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*Review*

# Carbon Farming with Bamboos in India: Opportunities and Challenges

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**ABSTRACT**

Carbon farming provides a great opportunity towards net-zero carbon emissions through enhanced land management and conservation practices. Most studies on carbon farming and carbon trading potential mainly focused on agroforestry/tree species/forest ecosystems; whereas, works on woody bamboo species are limited. Bamboos being highly productive, have gained popularity amongst the scientific community for their diverse roles such as carbon stocking, ecosystem carbon budget, and other ecosystem services. Of the 136 bamboo species found in India, 125 are indigenous, and 11 are exotic. Studies from India show carbon sequestration rate ranges between 1 – 2.3 Mg $ha^{-1}$ $yr^{-1}$ in aboveground biomass and between 0.14 – 0.39 Mg $ha^{-1}$ $yr^{-1}$ in soil. The numerous benefits of bamboo, including its great significance in rural livelihoods for various traditional purposes and its wide geographical adaptability, suggest using bamboos to increase carbon stocks. The present synthesis highlights the tremendous opportunities offered by bamboos for carbon farming and carbon trading in India.

**Key words**: carbon sequestration, net-zero emissions, ecosystem services, harvesting guidelines, carbon trading, climate change

## INTRODUCTION

The Paris Agreement (COP 21) placed a target of "*holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels*". The IPCC 5th Assessment Report highlighted that most scenarios considered biomass energy with carbon capture and storage (BECCS) with afforestation and reforestation to remove carbon dioxide from the atmosphere (Fuss et al. 2014). Contemporary studies also suggest a crucial role of land-based mitigation strategies towards addressing the 2°C target (Popp et al. 2017, Griscom et al. 2017). Smith et al. (2016) suggested that around 320 M ha of a new forest would be required to remove 1.1 Gt C $yr^{-1}$ carbon dioxide by 2100. Another study demonstrated land-use/land-cover managements, e.g., afforestation/reforestation, avoided deforestation, natural forest management, forest plantations, fire management, avoided wood fuel harvesting, etc. in removing around 0.6–2.0 Gt C $yr^{-1}$ greenhouse gases (GHG) from the atmosphere (Griscom et al. 2017). Therefore, land-based climate mitigation strategies through maintaining or growing forest carbon stocks could be an essential option to advance climate change adaptation/mitigation protocols.

Within the global climate governance, a forest-specific mechanism — Reducing Emissions from Deforestation and Forest Degradation and enhancing forest carbon stocks in developing countries (REDD+) — has been negotiated as the key component of the post-Kyoto climate agreement amongst other negotiations (Lövbrand 2009). Under the United Nations Framework Convention on Climate Change (UNFCCC), India has emerged as one of the key actors in global climate politics

(Atteridge et al. 2012). Although India's per capita GHG emissions are among the lowest globally, when accounted in total tons, it's the fourth largest GHG emitter globally (PBL-NEAA 2016). The REDD+ program aids in providing positive financial incentives to developing countries to reduce their deforestation rates (Karsenty and Ongolo 2012). Thus, the REDD+ can act as an offset scheme within the carbon markets, while carbon- farming and trading could serve as the essential strategies to facilitate carbon credits earning.

Carbon farming implicates the adoption of management practices that accelerates the rate of removal of atmospheric carbon dioxide and locking them up into the plant material and/or soil organic matter. When these carbon gains resulting from enhanced land management and/or conservation practices exceed carbon losses, carbon farming is successful (IPCC 2007, Smith et al. 2014).

Bamboo has an uneven distribution depending on annual precipitation, altitude, soil conditions, and temperature. Belonging to the family Poaceae, it grows in the world's tropical, subtropical, and temperate regions. India is endowed with high bamboo species diversity. It has vast geographical distribution, and therefore understanding its potentiality in carbon storage would advance our understanding of its possible consideration for REDD+ mechanisms and its role in climate change mitigation. In the present study, we attempted to present the carbon farming potential of bamboos in India.

## MATERIALS AND METHODS

A meta-analysis of peer-reviewed literature reporting case studies on carbon stocks in bamboo plantations, bamboo agroforestry, and bamboo forests was performed in the present study. Scientific articles published in the English language were obtained using the Core Collection database of ISI Web of Science until April 2020. The literature search involved using a combination of relevant keywords such as "bamboo*" "ecosystem service*", "aboveground biomass*", "belowground biomass*", "carbon stock*", "bamboo carbon storage* "bamboo carbon sequestration*", "soil organic carbon*". To allow the flexibility in incorporating alternative endings (e.g., "sequester" or "sequestration"), or plurals (e.g., "bamboo" or "bamboos"), the asterisk (*) symbol used with the keywords during the search. For comprehensive coverage of literature, we also performed a literature search using other journal databases namely Scopus, and Google Scholar using the exact keywords mentioned above. In addition, we selectively mined grey literature (e.g., government documents) in the English language published by Intergovernmental Panel on Climate Change (IPCC); International Bamboo and Rattan Organization (INBAR); Ministry of Environment, Forest and Climate Change (MoEFCC), Govt. of India; Department of Science and Technology, India and other government policy briefs. Synthesis of grey literature was done to confirm comprehensive and representative coverage of literature (Drescher et al. 2013, Haddaway and Bayliss 2015). Our estimate was based on the following studies for the belowground carbon pool (below ground biomass carbon and soil organic carbon) (Table 1). According to Tripathi and Singh (1996), 75.4 Mg $ha^{-1}$ of carbon stock in *Dendrocalamus strictus* stands in the Indian dry tropics, of which 70–75% was locked up in soil. Whereas, in Moso bamboo (*Phyllostachys pubescens*), the total carbon storage capacity was estimated at 106.36 Mg $ha^{-1}$, of which the belowground pools comprised of 72.1 Mg C $ha^{-1}$ (or 67.8%) (Zhou and Jiang 2004). Similarly, in *Phyllostachys bambusoides* in Japan, the total carbon storage was 165.1 Mg $ha^{-1}$, of which the belowground pool stored 68.3% of carbon (Isagi et al. 1994).

Table 1. Descriptive statistics for carbon storage (Mg $ha^{-1}$) in bamboo stands in India (N=14)

| Parameter | AGBC | BGC | TC |
|---|---|---|---|
| Min | 12.96 | 25.92 | 38.88 |
| Max | 153.45 | 306.9 | 460.35 |
| Mean | 58.68 | 117.36 | 176.35 |
| Std. error | 12.67 | 23.35 | 35.03 |
| Median | 50.01 | 100.02 | 150.03 |

AGBC: aboveground biomass carbon; BGC: belowground carbon (including belowground biomass carbon and soil organic carbon), TC: total carbon (AGBC+BGC)

Therefore, in the present study, the belowground carbon pool was estimated by multiplying the AGBC by a factor of 2. With these estimates in bamboo stands, we computed one-third of the total ecosystem carbon stored in vegetation and two-thirds in the belowground pool.

To enumerate bamboo resources in India, we synthesized data from published literature 'India State of Forest Report (ISFR) 2017: Bamboo Resources of the Country'. State-wise distribution of bamboo area, number of estimated culms, and comparable green weight data were compiled and presented for six major geographical zones of the country: north zone, northeast zone, east zone, west zone, south zone, and central zone. Fresh weight: dry weight ratio reported for different bamboo species (Nath et al. 2009, Singnar et al. 2017, Nath et al. 2018) was used to compute the dry mass and expanded to the national scale. The default value of 0.47 (IPCC 2006) was used to calculate carbon stock in bamboo stands (Singnar et al. 2017).

## OPPORTUNITIES

### High species diversity

Out of the 136 species belonging to 23 genera of bamboo found in India, 125 species are indigenous, and 11 are exotic. The principal bamboo genera found in India includes *Arundinaria*, *Bambusa*, *Chimnobambusa, Dendrocalamus, Dinochloa, Gigantochloa, Schizostachyum, Melocanna,* etc. and 60% of these bamboo species grow in Eastern Indian states, namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and West Bengal. In addition, Andaman and Nicobar Islands, Chhattisgarh, Madhya Pradesh, and the Western Ghats in India also harbour rich bamboo resources.

Studies suggest that many bamboo species are essential for local economies in India due to their essential economic utilization, including food, house making, fencing, and raw materials for cottage industries (Kumar et al. 2005, Nath et al. 2015). In addition, bamboos play a significant role in providing vital ecological services such as biodiversity conservation, management of soil and water, and more importantly, its vital role as a carbon sink, thus contributing towards mitigation of climate change (Kumar et al. 2005, Nath et al. 2015, Singnar et al. 2017, Yuen et al. 2017).

### Bamboo biomass carbon stock in India

Currently, 15.69 million ha of land in India is under bamboo, and the northeast zone contributes 34% of

Table 2. Bamboo growing area, number of standing culms and above ground biomass carbon stock in six major geographical zones of India

| Geographical areas | Area* (million sq. km) | Culm density (culm ha$^{-1}$) | No of culm* (in million) | AGBC stock (in '000 ton) | AGBC density (Mg ha$^{-1}$) |
|---|---|---|---|---|---|
| North East Zone | 54172 | 2415 | 13085 | 29747 | 5.49 |
| North Zone | 2619 | 2936 | 769 | 975 | 3.72 |
| East Zone | 18525 | 1656 | 3068 | 5258 | 2.84 |
| West Zone | 21829 | 1447 | 3158 | 9003 | 4.12 |
| South Zone | 30436 | 1480 | 4504 | 15799 | 5.19 |
| Central Zone | 29227 | 1194 | 3481 | 5255 | 1.80 |
| **Total** | **156808** | — | **28065** | **66037** | **N/A** |

*Data compiled from FSI 2017 report, AGBC: aboveground biomass carbon

**North East Zone** - Assam, Sikkim, Nagaland, Meghalaya, Manipur, Mizoram, Tripura and Arunachal Pradesh; **North Zone:** Jammu and Kashmir, Himachal Pradesh, Punjab, Uttarakhand, Uttar Pradesh, and Haryana; **East Zone:** Bihar, Odisha, Jharkhand, and West Bengal; **West Zone**: Rajasthan , Gujarat, Goa and Maharashtra; **South Zone:** Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu; **Central Zone:** Madhya Pradesh and Chhattisgarh the total bamboo growing area. Out of the total number of standing culms in India (28065 million), the highest number of culms (13085 million) is found in the northeast zone. The culm density $ha^{-1}$ reveals the highest density in the northern zone (2936 culms $ha^{-1}$), followed by the northeast zone (2415 culms $ha^{-1}$) (Table 2).

The AGBC stock in bamboo stands in India was computed at 6.60 Tg ($1Tg=10^{12}g$), of which 45% (2.97 Tg) was stocked in the northeast zone, followed by 24% (1.58 Tg) in the south zone of India. In terms of AGBC density, the highest density was recorded in the northeast zone (5.49 Mg C $ha^{-1}$), followed by the south zone (5.19 Mg C $ha^{-1}$). The lowest AGBC density was recorded in the central zone (1.80 Mg $ha^{-1}$) (Table 2).

**Sequestration of organic carbon**

Studies from the state of Assam revealed that the rate of biomass C accumulation in village bamboos was 1.3, 2.3, and 1.6 Mg $ha^{-1}$ $yr^{-1}$, respectively for species namely *B. cacharensis*, *B. vulgaris* and *B. balcooa*, corresponding to 4.7, 8.3 and 6.0 Mg $ha^{-1}$ $yr^{-1}$ of equivalent sequestered carbon dioxide (Nath et al. 2018). Whereas, in the western Himalayas, the rate of biomass carbon sequestration in species *Dendrocalamus strictus* was estimated as 0.4–1.0 Mg $ha^{-1}$ $yr^{-1}$ (Kaushal et al. 2016).

In terms of carbon density, the aboveground biomass carbon density in forest bamboo species was 22.7 Mg $ha^{-1}$ for *S. dullooa* and 21.3 Mg $ha^{-1}$ *P. polymorphum* (Singnar et al. 2017). In *Dendrocalamus strictus*, total biomass carbon stock was found to be 23 Mg $ha^{-1}$ and 37 Mg $ha^{-1}$ respectively in 3-year and 5-year old plantations in mine spoil in a dry tropical region of India (Singh and Singh 1999). Studies reported that a higher carbon sequestration rate in bamboo depends on the current culm density and the culm wall thickness of the species. The soil organic carbon (SOC) stock (up to 10 cm soil depth) under bamboo in North East India (NEI) ranges from 9.7 Mg $ha^{-1}$ under 2-yr-old plantations to 14.9 Mg $ha^{-1}$ under 20-yr-old plantations and increases linearly with an increase in age (Nath et al. 2015, 2017, 2018). The SOC sequestration rate (0-10 cm depth) varies with plantation age. The highest SOC sequestration rate is 0.39 Mg $ha^{-1}$ $yr^{-1}$ for 5–10-yr-old plantation that gradually decreases to 0.14 Mg $ha^{-1}$ $yr^{-1}$ in 15–20-yr old plantation. The SOC stock under acacia (*Acacia nilotica*), white catechu (*Acacia polyacantha*), and mangium (*Acacia mangium*) agroforestry systems after five years of plantation establishment was estimated at 21.6-25.6 Mg C $ha^{-1}$ (Kimaro et al. 2011). The estimated SOC stock of bamboo plantation (10-15 Mg $ha^{-1}$, 10 cm depth) is comparable to those for other species in 0–10 cm depth, signifying the role of village bamboo in SOC stock management.

**Phytolith carbon storage**

Phytolith, also referred to as plant opal, are silicified features formed due to bio-mineralization within plants. They are very much resistant against decomposition and accumulate in the soil as a fraction of soil organic matter (SOM) for thousands of years after plant decomposition (Parr et al. 2005); thus, they can act as a safe carbon sink.

Herbaceous grass and woody bamboo species contain high Phytolith carbon storage (Parr et al. 2010). Therefore, bamboos have been recommended as a proficient phytolith-accumulator (Drees et al. 1989, Parr et al. 2010, Li et al. 2014). Bamboos and similar grass crops are known to have great potential in sequestering around 1.5 billion tonne of carbon-dioxide equivalent $yr^{-1}$ within phytoliths globally, contributing to 11% of the current rise in atmospheric carbon dioxide (Parr et al. 2010). In the Indian context, bamboo (Poaceae: Bambuseae) with 136 different species dominates forests as wet, moist, and secondary moist bamboo brakes and covers 2.25% of the total geographical area (TGA) of the country (NMBA 2004, IIRS 2012). Although there is no record on the rate of phytolith carbon sequestration of Indian bamboos yet, studies from China reported up to 0.7 t-e-carbon di-oxide $ha^{-1}$ $yr^{-1}$ phytolith carbon bio-sequestration rates in bamboo leaf-litter (Parr et al. 2010) and higher concentrations of phytolith in bamboos than other vegetation types (Wang et al. 2013). This indicates the potential of vegetation management, e.g., bamboo forests, in maximizing phytolith-occluded carbon production, thus securely increasing the sequestration of substantial quantities of bio-carbon (Parr et al. 2010), and significantly contributing towards global climate change mitigation. Therefore, carbon farming with bamboos may provide an essential strategy for long term carbon sink management in India and globally.

**Bamboo for bio-energy production**

Recovery of bio-energy from bamboo biomass can be made in three main ways: thermal, thermochemical, and biochemical (Boyle, 2004). Characteristics such as high calorific values, lower ash- and moisture content (8-23%), and volatile contents make bamboo a good fuel source. The provision of continuous harvesting of bamboo makes it a befitting crop for the production of bioenergy (Scurlock et al. 2000), and more reliable than other renewable sources, for instance, solar or wind energy. According to the International Bamboo and Rattan Organization (INBAR), bamboo has a very high yield of ~ 40 t $ha^{-1}$ $yr^{-1}$. After gasification (thermal conversion) of bamboo, 15% of the biomass would be available as a by-product in the form of high-grade charcoal – a renewable energy carrier (Moen et al. 1984). In this context, India with high species diversity and vast geographical distribution under bamboo, as mentioned elsewhere, may be explored for the production of bio-energy.

**Land restoration**

Land degradation in India has severe adverse impacts on the environment. Currently, 114-147 M ha of land is considered degraded in India (ICAR 2010). Therefore, large scale adoption of bamboo-based carbon farming practices focusing on indigenous bamboo species can enhance land productivity and increase vegetation and soil carbon sequestration. Additionally, in India, 0.7 M ha of land is currently under the traditional brick kilns industry (Nath et al. 2018b), requiring immediate rehabilitation from environmental management and food security. A study on the restoration of abandoned brick kilns through bamboo plantation in Kotwa and Rahimabad villages of Indian district in Allahabad over seven years (1996–2003) revealed enhanced SOC sequestration from almost 0 Mg $ha^{-1}$ (in 1996) to 0.7 (in 2003) Mg $ha^{-1}$ $yr^{-1}$ (INBAR 2003). In India, ravines are spread over 3.67 million hectares (M ha) to 4.0 M ha, mainly along the rivers and tributaries (Pande et al. 2012). Bamboo can be an essential alternative to rehabilitate such ravines. Bamboo species requires minimal maintenance for growing well, even in polluted environments (Sinha et al. 2013). Therefore, the promotion of carbon farming through bamboos can restore soil health, bio-remediate toxic elements while sequestering atmospheric carbon dioxide. Bamboo also plays a significant role in regulating water flows, checking sedimentation and pollution from non-point sources, including agricultural runoff and wastewater discharge (Vigiak et al. 2007). Additionally, bamboo stands check soil erosion and offer shelter against earthquakes, floods and tsunamis by acting as natural rafts due to their tightly woven root mats (Singh et al. 2006).

**Bio-diversity conservation**

Bamboos enhance biodiversity; include true micro-ecosystems within the culms to woody species richness (Larpkern et al. 2008). The internodes of bamboo with lateral perforations contain diverse aquatic fauna. Bamboos are also the host colonies of several species of coccids and ants in their culms, leaves and sheaths (Davidson et al. 2006). In SE-Asia, bamboo provides ideal nesting space for several tree ants and animal. Several insects suck on the bamboo culm, young shoots and leaves as one primary food source for several herbivore wildlife *viz.* red panda *(Ailurus fulgens*) (Srivastava and Dutta 2010), deer (*Cervus Nippon*) and bison (*Bison bison*) (Rivals et al. 2014). The hollow internodes of the culms offer an ideal nest for several birds. Evidence supports the positive correlation between species richness with bamboo cover (Reid et al. 2004). Many reptiles and amphibians prefer to live in the bamboo forest (Stuart et al. 2006). Several primates use bamboo as foraging, sleeping and nesting trees (Eppley et al. 2016). For example, the young bamboo shoots comprise an important diet component of Phayre's leaf monkey (*Trachypithecus phayrei*) (WTI 2003; Nath and Das, 2010). Also, certain bamboo species can increase soil fertility through high microbial biomass in the rhizosphere zone due to the extensive root surface (Arunachalam and Arunachalam, 2002). Such influence of bamboo forest expansion on soil C sequestration can be attributed to its indirect role in supporting Arbuscular Mycorrhizal Fungi (AMF) colonies (Qin et al. 2017).

**Rural economy and livelihood**

There are approximately 1500 known available commercial bamboo products ranging from handicrafts to edible bamboo shoots (produced from about 200 species), to high-value industrial goods, such as flooring and furniture, paper and textiles, bio-fuels, charcoal, housing, etc. (Scurlock et al. 2000, FAO 2007). Bamboo has a significant role in boosting the rural economy (FAO 2009) through multiple product generation ability and several ecological services. In North-East India, the sales of fresh bamboo shoots were estimated at 5,685 tons $yr^{-1}$, accounting for a gross and net income of INR 37.76 million and INR 18.85 million per annum, respectively. The sales of various food items, such as fermented, roasted, and boiled bamboo shoots, amounted to 680 tons $yr^{-1}$ with INR 40.38 million and INR 22.90 million as gross and net incomes. Thus, this sector generated employment opportunities for 3,285 persons throughout the year @ INR. 100 $day^{-1}$ by only merchandizing fresh and processed bamboo shoots for the edible purpose (Singha et al. 2008). The monthly income of the tribal people in Nagaland was around INR10,000 during the availability of bamboo shoot season (June – Oct) (Kithan et al. 2016). A recent estimate show farmer can earn up to INR 56000 $ha^{-1}$ $yr^{-1}$ by selling raw bamboo from their degraded land (Dwivedi et al. 2019). They also reported that bamboo cultivation could generate around 10 Certified Emission Reductions (CERs) $ha^{-1}$ $yr^{-1}$, which can be traded as carbon credits. In addition to this, the under-employed farmers can work as skilled labours in bamboo-based cottage industries and earn up to INR 18,900 $yr^{-1}$ at current exchange rates, which is significantly higher than the current average income

Figure 1. Value-added bamboo products manufactured in Tripura state of India

of the farmers (INR 122,500 $yr^{-1}$) (Dwivedi et al. 2019). Some of the value-added bamboo products from Tripura state are shown in Figure 1. Therefore, the promotion of bamboo cultivation and its proper utilization can be employed in rural areas and improve livelihood. In addition, carbon credits through carbon farming may help to create jobs and wealth generation in India and other developing countries.

**Policy perspective**

The recent amendment of the Forest Act 1927, Government of India, has removed the bamboo grown in non-forest areas from the purview of restrictions on its felling and interstate transportation to increase the commercialization of bamboo and achieve the government's commitment to double farmers' income by 2022. This policy implementation will boost the interests of farmers and entrepreneurs for bamboo cultivation and processing towards opening new avenues for income while increasing country's green cover at the same time (Dwivedi et al. 2019).

## CHALLENGES

**Bamboo flowering**

One of the unpredictability in long-term carbon management using bamboos is their gregarious flowering, dieback of stands (INBAR 2010), and ecosystem carbon loss (Yuen et al. 2017). For example, in 2005-2010, species such as *Melocanna baccifera* and *Schizostachyum dullooa* flowered gregariously in the Barak valley region of North East India, and the entire population died afterwards (Nath and Das 2010). However, under the 'sporadic flowering' event, only a few culms within the bamboo stand flowered and died (Das et al. 2017a, b), in contrast to 'gregarious flowering', where the entire population flower concurrently and die subsequently. Therefore, the selection of sporadic flowering bamboo species for carbon farming may check the loss of ecosystem carbon through gregarious flowering, ensure long-term storage of carbon in vegetation and soil (Nath et al. 2018). In this context, we suggest that, region-specific potential sporadic flowering bamboo species may be given priority for promotion under carbon farming.

**Harvesting guidelines**

Over-exploitation of bamboo takes place in the form of clear felling of clumps (Nath et al. 2006). Clear felling is a standard managerial system for ease in harvesting. Harvesting regimes determine the culm population structure of a bamboo clump (Nath et al. 2006). Under the clear-felling regime, the no or lower number of culms per clump cannot maintain the vigour of underground rhizome and therefore substantially reduces productivity. Therefore, selective felling of culms should be promoted for greater vigour and higher productivity in bamboo stands. Bamboo harvesting strategies like horseshoe and tunnel methods (MOEF 1992) may also be adopted under the selective felling technique.

## IMPLICATIONS OF THE STUDY

From the Stockholm Conference on Environment (1972) to COP 26 in Glasgow (2021), UNFCCC has suggested some definitive international actions towards reducing the concentration of atmospheric carbon dioxide. In the context of bamboos, despite their high potential in carbon storage and sequestration and their vital role in sustaining millions of rural livelihoods globally, the opportunities provided by bamboos are yet to be investigated in schemes like CDM and REDD+. Hence, there is an urgent need to recognize ecosystem services provided by woody bamboos towards sustaining the rural poor and the natural environment.

The present synthesis portrays the various opportunities offered by bamboos for carbon-farming and trading. Indeed, biomass carbon stock and sequestration rate in woody bamboos in India are comparable with global reports (Nath et al. 2015, Yuen 2017). Additionally, the bamboo ecosystems can provide twin source an income for the rural poor such as (i) preparing and selling of various bamboo products (e.g. shoots as eatables, for scaffolding, to papermaking and cottage industries) and, (ii) under various afforestation/reforestation mechanisms for trading of carbon credits (Certified Emission Reductions) under CDM and $REDD^{+}$.

## CONCLUSIONS AND RECOMMENDATIONS

It is evident that when deployed in the right place, bamboos can provide various ecosystem services (Fig. 2). Despite this, bamboo has received very little attention in research, development, and policy agreements related to climate change. The intensive bamboo management systems may be promoted to enhance the carbon sequestration rate in low productivity zones (east zone, central zone) in India. We recommend that carbon farming with bamboos be given greater recognition in research and policy decisions for its value in climate change mitigation and its potential to provide industrial raw materials, watershed management, and income generation. Since the populations of native species are shrinking, on-farm plantation of bamboos must be given greater emphasis to reduce disruption in the supply of raw materials. Rehabilitation of ravines and cultivable wastelands through bamboos should be given priority in policy formulations. We also recommend the implementation of community-based bamboo grove management for the effective utilization of bamboo resources. Diversification of the resource base through the introduction of sporadically flowered and high carbon sequestration potential suitable exotic species may be considered.

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Figure 2. Ecosystem services provisioned by bamboo-based ecosystems

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