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Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India

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Abstract: Bamboo forms an important component in the rural landscape of northeast India. Carbon (C) pool and sequestration potential of bamboos in the land managed by farmers was studied in Cachar district, Assam, northeast India. Allometric equations were developed by harvest method relating leaf, branch and culm biomass with DBH as an independent variable to determine the stand biomass and productivity. C pool and C sequestration in different bamboo culm components was determined by multiplying the biomass with C concentration. C pool in the above ground biomass ranged from 21.69 Mg ha^{-1} during 2003 to 76.55 Mg ha^{-1} during 2006. Allocation of C was more in culm components (85 - 89 %) than in branch (8 - 10 %) and leaf (3 - 4 %). Both current and one year old culm constituted 58 - 73 % (15.86 - 35.63 Mg ha^{-1}) of the total above ground C pool. The rate of above ground C sequestration was 18.93 - 23.55 Mg ha^{-1} yr^{-1} with the mean of 21.36 Mg ha^{-1} yr^{-1}. Of the total annual C sequestration, 82 - 89 % was contributed by new culms and through culm age increment and 14 - 18 % by annual total litter production. Management of village bamboos as a potential source of C sink by smallholder farmers is discussed.

Resumen: El bambú constituye un componenteimportante en el paisaje rural del nordestede la India. Se estudió el almacén y el secuestro potencial de carbono (C) de los bambúes en terrenos agrícolas manejados en el distrito Cachar, Assam, nordeste de la India. Por medio del método de la cosecha se desarrollaron ecuaciones alométricas que relacionan la biomasa de la hoja, la rama y el culmo con el DAPcomo variable independiente,a fin de determinarla biomasa y la productividad del rodal. El almacén de C y el secuestro de C en diferentescomponentes del culmo del bambúfueron determinados multiplicandolabiomasapor la concentración de C. El almacén de C en labiomasa aérea fluctuó entre 21.69 Mg ha^{-1}en 2003 y 76.55 Mg ha^{-1} en2006. La asignación de C fue mayor en los componentesdel culmo (85 - 89 %) que en el tallo (8 - 10 %) y las hojas (3 - 4 %). Tanto el culmo actual como el de un año de edad constituyeron 58 - 73 % (15.86-35.63 Mg ha^{-1}) del almacén aéreo total de C. La tasa de secuestro aéreo de carbono fue de 18.93-23.55 Mg ha^{-1} $año^{-1}$, con una media de 21.36 Mg ha^{-1} $año^{-1}$. Del secuestro total anual de C, los nuevos culmos contribuyeron con entre 82 y 89 % a través del incremento en edad de los culmos, y 14 - 18 % por la producción total anual de mantillo. Se discute el manejo de los bambúes de las aldeas por parte de los pequeños agricultores como unafuente potencial de sumideros de C.

Resumo: Os bambussão uma componente importante da paisagem rural do nordeste da Índia. O reservatório de carbono (C) e o sequestro potencial dos bambus no solo gerido pelos agricultores foi estudado no distrito de Cachar, Assam, nordeste da Índia. Desenvolveram-se equações alométricas por um método de abate relacionando a biomassa das folhas, ramos e colmo com o DAP, como variável independente, para determinar a biomassa da parcela e a produtividade. O reservatório de C e o seu sequestro nas diferentes componentes do colmo dos

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bambus foi determinado por multiplicação da biomassa pela concentração de C. O reservatório de C na biomassa aérea variou entre 21,69 Mg ha^{-1} durante 2003 a 76,55 Mg ha^{-1}durante 2006. A afectação do C era maior nas componentes do colmo (85 - 89 %) do que nos ramos (8 - 10 %) e folha (3 - 4 %). Em conjunto, a biomassa corrente dos colmos e a dos de um ano de idade constituem 58 - 73 % (15,86 - 35,63 Mg ha-^{1}) do reservatório aéreo total de C. A taxa do sequestro de C acima do solo foi de 18,93 - 23,55 Mg ha-1 ano^{-1} com uma média de 21,36 Mg ha^{-1} yr^{-1}. Do sequestro anual de carbono, a contribuição dos novos colmos através do acréscimo anual foi de 82 - 89 % sendo de 14 - 18 % o que resultou da produção anual de folhada. A gestão dos bambus da aldeia como uma fonte potencial de sumidouro de carbono pelos pequenos agricultores é discutida.

Key words: Bamboo agroforestry, carbon sequestration, Clean Development Mechanism (CDM), management systems, smallholder farmer.

Introduction

In 1997, during the Third Conference of Parties (COP-3) of the UNFCCC, the Kyoto Protocol was drafted which is the first international agreement that places legally binding limits on GHG emissions from developed countries (UNFCCC 1997). The Kyoto Protocol proposed that C reduction could take place by decreasing fossil fuel emissions, or by accumulating C in vegetation and in the soil of terrestrial ecosystems. Tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing C pools (e.g. reduced impact logging), expansion of C sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (Brown *et al.* 2000).

Agroforestry systems have also been incorporated under the Kyoto Protocol as an environmental service for sequestrating and trading C. Agroforestry is one means by which farmers could benefit from C investment projects (Sampson & Scholes 2000; Smith & Scherr 2002). Reliable estimates of C inputs in temperate and tropical agroforestry systems are essential for national C inventories used in the Conferences of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) (Watson *et al.* 2000). Bamboo forms an important component in the traditional agroforestry system of northeast India. Bamboos in the agroforestry system are grown in the home gardens and in the extended part of it in the form of grove where bamboo is grown in pure or mixed with other vegetation. Farmers in the rural landscape maintain high density of bamboo culms. Bamboos in home garden are principally managed for household purposes and in bamboo grove for commercial purposes (Nath & Das 2008). Selective felling is mainly practiced in home garden and clear felling in bamboo grove. Under selective felling system 20 - 30 % of the total culms per clump are harvested annually, whereas in clear-felling systems, leaving few current and one year old culms all the culms are felled at 5-6 yr cycle. Around 25 % of the bamboo growers in the study site are involved in commercial utilization of bamboo resources and they resort to clear felling (Nath *et al.* 2006).

The ability of bamboo to sequester high amount of C per unit time can make the bamboo based agroforestry system a possible prototype for Clean Development Mechanism (CDM) type projects. Beside a potential source of C sink, such agroforestry system can provide other environmental services like improved land and water quality and hence improved microclimate (Nath & Das 2009). Role of bamboo in C storage and sequestration has not been studied adequately in northeast India (Nath *et al.* 2009a, Nath & Das 2011). In the Philippines, C sequestration through *Paraserianthes falcataria* based agroforestry systems was found to be less costly than pure tree-based systems suggesting that agroforestry systems are the more attractive option (Shively *et al.* 2004). Economic and financial analyses of agroforestry systems with potential for CDM in Indonesia are encouraging (Ginoga *et al.* 2005). Proper design and management of agroforestry systems can increase biomass accumulation rates, making them effective C sinks (Shepherd & Montagnini 2001). Keeping this in view, the present study attempts to underline the benefits of

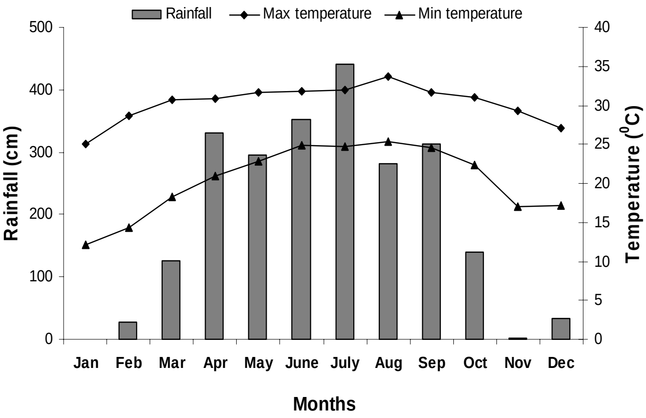

Fig. 1. Climate data of the study site (2003 - 2006).

bamboo agroforestry in mitigating C emissions through offsetting emissions in C sinks and as to how benefits can be accrued to smallholder farmer under CDM of Kyoto Protocol.

Materials and methods

Study area

Barak valley region of Assam, northeast India is comprised of three districts, namely the Cachar, the Karimganj and the Hailakandi. The Cachar is the largest district with total geographical area of 3786 sq km. The Barak valley region has an undulating topography characterized by hills, hillocks, wide plains and low lying waterlogged areas. Geologically the valley is composed of sand stones and sandy shales, mudstones and thin conglomerates, generally free from carbonaceous content.

The study was conducted in a farmer managed bamboo grove of 1.5 ha in Dargakona village, Cachar district and situated at longitude 92°45' East and latitude 24° 41' North. One bamboo stand of 5000 m^2 area within the bamboo grove was selected for the present study. The study site constitutes a mixed patch of three bamboo species of *Bambusa cacharensis* R. Majumder (*Betua*), *B. vulgaris* Schrad. ex Wendl. (*Jai borua*) and *B. balcooa* Roxb. (*Sil borua*). Total number of culms within the selected stand was counted for 2003, 2004, 2005 and 2006 during November each year and expanded to hectare basis.

Climatic condition

The climate of the study site is sub-tropical warm and humid with average rainfall of 2226 mm, most of which is received during the south-west monsoon season (May to September). Southwest monsoon usually operates for a longer spell in the northeastern region compared to the other parts of India. Average maximum and minimum temperatures were 30.5 °C and 20.3 °C, respectively. The climatic variables for the study area are represented in Fig. 1. The average relative humidity varied between 48 % (January) to 97 % (June).

Stand feature

The culm density of the stand was 3380, 6100, 8950 and 11030 culms ha^{-1} during 2003, 2004, 2005 and 2006, respectively. Of the total growing stock 60 - 67 % was represented by *B. cacharensis*, 16 - 20 % by *B. vulgaris* and 15 - 20 % by *B. balcooa*. Culm population structure was represented by four culm ages during 2003 and by five culm ages for the rest of the three observation periods; culm being aged into current year, one year, two year, three year and four year following Banik (2000). A stand population structure of almost 5:4:1; 4:3:2:1; 3:3:2:1:1 and 2:3:3:1:1 was recognized for the current, one, two, three and four year old culms for the period 2003, 2004, 2005 and 2006, respectively. The mean culm height and culm DBH (diameter at breast height) for *B. cacharensis*, *B. vulgaris* and *B. balcooa* were 11.35 m and 5.1 cm, 14.52 m and 7.35 cm and 14.25 m and 7.39 cm, respectively. Mean leaf area index of the stand was 6.17 m^2 m^{-2} (Nath 2008).

Soil properties

Nath (2008) has studied soil properties of the study site. Bulk density of the selected bamboo grove soil is 1.17 - 1.36 g cm^{-3} with soil pH, water holding capacity and organic carbon content of 5.11 - 5.13, 34.28 - 41.36 % and 0.87 - 1.39 %, respectively. Soil texture is sandy clay loam (58 % sand, 20 % silt and 22 % clay). Total nutrient content up to 30 cm depth was N 6000 kg ha^{-1}, P 1020 kg ha^{-1} and K 1356 kg ha^{-1} (Nath 2008).

Biomass estimation

Following regression models based after Nath *et al.* (2009a) were used to determine the dry weight of different culm components using DBH as independent variable for culms of five different ages for the three species: (i) $Y = a+b\ X$, (ii) $Y = a+b\ \mathrm{Ln}(X)$, (iii) $Y = a+bX+bX^2$, (iv) $Y = a{*}e^{\,bx}$, and (v) $\log Y = a+b \log X$;

where, Y is culm component dry weight (g),

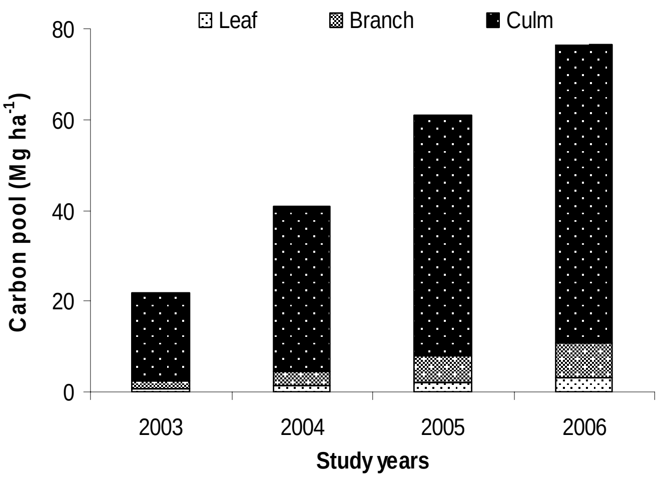

Fig. 2. Carbon pool of the village bamboo stand over four year study period (2003 - 2006).

X is the diameter of culm at breast height (cm), *a* and *b* are the regression coefficients.

Carbon content determination

Sub-samples of culm, branch and leaf from culms of different ages for the three bamboo species were taken to the laboratory and ground in a Wiley Mill and analyzed for carbon content. A total of 50 % of the ash free mass was taken as the C content (Allen 1989). Ash content was determined by igniting 1 g of powdered litter sample at 550 ^{0}C for 6 h in a muffle furnace (Allen 1989). C storage in the different culm components was determined by multiplying the biomass with carbon content. The total C storage in the above ground standing biomass was obtained by summing the C content values for leaf, branch and culm components and then computed on hectare basis. The rate of C sequestration for the period 2004, 2005 and 2006 was calculated from the standing C storage contents of the respective year. The rate of C sequestration also includes C gain through culm maturation and through litter fall.

Results and discussion

Log linear model was found to be the best fit model (Nath *et al.* 2009a) and was used to estimate the stand biomass and productivity. C pool in the above ground vegetation is depicted in Fig. 2. Culm component contributed the highest proportion of the stand C stock (85 - 89 %) followed by branch (8 - 10 %) and leaf (3 - 4 %). C pool of 21.69 Mg ha^{-1} during 2003 rapidly increased over the study period and was computed at 76.55 Mg ha^{-1} during 2006. Such rapid increase over the study period is due to increase in the culm density of the study stand. Mean C stock of the stand is 50.03 Mg ha^{-1}. Recently Nath & Das (2011) reported C stock of 6.51 - 8.95 Mg ha^{-1} in bamboo dominated smallholder home garden in Barak Valley. In comparison to home garden, where multi-species management practice prevails, bamboo grove is a pure patch of bamboo stand and has around eight-fold higher culm density than the former. Higher culm density subsequently resulted in increased C stock in the bamboo grove. Reported above ground carbon storage for *Phyllostachys bambusoides* was 52.3 Mg ha^{-1} (Isagi *et al.* 1997). C stock of the present study is lower than that reported (91.35 - 103.70 Mg ha^{-1}) for *D. strictus* plantation in dry deciduous forest region of India (Singh *et al.* 2004). C storage of 83.3 - 103.8 Mg ha^{-1} was reported for *B. bamboos* (Das & Chaturvedi 2006). Average C storage by agro-forestry practices has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semiarid, subhumid, humid and temperate regions (Dixon *et al.* 1994; Palm *et al.* 2000; Montagnini & Nair 2004).

The rate of above ground C sequestration was 18.93 - 23.55 Mg ha^{-1} yr^{-1} with the mean value of 21.36 Mg ha^{-1} yr^{-1} (Fig. 3). Rate of C accumulation was highest (23.55 Mg ha^{-1}) for the period 2004 - 2005. Of the total annual C accumulation, 82 - 89 % was contributed by new culms and C accumulation through culm age increment and 14 - 18 % by annual total litter production. Above ground C sequestration of the present study is higher than above ground C sequestration of 1.20 - 1.46 Mg ha^{-1} yr^{-1} in bamboo based smallholder homegarden in Barak Valley (Nath & Das 2011). C sequestration in abandoned agricultural land and degraded forest land sites in Central Himalayan region was 1.79 - 3.13 Mg ha^{-1} (Maikhuri *et al.* 2000). For smallholder agroforestry systems in the tropics, potential C sequestration rates ranged from 1.5 to 3.5 Mg C ha^{-1} yr^{-1} (Watson *et al.* 2000). Therefore, by promoting bamboo based land-use systems that have greater C sequestration ability, increase in C stocks can be realized. Greater C sequestration ability can be attributed to higher NPP of the stand that resulted from good site condition and villager's management system of soil moulding and farmyard manure application around the clump each year (Nath *et al.* 2009b). Globally, the greatest potential area for expanding agroforestry practices and other forms of landuse intensification

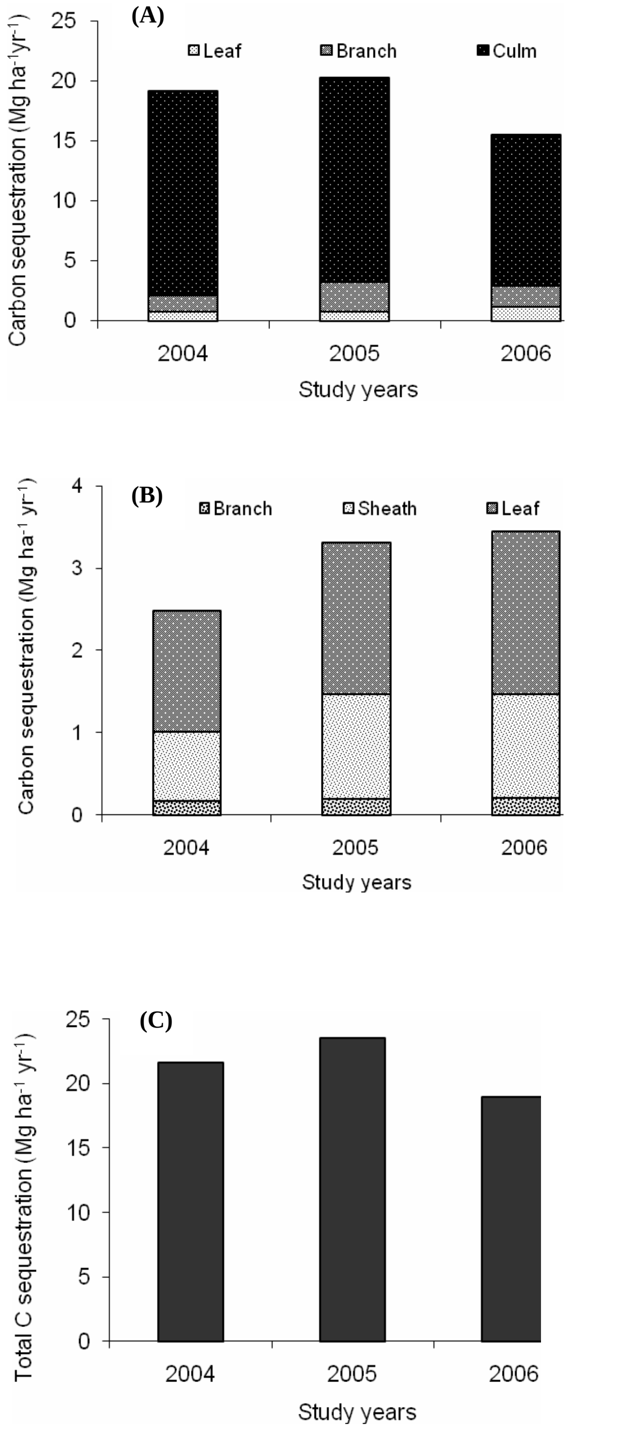

Fig. 3. **(A)** Carbon sequestration through new shoot production and culm maturation for the years 2004, 2005 and 2006; **(B)** Carbon sequestration through litter fall for the year 2004, 2005 and 2006; **(C)** Total C sequestration of the village bamboo stand estimated by summing **A** and **B** for the year 2004, 2005 and 2006.

is in areas considered 'degraded' at the margins of the humid tropics, such as many secondary forest fallows, *Imperata* grasslands, and degraded pastures (Sampson & Scholes 2000). Tools of conservation biology and restoration ecology shall be the vital option for climate change mitigation in future (Pandey 2002). Southeast Asia contains vast areas of degraded and underutilized lands that could be used for C investment (Roshetko *et al.* 2007). Therefore, such landuse systems can be better utilized in terms of C storage and C sequestration if converted and conserved into bamboo agroforestry system. The ability of bamboo to grow on degraded land with minimum management approach coupled with higher C sequestration rate can make the bamboo based agroforestry system a possible prototype for the CDM projects under Kyoto Protocol. Proper utilization and management of village bamboos in rural landscape can also achieve the poverty eradication and environmental sustainability of the Millennium Development Goals (MDGs) of the United Nations.

Considering the harvesting pattern, bamboo resources of grove is not a very permanent source of C stock than home garden, as in the latter farmers maintain a growing stock of bamboo throughout the year. Moreover, selective harvesting is practiced in a sustainable manner that yields little net CO_2 and the system maintains the growing stock in equilibrium. A shift in the socioeconomic characterization of the commercial bamboo growers from subsistence economy to more stable and viable economy through funding to smallholder farmers under CDM projects can lead to conservation type resource management. CDM offered by the Kyoto Protocol could reduce rural poverty by extending payments to low-income farmers who provide carbon storage through landuse management such as agroforestry (Smith & Scherr 2002). Moreover, conservation type projects are said to represent permanent C storage systems because they are protected through legal, political or social action (Roshetko *et al.* 2007).

Taking into account the capabilities for C storage and C sequestration the bamboo agroforestry can be considered for CDM projects under Kyoto Protocol. Bamboo agroforestry can eliminate the ill-effects of poverty and environmental degradation through sustainable management. The vast potential of bamboo in smallholder agroforestry system for C storage and sequestration remains underexploited and proper utilization, management and innovative policies can make this an effective carbon sink besides fulfilling the diverse needs of rural livelihoods in northeast India.

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