Introduction of *Dendrocalamus stocksii* (Munro.) in the Northwestern Himalayan foothills for sustainable production and resource conservation

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The present study evaluates the growth performance and resource conservation attributes of *Dendrocalamus stocksii* introduced in the Himalayan foothills, India in 2012. The growth and biomass production after seven years were comparable with the growth performance of species in its native region in the Western Ghats. Maximum culm weight of 7.9 kg was recorded in the fifth year. The litterfall reached 8.70 Mg ha^{-1} in 2019. The basal portion up to 2.25 m was entirely solid after the fifth year of harvesting, which offers a good market potential and a substitute to *Dendrocalamus strictus*. Studies revealed that about one-third of the root number and root biomass was observed in 0–10 cm soil layer, whereas about 74% of total root number and about 79% of total root biomass was recorded in the 0–30 cm soil layer. The dense shallow root system can help prevent soil erosion and make the species suitable for the sites having indurate pan at varying depths. Soil hydraulic conductivity and aggregate stability showed marked improvement after six years. Overall, the species can be recommended for large-scale cultivation in the Himalayan foothills.

Keywords: Bamboo, biomass, culm, hydraulic conductivity, rooting intensity.

IN north India, *Dendrocalamus strictus* and *Bambusa bambos* are two widely grown bamboo species. Both species are hardy, and can withstand adverse climatic and edaphic conditions. The productivity of both species is, however, very low which discourage farmers from undertaking large-scale plantation of these species. The culm congestion in *D. strictus* and the presence of thorns in *B. bambos* make these species difficult to harvest and manage. As a result, the economic returns from both species are low and its adoption by farmers is poor. Keeping this in view, *Dendrocalamus stocksii* (Munro), a domesticated species from the Western Ghats was introduced to explore its possibility of cultivation in the Doon valley of Northwestern Himalayan foothills.

D. stocksii, locally known as chivari/marihal/manga, is endemic to Central Western Ghats and is found in Karnataka, Goa, Kerala and Maharashtra. The species is widely domesticated in South Konkan and Goa regions of Central Western Ghats and is cultivated in the coastal belts of Karnataka[1]. It is primarily planted around areca-nut gardens and paddy fields in many parts of northern Karnataka. The species due to its solid nature and good culm wall thickness is a better substitute for the furniture industry. The species is also used for construction, handicrafts, scaffolding, paper and pulp, heck, poles, and as support-prop for banana, grape and tomato cultivation[2]. It is among 18 economically important bamboo species, recommended for cultivation in peninsular India by the National Bamboo Mission[3].

The present study was conducted at Dhulkot Research farm of ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand, located in the Himalayan foothills at 30″20′59″N lat., 77″53′05″E long. at 548 m amsl. One-year-old, nursery-grown *D. stocksii* plants procured from Sindhudurg district, Maharashtra, were planted at the study site during 2012 at a spacing of 5 m × 4 m. Growth parameters, viz. clump diameter, clump height, number of new culms/clump and culm biomass were recorded every year. Three mature culms from each clump were sampled in 2018 to measure culm wall thickness at various height intervals and extent of solidness. Litterfall was measured annually using litter traps of 1 m × 1 m size. Root intensity was studied by the profile wall method. Root biomass was studied using a core sampler. Soil bulk density was measured by the core method. Saturated hydraulic conductivity (K_s) was measured by the constant head method. The aggregate size distribution was determined by the wet sieving method. Composite soil samples were collected from the surface soil (0–30 cm) and analysed for pH, organic carbon (OC) content, total nitrogen, available P and exchangeable K using standard methods.

Results of growth and biomass production revealed that culm diameter increased with increase in age (Table 1). It reached a maximum of 4.92 cm in 2017, i.e. after five years of planting. The plantation was harvested in March 2018, after which there was a decline in the diameter of new culms. Height reached to about 9.5 m after the fifth year; then there was not much change in height (Table 1). The growth performance in terms of diameter and height is comparable to the growth of the species in the Western Ghats[2,4]. The number of new culms that emerged per clump ranged between 5.99 and 8.25, which is in line with the findings of Rane *et al.*[2], who reported that around 5 culms/culm can be harvested in the fifth year and 10 extractable culms/clump/year from the sixth year onwards. In the natural distribution range, however, the species has been reported to produce 12–18 culms from the third year onwards[2]. The culm weight increased from

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Table 1. Growth and biomass behaviour in *Dendrocalamus stocksii*

Year	Culm diameter (cm)	Height (m)	Number of new culms/clump	Culm weight (kg)	Fifth internode length	Litterfall (Mg/ha)
2013	2.40 ± 0.32	3.7 ± 1.18	6.44 ± 2.13	1.58 ± 0.55	21.7 ± 2.9	–
2014	3.24 ± 0.18	6.2 ± 0.64	5.9 ± 2.20	2.68 ± 0.73	29.3 ± 3.1	–
2015	3.69 ± 0.30	7.3 ± 1.04	7.22 ± 1.30	3.92 ± 1.19	33.3 ± 6.7	2.31 ± 0.31
2016	4.43 ± 0.43	9.5 ± 1.55	6.33 ± 2.06	6.42 ± 1.70	34.0 ± 5.3	2.83 ± 0.33
2017	4.92 ± 0.51	9.7 ± 0.96	6.11 ± 1.54	7.88 ± 1.38	35.7 ± 3.8	8.14 ± 0.35
2018	4.82 ± 0.36	9.0 ± 1.93	7.13 ± 1.87	5.98 ± 1.32	25.5 ± 3.5	8.50 ± 0.41
2019	4.85 ± 0.36	9.8 ± 1.15	8.25 ± 0.5	5.60 ± 1.28	26.6 ± 4.94	8.70 ± 0.43

Table 2. Culm wall thickness at different positions in *D. stocksii*

Position	Culm wall thickness (mm)	Diameter (mm)	Culm wall thickness : culm diameter	Height of culm solidness (m)
Base	44.51	44.51	1 : 1	2.25
Medium	12.18	32.82	1 : 2.6	
Top	7.12	27.93	1 : 3.9	

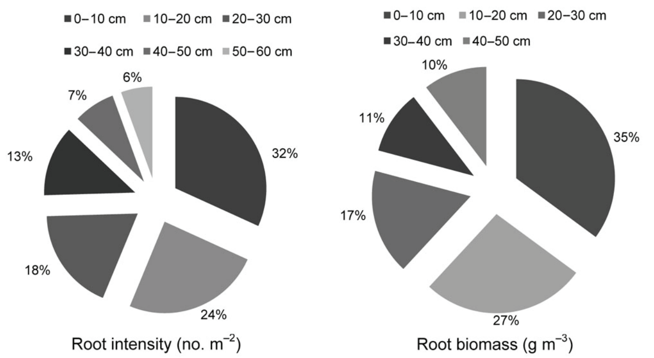

Figure 1. Root distribution in *Dendrocalamus stocksii.*

1.58 kg/culm in 2013 to 7.88 kg/culm in 2017, after which there was a decline in weight which can be attributed to the harvesting of culms carried out in March 2018. Internode length also showed an increase from 21.7 in 2013 to 35.7 in 2017, after which it declined (Table 1). Litterfall increased from 2.31 Mg ha^{-1} in 2015 to 8.70 Mg ha^{-1} in 2019.

The overall growth of *D. stocksii* in the study area was comparable to that of this species in the Western Ghats. The growth of the species can be rated as very good compared to reported values of *D. strictus* and *B. bambos* in north India[5]. Further, the non-thorny nature and loosely spaced culms facilitated easy management and harvesting of culms compared to *D. strictus* and *B. bambos*. Our observations also showed that culms produced by *D. stocksii* were straight and thus the species can be an ideal choice for agroforestry during the initial years. The high leaf litter produced by *D. stocksii* can add considerable amounts of N, P and K to the soil[6]. Bhave *et al.*[7] and Rane *et al.*[2] also reported successful intercropping of this species with agriculture crops in the Western Ghats. Further, they reported that intercropping could increase the number of culms by more than double in this species. However, the clumps need to be managed for root competition as majority of the roots are distributed in the 0–30 cm soil depth (Figure 1). The culms also need to be harvested in a systematic manner so that growth and biomass of the new culms are not affected.

Culm wall thickness (*cw*) revealed that at the time of harvesting of the culms, the basal portion up to 2.25 m was entirely solid (Table 2). The middle and top portions recorded wall thickness of 12.18 and 7.12 mm respectively, with *cw*, culm diameter (*cd*) ratio of 1 : 1.26 and 1 : 1.39 respectively (Table 2). Better *cw*/*cd* ratio (up to 1 : 3) makes the species suitable for the furniture and construction industry. Our reported values are within the range reported by Rane *et al.*[2,4], thereby indicating that the species can be a good choice for cultivation in the Himalayan foothills where solid culms of *D. strictus* are in great demand for making sticks (lathi).

Root studies revealed that about one-third of root numbers and root biomass was observed in the 0–10 cm soil layer (Figure 1). A total of 3757 roots m^{-2} was recorded up to 60 cm soil depth. The maximum number of roots (1193) was recorded in the 0–10 cm soil layer. Total root biomass of 2091 g m^{-3} was recorded up to 50 cm soil depth. Further analysis revealed that about 74% of total root numbers and about 79% of total root biomass were recorded in the 0–30 cm soil layer. Pearson's correlation coefficient (r) between root intensity (number of roots m^{-2}) and soil depth was negative and high ($r = -0.86$), thereby indicating a declining trend with an increase in soil depth (Figure 1). Pearson's correlation coefficient (r) between root biomass and soil depth was also negative and high ($r = -0.96$). More root distribution in the topsoil layer makes this species ideal for soil conservation and may enable clumps to capture nutrients that would otherwise be leached from the upper horizons of the soil profile[8,9]. However, more roots in the surface layer makes this species compete with agriculture crops, but offers scope for

Table 3. Soil physical and chemical properties under *D. stocksii*

Species	*D. stocksii*	Open (control)
Bulk density (Mg m^{-3})	1.52 ± 0.083	1.53 ± 0.009
Hydraulic conductivity (cm h^{-1})	1.10 ± 0.15	0.95 ± 0.20
Water stable aggregates (%)	92.8 ± 2.60	76.4 ± 4.28
Mean weight diameter (mm)	4.91 ± 0.52	2.74 ± 0.39
pH	5.81 ± 0.16	5.35 ± 0.049
Organic carbon (%)	0.612 ± 0.03	0.632 ± 0.026
N (%)	0.078 ± 0.01	0.079 ± 0.04
P (ppm)	6.69 ± 0.59	6.97 ± 0.51
K (ppm)	52.2 ± 9.96	92.0 ± 7.12

cultivation with fruit/forest trees as they have a deep root system and can efficiently tap nutrients from deeper soil layers where majority of bamboo roots cannot penetrate. Such spatial segregation of below-ground niches lowers root competition. Further, the culms under partial shade of trees are taller and thicker than those in the open[6].

Soil physical properties improved under *D. stocksii* after six years of plantation (Table 3). When compared to the control plots (without bamboo), there was an improvement of 16% in hydraulic conductivity (K_s). Higher K_s under bamboo indicates more permeability which is attributed to higher roots contributing to the development of macropores, better faunal activities that enhance K_s, preferential flow and macropore flow[9]. Water stable aggregates improved by 21.4% and mean weight diameter by 79% compared to open. This may be attributed to the protective covering of litterfall and dense fibrous root system which binds soil particles and results in larger-sized aggregates and enhances the ability of the soil to resist disintegration during soil erosion. Soil pH increased from 5.35 to 5.81 (Table 3). There were not much change in OC, total N and available P, which may be attributed to lower leaf litter during the establishment phase (first to fourth years) of clumps. It is, however, assumed that higher litterfall with increase in age will add significant carbon to the soil in the coming years. Exchangeable potassium reduced drastically under *D. stocksii*, indicating more potassium uptake from the soil and the need for its fertilization. Singh and Singh[10] also observed that increasing demand by growing bamboo plants over the years does not permit K to accumulate in the topsoil.

It can be concluded that *D. stocksii* has adapted well in the Himalayan foothills. Its non-thorny nature and loosely spaced culms facilitate easy management and reduce the cost of harvesting. The dense root network and high litterfall improve soil physical properties, and help in preventing soil erosion and better permeability. The shallow root system is useful for sites having indurated (clay/kankar) pan at varying depths (60 cm–1 m) in the soil. On better soil, the straight culm with shallow roots make the species a suitable combination with fruit or multipurpose trees having a deep root system. The solid nature of the culm offers a good market potential and is a better substitute to *D. strictus*. Overall, the species can be recommended for cultivation in the Himalayan foothills. Future research is required on the development of quality planting stock and standardization of silvicultural techniques for enhancing productivity and making it commercially viable for the farmers.

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