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Bamboo farming as green timber for Net Zero carbon emission – Nature Based Solution (NBS) for India

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ABSTRACT

Bamboo covers about 15 million ha of India i.e. 20% of the forest area and is among the fastest-growing plants that can sequester maximum biomass in short time. Bamboo is 70% cheaper than Timber or Steel with comparable strength and can be used for long term for Mobile tower building or as construction material if processed chemically. Promoting Bamboo plantation on degraded forests and common lands/ fallow farms can earn over $ 1,100/ acre/ year to the farmers and help in meeting at least 25% of the Net Zero carbon emission goal by 2030 as it can sequester 10 ton carbon/ ha/ year i.e. 37 carbon credits. It can employ 20 million rural artisans in planting processing and help the corporate compliance. Promoting Balcooa bamboo in the southern/ central Indian topical climate should be avoided to minimize the failure and loss to the farmers.

Keywords: *Biomass growth, reforestation, green timber, livelihoods, bamboo*

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One liner*- Bamboo can meet 25% of India's net zero pledge by 2030 as it can sequester up to 37 carbon credits/ ha/ year and earn farmers total over Rs. 1 lakh/ ha/ year.*

1. Introduction

Bamboo is a sustainable and renewable resource due to its fast vegetative growth and with little watering after 1-2 years. Its used to ecorestoration of the degraded land, carbon sequestration, and also poverty alleviation through crafts microenterprises, as a Nature Based Solution (NBS) for the climate change- being both mitigation and adaptation tool [1]. It is a crucial strategy tool in the agroforestry and construction sector towards "net zero" carbon emissions as it absorbs more carbon per unit area than tree species [2]. Bamboo occupied about 11.4 million i.e. 16% of the 66.7 million forest in the country and 4% of the nation's land area in 2003 [3]. It rose by 30% to 15 million ha by 2021 to cover nearby 20% of the forest area of 70 million ha [4], possibly due to the National Bamboo Mission's efforts to plant and use Bamboo since 2012. Remarkably, the majority 10 out of 17 "Sustainable Development Goals" (SDG) of the UN vide Box 1 [5]. It will also help the corporate such as Telecom companies or CSR (corporate social responsibility) partners to meet their environmental/ "net-zero" targets.

Box 1- SDGs and Bamboo compatibility [5]
SDG no. GOL
1) No Poverty
2) Zero Hunger
3) Good Health and Well-being
6) Clean Water and Sanitation
7) Affordable and Clean Energy
8) Decent Work and Economic Growth
9) Industry, Innovation and Infrastructure
12) Responsible Consumption and Production
13) Climate Action

Bamboo plantation arrests soil erosion, restores degraded land, conserves water and rejuvenatessprings, enhances biodiversity, and serves as raw materials to rural artisans people. Steel and concrete replaced the use of wood or bamboo in 20th century, causing nearly 1/3rd of the Global Warming and are costly than the later but are long lasting.

Making Wood/ Bamboo last for decades/ century is a technology challenge. Indian Bamboo productivity (mainly from forest area) is low- 1 ton/ha/ year. However, with commercial plantation it can increase by up to 40 times [6,7]. India has set ambitious target of 2.5 Billion ton of CO_2 equivalent (CO_2E) carbon offset by 2030. India can expand tree cover on another 25-30 Million ha of degraded land and Bamboo can help crucially in it. If this is done, at modest 20 ton/ ha/ year biomass growth rate it can sequester 10 ton/ha/ year Carbon as 50% of biomass is assumed to be carbon [2]. This implies 36.7 CO_2E/ ha/ year as CO_2 to carbon ratio is 3.67 [8]. This means 720 million CO_2E/ year even if just 20 Million ha are planted with Bamboo i.e. about 25% of India's net zero pledge.

However it is important to convert Bamboo into / furniture etc. for long-term carbon storage with proper treatment as described further and not let it roat on the floor leading to

Carbon leakage. Even at a modest price of $5 per CO_2E ton prevailing in the voluntary markets, it can earn $ 180 carbon credit/ ha/ year. This is besides the $1,100/ ha/ year the farmers can earn from retail sales of the Bamboo poles locally or 25% of it in bulk to Paper mill etc. For, 2,000 poles are easily available annually/ha and each sold at $ 0.6 on spot [9]. National Institute of Agriculture Extension Management (MANAGE) has documented 2.5 times more gross income/ ha than this [10].

We surveyed suitable Bamboo species and developed manual of their plantation for Green Telecom Tower purpose of the Association for Progressive Communications (APC) in 2022 [11], which is mainly summarized here, but with carbon neutrality and livelihoods focus added. It is based on our own experience, literature review, and experts' consultation. Wooden poles have limited length, so bamboo is better suited due to its physical strength for use as an electricity pole and also as mobile phone communication towers for setting antenna. For, bamboo pole has properties like **15 to 25 m** length, 7 to 8 cm diameter, compactness, tensile strength to withstand wind pressure (44 m/sec), long life span (10- 15 years). Some southeast Asian companies are already building bamboo towers [12].

Bamboo plantations are made worldwide but face few challenges that include biological ones- long gestation period (4-5 years) for the first harvest and the income, and technological- preservation and processing techniques, besides policy constraints e.g. lack of insurance (for instance, as in India).

Wild bamboo is abundant in some regions, but unsuitable for the market standards, causing poor price, a major constraint preventing farmers hesitate to cultivating bamboo [13]. Lack of knowledge and entrepreneurship on processing and preservation is another constraint.

Recently bamboo products are remerging such as in eco-friendly resorts as cottages, towers, paper, furniture, incense sticks, biofuels like briquettes and Bio-CNG etc. Bamboo can replace wood from the paper and pulp industry to flooring, construction to musical instruments etc. [14]. Bamboo is stronger than wood (Table 1) and is weather resilient so is a can replace "plastic" too to avoid the global pollution menace. The use of bamboo for tower purposes will add more value and remunerative livelihood incentives to rural masses for undertaking bamboo plantations as an enterprise activity through community participation. Removal of Bamboo trade and transport restriction by deleting it from the definition of "timber" in 2014 was a commendable policy whereby in the Indian Forest Act, 1927, in its application to the State of Maharashtra, in section 2, in clause (7), the words "bamboos, stumps, brushwood and canes" were deleted [15, 16].

2. Bamboo- Global and Asian Scenario

Bamboo species number over 1250 in 91 genera globally in different are agro-zones [17]. The bamboo geography falls into 3 major global regions; namely, the Asian-Pacific, the Americas, and Africa [*ibid.*, 18]. Asia and the Pacific region hosts about 80% of bamboo forest lands and species in the world as Africa has little area and bamboo diversity [19]. Asia has many advantages for bamboo growth comprising over 900 species from 50 genera. Asian countries are very rich in bamboo resources viz. China, India, Indonesia, Myanmar, Thailand, and Vietnam). Constant cold temperatures risk the Bamboo plants but not warmer climates. India and China; together account for about 70% of the bamboo in Asia [18].

3. Soil and Climatic suitability:

Bamboo prefers tropical and subtropical climates. Bamboos grows best in deep, well-drained, neutral to slightly acid soils (pH of 6.0 to 7.5) and can tolerate acidic soils with pH even up to 5.0 but not rocky soils [20]. The best-suited soils for bamboo farming are Sandy loam and clay loam. If the soil is deficient, its worthwhile to invest the time and expense of improving it in terms of irrigation and fortification. Bamboo can tolerate a wide range of temperatures ($6^{-}48^{0}$C), but the ideal is $20\text{-}35^{0}$ C.

Table 1 Comparison of bamboo strength Vs timber and steel [21,22, 23, 24]

SPECIES and Common Names	Geographical area/country	STRENGTH GPa*		
		COMPRE-SSIVE	TENSILE	BEND-ING
Bambusa bambos (L.) Voss.-	Across India- Moist zones	50	***158***	5.8
B. balcooa Roxb.	Eastern India	54	75	4.2
B. nutans Wall. ex Munro.		***98***	***208***	7.7
B. tulda Roxb.		66	***226***	6.6
Dendrocalamus strictus (Roxb.) Nees	All across	50	73	6.5
Psuedooxytenanthera stocksii (Munro) T. Q. Nguyen #	Southern India	37	60	9.6
Thyrsostachys oliveri Gamble	Eastern India	67	143	8
Timber (spruce)		43	**89**	11
Steel		250	**410**	21

Note: 1) Bamboo has higher compressive and tensile strength than spruce timber.
2) *B. balcooa* (Bima/ Female Bamboo) promoted widely by Indian Govt. is similar in strength to wood, but obviously lower than steel.
Factor of 0.098 was used to convert data in Kgf/cm2 into N/ mm2 (newton/ sq. millimeter). *- Gpa= Gigapascal i.e. Kilo Newton (force/ sq.m).. https://www.justintools.com/unit-conversion/pressure.php?

Most of the species come under "sympodial" type of "crown" i.e. in culms but is difficult to harvest while that of the monopodial Bamboo species (growing in single stem) is easy [11].

4. Nursery preparation through community: The bamboo plantation provides livelihoods to rural community with proper training for planting, maintenance and processing (post harvest management).

Table 2: Main Bamboo species in India- Agro-climatic distribution

Species	Common names	Natural occurrence	Soil pH	Rainfall range mm/ year	Temperature range ^{0}C.
Bambusa balcooa	Bima Bamboo, Female Bamboo	Eastern India- Himalaya- S E Asia	5-7	1,500-3,000	5-30
B. bambos	Giant thorny bamboo, Female bamboo, Kaante Baans	eastern, western coasts (moist zones)	5-7	2,000-5,000	10-35
B. nutans	Burmese timber Bamboo	Orissa, India (moist zone)	5-6	2,000-5,000	5-25
Bambusa tulda	Bengal Bamboo	Eastern India	5-6		
Dendrocalamus strictus	Male bamboo, Calcutta bamboo, Baans	dry zone county wide	7-8	1,000-2,000	5-45
				2,000-5,000	5-25
Pseudo-oxytenanthera stocksii	Male bamboo, Manga (Konkan)	West and southern India (moist zone)	5-6		
Thyrsostachys oliveri	Monastery/ Thai Bamboo	Northeastern India.	5-6		

5 Planting system

There are two types of plantation systems: Tower purpose Bamboo species require wider spacing as the main trunk grows 15 to 25 m tall. Further, their offshoot rhizome also spread to 3 m diameter. *Thyrostachys olivery* can be planted at 1 x 1 m distance for biomass/ foliage purpose but it is not for tower purpose [25].

5.1 Block or pit system: The space between two adjoining plants is at equal distances irrespective of species and is considered the most traditional system of bamboo plantation. Each species require different spacing depending upon its multiplication based on its economic life (5 to 50 years) [7].

Traditional system (block system model) considered 4 x 4 m spacing (approx.460 No's plants/hectare) is ideal, butsome species require different spacing (Table: 3).

Table 3: Following species required spacing and No's of plants /ha for plantation

S.No	Name of species	Minimum Spacing advocated	Mode of propagation	No of plants/ha
1.	*Bambusa nutans*	3x3 m	Seeds/ vegetative propagation	1110
2.	*B. balcooa*	5 x 5 m	Tissue culture	400
3.	*B. bambos*	5x5 m	Seeds/ tissue culture/ Rhizome	400
4.	*B. tulda/ D. strictus*	5 x 5 m	Seeds/ vegetative propagation	400
6.	*Dendrocalamus strictus* #	3x3 m	Seeds/ vegetative propagation	1110
5.	*Pseudooxytenanthera stocksii*	3 x 3 m	Rhizome / vegetative propagation	1110
6.	*Thyrostachys oliveri*	3 x 3 m	Rhizome/ vegetative propagation	1110

#- Usually planted peripheraly

Pits are dug of 1 m x m or lesser depending upon soil condition.

1. nearly 1/3rd pit is filled by manure or compost., It is followed by mixing soil with manure or chemical fertilizer, and the rest is covered with the soil after planting. Local chemicals can be applied at the bottom of the root zone while planting, to reduce the termite infestation, which is a major problem in Bamboo plantations.

- When plants are about 1 m tall, transplanting to the field is done.
- Seed grown plants are most economical and convenient method, but seed availability and germination may be limited, which is a major constraint, thus requiring vegetative means.
- The clump is the traditional and most prevalent vegetative propagation method of bamboo.
- In the summer season, active growth of young shoots /buds on the Bamboo rhizome is initiated. It is common to process vegetative propagules just before the initiation of the growth of these buds.
- A clump is divided into 2 equal parts, retaining the root system, branches, and leaves of each part as fully intact as possible. These propagules usually give the highest degree of success.

Note:

i) is the limited space for side branches pruning and other management care like weeding, extracting/ harvesting poles, is a constraint in this system.

i) Inter-cultivation and additional income generation is not possible.

Fig. 1 depicts pit or block and triangular systems.

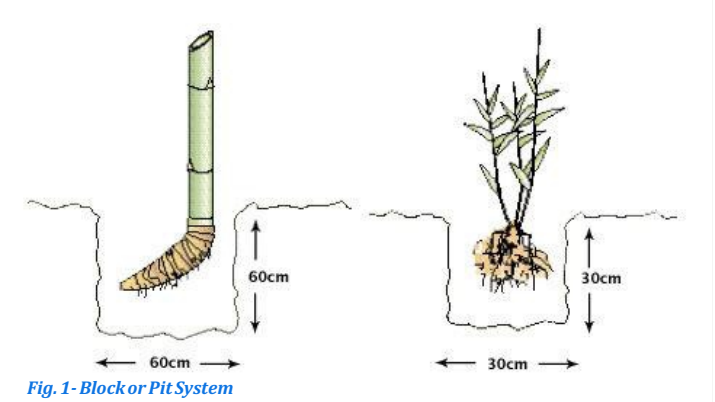

Fig. 1- Block or Pit System

Source- https://www.guaduabamboo.com/blog/how-to-plant-bamboo

5.2 Paired and row system:

- This system is very common at the individual or community level by overcoming the constraints in the previous model like irrigation, labor constraint, intercrops, machinery manoeuvrings, and more plant numbers.
- The system spacing is typically 6 x 2 m (833 No's plants/ha) or 4.5 x 3.5 m (900 plants), 4.26 x 2.43 m (1,000 plants), rarely 4.5 x4.5 m (5000 plants). Giant Bamboo requires more spacing viz. 10 x 10 m . Fig. 2 depicts this system.
- It is advised to plant from north to south direction, so that all the plants receive the sunlight equally, but scientific data are need on this aspect
- Bamboo has the advantage that it can be planted in many situations like farm bunds, along the banks of a river, ridges, and nallah (stream) i.e. moist conditions.

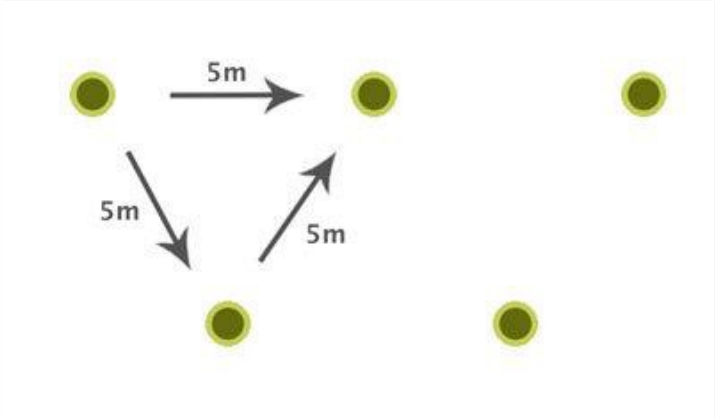

Fig. 2- Triangular System

Source- https://www.guaduabamboo.com/blog/how-to-plant-bamboo

Bamboo plantation tips are provided in Box 2 and some precautions in Table 4.

Box 2 Bamboo Plantation Tips

1. Bamboo species should be preferably selected be within local growing zone.
2. Species of one agro-climatic zone may not succeed if sourced from other agro-climatic conditions. The tropical species can suit tropical conditions but not subtropical and vice versa e.g. *Bambua balcooa* (Bima bamboo) may not fruit in west/ southern (tropical) India, being northeast Indian, subtropical species, explaining some of its failures [26].
3. A practical approach involves cuttings and rhizomes, being cost-effective and efficient. Rhizomes success rate is higher, but cuttings are much easier to plant and easily available.
4. Tissue culture assures genetic purity of species, it is disease-free, and the most reliable commercial way through its costly.
5. Pre-sowing soaking overnight in water is advised. In the winter season, warm water should be used to break the dormancy and ensure 95% germination.
6. While preparing the nursery Line sowing method is used. the seed sowing is done 2" deep below the surface, not deeper, and is covered with the soil to avoid birds, squirrels, etc. eating it away.
7. Nursery beds 4ft. wide and 40 to 100ft long are made with 2ft space between the beds.
8. Raised bed condition are made prior to the monsoon, sunken bed before the winter season- and flatbed during the summer or dry season. Raised bed makes it easy to uproot the nursery without injuring the rhizomes, so is a preferrrd method for nursery.
9. Transfer the 3 months old saplings (from seed /rhizomes) to the polybags for hardening purpose for the next 5 to 7 months. Saplings below 6 months or older incur high mortality (up to 40%) and cost.
10. For field plantation, 1 year old nursery plants are preferred as the survival rate is above 95% and thus, the growth success is higher.
11. Prefer degraded land over fertile land for bamboo planting as it is long gestation (4 to 5 yrs.) crop as compared to another cash crop community grows.
12. At individual level, minimum of 1 hectare of land and at community level, grow above 3 hectares (1200 plants/ha, spacing 3*2.75 m) for economic viability.
13. Grow 10 to 15% % extra nursery plants than the total requirement of the field, to replace if mortality is seen in the 1st or 2nd year.
14. Soil depth should be at least 1 m deep under degraded or normal plantation and well drained out an arrangement in plain land should be done.
15. In the sympodial varieties, follow branch pruning and fortification rigorously and each year and allow selected culm to grow while remove the undesired clumping.
16. Colour the culms year-wise to identify the matured culmns to enable harvest sequentially after 4 years growth.
17. Regular cleaning of leaf litter from the ground reduces the fire risk.

(Source- own experience)

Table 4 Do and Don't for plantation activity

S.NO	Dos	DON'T
1	Well drained land	Water logging is avoided
2	First 3 years irrigation	Avoid dryland farms
3	Soil depth of 1 m is desirable	Plantation in Rocky land with below 1 m soil depth plants causes mortality after 3 yrs.
4.	Plant the tropical or temperate species in respective zones	Don't shift tropical species in the temperate zone/ vice versa.
5.	Nursery plants should be 1 year old for planting	Avoid too young sapling due to mortality (up to 40%), so stock spaling to replace up to 2 yrs.
6.	Conduct regular irrigation and branch pruning annually, remove litter seasonally	Avoid full drying of the land and litter accumulation is discouraged
7.	Plant the sapling vegetatively (cuttings) in a slanting way	Planting Bamboo cuttings in the vertically straight fashion should be avoided

6. Harvest and Processing

Bamboo plantation is harvested in the 4th or 5th year if irrigated while 6 to 10 years in drylands. Check the Bamboo width at the 5th internode above the ground. A minimum of 4 years of growth is needed for a Bamboo pole thickening of minimum 3 inch for trade, while 5-7 inch is desired, but it takes time.

Each bamboo culm age is identified with colour code to get the desired quality required for the tower. Colour coding helps identify the desired age, to be harvested as per the demand.

Apply same colour to the new culms each year that are 4 inch wide 1 ft above ground. Shoots may be coloured year-wise e.g. red (year 1), blue (year 2), yellow (year 3 (year 3), pink (year 4(year 4), etc.

In a clump, first harvest the inner poles as they may be older and spare the outside poles. Monopodial or paired and row plantation systems are easy to harvest, but harvesting is challenging in the sympodial or block plantation. Hence, the pruning of branches and removal of excess culm is conducted each year to reduce the density. Every cut Bamboo culm is replaced by few culms in the next year, if all culms in a Bamboo are not harvested together, so this is sustainable and regenerative harvest method!

6.b) Post-harvest management-

Bamboo is soaked in water for a long and dried well. This avoids the microbial decay as it has high starch content. The following post- harvest techniques are suggested [27,28].

6.b.1) Storage

The bamboo poles should be kept vertically, so that sap inside rinses outby gravity. This avoids its bending upward due to the uneven surface. It can be arranged in any of the following formats-

a. Criss-cross structure- for aeration
b. Covering the poles to avoid exposure
c. in stacks, under shed.

6.b.2) Primary treatment

i) Water treatment: Tie the bamboo poles in a bundle and put them in a river /pond /canal or artificial tanks for 15 days. This dissolves the water-soluble glucose /fructose, so it avoids the oxidation inside the bamboo so as to increase its longevity and is called "leaching" [27].

ii) Smoke treatment- It avoids infestation from borer insect pests [*ibid.*].

iii) Bio-Oil: It is preservative against fungi and termites [28].

iv) Effluent of paper industry- These are preservative for a limited period [*ibid.*].

Traditional bamboo preservation methods above are absolutely safe, economical, and environmentally friendly [*ibid.*]. However, limited scientific data exist regarding their effectiveness and the mechanisms involved.

v) Chemical treatment

v.1- Chrome borate solution: This is a very common method where the poles are kept slanting 30 to 45 degree angles from the ground. The bamboo bottom is on the upper side and its tip to the lower end. The preservative solution solution is poured inside the hole and allowed to ooze out from another side by keeping it for 24 hrs.

This is repeated 3 to 4 days. Manual simple innovation using spray pumps is adopted. However, the modified Boucherie method is highly toxic and unsuited in farming areas, and without gloves and eye protection. The usual borax/ boric acid mix is not toxic to contact, unless swallowed but Chrome is toxic [27].

v.2- Vacuum pressure impregnation is common, but feasible only in the medium, not small sized enterprises [27].

v.3- PVC: PVC coating or varshinsh coating is the best treatment method to preserve dry bamboo against exposure to air insects and microbes- the biggest threats [29].

Eco-friendly methods such as bio-oil, hydrogels, and boron complexes, are efficient in making bamboo culms long lasting. New, innovative techniques like "flame-retardant" with Borax or Boucherie method are also emerging rapidly [30,31].

7. Economics and community entrepreneurship

7.1 **Economics**

- Bamboo is preferred over timber now as its shelf life has increased up to 10 to 15 yrs, due to advancements in processing. If maintained diligently and regularly, the utility can extend up to 20 yrs. There are even 50 years or older treated Bamboo buildings such as at Forest Research Institute of India at Dehradun (http://fridu.edu.in/) and in North Eastern India (https://www.caritasindia.org/a-bamboo-house-can-last-for-a-lifetime/). Bamboo is amply available, much faster growing raw materials, less priced than the timber, is light weight, and eco-friendly, making it fashionable in cities too.
- Bamboo plantation is viable on farms of 1 ha size for a family and 3 ha at the community level.
- Paired and row systems is suited for the low-income community, and income from intercropping say vegetavle/ spices is also possible for the first 3 years, while bamboo poles from the 4th year.
- Every single rhizome can give 12 to 35 new culms during 5 yrs. period. This will result in the anticipated production of more than 12,000 poles of bamboo/ ha/ year. usually, the harvested plants regenerate in 3 years as per our experience and literature [10].
- Bamboo plants number 1130 per ha (paired and row system) and yields from the 4th or 5th year if irrigated and well managed and the 7th to 10th year in the rain-fed plantation [*ibid.*]. It yields 2,500 to 3,000 bamboo poles/ ha /year depending upon species [20].
- About 15 to 20 feet long Bamboo pole fetches Rs, 50-80/- (fifty-eighty) each and 40 to 50 ft long pole fetches $2 (two) in the local market. If its well treated (chemically and preservative) it can fetch $ 4- (four) each. Timber costs $ 10-12 (3 ft. x 4") while a metal/ iron pole costs $ 12 (twelve) of 20 ft length. Bamboo is thus 70% cheaper in Pune-Mumbai cities we noticed and in Punjab [32] and Jammu and Kashmir states too [33].
- Bamboo economics depends on the sapling cost which is $0.2-0.25 - per sapling for *D. strictus/ B. tulda*. For rhizome, it's $ 4 (four) each, and for the cuttings, $ 1 (one) each. For planting, rhizome age of 1 year is suitable. From 6th year, labour and other costs are negligible (10 % of the initial years).
- An ideal bamboo model for tower-purpose can be a mix of bamboo species (*D. stocksii:50%, T. oliveri*: 25%, *B. balcooa*: 10%, *B. bambos*, and *D. strictus*: 5% each) can be.

However, Bima Bamboo (*B. Balcooa*) promotion in southern India/ Maharashtra is unsuitable and has failed often as it's a subtropical species unable to tolerate the tropical heat to so flowering and dying early- in few years [26]! Instead, aforesaid other Bamboo species suit here.

- Nursery can be a community-based entreprise as it provides income in short gestation (6 months to 1 year.). One community group can produce 1 lakh saplings easily and earn 20 times INR that number.

Table 5 depicts the Bamboo cultivation cost and table 6 depicts the cost- benefit analysis.

Table 5- Cost Of Plantation Per ha $

ACTIVITY	1st year	2nd Year Onwards	4th year onwards
1. Plant Sapling purchase ($ 0.25* 100 seedlings)	61	0	
2. FYM (farm yard manure)- 1 ton (100 plants * 10 kg)	183	183	-
3. Fertilizers (200 plant * 1 kg *$ 0.25/-)	122	122	-
4. Pesticides (neem based/ organic- first 1-2 years)	30	30	-
5. Drip Installation installing	1,524	0	-
6. Irrigation (electricity)	366	366	-
7. Labour	305	305	-
8. Machinery Cost (spade, shovel, tractor ploughing)	152	0	-
9. Miscellaneous (harvesting etc.)	305	152	152
Total	3,049	1,159	152

*Note- A clump may develop 10-15 culms (bamboo poles) and 4-5 of these can be harvested safely/ year from 5-6th year onwards. A pole is sold at US $1 i.e. Rs. 80/- (eighty) on average. About 200 culms imply 1,000 poles and income of $11*80= $880/-. This is farm gate income, and the marketing cost is negligible.*

Income starts from the 6th year and recurring cost of $ 1,000/- per ha occurs till then. Some reported only 50% of the above cost and 2 times income [10], but our estimate is modest based on our own experience. Table 6 depicts the cost-benefit analysis and the profit of $ 2,000 (two thousand) annually after 10 years. But cash crop growers earn it from the 1st year itself. So Bamboo farming is not competitive with the cash crops but suitable for harsh conditions such as Human-wildlife conflict (crop raising by wildlife such as deer) or difficult terrain- mountains, semi-desert lands, or for the absentee landlords (emigrated to cities/ abroad) on lease-rent.

7.2 Bamboo as a Community enterprise

Bamboo suits community enterprise as the value of the product increase 2 to 4 times over the years. Establishing common facility centre (CFC) and training and exposure in processing and making local products is necessary. This can promote entrepreneurship and better market connect. Startups often get incentives e.g. easy capital, land, water, electricity, initial tax sops so can succeed in the Bamboo sector also such as at Bhor block, Pune district, Maharashtra stae (https://era-india.org/nurseries/the-bamboo-nursery/) . Farmers producer organisations (FPO) promoted nationally by national Bank for Agriculture and Rural Development (NABARD) can adopt Bamboo. Policy amendments are required to initiate insurance for the Bamboo plantations to so the farmers can uptake it. Carbon credits are available for bamboo [34] and its fast growth can enable quicker net zero goal reaching in India, say by 2050 as per the global pledge, ahead of its 2070 commitment, and can contribute 16% of the carbon sequestration potential from tree cover (agro-forestry) [35]! In fact the paper argues that with Bamboo and agroforestry promotion, India can achieve net zero earlier say by 2050- the global deadline, ahead of India's committmnet of 2070. India's latest biannual report in 2024 end to United nations Framework Convention on Climate Change (UNFCCC) claims that India has completd that target ahead of time [36]. However, baseline used for this claim 2005 while Net Zero implementation should be computed post 2021 i.e. the 26th conference of paries at Glassgow, 2021 (COP-26) [37]. Thus, much yet remains to be done and Bamboo can be a useful tool to achive the reforestation/ green cover and "net zero carbon" goals.

Table 6- Bamboo Farming Cost-Benefit Projections Year Wise- US $/ ha

YEAR	Expense	Cumulative Cost	Income	Cumulative income	Balance
1	3049	3049	0	0	-3049
2	1159	4207	0	0	-1159
3	1159	5366	0	0	-1159
4	1159	6524	0	0	-1159
5	152	6677	0	0	-152
6	152	6829	0	0	-152
7	152	6982	2134	2134	1982
8	152	7134	2439	4573	2287
9	152	7287	2439	7012	2287
10	152	7439	2439	9451	2287
TOTAL	7439		9451		2012

Currency exchange rate US $ 1= INR 85/- (February 2025)

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Conflict of Interest
We declare no conflict of interest in this publication.

Artificial Intelligence
Artificial intelligence tools such as ChatGPT are not used to make this manuscript.

REFERENCES

1. IUCN. (n.d.) Nature Based Solutions. https://www.iucn.org/our-work/nature-based-solutions.
2. Ghate, U., Patwardhan, A. and Arunachalam, A. (2023). Agroforestry and organic farming scope in India towards net zero. *Indian Forester,* 149 (4): 418-421.
3. Singh O. (2008). Bamboo for sustainable livelihoods in India. *Indian Forester,* 134 (9): 1193-97.
4. ISFR (2021). Bamboo Resources of India. Chapter 6 in India's State of Forest Resource (IFSR), Forest Survey of India, Dehradun, pp. 14.
5. UN (n.d.) The Sustainable Development Goals (SDG). https://sdgs.un.org/goals,
6. Kumar, R S, Binu, N K, Nishant, N, Buxy, S, Sinha, G N. 2014. Review of bamboo based agroforestry models developed in different parts of India, productivity and marketing aspects. Conference. https://www.researchgate.net/publication/280029314.
7. Oberoi, V. S. (2008). Cultivating Bamboo. National Mission on Bamboo Applications, Govt. of India, New Delhi.
8. Anonymous, n.d. Frequent Questions: EPA's Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/frequent-questions-epas-greenhouse-gas-equivalencies-calculator
9. Tradeindia (n.d.). https://www.tradeindia.com/mumbai/bamboo-poles-city-207486.html
10. Arjumand T., Rani R. (2023). Case Study on Bamboo Farming. National Institute Of Agricultural Extension Management (MANAGE), Hyderabad.
11. Singh K. K., Kolte, V., Joshi, R., Ghate, U., Andhale, K., Viswadev, V. S. (2023). Bamboo for Community Networks. A plantation manual for green infrastructure. Association for Progressive Communications (APC) and Rhizomatica. https://www.apc.org/sites/default/files/final-book-english.pdf
12. Anonymous, n.d (2). https://edotcogroup.com/media/edotco-unveils-myanmars-first-bamboo-telecom-tower-1/).
13. Nautyial S. (2014). Farmers Friendly Bamboo Propagation Technologies- brochure. Forest Research Institute, Dehradun.
14. Rao., V., Gairola S. C., Shashikala S. and Sethi A. K. (2008). Bamboo utilization in southern India. Indian Forester. 134(3): 379- 386.
15. Anonymous. (2017). http://www.indiaenvironmentportal.org.in/content/450063/the-indian-forest-amendment-bill-2017/.
16. Pandey S. (2018). The amendment to the Indian Forest Act, 1927 will create new markets & jobs for poor communities. https://www.downtoearth.org.in/news/forests/the-indian-forest-act-1927-amendment-will-create-new-markets-generate-millions-of-jobs-for-poor-communities-59712.
17. Farrelly, D. (1984). The Book of Bamboo: A comprehensive guide to this remarkable Plants, its uses and its history. Sierra Club, San Francisco.
18. Lobovikov, M., Paudel S., Piazza M., Hong R., and Wu J. (2007). World Bamboo Resources. As part of the Global Forest Resource Assessment, Food and Agriculture Organization (FAO), Rome.
19. Brias, V., Hunde T. and Hierold, J. (2009). Bamboo Cultivation Manual: Guidelines For Cultivating Ethiopian Lowland Bamboo. United Nations Industrial Development Organization (UNIDO).
20. KFRI (n.d.). Harvesting and Yield of Bamboo, Bamboo Technical Support Group (BTSG - KFRI), Kerala Forest Research Institute, Peechi. https://www.bambooinfo.in/cultivation/harvesting-and-yield-of-bamboo.asp#
21. Awalluddin, D., Azreen, M., Ariffin, M. Osman, M. H., Hussain, M H., Ismail, M. A. et al. (2017). Mechanical properties of different bamboo species. MATEC Web of Conferences 138, 01024 pp. 10.
22. Kenneth, O. I., Uzodimma, U. O. (2021). Evaluation of the Compressive Strength of Bamboo Culms under Node and Internode Conditions. *Saudi J Civ Eng, 5*(8): 251-258.
23. Singh, K., Garg, H. Pabla, B. S. (2011). Evaluation of Mechanical Properties of Different Bamboo Species for Structural Applications. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8(11): 2927-35.
24. Sanchez, L., Mullins, A. G., Cunningham, J. A, Mihelcic, J. R. 2019. Mechanical properties of bamboo: a research synthesis of strength values and the factors influencing them, J. *Amer. Bamboo Soc.* 29: 1–21.

25. Zhang, Z.; Rao, F., Wang, Y. (2022). Morphological, Chemical, and Physical–Mechanical Properties of a Clumping Bamboo (*Thyrsostachys oliveri*) for Construction Applications. *Polymers*, 14: 3681.

26. Pinjarkar, V. (2022). *Balcooa* Bamboo Bubble Bursts. Toi, Nagpur, 22-05-2022. http://timesofindia.indiatimes.com/articleshow/91860194.cms

27. NMBA. (2006). Preservation of Bamboo- Training Manual TM 05-07/06. National Mission on Bamboo Applications (NMBA), Department of Science and Technology (DST), Government of India, New Delhi.

28. Kaur, P. J., Satya, S., Pant, K. K., and Naik, S. N. (2016). Eco-friendly preservation of bamboo species: Traditional to modern techniques, *BioRes.* 11(4): 10604-10624.

29. Venmalar, D. (2020). Preservative treatment of bamboo for value addition, Training manual on 'Value-addition – Bamboo Technologies', Inst. Wood Science & Technology (IWST), Bengaluru, pp. 50-59.

30. Sharma, N. K, Verma, C. S., Vijayaraghavan, M. Chariar, Prasad, R. (2015). Eco-friendly flame-retardant treatments for cellulosic green building materials. *Indoor and Built Environment,* 24(3): 422-432.

31. Stamm, J. and Vahanvati, M. (2018). Bamboo treatment user guide. United Nations Industrial Development Organization, Vienna.

32. Boity A K, Bhandari H, Shukla S. (2022). Bamboo as a sustainable building construction material, *Materials Today: Proceedings, Vol.* 71, *Part* 2 pp. 306-311.

33. Mir S. H. (2013) Bamboo as a Cost effective Structural Material in Buildings. *Intl. J. Eng. Tech. Res. (IJETR) Vol. -1, No. 9 pp.* 45-49.

34. Jenifer L. (2023). Voluntary Carbon Credit Buyers Willing to Pay More For Quality. Ecosystem marketplace. https://carboncredits.com/voluntary-carbon-credit-buyers-willing-to-pay-more-for-quality/

35. Kulkarni & Ghate U (2025). Agro-Forestry & Natural Farming for Bioeconomy, Speedy Net Zero Carbon and Climate Change Resilience in India*. Open access J Agri Res* 10(1): pp 1-5.

36. PIB (2025) India submits its 4th Biennial Update Report to the United Nations Framework Convention on Climate Change. Press Information Bureau, Govt. of India. 02 Jan. PIB GOI. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2089589

37. UNFCCC (2021) The United Nations Convention on Climate Change- 21st Conference of Parties, Glasgow- Outcome. https://unfccc.int/process-and-meetings/the-paris-agreement/the-glasgow-climate-pact-key-outcomes-from-cop26