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ARTICLE

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COMPARATIVE STUDY OF ABOVE GROUND BIOMASS AND CARBON STORAGE POTENTIAL OF BAMBOO SPECIES IN BOTH *IN-SITU* AND *EX-SITU* CONSERVATION SITES OF KORAPUT DISTRICT OF ODISHA

PRAKASH PARASETH, SWETA MOHANTY AND KAKOLI BANERJEE*

Bamboo trees are the most important vegetation resources that are mostly distributed in tropical and sub-tropical regions of Africa, Asia and Latin America. Bamboos are fast growing and ease propagating species that avails multiple services towards the society. While going through the novel services of the bamboo species, the present study focused on above-ground biomass (AGB) and above-ground carbon (AGC) assessment in two types of bamboo conservation sites viz. plantation site and sacred groves. The overall AGB and AGC of the plantation site ranged from 67.458±1.691 Mgha^{-1} and 31.704±0.803 MgCha^{-1} (Plot-2) to 71.714±1.716 Mgha^{-1} and 33.704±0.806 MgCha^{-1} (Plot-1). Similarly in sacred groves it ranged from 81.737±3.522 Mgha^{-1} and 38.41±1.652 MgCha^{-1} (Plot-2) to 87.192±3.529 Mgha^{-1} and 40.98±1.655 MgCha^{-1} (Plot-5) respectively. Species wise AGB ranged from 35 Mgha^{-1} to 120 Mgha^{-1} for Bambusa vulgaris and 30 Mgha^{-1} to 115 Mgha^{-1} for Bambusa nutans in plantation site. Similarly, in sacred groves the AGB values ranged from 47 Mgha^{-1} to 132 Mgha^{-1} for Bambusa bambos. More concentration of soil EC, N, P, K and SOC were observed in sacred groves than in plantation site where pH values were higher. For both the sites AGB and AGC has a significant positive relationship with N, P, K and SOC with R^2 value ranging from 0.62 to 0.99. Significant difference between the plantation site and sacred groves in terms of soil parameters, AGB and AGC was observed ($F_{obs} > F_{crit}$; $p<0.05$). Sacred groves as the in-situ *conservation site plays a major role in conserving the bamboo species in its own habitat along with the other species and therefore reflects its importance towards mitigating the global climate change.*

Introduction

Bamboos are globally known as the largest woody grasses from the sub – family Bambusoideae and Poaceae or Andropogoneae. About 1250 bamboo species within 75 genera are recorded in the world and all of them are fast growing, attaining maturity within 5 years[1]. The dwarf bamboo grows up to 10 cm in height whereas others can grow up to 40m. The largest one e.g. *Dendrocalamus giganteus* grows up to 40 m in height and 30cm in culm (stem) diameter[1]. It does not require chemical fertilizer or water to grow. Bamboo species meets the different aspects of the society such as ecological, economical and social. Bamboos play significant roles in the daily lives of local people in terms of materials and foods[2,3]. Bamboo plants require a precipitation range of 1200-1800mm and mean annual temperature range of 13–20°C[4]. Recent reviews have demonstrated that bamboos have high potential to store substantial amounts of carbon due to their wide distribution and rapid growth rates[5,6].

Department of Biodiversity and Conservation of Natural Resources, Central University of Odisha, Sunabeda, P.O. NAD, Koraput 763004, India.

* Corresponding author: banerjee.kakoli@yahoo.com

Most of the tropical, sub-tropical and temperate regions of all countries other than Europe are covered by bamboo species[7,8,9]. Around 13% of the total forest cover in India is occupied by bamboo species which extends in tropical moist deciduous and semi-evergreen forests of north and south part of the country[10].

In the past decade most of the timber-yielding tree species were given importance and the species like bamboo are ignored or of least concern, although it provides multiple traditional services towards the society[2]. Despite the multi-purpose use of bamboo by the local communities rare evidence about the conservation strategy and management planning are found in India[11]. Some of the robust conservation strategies i.e. *ex-situ*, *in-situ* and clonal orchards are ideal for the conservation of bamboo species**[12]**. *Ex situ* conservation in the form of plantation of bamboo trees in agricultural lands, barren lands, artificial forests and gardens are highly necessary to conserve the vanishing genes of bamboo species. *In-situ* conservation in the form of Sacred Groves, Biosphere Reserves and National Parks are highly necessary for conserving bamboo genes in the natural habitats.

India is no exception to many parts of the world in practicing various types of nature worships by communities. One such significant contribution in nature worship is by providing protection to forest patches where forest species are thought to be deities or ancestral spirits and often referred to as "sacred groves". Sacred groves are undisturbed virgin forest that are rich in biodiversity and are conserved by local communities[13]. They are generally small patches of artifact forest that are religiously worshiped as Gods and Goddesses *in-*

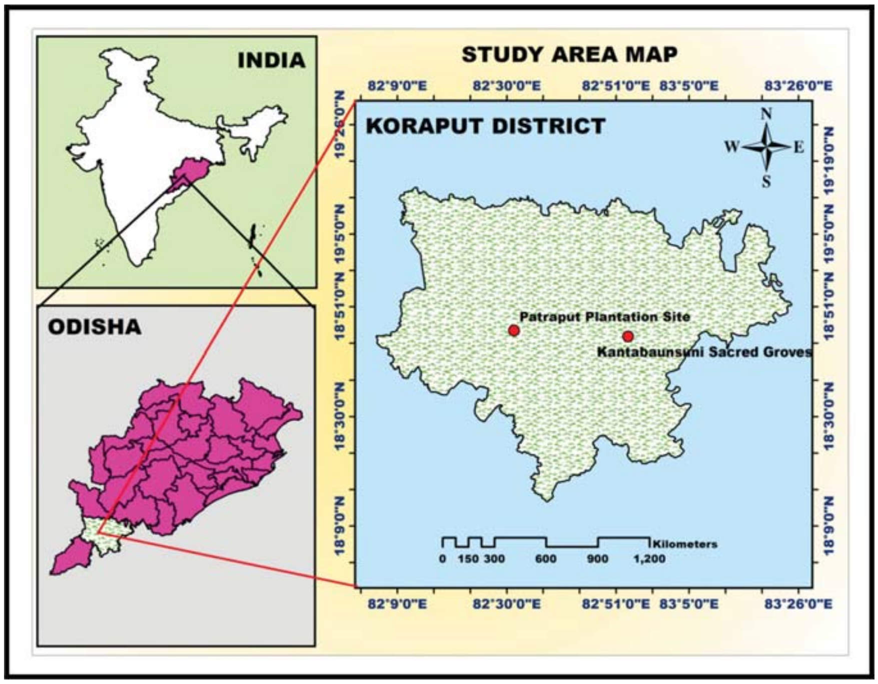


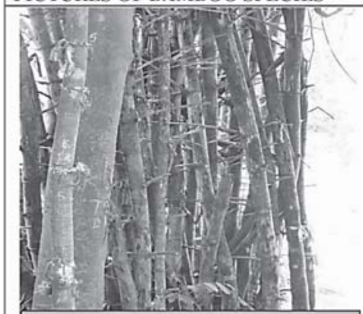
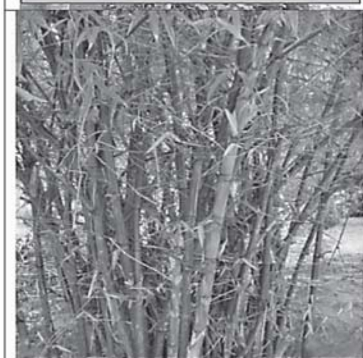
Fig. 1 Study area map showing two types of conservation site

Ex-situ conservation site through plantation (Patraput Village, Jeypore City, Koraput, Odisha)

In-situ conservation through sacred groves (Kantaabaunsuni, Damonjodi, Koraput, Odisha)

Plate 1 Study sites pictures during field work

Table 1 Classification of the targeted bamboo species along with their special features

PICTURES OF BAMBOO SPECIES	CLASSIFICATION	IMPORTANT FEATURES
 *Bambusa bambos* (Kantaabaunsa)	Systematic position Kingdom: Plantae Order: Poales Family: Poaceae Genus: *Bambusa* Species: *bambos*	❖ It is large and thorny bamboo emerging from thick rootstock. ❖ It grows in moist valleys, crop lands and waste lands. ❖ Branches are emerging from the base. ❖ The upper branches have thorny leaves. ❖ It is used for rafters, scaffolding, roof thatching, basket making and furniture.
 *Bambusa vulgaris* (Sundarakani baunsa)	Systematic position Kingdom: Plantae Order: Poales Family: Poaceae Genus: *Bambusa* Species: *vulgaris*	❖ It is an evergreen bamboo having clump-forming, thick walled, erect and woody stem. ❖ It is one among the main six common species used in the paper industry. ❖ It is cultivated in India, Bangladesh and Thailand. ❖ The culm is good, strong, straight and highly prized for construction. ❖ It is used locally as poles and also weaving rough baskets and mats.
 *Bambusa nutans* (Badi baunsa)	Systematic position Kingdom: Plantae Order: Poales Family: Poaceae Genus: *Bambusa* Species: *nutans*	❖ It is the moderate size bamboo, widely cultivated in the primitive lands of all the states. ❖ The culms are loosely packed, therefore it is easy to extract and preferred by the people. ❖ It is widely used for construction activities, scaffolding, thatching, poles, agricultural implements, manufacturing of household goods and handicrafts.

situ[14]. Sacred groves have been reported from the Himalayas, North-east India, highlands of Bihar, Odisha, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala. Koraput district of Odisha harbours a number of tribal communities like Paraja, Mali, Adibasi, Dora, Kandha and Gadaba who have specific religious beliefs[15]. These religious beliefs are now robustly helpful in the conservation of natural resources in terms of water, land, forests and the air we breathe.

Biomass is the amount of living tissue present inside the plant. It is very important to measure biomass of a plant to know the exact amount of carbon stored by the plant. Biomass estimation is used to estimate the weight of the tree on the basis of measured DBH and height of each tree in sample plots. This is a very common budget friendly method to estimate biomass. The dry standing either living or dead part of the plant is known as its above ground biomass (AGB) and the part below the tree is below ground biomass (BGB). In order to assess the carbon sequestration potential and the amount of biomass that can be harvested from *Bambusa* species, accurate estimates of their biomass and carbon content are needed. This requires a comprehensive understanding of the growth patterns and physiological characteristics of the plants, as well as the factors that influence their biomass and carbon content. Bamboo species are capable of absorbing plenty of carbon dioxide from the atmosphere than the amount of carbon dioxide they release on their own. Bamboo captures carbon dioxide very quickly and it helps restoring soil fertility, thus rejuvenates degraded land. Carbon dioxide is in the form of air plays important role in climate change which is caused by emission of excess amount of carbon dioxide and other green house gases. One hectare of bamboo absorbs 17 tonnes of carbon dioxide per year[16]. Bamboo is considered to be very sustainable and carbon fixing as well as the most productive and fastest growing plant on earth. Bamboos can be used for carbon trading which is otherwise known as cap and trade (a method used in developed countries to reduce the amount of carbon dioxide which leads to global warming). The leaf litter on plant growth reported significant improvement in physico-chemical parameters such as pH, EC, organic carbon and other major nutrients (N, P and K) in terrestrial ecosystem[17].

Several studies have been conducted to estimate the biomass and carbon content of bamboo species, but there is still a need for more research on *Bambusa* species specifically. Therefore, the present study focuses on comparative assessment of soil nutritional quality, AGB and AGC of the *Bambusa* species in both *ex-situ* and *in-*

situ conservation sites of Koraput district of Odisha. This study also tries to reveal the relationship between soil parameters with AGB and AGC.

Materials and Methods

Study Area: Koraput district of Odisha is a hilly region with high elevation ranging from 123 – 1672 m above MSL (Mean sea level) and occupies an area of 8379 km^2 in the southern tip of Odisha. Mostly this district is dominated by tribal communities and known for its higher biological diversity as it is an integral part of one of the agricultural hotspot of Eastern Ghats of India[18,19]. This district is located in the peninsular India extending between 18°13' N to 19°10' N and 82°05' E to 83°13' E (Fig. 1). As it is a hilly region and having high elevations in the Eastern Ghats, this district experiences annually three seasons *viz*. summer, monsoon (mostly southwest monsoon) and winters. The temperature varies from a minimum of 14° C to a maximum of 41.5° C with annual rainfall of approximately 2278 mm[20]. Special attention is given towards this district as it has three major industries (Natural Aluminum Company (NALCO), Damonjodi, Hindustan Aeronautics Limited (HAL), Sunabeda, Ballarpur Industries Limited (BILT), Jeypore) and two major bauxite mines (Panchpatmali, Ampavalli) are presently working in this area. Two types of forests are distributed in this region (tropical dry deciduous and tropical moist deciduous forest) which supports a wide range of biological diversity[21]. Mostly these forests are the part of community managed forest.

Table 2. Raw and dry weight of clump along with their moisture contents in percentage(%)

Culm size	Raw weight (Kg)	Dry weight (Kg)	Moisture content (Kg)	Moisture (%)
TL	1.108	0.63	0.478	43.141
TM	0.989	0.472	0.517	52.275
TU	0.147	0.065	0.082	55.782
ML	0.418	0.156	0.262	62.679
MM	0.147	0.074	0.073	49.660
MU	0.061	0.031	0.03	49.180
SL	0.052	0.023	0.029	55.769
SM	0.034	0.012	0.022	64.706
SU	0.016	0.009	0.007	43.750

Note- These are the different culm size of bamboo trees: TL=Thin lower, TM=Thin middle, TU=Thin upper, ML=Medium lower, MM=Medium middle, MU=Medium upper, SL=Small lower, SM=Small middle, SU=Small upper

Table 3a. Correlation values between AGB, AGC and soil parameters of plantation site

	pH	EC (mS)	N (kgha^{-1})	P (kgha^{-1})	K (kgha^{-1})	O C (%)	AGB (Mgha^{-1})	AGC (MgCha^{-1})
pH	1							
EC (mS)	0.18	1						
N (kgha^{-1})	-0.03	-0.63**	1					
P (kgha^{-1})	0.28	-0.60**	0.94**	1				
K (kgha^{-1})	0.12	-0.72**	0.98*	0.97**	1			
OC (%)	-0.64**	-0.13	0.54*	0.32*	0.36*	1		
AGB (Mgha^{-1})	-0.76**	-0.46*	0.62**	0.38*	0.49*	0.92**	1	
AGC (MgCha^{-1})	-0.76**	-0.46*	0.62**	0.38*	0.49*	0.92**	0.89**	1

*p<0.05), ** p<0.01

Table 3b. Correlation values between AGB, AGC and soil parameters of sacred groves

	pH	EC (mS)	N (kgha^{-1})	P (kgha^{-1})	K (kgha^{-1})	O C (%)	AGB (Mgha^{-1})	AGC (MgCha^{-1})
pH	1							
EC (mS)	-0.75**	1						
N (kgha^{-1})	-0.97**	0.83**	1					
P (kgha^{-1})	-0.80**	0.63**	0.83**	1				
K (kgha^{-1})	-0.76**	0.27	0.75**	0.77**	1			
OC (%)	-0.97**	0.75**	0.98**	0.90**	0.83**	1		
AGB (Mgha^{-1})	-0.98**	0.78**	0.87**	0.82**	0.80**	0.99**	1	
AGC (MgCha^{-1})	-0.98**	0.78**	0.87**	0.82**	0.80**	0.99**	0.97**	1

*p<0.05, **p<0.01

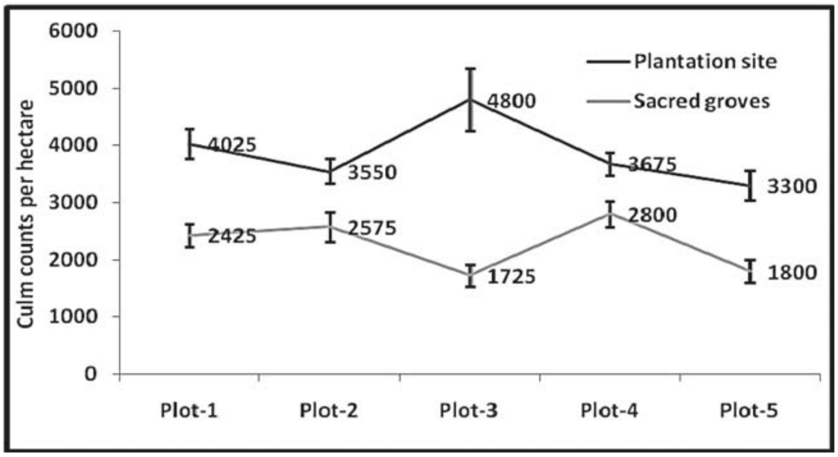


Fig. 2 Plot wise culm density in both plantation site and sacred groves

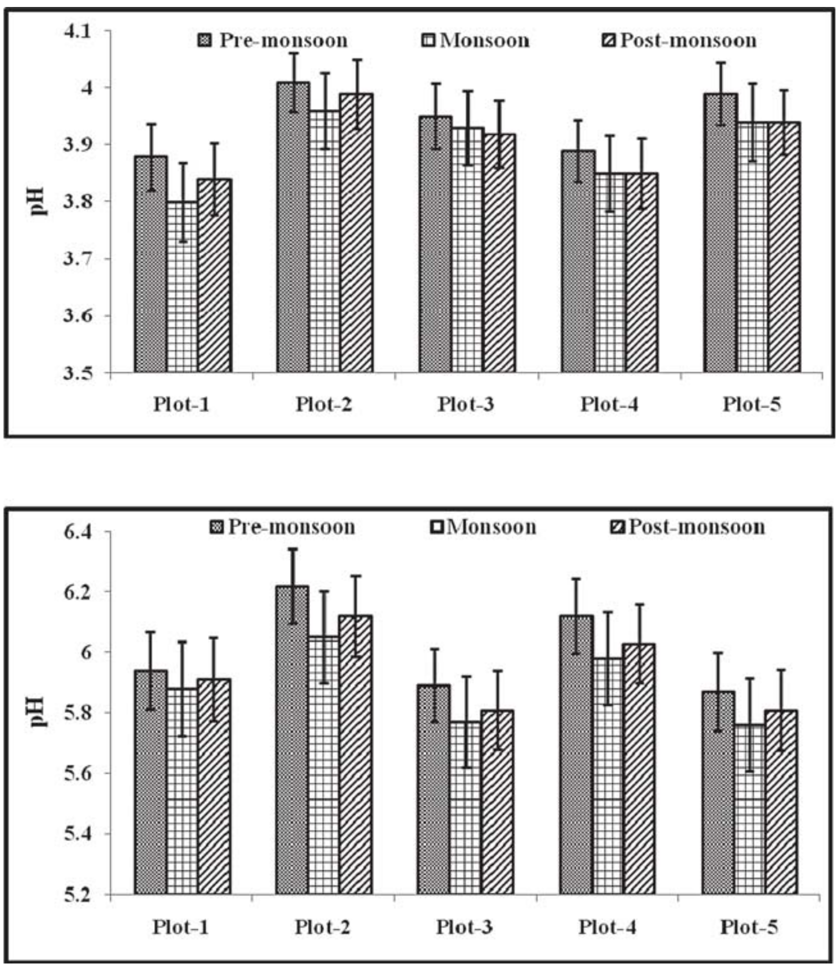


Fig. 3 Seasonal variation of pH in (a) Plantation site (b) Sacred Groves

The present study targeted the bamboo plantations zone in Patraput village near to Jeypore city as the *ex-situ* conservation site and Kantabausuni sacred groves near Damonjodi as *in-situ* conservation site of Koraput district, Odisha (Plate 1). The plantations site is based on organic farming site which is owned and maintained by Mr. Netrananda Lenka who was former staff in Forest Department of Government of Odisha. The sacred grove is managed by the local tribes (like Paraja, Mali, Adibasi, Dora, Kandha and Gadaba) since more than 50 years.

Targeted Bamboo Species: The targeted bamboo stand of plantation site is mostly dominated by two bamboo species viz. *Bambusa vulgaris* (Vittata) and *Bambusa nutans* (Munro). Similarly, in sacred groves *Bambusa bambos* (L.) Voss is the only dominant species. The detailed classification and important features are represented in Table 1.

Data Collection: The bamboo shoot data such as culm counts, tree occurrence, diameter at breast height (DBH) and height (H) were collected from the plantation site and sacred groves by plotting a plot size of 20m × 20m (0.04 hectare) for a time period of three seasons *viz*. monsoon (June to October 2022), post-monsoon (November to February of 2022-2023) and pre-monsoon (March to June of 2023) respectively. Culm's girth was measured by using the measuring tape and height was measured by using BOSCH Digital Range finder. Clump size of 20 cm of three portions (Lower, Middle and Upper) from each culm size of thick, medium and thin respectively were collected from the sites. The bamboo shoot litter samples of these two sites were collected by laying a plot size of 1m × 1m and same size of plots were also utilized for the collection of soil samples from each of these sampling stations.

Computation of Above Ground Biomass (AGB) and Carbon (AGC): The aboveground biomass of bamboo shoots was calculated by using the standard procedure[22]. According to this procedure, the collected clump of size 20cm from the three positions (lower, middle and upper) were taken for sun drying for 20days. After complete drying of the clumps the dry weight of each of these collected clumps for each culm size were taken. The total heights of culms from all sites were multiplied with culm weight to obtain the aboveground biomass of bamboo shoots. The branches and leaves of each size (thick, medium and thin) of the bamboo trees were recorded and one sample of branch and leaf were collected from each category of tree and was oven dried. Similarly, the collected litters were oven dried to get the dry weight. These entire component's (bamboo shoot, branches, leaves and litters) dry weight were added to get the total dry weight or above ground biomass of the study area. The above ground carbon was estimated by using the standard protocols[23] for all the terrestrial tree species.

Assessment of Soil Parameters

The soil parameters such as soil pH, electrical conductivity, nitrate, phosphate, potassium and soil organic carbon were calculated according to the standard procedures explained below:

Soil pH: The soil pH was measured with the help of digital soil pH meter (Model: ZD–05) with sensitivity ±0.02. The reading was taken directly dipping into the soil for 5 minutes.

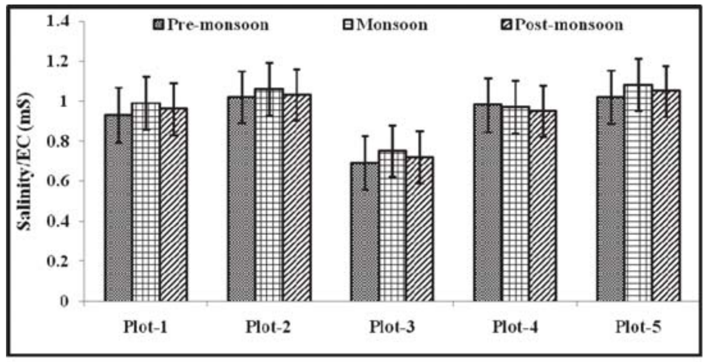
Soil Electrical Conductivity: The soil electrical conductivity was measured with soil EC meter (Accuracy ±1%, resolution 0.01mS) (Model: Spectrum technologies, Inc. EC testr) throughout the study. The reading was taken directly dipping into the soil for 1 minute. The readings were expressed as mS.

Soil Available Nitrogen: The soil nitrogen was estimated through the Kjeldal apparatus (Model–Classic DX auto–nitrogen analyzer). All the samples were analyzed within a week after sampling. The soil nitrogen was estimated by the automatic distillation system (Model Classic DX). The reading was expressed in kgha^{-1}.

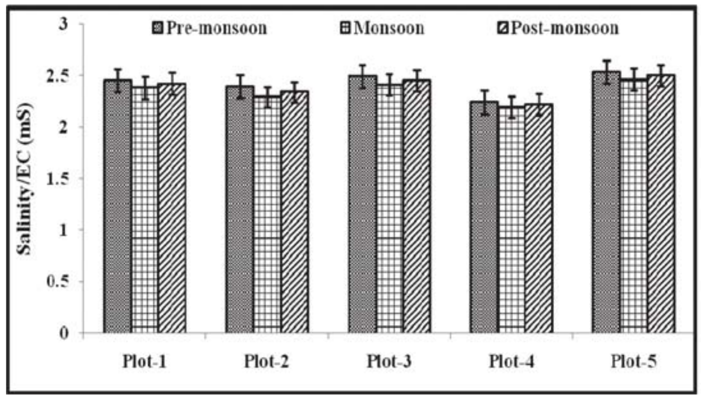
Soil Available Phosphorus: The phosphorus was determined mainly by two processes as per the standard procedure for neutral alkaline soils[24] and for acidic soil[25]. Most of the samples were acidic in nature and hence second method was followed. The reading was expressed in kgha^{-1}.

Soil Available Potassium: The soil potassium was estimated through standard flame photometry analysis. The reading was expressed in kgha^{-1}.

Soil Organic Carbon: Soil organic carbon content of the samples were analyzed by the standard method[26]. The values were expressed in percentage (%).

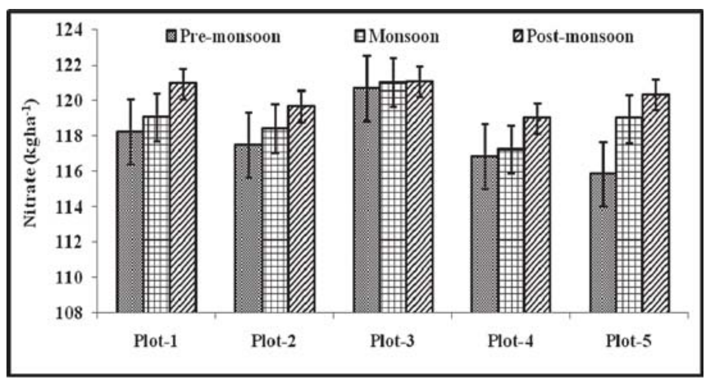


(a)



(b)

Fig. 4 Seasonal variation of EC in (a) Plantation site (b) Sacred Groves



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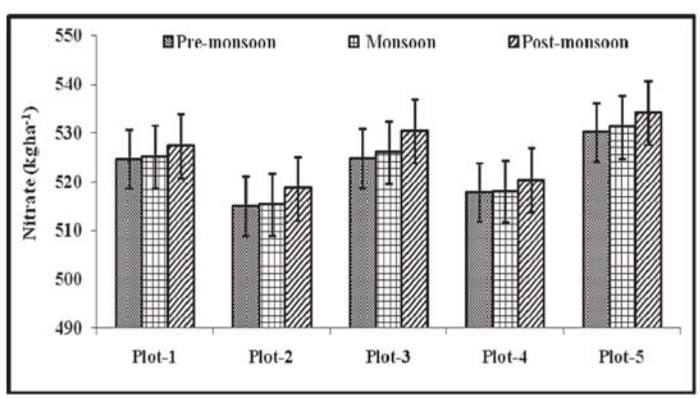
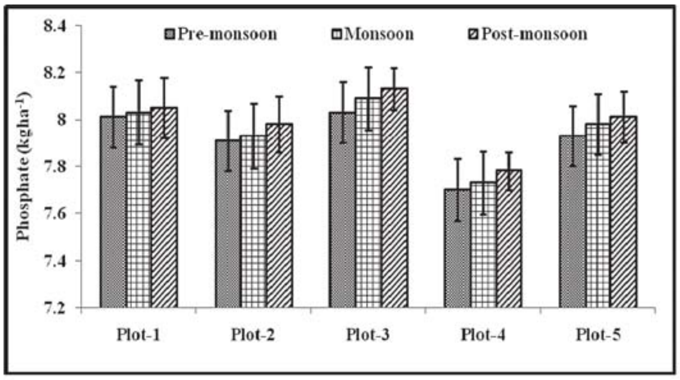


(b)

Fig. 5 Seasonal variation of nitrate (N) in (a) Plantation site (b) Sacred Groves



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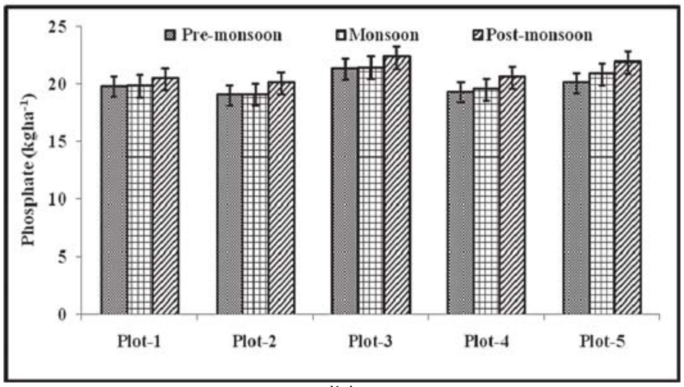
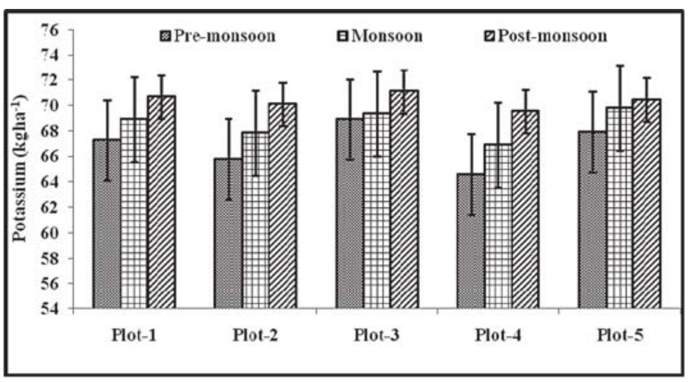


(b)

Fig. 6 Seasonal variation of phosphate in (P) in (a) Plantation site (b) Sacred Groves



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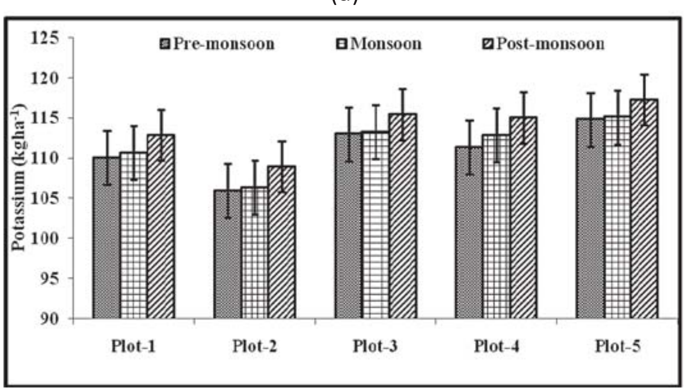


(b)

Fig. 7 Seasonal variation of potassium (K) in (a) Plantation site (b) Sacred Groves

Statistical Analysis

Correlation plot was developed between aboveground biomass (AGB), aboveground carbon (AGC) and soil parameters to explore the role of soil nutrients and minerals towards the bamboo species growth and carbon accumulation in the form of biomass using Microsoft Excel software.

Results

Culm Density and Count: The total area of plantation site is about 6ha which was planted in the year 2012, so the age of bamboo species sampled here is around 11-12 years. Similarly, total area of sacred groves is about 4ha and the age of the bamboo shoots are more than 5 decades. Five sampling plots were designed in each site by considering the uniform distribution of culm's density and rossete (R) counts. The present work laid down 5 plots size of 20m × 20m (0.04ha) in each bamboo sampling sites. In plantation site around 16 rossetes were recorded from each of these sampling plots and in sacred groves it varied 7-11 rossetes per plot. The present work reported two species of bamboo in plantation site viz. *Bambusa vulgaris* which covers more than 50% of the plantation sites and the second one is *Bambusa nutans* whose count is quite less than the *B. vulgaris*. In case of sacred groves only *Bambusa bambos* was observed. The average of 3 seasons (pre-monsoon, monsoon and post-monsoon) in plantation site rossete (R) wise culm density showed the range 10-18 per rossete (R^{-1}) in plot-1, 8-19 R^{-1} in plot-2, 12-19 R^{-1} in plot-3, 9-18 R^{-1} in plot-4 and 8-16 R^{-1} in plot-5. Similarly, in sacred groves rossete (R) wise culm density showed the range 10-21 per rossete (R^{-1}) in plot-1, 11-20 R^{-1} in plot-2, 7-29 R^{-1} in plot-3, 12-20 R^{-1} in plot-4 and 8-18 R^{-1} in plot-5. The overall culm density in the plantation site showed the trend as 4800 ha^{-1} (Plot-3) > 4025ha^{-1} (Plot-1) > 3675ha^{-1} (Plot-4) > 3550ha^{-1} (Plot-2) > 3300ha^{-1} (Plot-5) where as in sacred groves 2800ha^{-1} (Plot-4) > 2575ha^{-1} (Plot-2) > 2425ha^{-1} (Plot-1) > 1800ha^{-1} (Plot-5) > 1725ha^{-1} (Plot-3) (Fig. 2).

Variation of Soil Parameters: About six (06) soil parameters were analyzed in the present study viz. soil pH, soil electrical conductivity (EC), soil nitrogen (N), soil phosphate (P), soil potassium (K) and soil organic carbon (SOC) in both the study sites. The average pH value of three seasons at plantation site ranged from 3.84±0.063 to 3.99±0.060 where as in sacred groves from 5.81±0.138 to 6.13±0.136 (Fig. 3a, b). The average EC values of plantation sites were same in all the plots from 0.72±0.130 to 1.05±0.130 mS but in sacred groves it ranged from 2.22±0.107 to 2.50±0.109 mS (Fig. 4a, b). In plantation site the average nitrogen value ranged from 117.70±1.355 to 120.93±1.355 $kgha^{-1}$ but in case of sacred groves it ranged from 516.33±6.340 to 531.87±6.348 $kgha^{-1}$ (Fig. 5a, b). The average phosphate value of plantation site ranged from 7.74±0.115 to 8.08±0.118 $kgha^{-1}$ where as in sacred groves 19.39±0.940 to 21.67±0.937 $kgha^{-1}$ (Fig. 6a, b). In plantation site the average potassium value ranged from 67.00±2.749 to 69.79±2.748 $kgha^{-1}$ but in case of sacred groves it ranged from 107.09±3.291 to 115.72±3.289 $kgha^{-1}$ (Fig. 7a, b). The average soil organic carbon in plantation site ranged from 4.03±0.786 to 5.91±0.805% where as in sacred groves it ranged from 8.07±0.368 to 8.98±0.369% (Fig. 8a, b). More concentration of soil EC, N, P, K and SOC were recorded in sacred groves than in plantation site (except pH values) due to the generation of huge amount of nutrients added due to litter decomposition and the offerings of the devotees at the base of the plants every day.

Variation of AGB and AGC along with the Tree Inventories: For the estimation of AGB and AGC of bamboo species (*Bambusa vulgaris*, *Bambusa nutans* and *Bambusa bambos*), some of the tree inventories (culm diameter, culm height, branches, leaves and branches) were collected from the sampled area. In case of thin culm size, the GBH value ranged from 0.04m to 0.098m and the height ranged from 1.3m to 2.3m. Similarly in case of medium culm size, DBH value ranged from 0.102m to 0.16m and height ranged from 3.52m to 9.75m and in case of thick size culm GBH ranged from 0.2m to 0.42m and height ranged from 6.6m to16.04m. To estimate the whole culm dry weight or biomass small pieces of size 20cm long clumps were collected from three position (upper, middle, lower) of each culm size (thick, medium, thin) of bamboo species. The raw and dry weight of all clumps of each culm sizes are recorded along with their moisture contents in percentage which is represented in Table 2.

Present study recorded an average AGB range of 35 $Mgha^{-1}$ to 120 $Mgha^{-1}$ for *Bambusa vulgaris* and 30 $Mgha^{-1}$ to 115 $Mgha^{-1}$ for *Bambusa nutans* in plantation site. Similarly, in sacred groves the average AGB values ranged from 47 $Mgha^{-1}$ to 132 $Mgha^{-1}$ for *Bambusa bambos*. Plot wise average values of AGB and AGC of three seasons showed the trend as Plot-1 > Plot-3 > Plot-4 > Plot-5 > Plot-2 in plantation site (Fig. 9a, 10a). In sacred groves the plot wise average AGB and AGC distribution in bamboo shoots showed the trend as Plot-5 > Plot-3 > Plot-1 > Plot-4 > Plot-2

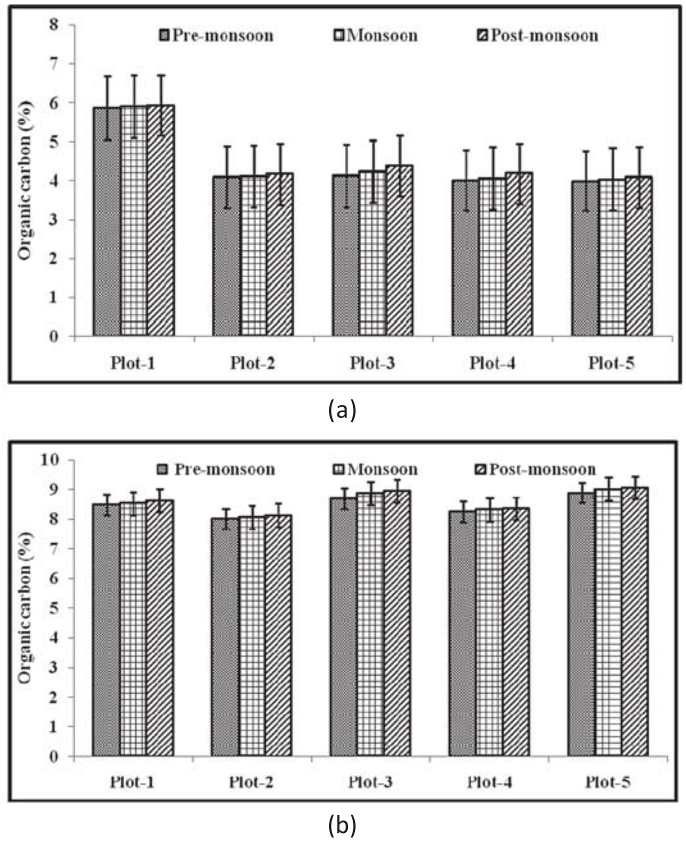


Fig. 8 Seasonal variation of soil organic carbon (SOC) in (a) Plantation site (b) Sacred Groves

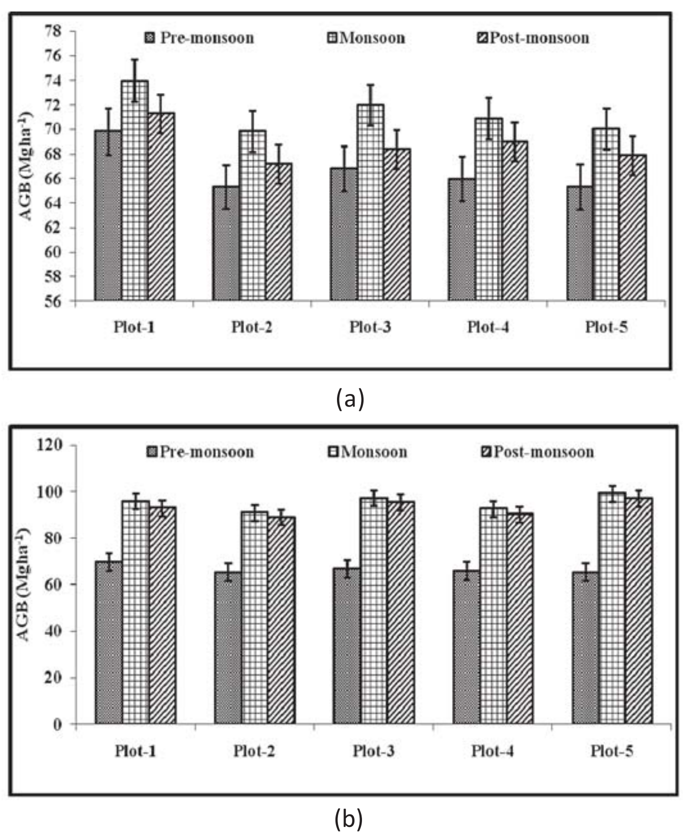
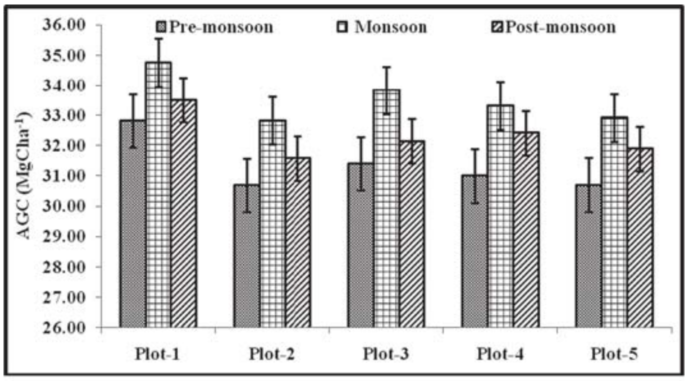
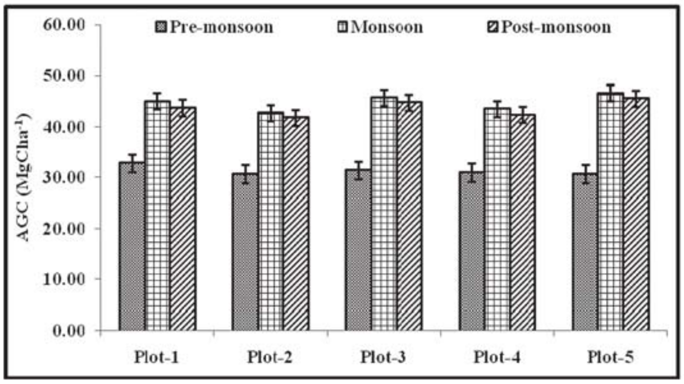


Fig. 9 Seasonal variation of AGB in (a) Plantation site (b) Sacred Groves

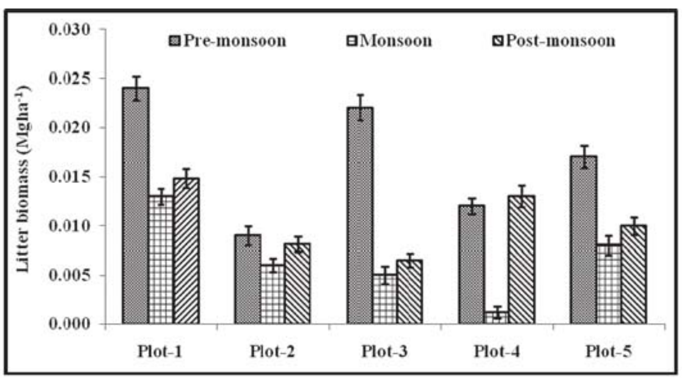


(a)

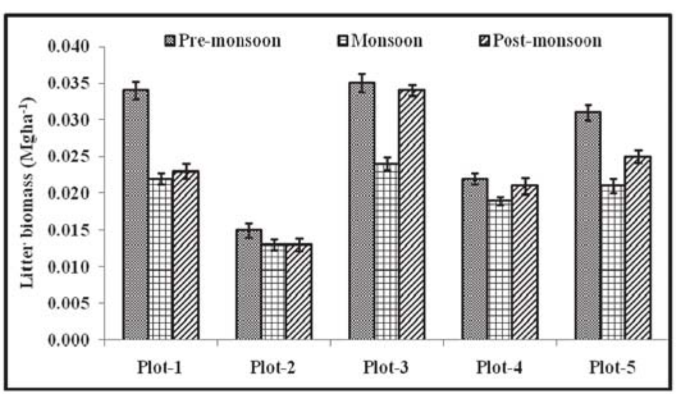


(b)

Fig. 10 Seasonal variation of AGC in (a) Plantation site (b) Sacred Groves



(a)



(b)

Fig. 11 Seasonal variation of litter biomass in (a) Plantation site (b) Sacred Groves

(Fig. 9b, 10b). Similarly, the plot wise average AGB and AGC concentration in litters showed the trend as Plot-1 > Plot-5 > Plot-3 > Plot-4 > Plot-2 in plantation site (Fig. 11a, 12a). In case of sacred groves the plot wise AGB and AGC concentration in litters showed the trend as Plot-1 = Plot-3 > Plot-5 > Plot-4 > Plot-2 (Fig. 11b, 12b).

The total average AGB and AGC (culm's AGB and AGC +leaves AGB & AGC + branch AGB & AGC + litters AGB and AGC) of the plantation site is as Plot-1 (71.714±1.716 $Mgha^{-1}$ and 33.704±0.806 $MgCha^{-1}$) > Plot-3 (69.071±1.692 $Mgha^{-1}$ and 32.464±0.803 $MgCha^{-1}$) > Plot-4 (68.615±1.697 $Mgha^{-1}$ and 32.248±0.804 $MgCha^{-1}$) > Plot-5 (67.752±1.701 $Mgha^{-1}$ and 31.842±0.805 $MgCha^{-1}$) > Plot-2 (67.458±1.691 $Mgha^{-1}$ and 31.704±0.803 $MgCha^{-1}$) (Fig. 13a, b). Similarly in sacred groves it showed the trend as Plot-5 (87.192±3.529 $Mgha^{-1}$ and 40.98±1.655 $MgCha^{-1}$) > Plot-3 (86.508±3.523 $Mgha^{-1}$ and 40.65±1.651 $MgCha^{-1}$) > Plot-1 (86.280±3.529 $Mgha^{-1}$ and 40.55±1.657 $MgCha^{-1}$) > Plot-4 (82.941±3.525 $Mgha^{-1}$ and 38.98±1.655 $MgCha^{-1}$) > Plot-2 (81.737±3.522 $Mgha^{-1}$ and 38.41±1.652 $MgCha^{-1}$) respectively (Fig. 13a, b).

Inter-relationship Between Concentration of Soil Parameters and AGB Growth: In plantation site the AGB and AGC values has a significant positive relationship with soil nitrogen, phosphate, potassium and soil organic carbon ($p<0.01$, $p<0.05$). Again AGB and AGC have a significant negative relationship with pH and EC ($p<0.01$, $p<0.05$) (Table 3a). In sacred groves the AGB and AGC values has a significant positive relationship with electrical conductivity, nitrogen, phosphate, potassium and soil organic carbon ($p<0.01$) and negatively related to pH ($p<0.01$) respectively (Table 3b). The above observations highlighted that the soil organic carbon directly influences the carbon storage potential of the bamboo species. AGB is directly proportional to nitrogen, phosphate, potassium and soil organic carbon in both plantation site and sacred groves.

The present research work performed single factor ANOVA between the groups (between soil parameters of plantation site and soil parameters of sacred groves, AGB of plantation site and AGB of sacred groves). Before going for this analysis two hypothesis were formulated, first one is the null hypothesis (H_0=There is no significant difference between the soil parameters and AGB values of both *in-situ* and *ex-situ* conservation sites of bamboo species) and the second one is alternate hypothesis (H_1= There is a significant difference between the soil parameters and AGB values of both *in-situ* and *ex-situ* conservation sites of bamboo species). After the ANOVA simulation it was observed that all the soil parameters along with AGB and AGC values has a significant difference between the plantation site and sacred groves because F_{obs} values > F_{crit} value, therefore the present study rejected null hypothesis and accepted alternate hypothesis (Table 4).

Discussion

All type of vegetation growth mostly depends on availability of oxygen, carbon dioxide and water. Along with these parameters some of the essential mineral elements such as nitrogen, phosphate and potassium are needed in the form of adequate nutrients[27,28]. Concentration of soil organic carbon mostly depends on the availability of organic matter in the upper part of soil in the form of humus[29, 30]. Alteration of carbon accumulation pattern in the soil is mostly affected by the qualitative and quantitative measure of litters and the type of particle composed (particularly clay particles)[31,32].

In the present study the Kantabaunsuni sacred groves bearing high amounts of electrical conductivity, nitrate, phosphate, potassium and soil organic carbon because of the litters consisting of fruits, flowers, gonads, leaves, twigs, seeds and branches are completely decomposed to form the detritus. As it is sacred place, in relation to the religious belief, anthropogenic pressure like collecting timber and non-timber forests products (NTFPs) from the sacred groves are prohibited. As a result, sacred groves are rich in organic matter and mineral contents. These organic matters and mineral contents provide useful nutrition for enriching soil increasing the soil organic carbon[14]. Although both the study areas (Patraput bamboo plantation site and Kantabaunsuni sacred groves, Damonjodi) are located in the moist climatic regime, the return of high amount of litters in sacred groves has led to more release of nutrients (N, P, K and SOC) from litter decomposition.

Along with the soil nutrients, soil pH also plays an important role in examining the chemical nature of the soil[33]. pH is the calculation of hydrogen ion concentration present in the soil which determines whether the soil is acidic or alkaline in nature[34]. Soil pH plays a key role in plant growth and development

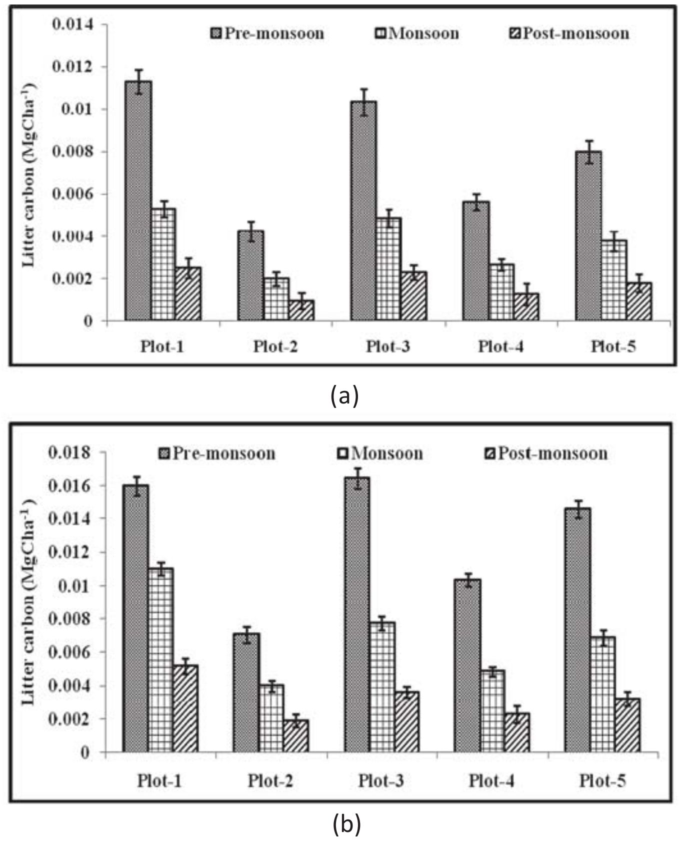


Fig. 12 Seasonal variation of litter carbon in (a) Plantation site (b) Sacred Groves

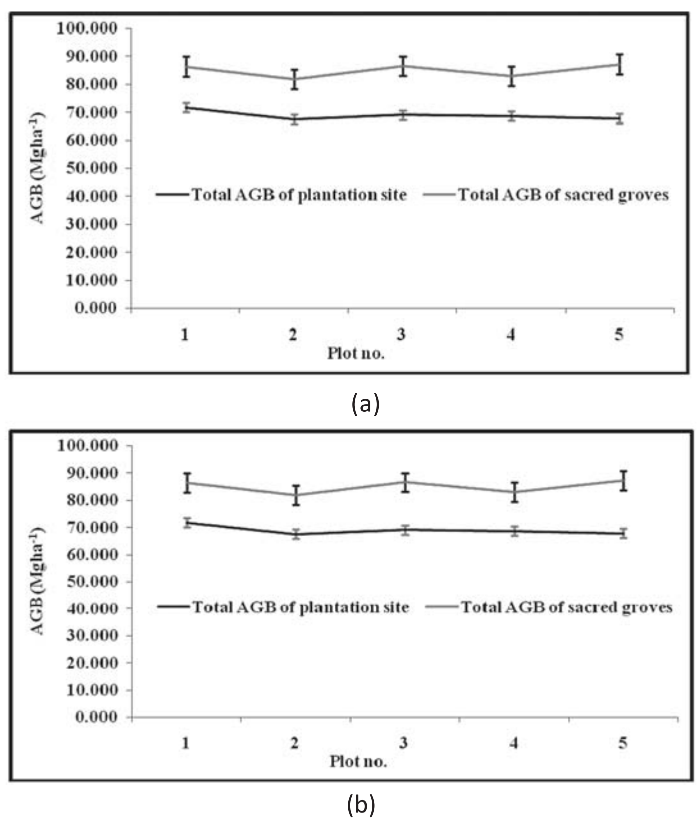


Fig. 13 Total (a) AGB and (b) AGC accumulation in plantation site and sacred groves

Table 4 Single way ANOVA table showing F_{obs} and F_{crit} values between two study sites

Between the group	F_{obs}	F_{crit}
AGB of plantation site × AGB of sacred groves	199.942	5.317655
AGC of plantation site × AGC of sacred groves	2044.91	5.317655
pH of plantation site × pH of sacred groves	784.548	5.317655
EC of plantation site × EC of sacred groves	349.241	5.317655
N of plantation site × N of sacred groves	18839.18	5.317655
P of plantation site × P of sacred groves	893.347	5.317655
K of plantation site × K of sacred groves	910.278	5.317655
SOC of plantation site × SOC of sacred groves	108.165	5.317655

$p<0.05$

by enriching ambient characteristics and nutrient availability for plant uptake. However, a lower pH value binds the soil nutrition tightly and it makes nutrient efficient for the plants. The optimum range of pH for plant nutrient uptake is 5.39 – 6.73[35] and our recorded pH values of both the sites are also in between these optimum range. It has been noted that in all the sites the high organic carbon resulted in low pH because the decomposition of plant litter has led to increase in organic carbon and decrease in pH as has already been reported by earlier workers[36-40].

The present research reported the AGB range of three bamboo species in two different sites are *B. vulgaris*, *B. nutans and B. bambos* which at par with the result observed by Devi and Singh[10]. In a previous work, it was recorded that the AGB ranges from 73.58 to 127 $Mgha^{-1}$ in *Bambusa tulda* and 115 to 150 $Mgha^{-1}$ in *Dendrocalamus longispathus*. C-storage ranged from 36.34 to 64.00 $MgCha^{-1}$ in *Bambusa tulda* and 50.11 to 65.16 $MgCha^{-1}$ in *Dendrocalamus longispathus* which is also similar to the current results. In comparison to *B. vulgaris* and *B. nutan*, *B. bambos* accumulated higher amount of carbon in terms of biomass because the species have large girth, maximum heights and huge number of thorny branches[41]. *Bambusa bambos* being a single species which grows in sacred groves is free from competition to get water and nutrition from the soil, therefore its growth potential is more which reflects in terms of carbon accumulation. Current study found the culm density range of 1725 ha^{-1} to 4800 ha^{-1} which is within the range of the results of Amoah et al[42] (2296 ha^{-1} to 7171 ha^{-1} for *B. vulgaris* species). The above results regarding the relationship between AGB, AGC and soil parameters were also supported by Paoli[43].

Conclusion

The comparison of carbon sequestration potential of two types of conservation sites viz. plantation site (*ex-situ*) and sacred groves (*in-situ*) revealed that the soil parameters like pH, EC, N, P, K and SOC are highly influencing the carbon contents accumulation in the form of AGB in bamboo species. The novelty of the present research lies on the assessment of litter biomass because most of the researchers have neglected the forest floor while calculating biomass of terrestrial ecosystems. Plantation sites of bamboos are greatly influenced by anthropogenic disturbances but sacred groves are free from the anthropogenic pressure because of the religious beliefs of the local people. The present work highlighted that the organic matter concentration are high in sacred groves than the plantation site because of the complete decomposition of the bamboo trees in the soil. The culm density of bamboo species in plantation site is higher as compared to sacred groves, still sacred groves stored huge amount of AGB because of the enrichment of soil with mineral elements in the form of plant nutrition. Sacred groves are worshiped in the name of gods and goddesses which might be the crucial reason for its conservation. Therefore, sacred groves can be declared as ideal conservation sites for both floral and faunal diversities in their natural habitats. Hence tribal community culture in conservation of natural habitats play a vital role in global climate change mitigation measure.

Ethical Approval: NA

Competing Interests: The authors declare that they have no conflict of interest.

Availability of Data and Materials: Data and materials can be made available on request

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