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Ranjitsinh Bira Dhale
PG Scholar, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

PD Raut
Assistant Professor, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

RN Katkar
Associate Dean, LAE, Dr. P.D.K.V. Akola, Maharashtra, India

VM Illorkar
Senior Scientist and Head, AICRP on Agroforestry, College of Agriculture, Nagpur, Maharashtra, India

ST Dangore
Assistant Professor, Agronomy section, College of Agriculture, Nagpur, Maharashtra, India

UB Dolaskar
PG Scholar, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

SS Nagdeve
PG Scholar, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

NJ Shahare
PG Scholar, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

Corresponding Author:
Ranjitsinh Bira Dhale
PG Scholar, Soil Science Section, College of Agriculture, Nagpur, Maharashtra, India

Impact of bamboo based agroforestry system on yield and quality of turmeric (*Curcuma longa*) grown in entisols

Ranjitsinh Bira Dhale, PD Raut, RN Katkar, VM Illorkar, ST Dangore, UB Dolaskar, SS Nagdeve and NJ Shahare

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Abstract
A field experiment with randomized block design (RBD) with 3 replication and 9 treatments was conducted at the AICRP on Agroforestry, College of Agriculture, Nagpur (Maharashtra) during the Kharif season of 2023-24 at research farm. The treatments included turmeric with T_1-open plot, T_2-*Bambusa vulgaris*, T_3-*Dendrocalamus longipathus*, T_4- *Bambusa tulda*, T_5-*Bambusa cacherensis*, T_6-*Dendrocalamus stocksii*, T_7-*Bambusa polymorpha*, T_8-*Bambusa balcooa*, and T_9-*Dendrocalamus strictus* with application of recommended dose of fertilizer (120;60;60 NPK kg ha^{-1}) in each treatment. The results showed that, yield of turmeric was highest in open plot (235.18 q ha^{-1}) than under different bamboo species, while *Bambusa tulda* (230.93 q ha^{-1}) and *Bambusa balcooa* (220 q ha^{-1}) showed relatively higher yield of turmeric than other bamboo species. Curcumin content (%) was found to be significantly higher in shade under bamboo-based agroforestry than open. *Dendrocalamus stocksii* (3.99%) shows highest curcumin percentage followed closely by *Dendrocalamus longipathus* (3.94%) and *Bambusa cacherensis* (3.92%) and turmeric in open plot shows lowest Curcumin % (3.37).

Keywords: Turmeric, bamboo, intercropping, yield and quality attributes

Introduction
Bamboo is commonly known as ‘‘poor man timber’’ and play a vital role in improving the socio-economic status of rural population. The most traditional uses of bamboo include housing, food and other material for handicraft. Worldwide, approximately more than 2.5 billion people trade in or use bamboo (INBAR 1999) [1]. India is one of the leading countries of the world, second to China in Bamboo production with 32.2 million tonnes per year. Bamboo species cover an area of 10.03 million hectare with 22 genera and 135 species. They contribute 12.8% of total forest cover of India (as quoted by Berry *et al*., 2008) [2].

Turmeric (*Curcuma longa*) is a rhizomatous herbaceous perennial plant of the family Zingiberaceae. It is native to Asia and India, and occupies about 6% of the total area under spices and condiments in India. India is the largest producer of turmeric in the world (93.7% of the total world production) (Sasikumar, 2005) [3]. It is used mainly for domestic use as a condiment and occupies 6% of the total area under spices in the country. About 92% of the produce is consumed in the domestic market and 8% exported annually. Maximum area under turmeric is in Andhra Pradesh followed by Maharashtra, Tamil Nadu, Orissa, Karnataka and Kerala. The genus *Curcuma longa* L. (Zingiberaceae) contains many taxa which are economically important as food, condiment and as colouring, medicinal and ornamental materials. It is found throughout the South and South East Asia with a few species extending to China, Australia and the South Pacific. The highest diversity is concentrated in India and Thailand, with at least 40 species in each area, followed by Myanmar, Bangladesh, Indonesia and Vietnam. Commercially, it is traded as a spice, dye, oleo-resin and source of industrial starch. Curcumin is the principal component of turmeric, which has anti-inflammatory, anti- cancer, anti-tumour, anti-bacterial, anti-oxidant, anti-fungal and antiparasitic properties (Hermann and Martin, 1991; Osawa *et al*., 1995; Nakamura *et al*., 1998) [4, 5, 6].

Agroforestry has wide scope in improving socio- economic status of farmers in India so study will give insights for best species of bamboo for intercropping.

Methods and Materials

During the kharif season of 2023-2024, experiment was conducted at research farm of AICRP on Agroforestry, Futala, College of Agriculture, Nagpur (Maharashtra). The research site has sub-tropical climate with dry conditions prevailing for most of the year. An average annual rainfall of 1064.1 mm. The mean annual temperature of the region is 25.9 °C

Bamboo plantation was 3 year old with spacing of 7×2 m. Turmeric was planted between rows of eight different bamboo species and also in open plot for reference. Per plot yield of turmeric recorded using weighing balance. The curcumin content and essential oil content was determined following the method as described by ASTA (1997) [7]

The average maximum temperature is 33.70 °C in *Kharif* (June-Sept), 27.50 °C in *Rabi* (Oct- Jan) and 38.80 °C in *summer* (Feb-May). May is generally hottest month with maximum temperature reaching above 45 °C for a short period of 5 to 10 days. Whereas minimum temperature varies between 8 °C to 30.80 °C and humidity ranges from 26.4 to 94.1 percent. In order to conduct a chemical study of the soil in the experiment area prior to planning the layout, 5 samples were randomly selected from the soil profile between 0 and 15 cm deep. The soil type at the experimental location was clayey, with accessible soil nutrients (N, P, K) total of 225.00, 17.63 and 310.00 kg ha^{-1}, as well as soil organic carbon 5.21 g kg-1 and pH of soil 7.93 at the time. The experiment was set up using a randomized block design (RBD), with 9 treatments with different bamboo species. The results obtained was statistically analysed as per methods suggested by Gomez and Gomez (1984) [8].

Results and Discussions

a) Effect of bamboo-based agroforestry system on yield of turmeric

In agroforestry systems, the yield of intercrops plays a critical role, as higher yields translate into increased economic returns for farmers. Thus, the assessment of intercrop yields is essential for evaluating and optimizing the productivity and profitability of agroforestry practices. The data from Table1 revealed that the rhizome yield ranged from 181.48 to 235.18 q ha^{-1}. The highest rhizome yield was recorded under T1-open plot (235.18 q ha^{-1}), followed by T4-*Bambusa tulda* (230.93 q ha^{-1}) and T8-*Bambusa balcooa* (220.00 q ha^{-1}). The lowest rhizome yield was observed under T6-*Dendrocalamus stocksii* (181.48 q ha^{-1}). This suggests that the open plot treatment resulted in the highest rhizome yield, potentially due to the absence of competition for resources.

In comparison to the open plot treatment, which had the highest rhizome yield of 235.18 kg ha^{-1}, all bamboo treatments showed a reduction in yield. The treatment with *Bambusa vulgaris* resulted in a 9.29% reduction in yield, while *Dendrocalamus longipathus* showed a more significant decrease of 19.82%. *Bambusa tulda* had the smallest reduction at 1.80%. *Bambusa cacherensis* and *Dendrocalamus stocksii* experienced reductions of 18.89% and 22.83%, respectively. *Bambusa polymorpha* had a 15.26% reduction, and *Bambusa balcooa* saw a 6.47% reduction in yield. Lastly, *Dendrocalamus strictus* experienced a 13.08% reduction in yield compared to the open plot. This indicates that, while all bamboo treatments resulted in some yield reduction, the extent varied across different species, with *Bambusa tulda* showing the least impact and *Dendrocalamus stocksii* the most

Table 1: Effect of bamboo-based agroforestry on yield of turmeric

Treatments	Rhizome Yield q ha^{-1}
T_1- open plot	235.18
T_2- *Bambusa vulgaris*	213.33
T_3- *Dendrocalamus longipathus*	188.52
T_4- *Bambusa tulda*	230.93
T_5- *Bambusa cacherensis*	190.74
T_6- *Dendrocalamus stocksii*	181.48
T_7- *Bambusa polymorpha*	199.26
T_8- *Bambusa balcooa*	220.00
T_9- *Dendrocalamus strictus*	204.44
SE	1.602
CD at 5%	4.804

It was observed that the reduced yields in agroforestry compared to sole cropping can be attributed to several key factors. Competition for essential resources such as light, water, and nutrients between trees and intercrops can limit the growth and productivity of intercrops. Root interactions, which lead to competition for soil space and nutrients, Shade from trees can decrease photosynthesis in intercrops, further contribute to reduced yields.

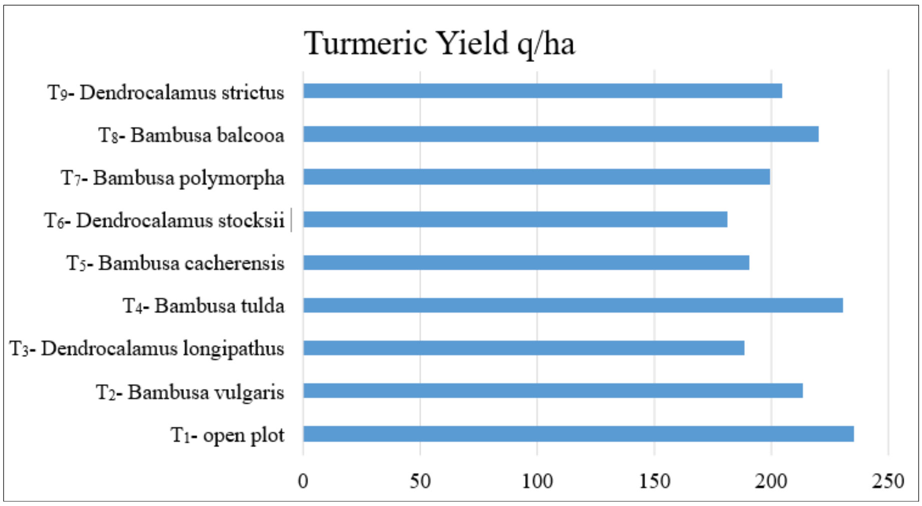

Fig 1: Turmeric yield q/ha

Present findings are in line with the studies of Conway *et al*. (2022) [9] investigated turmeric intercropped with pepper and maize, noting that the fresh yield of turmeric in intercropping with fodder maize (228.5 q ha^{-1}) was lower than in sole cropping of turmeric (241.2 q ha^{-1}). Kumar and Naugraiya (2020) [14] found that the fresh yield of turmeric in an open field (225.79 q ha^{-1}) was significantly higher compared to under a bamboo-based agroforestry system (161.46 q ha^{-1}). Similarly, Kumar *et al*. (2018) [11], Vikram and Hegde (2014) [12] found same results.

b) Photosynthetically active radiation (PAR), leaf area index (LAI) of different bamboo species

The study measured growth parameters of bamboo, focusing on the photosynthetically active radiation (PAR) and leaf area index (LAI) across different bamboo species.

Photosynthetically active radiations: The PAR values ranged from 263.10 to 598.72 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The highest PAR was recorded in the open plot (T_1) at 598.72 $\mu mol \cdot m^{-2} \cdot s^{-1}$, as expected due to the absence of shading. Among the bamboo treatments, *Bambusa balcooa* (T_8) recorded the highest PAR (419.39 $\mu mol \cdot m^{-2} \cdot s^{-1}$), followed by *Bambusa vulgaris* (T_2) at 386.90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and *Dendrocalamus strictus* (T_9) at 368.00 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The lowest PAR was observed under *Dendrocalamus stocksii* (T_6) at 263.10 $\mu mol \cdot m^{-2} \cdot s^{-1}$, indicating significant shading due to dense canopy cover.
Similar results were obtained by Kumar (2020) [10, 14].

Table 2: PAR under different bamboo species, leaf area index of bamboo

Treatments	Growth parameters of bamboo	
	PAR ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	LAI
T_1- open plot	598.72	-
T_2- *Bambusa vulgaris*	386.90	3.26
T_3- *Dendrocalamus longipathus*	264.33	3.88
T_4- *Bambusa tulda*	311.70	2.88
T_5- *Bambusa cacherensis*	302.02	3.47
T_6- *Dendrocalamus stocksii*	263.10	4.10
T_7- *Bambusa polymorpha*	352.44	3.47
T_8- *Bambusa balcooa*	419.39	2.98
T_9- *Dendrocalamus strictus*	368.00	3.38
SE	22.45	0.007
CD at 5%	67.3	0.0022

Leaf area index: Regarding the LAI, which indicates canopy density, values ranged from 2.88 to 4.10. *Dendrocalamus stocksii* (T_6) had the highest LAI at 4.10, indicating a dense leaf cover that strongly affects light penetration. *Dendrocalamus longipathus* (T_3) followed with an LAI of 3.88, while *Bambusa vulgaris* (T_2) had an LAI of 3.26. On the lower end, *Bambusa tulda* (T_4) and *Bambusa balcooa* (T_8) recorded LAI values of 2.88 and 2.98, respectively, indicating relatively sparser canopies.
The data suggest that different bamboo species vary significantly in their impact on light availability and canopy density, influencing potential intercrop performance. *Dendrocalamus stocksii* (T_6), with its dense canopy (high LAI) and low PAR, may provide more shade, while species like *Bambusa balcooa* (T_8) allow more light penetration, making them potentially better suited for light-demanding intercrops.

Similar results were obtained by Chen *et al*. (1997) [15]; Luo *et al*., (2002) [16]; Singh (2017) [17].

c) Effect of bamboo-based agroforestry on quality parameters of turmeric

Turmeric contains several plant substances, but one group, curcuminoids, has the greatest health-promoting effects. Three outstanding curcuminoids are curcumin, demethoxycurcumin and bisdemethoxycurcumin (Lee *et al*., 2016) [18]. Of these, curcumin is the most active and useful to health. It represents about 2–8% of most turmeric preparations and gives turmeric its distinct color and flavor. It is assumed that growth, yield, and curcumin content of turmeric vary with the sunlight level. Curcumin is susceptible to light and undergoes oxidative degradation (Nelson *et al*., 2017) [19] thereby reducing its quality. Sunlight exposure accelerates curcumin degradation Priyadarsini (2009) [20].

Table 3: Effect of bamboo-based agroforestry on quality parameters of turmeric

Treatments	Quality parameters	
	Curcumin%	Essential oil%
T_1- open plot	3.37	5.58
T_2- *Bambusa vulgaris*	3.61	5.36
T_3- *Dendrocalamus longipathus*	3.94	4.31
T_4- *Bambusa tulda*	3.43	5.12
T_5- *Bambusa cacherensis*	3.92	5.38
T_6- *Dendrocalamus stocksii*	3.99	5.18
T_7- *Bambusa polymorpha*	3.75	5.53
T_8- *Bambusa balcooa*	3.53	4.95
T_9- *Dendrocalamus strictus*	3.69	5.61
SE	0.019	0.341
CD at 5%	0.057	-

Curcumin Content (%): The curcumin content ranged from 3.37% to 3.99%. The highest curcumin percentage was recorded under T_6-*Dendrocalamus stocksii* at 3.99%, followed closely by T_3-*Dendrocalamus longipathus* at 3.94% and T_5-*Bambusa cacherensis* at 3.92%. The lowest curcumin content was observed in the T_1-open plot at 3.37%. The higher curcumin levels under certain bamboo species could be attributed to the partial shade they provide, which reduces light intensity and enhances the synthesis of secondary metabolites like curcumin. Species like *Dendrocalamus stocksii* and *Dendrocalamus longipathus* have denser canopies, which may create an environment conducive to curcumin production.
The curcumin percentage in the highest treatment, *Dendrocalamus stocksii*, was 4.15%, reflecting a 23.15% increase compared to the sole cropping treatment in the open plot, which had a curcumin content of 3.37%. Other treatments also showed higher curcumin percentages compared to the open plot. Specifically, *Dendrocalamus longipathus* had a curcumin content of 4.00%, representing an 18.69% increase; *Bambusa cacherensis* with 3.92% showed a 16.34% increase; *Bambusa polymorpha*, with 3.74%, had a 10.98% increase; *Dendrocalamus strictus* at 3.69% displayed a 9.50% increase; and Bambusa vulgaris, with 3.61%, had a 7.12% increase. These results indicate that various bamboo species can significantly enhance curcumin content compared to traditional open plot conditions.

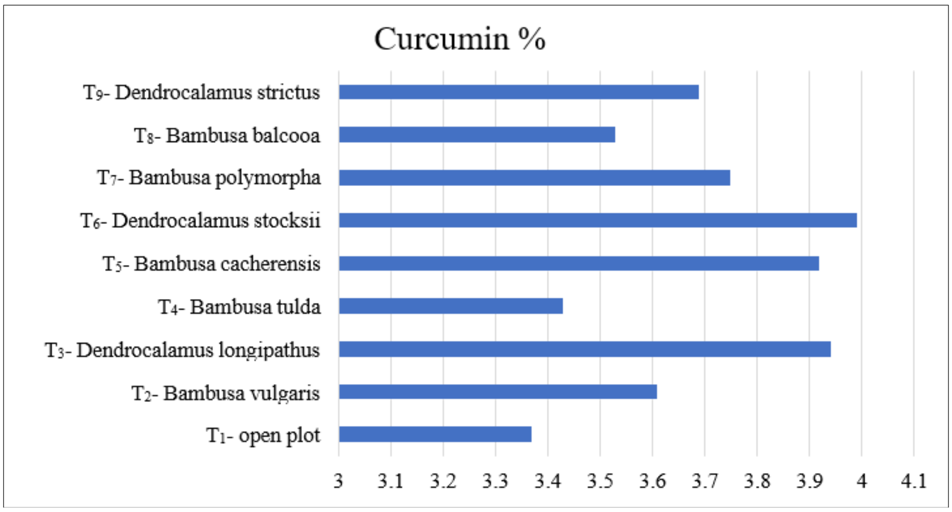

Fig 2: Curcumin %

Essential Oil Content (%): Bamboo based agroforestry system showed non- significant effect on essential oil content in turmeric. Essential oil content varied from 4.31% to 5.61%.

Overall, the results indicate that bamboo species with moderate to dense canopies tend to promote higher curcumin content, likely due to shade-induced stress, which triggers secondary metabolite production. On the other hand, essential oil shows non significant effect of all treatments.

Most studies indicate that shade generally has a positive effect on curcumin content in turmeric and non-significant effect on essential of turmeric. Studies by Kumar *et al.* (2018) [11] and Singh (2016) [21] support the positive influence of agroforestry systems on curcumin content, attributing this to better synthesis, translocation, and assimilation of curcumin under shaded conditions. Bhardwaj *et al.* (2017) [22] and Kikon (2016) [23] found that bamboo species and mulching significantly affect curcumin content, with higher levels observed under shaded conditions. These studies collectively highlight the importance of shaded environments and specific agroforestry systems in enhancing the curcumin content in turmeric, making them valuable strategies for optimizing turmeric production.

Conclusion

Turmeric yields are typically higher in sole cropping systems compared to intercropping. Nonetheless, in agroforestry systems, bamboo species such as *Bambusa tulda* and *Bambusa balcooa* are linked with improved turmeric yields. On the other hand, bamboo species that create more shading tend to increase the curcumin percentage in turmeric. This indicates that while increased shading may lower overall yields, it enhances turmeric quality by elevating curcumin content.

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