Bamboos: Emerging carbon sink for global climate change mitigation

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Abstract

Global warming and associated climate change is one of the greatest challenges of this millennium. Emission of carbon into the ecosystem due to industrial and technological advancement is one of the strongest causal factors of the global warming. Three common options viz., mitigative, adaptive and indirect are adopted to control it. One of the major mitigation measures is the carbon dioxide sequestration. With global climate change, aspects such as carbon sequestration and biomass production potential of bamboo have been receiving increasing attention. Bamboos, also known as 'poor man's timber' or 'Green Gold' belonging to the family *Poaceae*, subfamily *Bambusoideae*, tribe *Bambuseae,* can play a major role in carbon sequestration due to vigorous growth and addition of biomass annually both above and below ground. Bamboos which can act as great carbon sink have significant advantage over other biomass resources due to species diversity, vigorous growth, early establishment, adaptability to various soil and climatic conditions, short harvesting period, sustainability in yield and multifarious uses. Hence, bamboos may be regarded as the best among the biomass resources. The growth pattern in bamboos is known to be exponential i.e., each year a fresh set of vegetative shoots originate from the base of the clump soon after monsoon showers. India is one of the major bamboo producing countries in Asia, (almost 11.4 million hectares) which accounts for roughly half the total area of bamboo in Asia. Bamboo occurs in almost all the states of India, from the tropical to the temperate regions and the alluvial plains to the high mountains. Bamboo has been successfully integrated in various Agroforestry systems, monocropping and in restoration of marginal lands. Bamboo has several advantages over tree species in terms of sustainability and carbon fixing capacity. International network on Bamboo and Rattan (INBAR) reports that bamboo biomass and carbon production may be seven to 30 per cent higher compared to the fast growing wood species. However, only limited studies have been carried out at International and national level on biomass production and carbon sequestration potential of bamboo species. Studies on carbon sequestration potential of many Indian bamboo species are still lacking. Perusal of literature indicates that most of the studies on biomass production are limited to above ground biomass and the methodology adopted to calculate the biomass are assumptions and regression. The present paper depicts an over

view of the biomass production and carbon sequestration potential of bamboos in India.

Introduction

International Panel on Climate Change (IPCC, 2000) defines carbon sequestration as an increase in carbon stock in any non atmosphere reservoir. Bamboos, the arborascent grasses belonging to Poaceae are multipurpose plants with high economic and environmental values and have the potential to convert solar radiation into useful goods and services better than most other tree species (Embaye *et al.*, 2005). in the era of global climate change, aspects such as carbon sequestration and biomass production potential of bamboos have been receiving increasing attention (Kumar *et al.*, 2005; Das and Chaturvedi, 2006; Nath and Das, 2008; Nath *et al.*, 2009).

Bamboo resources

Bamboo stands occupy an area of 36 million hectares worldwide which is equivalent to 3.2 per cent of the total forest area. It occupies over one per cent of the tropical and subtropical forest area - over 22 million ha. Over 80 per cent of the total area covered by bamboo is located in Asia, 10 per cent in Africa and 10 per cent in America (Lobovikov *et al.*, 2007). India is one of the major bamboo producing countries in Asia, (almost 11.4 million hectares) which accounts for roughly half the total area of bamboo in Asia (Lobovikov *et al.*, 2007). As per the latest compilation, there are 18 genera and 128 species (Seethalakshmi and Kumar, 1998) of which about 20 are commercially used. There are different reports about the bamboo resources in the country using both survey and remote sensing methods (Muraleedharan *et al.*, 2007). FSI (2011) reported total bamboo bearing area of the country to be 13.96 M ha.

Bamboos have a cosmopolitan distribution in the tropical, subtropical and temperate regions except Europe (Dransfield, 1992; Zhu *et al.*, 1994; Nguyen, 2006). There are over 110 genera of bamboos with more than 1500 species all over the world (Subramaniam, 1998, Orhnberger and Goerrings, 1985). The large diversity of species allows it to grow in any part of the world (except Polar Regions) and to tolerate the climatic exigencies. Different growth forms of bamboos such as trees, shrubs and climbers are found naturally (Prasad and Gadgil, 1981). It is observed as pure stands, mixed with other species and also cultivated in homesteads, farmlands and other Agroforestry systems.

Uses of bamboos

Bamboo has invited the attention of mankind from time immemorial due to its unique uses such as the carbonized filament by Edison in his experiments to light a bulb, phonograph needle by Graham Bell and pioneering plants to come up after atom bomb blasts in Hiroshima. With regard to strength, tensile strength of bamboo is greater than that of mild steel and for compression, bamboo species such as *Guadua angustifolia* is stronger than concrete. From top to bottom all parts of the plant is useful. The number of uses of bamboo is growing with new development initiatives taken across the world. in India bamboo is used for a variety of purposes and the major consumption pattern is consolidated below (Table 1).

Table 1: Consumption pattern of bamboos in India

S. No.	Uses	Consumption (%)
1.	Pulp	35.0
2.	Housing	20.0
3.	Non-residential	5.0
4.	Rural uses	20.0
5.	Fuel (non-industrial)	8.5
6.	Packing including basket	5.0
7.	Wood based industries and transport	2.5
8.	Furniture	1.0
9.	Others including ladders, mats etc	3.0

Source: Tewari, 1992

Growth of bamboos

Growth of the new shoots in bamboo clumps occurs as a result of transfer of the energy accumulated in culms through photosynthesis in the previous year (Magel *et al.*, 2005). As such, the growth of a bamboo culm is not driven by its own carbon sequestration, but by sequestration in previous seasons in other parts of the bamboo system, and as such growth of new shoots is not an indicator of sequestration rate. On the other hand, as the bamboo system requires more inputs in the shooting season of young culms (when new shoots grow), high growth in bamboo shoots can be equated with a high rate of carbon sequestration (Zhou *et al.*, 2009). Bamboo has several advantages over tree species in terms of sustainability and carbon fixing capacity. International network on Bamboo and Rattan (INBAR) reports that bamboo biomass and carbon production may be seven to 30 per cent higher compared to the fast growing wood species. Available studies conclude that bamboo biomass and carbon production may be 7-30 per cent higher compared to the fast growing wood species (http://www.inbar.int/show.asp?NewsID=373). A well-managed bamboo ecosystem, like forests of other fast growing species, is likely to have a lower carbon accumulation than natural forests, but the data for such comparisons are scarce. The differences may in part be due to higher levels of soil carbon in natural forests.

Biomass production of bamboos

Only limited studies have been carried out at International level on biomass production and carbon sequestration potential of monopodial bamboo species those are structurally different from sympodial bamboo species. Studies conducted on *Chusquea culeou, C. Tenuiflora* (Chile), *Phyllostachys bambusoides* (Japan) and *P. pubescens* (Japan and China) indicated a higher biomass production and above ground net primary productivity (Isagi *et al.*, 1993; Qiu *et al.*, 1992; Isagi *et al.*, 1997). Gratani *et al.* (2008) studied the growth pattern and photosynthetic activity *Phyllostachys viridi-glaucescens, P. pubescens,* and *P. bambusoides* and stated that owing to the great potential for biomass production, bamboos could be a significant net sink for CO_2 sequestration. Variation in biomass production of *Fargesia yunnanensis*, an alpine bamboo with sites due to total nitrogen (N) and organic matter status of soil was reported from China (Shuguang *et al.*, 2009). Yen and Lee (2011) on comparison of aboveground carbon storage between *P. heterocycla* (moso bamboo) and *Cunninghamia lanceolata* (China fir) reported higher carbon storage for China fir forests than for moso bamboo, 99.5 vs. 40.6 Mega gram per hectare (Mg ha^{-1}). But there was variation in age between the plantations and the mean aboveground carbon sequestration was higher in moso bamboo (8.13±2.15 Mg ha^{-1}) compared to China fir (3.35±2.02 Mg ha^{-1}). Wen *et al.* (2011) reported that the capability of carbon fixation of *P. pubescens* leaves had obvious temporal and spatial dynamic variations. Daily and seasonal carbon fixation showed a negative correlation with the CO_2 concentration. Yongfu *et al.* (2011) studied the dynamic changes in height, biomass, and carbon accumulation in young *Phyllostachys pubescens.* They found that the accumulation of biomass and carbon in young bamboos depended mainly on ground diameter and the length of time after the bamboo shoots sprouted. Studies conducted in Vietnam indicated that a shift in land use from annual crops to bamboo provides an annual net gain of soil organic carbon of approximately 0.44 t ha^{-1} (Proyuth *et al.* 2012).

Although, India is endowed with rich bamboo resources both in species and area, the studies on biomass production of many of the bamboo species are lacking. The Culm production and clump expansion studies in *Bambusa balcooa, B. longispiculata, B. tulda, B. vulgaris* and *Melocanna baccifera* indicated that only one to three full grown clumps were produced per clump in the first year after planting (Banik, 1988). Studies on Culm dynamics of plantation grown *B. bambos* revealed that the rate of production of new culms was linearly related to clump size (Das and Chaturvedi, 2006). Population structure of *Bambusa cacharensis, B. vulgaris* and *B. balcooa* under traditional harvest regimes had exhibited preponderance of younger age class than older ones (Nath *et al.*, 2006). Studies on population structure of bamboos viz. *Schizostachyum dullooa* and *Dendrocalamus strictus* also indicated the preponderance of younger culms over the old ones (Nath *et al.*, 2007; Jha and Das, 2008; Nath and Das, 2011_b).

Singh and Singh (1999) examined the growth and impact of *Dendrocalamus strictus* plantation on mine soil in a dry tropical region at the ages 3, 4, and 5 years. Total biomass accumulation was 46.9 t ha^{-1} $year^{-1}$ in the 3 year old to 74.7 t ha^{-1} $year^{-1}$ in the 5 year old plantation with 35 per cent at below ground. Total net primary production (NPP) ranged between 20.7 t ha^{-1} $year^{-1}$ (3 year old) and 32.0 t ha^{-1} $year^{-1}$ (5 year old), of which aboveground net production was 17.0 to 24.7 t ha^{-1} $year^{-1}$ (between 3 to 4, and 4 to 5 years, respectively).

The progressive increment of biomass related morphometric parameters correlated optimally with the age of the clump in *Dendrocalamus longispathus* Kurz. On aging of the clumps, the culms emerged in subsequent years were gradually taller with larger diameter and with more internodes. in the third and fourth years leaf production and growth were getting low, but in the fifth and sixth years these sharply declined and ultimately the Culm died. Thus harvesting of Culm within 3 to 4 years of age could be an ideal management practice in the species (Banik and Islam, 2005).

Aboveground biomass of *Bambusa bambos* clumps from Thrissur, Kerala planted in hedgerows averaged 2417 kg per clump with an average per ha accumulation of 241.7 Mg ha^{1}. The highest biomass accumulation was observed in the live culms (82 per cent), followed by thorns + foliage (13 per cent); dead culms accounted for only nearly 5 per cent of the biomass accumulation. Average N, P and K removals on harvesting were 9.22, 1.22 and 14.4 kg per clump, respectively (Kumar *et al.*, 2005). Upadhyaya *et al.* (2008) also reported the highest biomass allocation in culms and lowest in leaves and the species wise total above ground biomass was in the sequence of *B. balcooa* > *B. pallida* > *Phyllostachys bambusoides* > *Arundinaria racemosa.*

Nath *et al.* (2009) reported that above ground stand biomass of village bamboos of Barak Valley, North East India was 121.51 t ha^{-1} of which 86 per cent was contributed by Culm component followed by branch (10 per cent) and leaf (4 per cent). With respect to species, *B. cacharensis* made up to 46 per cent of total stand biomass followed by *B. vulgaris* (28 per cent) and *B. balcooa* (26 per cent). Carbon storage in the above ground biomass was 61.05 t ha^{-1}. Allocation of C was more in Culm components (53.05 t ha^{-1}) than in branch (5.81 t ha^{-1}) and leaf (2.19 t ha^{-1}). Carbon storage in the litter floor mass was 2.40 t ha^{-1}, of which leaf litter made up the highest amount (1.37 t ha^{-1}) followed by sheath (0.86 t ha-^{1}) and branch (0.17 t ha^{-1}). Carbon stock in the soil up to 30 cm depth was 57.3 t ha^{-1}. Gross C stock in the plantation was estimated to be 120.75 t ha^{-1}.

B. balcooa plantation raised under precision farming has shown annual yields of over 100 t ha^{-1} and stabilization at 150 t ha^{-1} The quality of biomass generated by this species is high, having 4,000 kilo calories of heating value per kg with ash content of less than 0.5 per cent. Generation of renewable energy of 1 MW per hour (8,000 MW hours per year) requires only 80 ha of bamboo based energy plantation against over 400 ha of energy plantation based on many other tree species. The presence of 48 per cent carbon in bamboo biomass with the average annual yield of 100 t ha^{-1} makes it possible to sequester carbon dioxide of over 200 t ha^{-1} $year^{-1}$ which is currently the most superior plant. Gasification of bamboo biomass generates 10 to 15 per cent carbon as biochar apart from generation of electricity, which makes this process "Carbon negative" (Barathi, 2010).

Agarwal and Purwar (2010) had developed linear regression models to estimate the above-ground biomass of five bamboo species in Uttarakhand, India viz. *Dendrocalamus strictus, B. vulgaris, B. multiplex, B. bambos* and *Phyllostachys nigra* which differ in size and growth pattern. Linear regression model indicated that above-ground biomass depends on the height of the pole, girth to height ratio at 1.0 m and 1.5 m by 107, 67, 98, 125 and 99 per cent on dry weight basis, and 104, 65, 107, 168 and 100 per cent on fresh weight basis in *D. strictus, B. vulgaris, B. multiplex, B. bambos* and *P. nigra,* respectively. Biomass produced was 30 per cent more on fresh weight basis than dry weight in all the species. Average biomass produced was *D. strictus* - 581.8, *B. vulgaris* - 832.4, *B. multiplex* - 15.9, *B. bambos* 703.1 and *P. nigra*, - 72.5 kg ha^{-1} $pole^{-1}$ on dry weight basis. Percentage of organic carbon in the soil also increased due to planting of various species, which was 20.4 to 74.5 per cent higher over control.

Studies on carbon sequestration potential of many Indian bamboo species are still lacking. Nath and Das (2007) stated that the bamboos form the imperative component of the agrosilvicultural system in North East India and have an important influence on the C balance of the ecosystem through assimilating atmospheric CO_2. Nath *et al.* (2008) reported that the above ground carbon sequestration potential of a bamboo stand consisting of *Bambusa balcooa, B. cacharensis*, and *B.vulgaris* was in the tune of 21.36 Mg ha^{-1}. Nath and Das (2011_a) reported that the carbon sequestration rate of *B. balcooa, B. cacharensis*, and *B. vulgaris* in the small holder homegardens was 1.32 Mg ha^{-1} $year^{-1}$. They observed that the harvesting of mature culms was balanced by the carbon gains from the new culms. The biomass accumulation (above ground) of bamboo species in different locations of the world is summarized in Table 2.

Table 2: Biomass accumulation (above ground) of bamboo species in different locations of the world

Species	Country	Total biomass Mg ha^{-1} (age)	Reference
Bambusa bambos	India	122.0 (at 4) 225.0 (at 6) 287.0 (at 8)	Shamnughavel and Francis, 1996
		170.8 (at 3) 206.7 (at 4) 257.3 (at 5)	Das and Chathurvedi, 2006
Bashania fangiana	China	0.35	Zhou and Huang, 1997
Dendrocalamus latiflorus	China	28.49	Lin Yiming *et al.*, 2000
D. strictus	India	4.0 – 22.0	Tripathi and Singh, 1994
		182.7-207.4 (at 3)	Singh *et al.*, 2004
D. oldhami	China	134.5	Lin Yiming *et al.*, 1998
Gigantochloa ater, G. verticilata	indonesia	45.0	Christanty *et al.*, 1996
Guadua anguistifolia	Colombia	54.3 (at 6)	Riano *et al.*, 2002

Allometric equations have been developed to estimate per ha biomass in bamboos by many workers. Kumar *et al.* (2005) related clump biomass and Culm number with clump diameter of 20 year old hedge rows of *Bambusa bambos* and the fitted equations gave high R^2 value and gave reasonably good predictions of Culm number per clump and standing stock of clump biomass. Biomass production potential of different bamboo species in Nepal was recorded by various authors and regression equations were developed to predict the biomass. Oli (2003) estimated the biomass production of *Bambusa nutans* subspecies *nutans* grown at Eastern Terai, Nepal by using regression technique. The regression equations linking measurements of diameter at 15 cm of the base (D_{15}), vertical height of the Culm (L), green and dry weight of the Culm, branches and foliage of *Bambusa tulda* were developed by Oli (2005). To estimate the biomass, a regression model $W = a + b \times (D^2 L)$ was developed on the basis of oven dry and green weight. The biomass tables of *Bambusa tulda* grown at Belbari, Morang district of Eastern Nepal was prepared out of this data. Oli and Kandal (2005) prepared biomass table of *Bambusa nutans* subspecies *cupulata* grown at Belbari, Morang district of Eastern Terai. While, Oli and Kandel (2006) prepared biomass tables of *Dendrocalamus hookeri* grown at Jhanjhatpur, Kailali district of Far-western Terai by linking measurements of Diameter at 15 cm of the base (D_{15}), vertical height of the Culm and green weight of the Culm, branches and foliage.

Jijeesh (2014) reported the average Culm production of *B. balcooa, B. bambos, O. travancorica* and *T. oliveri* at the age of seven years was 7799, 7000, 29945 and 3725 culms ha^{-1} respectively. The biomass production of bamboo clumps increased with age. The average biomass accumulation in six year old *B. balcooa, B. bambos, O. travancorica* and *T. oliveri* clumps was to the tune of 116.079, 31.660, 12.145 and 99.067 kg and that of seven year old clumps was 159.935, 51.334, 17.731 and 111.286 kg, respectively. Among the clump components like culm, branch, leaf, rhizome and root, culms contributed major share of biomass accumulated in a clump. Carbon concentration of the clump components varied significantly irrespective of species and the average carbon concentration in the components was 40.53 per cent. Aboveground biomass components recorded a higher carbon concentration than belowground in all the bamboo species. Carbon sequestration of *B. balcooa* at the age of six and seven years was to the tune of 22.34±6.87 and 30.66±10.01 Mg ha^{-1} and that of *B. bambos* was 7.19±0.53 and 10.33±2.58 Mg ha^{-1} respectively. Meanwhile, carbon sequestration of *O. travancorica* at the age of six and seven years was 2.690±0.14 and 3.02±0.23 Mg ha^{-1} and that of *T. oliveri* was 18.66±2.19 and 21.14±6.15 Mg ha^{-1}, respectively. Soil also played an important role in carbon sequestration. Soil carbon content and density declined with increasing depth. Total carbon density of soil under *B. balcooa, B. bambos, O. travancorica* and *T. oliveri* at the age of seven was 56.95±4.34, 62.86±6.26, 46.28±4.31 and 54.02±3.17 Mg ha^{-1}, respectively.

Kittur (2014) studied the biomass production of 9 year old bamboo (*Dendrocalamus strictus* (Roxb.) Nees) planted under varying spacings (4x4, 6x6, 8x8, 10x10 and 12x12 m; Densities: 625, 277, 156, 100 and 69 clumps/ha) in Kerala.). Results indicated that the clump wood constituted the largest (60-70 %) share to the total biomass in all the spacings. The leaf biomass in widest spacings was increased by 325 per cent compared to closest spacings. The densest (625 clump/ha) stand though recorded maximum biomass, the eventual clump-wise biomass was highest in least dense stand (69 clumps/ha). The C in clump wood decreased by 55 % in closest spacings compared to widest spacings. The majority of C was accumulated in clump wood (5.45 to 22 Mg/ha). When spacings increased to 12x12 m, the C storage in above ground biomass increased by 3.61 times compared to densest stand (4x4 m).

Carbon credits for bamboo

Bamboo plantations can play major role in carbon sequestration (Seethalakshmi *et al.*, 2009) and Afforestation/Reforestation CDM (Jijeesh and Seethalakshmi, 2009). Bamboos have extensive underground rhizome and root systems which can live even up to 100 years (http://blog.cifor.org/13245/bamboo-carbon-credits-now-on-sale-in-china/). Even if the bamboo stems are harvested, the underground carbon is not lost into the atmosphere, as the plant continues to live. When the harvested bamboo is turned into durable products, the ecosystem can actually store more carbon when it is being used productively, than if it is left to grow wild. Life cycle analysis of industrial bamboo products had indicated that if best practice technology is employed bamboo products can be labelled as carbon neutral (Lugt *et al.,* 2012).

Since bamboo is botanically a grass and not a tree, many carbon accounting documents fail to include bamboo, or do not consider bamboo within forestry. Bamboo, therefore, does not adequately fit under the terminology for a 'forest' in the Kyoto Protocol, Marrakech Accords or IPCC. If bamboo were to be adequately recognized within 'forestry,' bamboo could potentially occupy an important position in climate change mitigation, adaptation, and sustainable development (Lobovikov *et al.*, 2009). The possibility of including tall and medium height woody bamboos as trees under UNFCCC and the Kyoto Protocol, and in the future, under REDD and REDD+ is under consideration. The Executive Board of the CDM in 39th meeting decided that "Palm (trees) and bamboos can be considered equivalent to trees in the context of A/R". However, the final decision on what constitutes a 'forest' lies with the country Designated National Authorities (DNAs), therefore potentially affecting whether CDM or other schemes include palms and/or bamboos (Lobovikov *et al.*, 2009). in an International first, Food and Trees for Africa's Bamboo for Africa has been registered as a Verified Emissions Reduction programme under the International Verified Carbon Standard. This brings cost effective carbon sequestration to South Africa and addresses enterprise development, corporate social investment and black economic empowerment (http://www.trees.co.za/announcements/food-trees-for-africa-announces-first-bamboo-carbon-registration.html).

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