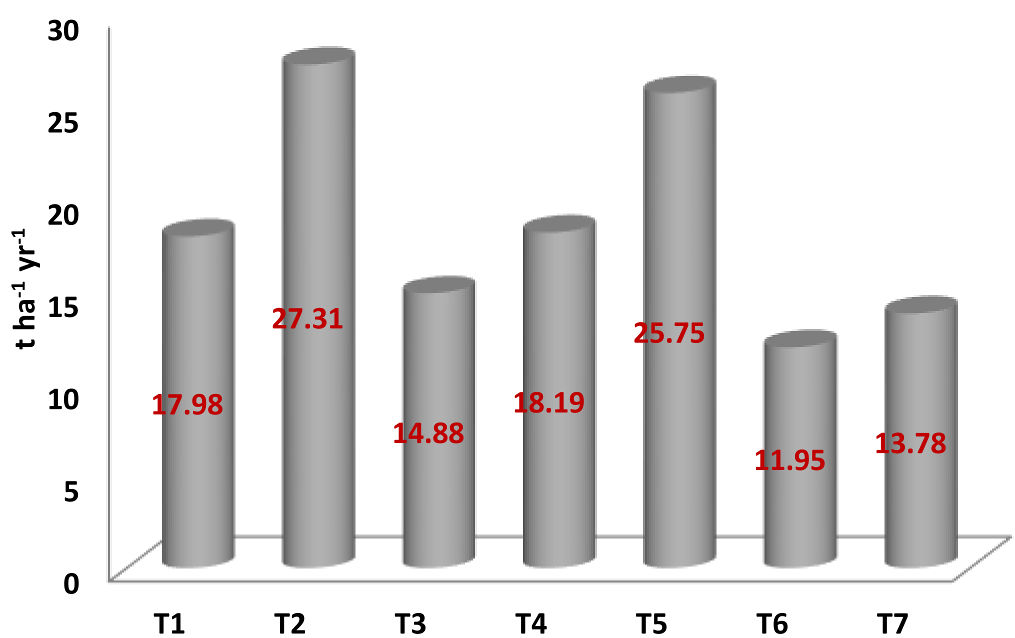

Fig 12 : Effect of different bamboo species on carbon sequestration rate

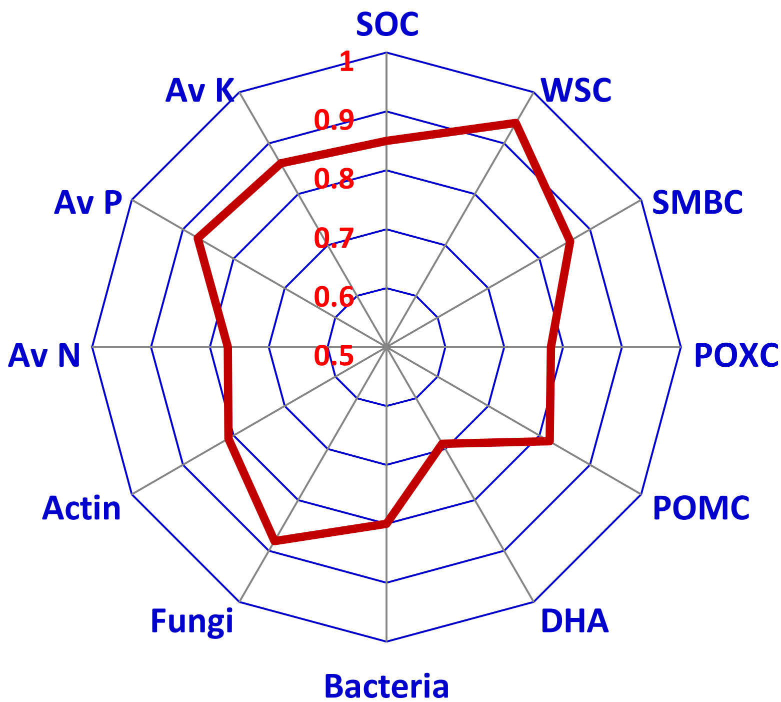

Fig. 13 : Correlation of total soil organic carbon with soil carbon fractions, microbial population, soil enzyme activity and soil available nutrients

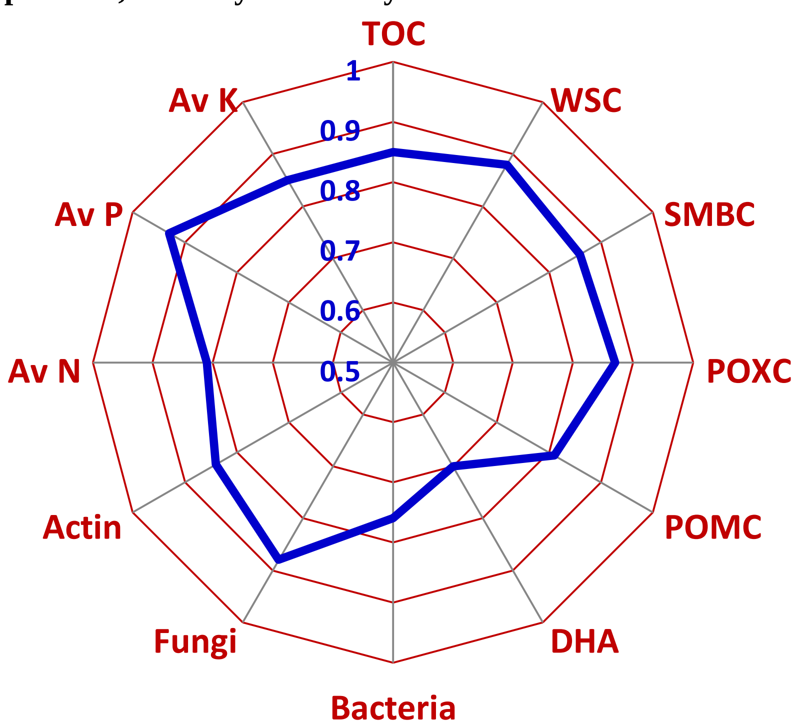

Fig. 14 : Correlation of potassium dichromate oxidizable soil organic C with soil carbon fractions, microbial population, soil enzyme activity and soil available nutrients

T$_1$ - *Dendrocalamus brandisii*

T$_2$ - *Bambusa nutans*

T$_3$ - *Bambusa balcooa*

T$_4$ - *Dendrocalamus strictus*

T$_5$ - *Bambusa tulda*

T$_6$ - *Bambusa bamboos*

T$_7$ - *Dendrocalamus asper*

Plate No. 1: Treatment Details (Bamboo species)