J. Bamboo and Rattan, Vol. 19, Nos. 1, pp. 13 - 22 (2020) www.jbronline.org

Effect of spacing on rooting intensity and root distribution pattern of *Dendrocalamus stocksii* plantation under rainfed moist semi-arid zones of Peninsular India

Lubina P A[1*] · Anil Kumar K S[2] · Viswanath S[3]

Received: 23 July 2020/Accepted: 8 November 2020

Abstract: *Dendrocalamus stocksii* is a potential multiuse bamboo species that can come up well in moist semi-arid zones of Peninsular India. If it is to be introduced to the realm of cultivation with other crops, accurate scientific data has to be generated for better management plans. Analysing the below-ground rooting architecture of bamboo helps in better management decisions. Root architecture study was carried out in 13 year old *D. stocksii* plantation with the spacing of 5 x 5m and 9 x 9m in Hosekote, Bengaluru Rural District, which experiences moist semi-arid climate under Eastern Dry Zone. To estimate the root distribution pattern, bamboo clumps were selected and excavated using a logarithmic spiral trenching technique. Variation in the number of roots with horizontal and vertical distance from the clump base was done, and the effect of interactions was elucidated by using general linear model univariate analysis. Majority of roots (>95 %) observed were of less than 2 mm diameter in topsoil. The number of *D. stocksii* roots was significantly higher in 5 x 5m spaced plots compared to that of 9 x 9m plots for the surface horizon of 30 cm depth. Spacing between bamboo clumps played a significant role in the development of root architecture and foraging zone, which ultimately helps in the planning of intercrops to maximize farm output in bamboo-based agroforestry systems of rainfed semi-arid tropics.

Keywords: *Dendrocalamus stocksii*, intercropping, moist semi-arid tropics, root intensity, spacing regime, spiral trench

*Corresponding Author

[1]Silviculture and Forest Management Division, Institute of Wood Science and Technology, Bengaluru, India
E-mail: lubina.p.a@gmail.com

[2]Principal Scientist, ICAR- National Bureau of Soil Survey and Land Use Planning, Bengaluru, India

[3]Director, KSCSTE-Kerala Forest Research Institute, Peechi, Kerala, India

Published online 31 March 2021

Introduction

Bamboo has been gaining increased global attention as an alternate horticulture/plantation crop with multiple uses and benefits, providing human beings with various resources. *Dendrocalamus stocksii* (Munro) M. Kumar, Remesh and Unnikrishnan (Kumar *et al*., 2004) (Synonyms -*Pseudoxytenanthera stocksii* (Munro) Naithani, *Oxytenanthera stocksii* (Munro) is an endemic bamboo species seen in the Western Ghats. Owing to its myriad uses and perceived importance, National Bamboo Mission (NBM) has prioritized this species for large scale cultivation in Peninsular India. Preliminary studies have also revealed that this species has the potential to come up well in rainfed moist semi-arid zones of Peninsular India.

In recent times due to scarcity of cane/rattan, this species has also been seen as a substitute in furniture industry due to its typical anatomical characteristics like the presence of non predominant nodes, solid nature and suitable culm wall thickness. There is a vast potential for this bamboo in smallholder agroforestry systems (Rane *et al*., 2016 and Viswanath *et al.,* 2013). If *D. stocksii* is to be introduced to the realm of cultivation with other crops, accurate scientific data has to be generated for better management options. Analyzing the belowground rooting architecture of bamboo may help in better management decisions (Dhyani and Tripathi, 2000).

A significant portion of global root distribution studies has been limited to tree species and some monopodial bamboos (George *et al*., 1996, Verma *et al*., 2014 and Kaushal *et al*., 2019). Innovative and less destructive techniques are coming in bamboo research like the maximum heights of culms of 67 clones were closely predicted by the maximum measured root pressure overnight (Cao *et al*., 2012). Root distribution pattern of six commercial bamboo species, namely *Bambusa balcooa, Bambusa bambos, Bambusa nutans, Dendrocalamus asper, Dendrocalamus hamiltonii,* and *Dendrocalamus strictus* and their impact on soil properties were studied (Kaushal *et al*., 2020b). Canopy cover and rain interception were higher in rubber plantations in association with bamboo (Andriyana *et al*., 2020). Seasonal variation, depth-wise and lateral distribution of biomass in roots of different diameter classes and their annual production were studied using sequential core sampling (Dhyani and Tripathi, 2000). Fine root dynamics and net primary production were studied using the sequential soil coring method (Yang *et al.,* 2010).

Spacing exerts a profound influence on the growth of bamboo. The occurrence of two or more tree species close to one another may favour diminished lateral spread, and deeper root penetration of the woody components and closer the tree components are located greater will be the sub-soil root activity. The proximity of species/individuals favoured competitive downward displacement of roots (Kumar and Jose, 2018). Root competitiveness in polyculture systems involving bamboo is a function of the proximity of bamboo to the associated tree/crop (Kumar and Divakara, 2002). Logarithmic spiral trenching and 32P soil injection techniques were used to evaluate the root distribution pattern and competitiveness of bamboo (*Bambusa arundinacea* (Retz.) Wild.) for below-ground resources in mixed-species systems.

In bamboo-based systems, the belowground rooting architecture can be varying depending on the proximity of other species. Agroforestry practices may be beneficial in terms of utilizing resources in sub-soils and can result in improvement of site nutrient conservation/nutrient pumping. Various bamboo-based agroforestry combination should be experimented to develop a sustainable agroforestry model. Not much information is available on appropriate intercropping practices and crop combinations in bamboo-based agro forestry systems. The main objective of the present study was to understand rooting pattern of bamboo plantations in the moist semi-arid regions of Peninsular India at two different spacings so that the information will be helpful for judicious selection of intercrops in bamboo based agroforestry systems.

Materials and Methods

Root architecture study was carried out in 13 year old *D. stocksii* plantation at a spacing of 5 x 5m and 9 x 9m in Hosokotte, Bengaluru, which falls under hot moist semi-arid agro-climatic zone. In order to estimate the root distribution pattern, bamboo clumps were selected and the crown radius of the chosen clumps was measured by projecting the crown edges to the ground. Root systems of each selected clump were partially excavated using a logarithmic spiral trenching technique (Tomlinson *et al*., 1998, Divakara *et al*., 2001 and Kittur *et al*., 2017).

$$x = 0.75\ (d) \quad (1)$$

$$y = [\ln(r/d)]/\pi/2 \quad (2)$$

$$z = xey\theta \quad (3)$$

Where,

d= clump diameter in m;

r= the average of the crown radius at four cardinal points in m;

x= the distance of the starting point of the spiral from the clump in m;

y= natural logarithm of the ratio of crown radius to the diameter of clump divided by π/2;

z= the distance of any point on the spiral from the clump base in m

The inside trajectory of each trench (A) was obtained by computing ‘x’ from a north-facing point on the clump base, the origin (O), with the

Table 1. Details of experiment location

Location	Hosakote, Bangalore (Karnataka)
Geographical location	Lat: 13° 06' 08. 20" N Lon: 77° 50' 44. 04" E
Altitude (m above MSL)	892
Average Rainfall (mm)	808
Maximum temperature (°C)	32
Minimum temperature (°C)	18
Maximum Relative Humidity (%)	75
Minimum Relative Humidity (%)	54

spiral bending clockwise in the opposite direction, thus sampling a 135° sector of the root system. Θ was assigned 0°, 22.5° (π/8), 45° (π/4), 67.5° (3π/8), 90° (π/2), 112.5° (5π/8) and 135° (3π/4) to obtain the seven co-ordinates of the inside trench OA, OB, OC, OD, OE, OF and OG as shown in fig. 1. Exterior side of the trench, was fixed by stretching the co-ordinates for the internal side by 60 cm to give OA′, OB′, OC′, OD′, OE′, OF′ and OG′.

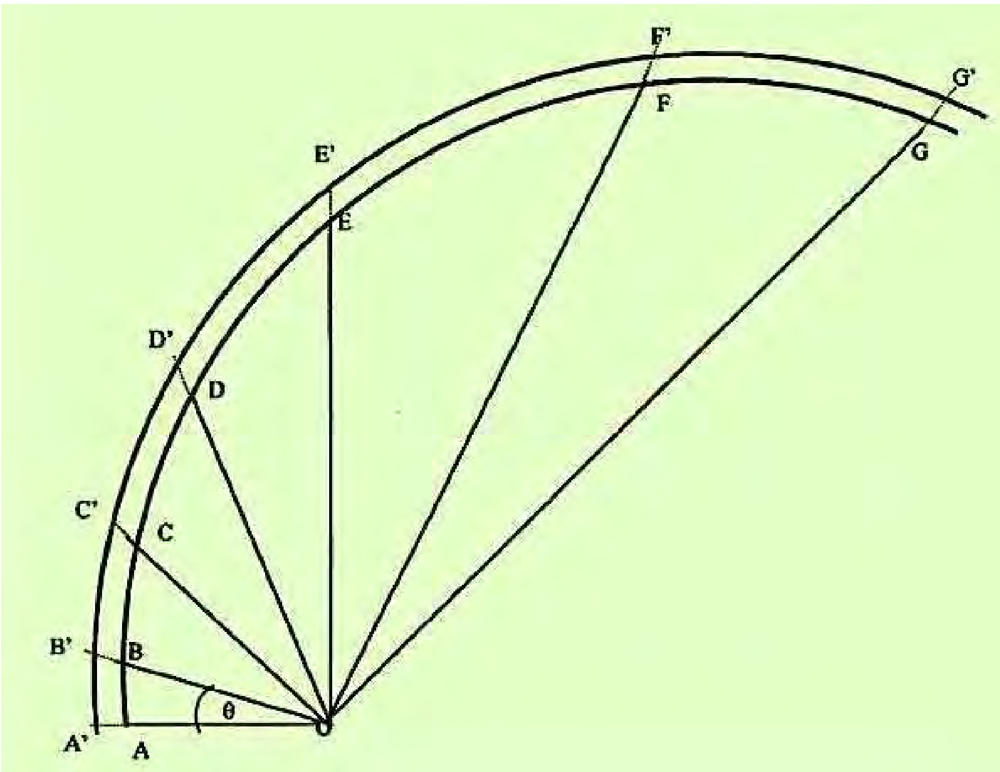

Fig 1. Diagram showing co-ordinates of the logarithmic spiral trench (after Huguet, 1973); where O-origin of the spiral at a north-facing point on the bamboo clumpand OA, OB, OC, OD, OE are co-ordinates of the internal spiral at θ = 0°, 22.5°, 45°, 67.5°, 90°, 112.5° and 135° (modified from Kumar and Divakara, 2002)

Fig 2. Spiral trenching using JCB in *D. stocksii* plantation

Fig 3. Root intensity and thickness observation from *D. stocksii* plantation

Contours of both internal and external spirals were marked on the ground using bamboo poles. Grids of 10 x 10 cm of 30 blocks were prepared for estimation of the number of roots and counted the total no roots in the spiral trenched area. The number of roots were counted by placing the grid at various distances from the clump base like 0.75 m, 1.75m, 2.75m, 3.75m and 4.75m. Roots in two different spacings were counted with the help of the 50 x 60 cm grid.

The total number of roots in each grid of 10 x 10 cm were counted individually. The whole roots in 0 to 10 cm depth was calculated by adding the root number in each 10 ×10 cm grid, so the total number of roots in 0 to 10 cm were from 500 cm^2. The spiral nature of the trench helped to examine a large proportion of the root system with minimal damage to the clumps. The trench was then dug to a depth of 60 cm and to a breadth of 60 cm taking care that the sides remained intact. Roots were

Table 2. Comparison of the number of roots between soil depth and between two spacings of *D. stocksii* plantation

Soil depth (cm)	**Mean ± SE of the number of roots at different spacings (m)**	
	5m x 5m	**9m x 9m**
0-10**	63.7 ± 6.58^{a}	34.5 ± 3.63^{a}
10-20**	54.4 ± 7.52^{b}	28.3 ± 3.21^{a}
20-30**	32.9 ± 6.38^{c}	17.5 ± 3.22^{b}
$30\text{-}40^{ns}$	15.9 ± 4.13^{d}	13.1 ± 3.06^{b}
$40\text{-}50^{ns}$	9.9 ± 3.5^{de}	4.8 ± 1.4^{c}
$50\text{-}60^{ns}$	5.4 ± 2.17^{e}	2.4 ± 0.69^{c}

F value for the interaction between soil depth and spacing = 7.075**
*** significant at 0.01 level (P value<0.01)*
Means having different letter as super script differ significantly within a column

classified into <2 and >2 mm diameter classes at the time of counting. Variation in the number of roots between spacing, between soil depth and between distance was done and the effect of interactions was evaluated using general linear model univariate analysis.

Results and discussion

The average number of total roots in 1.5 m^2 (area of the grid used was 3000 cm^2. It was placed at five points in spiral trench ie. 1.5 m^2) was counted in *D. stocksii* plantation at two different spacings. The average number of total roots at 9m x 9m was 743. Roots >2 mm diameter in *D. stocksii* at 9m x 9m spacing was 5.29 percent. The average number of total roots in 5m x 5m was 1518. Roots with > 2mm diameter in *D. stocksii* at 5m x 5m spacing was 3.491 percent.

F value for three-factor interaction (F value =1.16) was found to be non-significant (p value = 0. 319). F value for the interaction between soil depth and distance from the start of the clump (F value = 2.26), spacing and soil depth (F value = 7.07) and spacing and distance from the start of the clump (F value = 4.174) was found to be significant at 0.01 level (Table 2).

A significant interaction between soil depth and spacing indicates that the variation in the number of roots between soil depth is not the same in different spacings and variation between spacing is not the same for all soil depths. Hence, comparison of least square means between soil depth was done for each spacing and also between spacings for each soil depth separately. Results in table 2 shows that between spacing difference was found to be significant in the case of soil depths 0-10 cm, 10-20 cm and 20-30 cm. Comparison of mean values shows that the number of roots was significantly higher in 5m x 5m spacing compared to 9m x 9m. However, no significant difference was noted between spacing the soil depths 30-40 cm, 40-50 cm and 50-60 cm.

Between soil depth comparison in 5m x 5m spacing shows that there exists a significant difference in the number of roots in all soil depths. It was also noted that the number of roots significantly decreases as soil depth increases. In the case, 9m x 9m spacing, a higher number of roots was observed is 0-10 cm soil depth and it shows no significant difference with 10-20 cm soil depth. No significant difference in the number of roots was noted in the soil depths 20-30 cm and 30-40 cm, but the number of roots in these depths was significantly lower than 0-10 cm and 10-20 cm soil depths. Similarly, no significant difference was noted in the soil depths 40-50 cm and 50-60 cm. However, these two depths have a significantly lower number of roots compared to other soil depths.

As the interaction between distance from clump base and spacing was found to be significant, comparison of least-square means in the number of roots between different distance from clump base was done for each spacing and also between spacing was done for each distance from clump base separately (Table 3). Results showed that between spacing, difference was found to be significant in all cases except 4.75m distance from clump base. Comparison of mean values shows that the number of roots is significantly higher in 5m x 5m spacing compared to 9m x 9m. Between distance from the clump base comparison in 5m x 5m spacing showed no significant difference in the number of roots up to 3.75m. However, the number of roots in 4.75m (10.25) was significantly lower than all the other distances. In 9m x 9m spacing, the highest number of roots was observed in 1.75m distance from the clump base. However, in this spacing, a significant difference in the number of roots was noted only between 1.75m and 4.75m. Trends in the number of roots along different distances in two different spacing are given in fig. 4.

The trend given in fig. 4 also confirms that there is a slight increase in the number of roots from 0.75m to 1.75m, which was found to decrease with the increase in distance. A higher decrease was noted from 3.75 to 4.75m indicating that decreasing the number of roots with distance is a quadratic functionwith a coefficient of determination (R2) 0.947 in the case of 5m x 5m and 0.94 in the case of 9m x 9m.

Results of comparison of the number of roots between soil depths in each distance from clump baseis given in table 4 and fig. 5. A decreasing trend was observed as the depth increases in each distance from clump base. In all depths, the number of roots was lowest at 4.75m distance from clump base.

Table 3. Comparison of the number of roots between distance from the clump base and between two spacings of *D.stocksii* plantation

Distance from clump base (m)	Mean ± SE of the number of roots at different spacings (m)	
	5m x 5m	9m x 9m
0.75**	34.17 ± 5.25[a]	16.58 ± 2.77[ab]
1.75**	40.08 ± 8.56[a]	20.75 ± 4.02[a]
2.75**	34.75 ± 9.12[a]	18.33 ± 4.07[ab]
3.75**	32.58 ± 9.12[a]	16.83 ± 5.47[ab]
4.75[ns]	10.25 ± 5.11[b]	11.33 ± 4.22[b]

F value for the interaction between spacing and distance = 4.174**
*** significant at 0.01 level (p value <0.01)*
Means having different letter as superscript differ significantly within a column

The number of roots is higher in 0-10 cm depth andnotmany differences were noted in the number of roots at 40-50 cm and 50-60 cm depths.

It is necessary to study and compare the available root distribution results to conjointly validate the present study. It may beconcluded that the intensive for aging zone of bamboo is within a 50 cm radius around the clump (Kittur *et al*., 2017). In a study on the spatial distribution of roots and yield of intercrops in a *Dendrocalamus strictus* (Salia bamboo) based agroforestry system at two spacings (12m x 10m and 10m x 10m) it was found that the growth of bamboo clumps and root intensity were significantly higher with all four intercrops over the clumps grown without intercrop (Bhol and Nayak, 2014). Bhol and Nayak (2014) also reported that the root intensity was found to decrease with

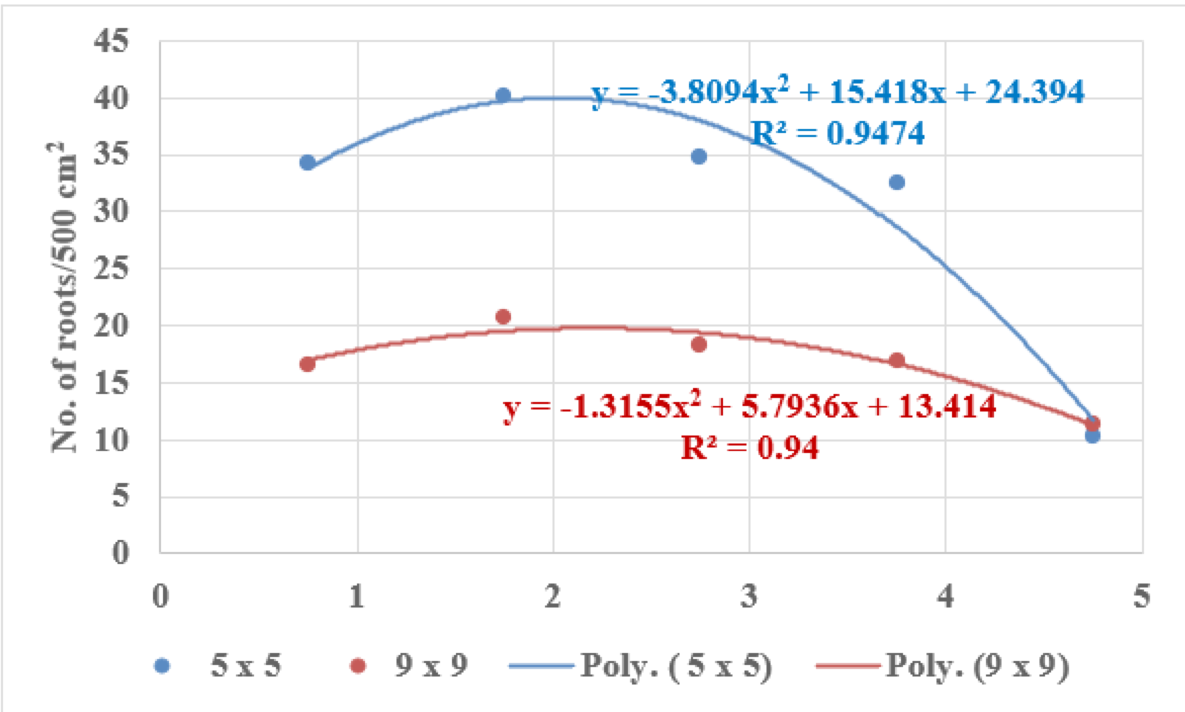

Fig 4. Number of roots /500 cm^2in 5m x 5m and 9m x 9m spacing of *D. stocksii* plantations

Table 4. Comparison of the number of *D. stocksii* roots between distance from clump base and soil depth class

Soil Depth (cm)	Mean ± SE of the number of roots at a different distance from the clump base				
	0.75 m	1.75 m	2.75 m	3.75 m	4.75 m
0-10	39.50 ± 8.01[a]	51.00 ± 14.97[a]	51.00 ± 14.24[a]	64.75 ± 7.94[a]	39.25 ± 8.79[a]
10-20	39.00 ± 11.16[ab]	55.75 ± 10.83[a]	48.5 ± 13.62[a]	45.50 ± 8.99[b]	18.00 ± 1.15[b]
20-30	25.25 ± 5.88[bc]	37.5 ± 5.91[ab]	31.5 ± 10.69[b]	25.75 ± 10.42[c]	6.00 ± 1.73[bc]
30-40	22.75 ± 3.33[cd]	24.75 ± 5.5[4b]	17.25 ± 3.57[c]	6.25 ± 2.59[d]	1.50 ± 0.87[c]
40-50	17.00 ± 6.62[cd]	7.25 ± 1.6[c]	9.50 ± 3.66[cd]	3.00 ± 0.82[d]	0 ± 0[c]
50-60	8.75 ± 4.19[d]	6.25 ± 2.29[c]	1.50 ± 1.19[cd]	3.00 ± 1.22[d]	0 ± 0[c]

F value for the interaction between soil depth and distance = 2.268**
*** significant at o.o1 level (P-value<0.01)*
Means having different letter as superscript differ significantly within a column

the increase of distance from the clump and the highest root intensity was found at 0-15 cm depth (317/m^2) and lowest in 30-45 cm depth (29/m^2) With increasing soil depth and lateral distance, root activity decreased significantly wider distribution of root activity with an increase in clump spacing.

The results of trends in rooting density and area of foraging zone differ among different studies. Excavation studies indicate that rooting intensity declined linearly with increasing lateral distance. Larger clumps manifested wider foraging zones. Eighty-three percent of the large clumps (> 4.0m dia.) extended roots beyond 8m while only 33 per cent of the small (< 2.5m dia.) clumps extended roots up to 8m. Highest root counts were found in the 10-20 cm layer with nearly 30 percent of total roots. Studies have shown that interspecific root competition can be regulated by planting crops 8-9m away from the bamboo clumps and/or by canopy reduction treatments (Divakara *et al*., 2001). Excavation studies indicated that rooting intensity in different soil horizons declined either exponentially or quadratically with increasing lateral distance from the bamboo clump (Kumar and Divakara, 2002).

Farmers may prefer tree species with deeper and less spreading roots that do not compete strongly with crops for water and nutrients in agroforestry systems (Das and Chaturvedi, 2008). Fine root biomass showed a declining trend with the increase in soil depth in all the species (Kaushal *et al.*, 2020). The contribution of fine roots was higher in genus *Dendrocalamus* (*D. strictus, D. hamiltonii* and *D. asper*) as compared to other species in genus *Bambusa*. Depth wise distribution of coarse root intensity revealed that roots were more or less uniformly distributed in 0–30 cm soil depth while fine root intensity was higher in 0–10 cm where 47 percent roots were observed. From the study, it could be concluded that *D. hamiltonii*, due to higher fine root biomass, is suitably recommended for resisting soil erosion, enhancing groundwater recharge and maintaining soil fertility (Kaushal *et al*., 2020c).

Bamboos, in general, have high superficial water use and increased water retention in soil depth (Andriyana *et al*., 2020). The proximity of other species can result in a downward displacement of roots (Kumar and Jose, 2018). Root competition intensity between individual plants generally decreases as resource availability increases (Schenk, 2006). It has a significant impact on improving soil fertility through the profuse root system and onsite nutrient conservation. It recovers much of the nutrients leached deeper into the soil profile during the two years of cropping and deposits them at or near the soil surface as above-ground litter and dead fine roots (Christanty *et al*., 1996). Soil carbon stock (25-35 MgCha^{-1}) and sequestration rate (0.28-0.59

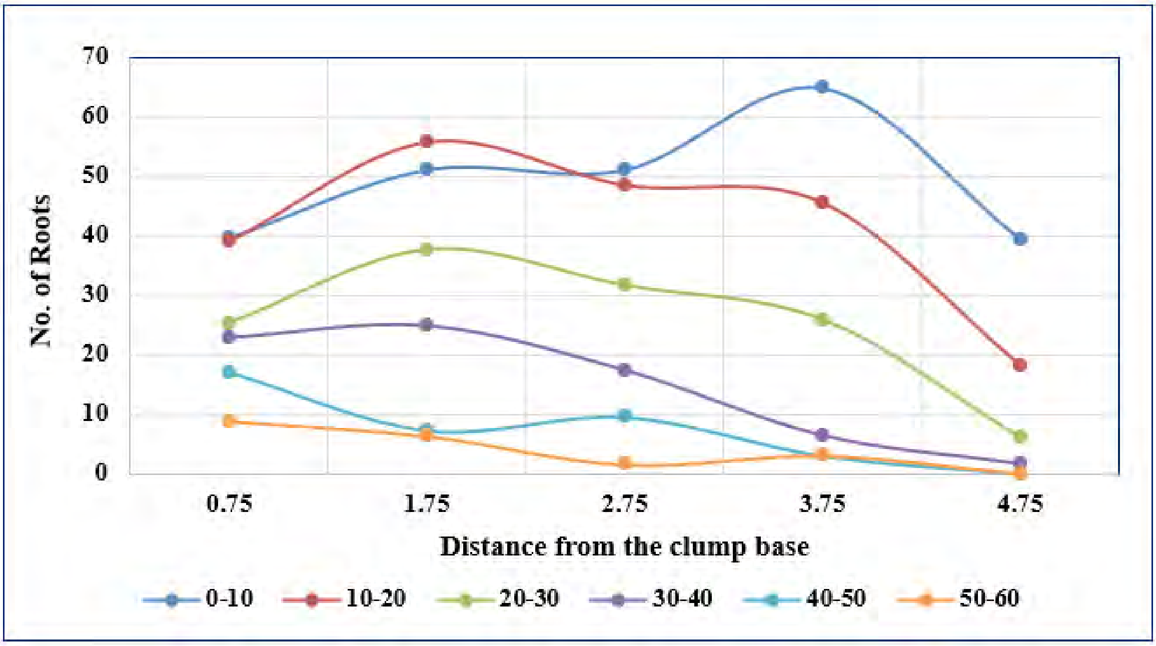

Fig 5. Trends in number of roots according to distance from clump base (m) in different depths (cm)

$MgCha^{-1}year^{-1}$) up to 30 cm soil depth of bamboo agroforestry also suggest its potential role in soil carbon sink management (A. Jyoti *et al*., 2015).

In forest ecosystems, litter fall and fine roots are the main sources of underground forest carbon and nitrogen (Yang *et al*., 2010). The quantum of fine root biomass is a good indicator of soil health. The root turnover play role in regulating C and N cycles (Aerts *et al*., 1992). Soil binding capacity will be enhanced by organic exudates from dead roots due to its rapid turnover. Soil stability to resist water dispersion is improved by fine roots by improving the number and diameter of soil water-stable aggregates. As a result, there will less runoff (Xiong *et al*., 2007).

Soil organic carbon stocks in *D. stocksii* in different agro-climatic conditions also suggest that this species is suitable for land development in degraded areas of moist semi arid.climate In the same location the SOC stock in 0-30 cm layer was found to be higher than the 30-100 cm layer. The total SOC content (0-100 cm) of thirteen year old *D. stocksii* plantation semi-arid region was 6.48 kgm^{-3} that comes in medium land quality class (Lubina *et al*., 2018). The soil quality was also found to better compared to adjacent Eucalyptus plantations (data not given). The current study also includes certain observations on clump diameter and crown width, which were found directly proportional to spacing and inversely proportionalclump height. These results were similar to the observations by Kumar and Divakara (2002).

Conclusion

A sustainable agroforestry system should have a combination of trees and plants of divergent root growth habitats. Identifying the spatial distribution of competitive zone is essential for the meticulous planning of bamboo-based agroforestry systems. Accordingly, *D. stocksii* is well suited in agroforestry systems owing to its favourable morphological characteristics like feathery compact canopy, self-pruning nature in the base and profuse root system which helps in soil fertility improvement. Majority of roots (>95 %) of this species belong to less than 2mm diameter class thereby providing a fine mesh for soil binding. The number of *D. stocksii* roots was found to be significantly higher in 5m x 5m spacing compared to 9m x 9m for 0-30 cm depth. The study proves that spacing between bamboo clumps plays a significant role in the development of correct root architecture pattern for main crop as well as intercrops, which will encourage optimum production from intercrops.

Acknowledgements

I gratefully acknowledge the funding agency, the University Grant Commission (UGC) of the Government of India, for providing financial support, to complete my work, in the form of UGC NET-JRF/SRF. The funding and staff support (M.C Sandya, JRF and Aparna Rajan, JRF) through ICFRE project is also acknowledged. I also thank for the time and effort taken by Dr. Sunanda C, Statistical Consultant and Former Assistant Professor (Statistics), COVAS, Pookode on giving suggestions, which helped in the improvement of statistical data analyses and interpretation. A part of this work was presented as a poster in National Conference on "Challenges and innovative approaches in agriculture and allied sciences research" held on 26-27th July 2019 in Salem, Tamil Nadu.

References

Aerts, R., Bakker, C., & De Caluwe, H. 1992. Root turnover as determinant of the cycling of C, N, and P in a dry heath land ecosystem. *Biogeochemistry*, 15(3), 175–190. https://doi.org/10.1007/BF00002935.

Andriyana, Y., Thaler, P., Chiarawipa, R., and Sopharat, J. 2020. On-farm effect of bamboo intercropping on soil water content and root distribution in rubber tree plantation. *Forests Trees and Livelihoods*, 29(4), 205–221. https://doi.org/10.1080/14728028.2020.1798818.

Arun Jyoti, N., Lal, R., and Das, A. K. 2015. Ethnopedology and soil quality of bamboo (Bambusa sp.) based agroforestry system. *Science of the Total Environment*, pp.521–522, 372–379. https://doi.org/10.1016/j.scitotenv.2015.03.059.

Ben-zhi, Z., Mao-yi, F., Jin-zhong, X., Xiao-sheng, Y., and Zheng-cai, L. 2005. Ecological functions of the bamboo forest: Research and Application. *Journal of Forestry Research*, 16(2), pp.143–147. https://doi.org/10.1007/bf02857909.

Bhol, N., and Nayak, H. 2014. Spatial distribution of root and crop yield in a bamboo-based agroforestry system. *Indian Forester*, 140(6), pp.585–591. http://indianforester.co.in.

Cao, K. F., Yang, S. J., Zhang, Y. J., and Brodribb, T. J. 2012. The maximum height of grasses is determined by roots. Ecology *Letters*. https://doi.org/10.1111/j.1461-0248.2012.01783.x.

Christanty, L., Mailly, D., and Kimmins, J. P. 1996. "Without bamboo, the land dies": Biomass, litterfall, and soil organic matter dynamics of a Javanese bamboo talun-kebun system. *Forest Ecology and Management*, 87(1–3), pp.75–88. https://doi.org/10.1016/S0378-1127(96)03834-0.

Das, D. K., and Chaturvedi, O. P. 2008. Root biomass and distribution of five agroforestry tree species. *Agroforestry Systems*, 74(3), pp. 223–230. https://doi.org/10.1007/s10457-008-9159-9.

Dhyani, S. K., and Tripathi, R. S. 2000. Biomass and production of fine and coarse roots of trees under agrisilvicultural practices in north-east India. *Agroforestry Systems*, 50(2), pp.107–121. https://doi.org/10.1023/A:1006439018621.

Divakara, B. N., Mohan Kumar, B., Balachandran, P. V., and Kamalam, N. V. 2001. Bamboo hedgerow systems in Kerala, India: Root distribution and competition with trees for phosphorus. *Agroforestry Systems*, 51(3), pp.189–200. https://doi.org/10.1023/A:1010730314507.

George, S. J., Kumar, B. M., Wahid, P. A., and Kamalam, N. V. 1996. Root competition for phosphorus between the tree and herbaceous components of silvopastoral systems in Kerala, India. *Plant and Soil*, 179(2), pp.189–196. https://doi.org/10.1007/BF00009328.

Kaushal, R., Jayaparkash, J., Mandal, D., Kumar, A., Alam, N. M., Tomar, J. M. S., Mehta, H., and Chaturvedi, O. P. 2019. Canopy management practices in mulberry: impact on fine and coarse roots. *Agroforestry Systems*, 93(2), pp.545–556. https://doi.org/10.1007/s10457-017-0148-8.

Kaushal, R., Singh, I., Thapliyal, S. D., Gupta, A. K., Mandal, D., Tomar, J. M. S., Kumar, A., Alam, N. M., Kadam, D., Singh, D. V., Mehta, H., Dogra, P., Ojasvi, P. R., Reza, S., and Durai, J. 2020. Rooting behaviour and soil properties in different bamboo species of Western Himalayan Foothills, India. *Scientific Reports*, 10 (1). https://doi.org/10.1038/s41598-020-61418-z.

Kaushal, R., Tewari, S., Banik, R. L., Thapliyal, S. D., Singh, I., Reza, S., and Durai, J. 2020a. Root distribution and soil properties under 12-year old sympodial bamboo plantation in Central Himalayan Tarai Region, India. *Agroforestry Systems*, 94(3), pp.917–932. https://doi.org/10.1007/s10457-019-00459-4.

Kaushal, R., Tewari, S., Banik, R. L., Thapliyal, S. D., Singh, I., Reza, S., and Durai, J. 2020b. Root distribution and soil properties under 12-year old sympodial bamboo plantation in Central Himalayan Tarai Region, India. *Agroforestry Systems*, 94(3), pp 917–932. https://doi.org/10.1007/s10457-019-00459-4.

Kaushal, R., Tewari, S., Banik, R. L., Thapliyal, S. D., Singh, I., Reza, S., and Durai, J. 2020c. Root distribution and soil properties under 12-year old sympodial bamboo plantation in Central Himalayan Tarai Region, India. *Agroforestry Systems*, 94(3), pp. 917–932. https://doi.org/10.1007/s10457-019-00459-4.

Kittur, B. H., Sudhakara, K., Kumar, B. M., Kunhamu, T. K., and Sureshkumar, P. 2017. Effects of clump spacing on nutrient distribution and root activity of *Dendrocalamus strictus* in the humid region of Kerala, peninsular India. *Journal of Forestry Research*, 28(6), pp.1135–1146. https://doi.org/10.1007/s11676-017-0391-x.

Kumar, B. M., and Divakara, B. N. 2002. Proximity, clump size and root distribution pattern in bamboo: A case study of *Bambusa arundinacea* (Retz.) Wild., Poaceae, in the Ultisols of Kerala, India. *Journal of Bamboo and Rattan*, 1(1), pp.43–58. https://doi.org/10.1163/156915901753313605.

Kumar, B. M., and Jose, S. 2018. Phenotypic plasticity of roots in mixed tree species agroforestry systems: review with examples from peninsular India. In *Agroforestry Systems* 92(1), pp. 59–69. Springer Netherlands. https://doi.org/10.1007/s10457-016-0012-2.

Kumar, M., Remesh, M., and Unnikrishnan, N. 2004. A new combination in *Dendrocalamus* (Poaceae: Bambusoideae). SIDA, *Contributions to Botany*, 21(1), pp. 93–96. https://www.jstor.org/stable/41968980.

Lubina, P.A., Aparna, R., Pavithra, G.M., Ravi, N., Anilkumar, K.S. and Viswanath, S., 2019. Assessment of soil organic carbon stocks in *Dendrocalamus stocksii* and *Dendrocalamus strictus* plantations in three different agroclimatic zones. *Journal of Bamboo and Rattan*, 18(3), pp.55-62.

Rane, A. D., Chandramouli, S., and Viswanath, S. 2016. Can *Dendrocalamus stocksii* (Munro.) be the ideal multipurpose bamboo species for domestication in Peninsular India? *Journal of Bamboo and Rattan,* 15(1–4), pp. 23–32.

Tomlinson, H., Traore, A., and Teklehaimanot, Z. 1998. An investigation of the root distribution of Parkia biglobosa in Burkina Faso, West Africa, using a logarithmic spiral trench. *Forest Ecology and Management*, 107(1–3), pp.173–182. https://doi.org/10.1016/S0378-1127(97)00340-X.

Viswanath S, Joshi G, Somashekar PV, Rane AD, Sowmya C and Joshi SC 2013. *Dendrocalamus stocksii* (Munro.): A potential multipurpose bamboo species for Peninsular India. Institute of Wood Science and Technology Technical Bulletin No.11. IWST publication, Bangalore.

Verma, K. S., Kohli, S., Kaushal, R., and Chaturvedi, O. P. 2014. Root structure, distribution and biomass in five multipurpose tree species of western Himalayas. *Journal of Mountain Science*, 11(2), pp.519–525. https://doi.org/10.1007/s11629-013-2479-x.

White, D. G., and Childers, N. F. (1945). Bamboo for Controlling Soil Erosion 1. *Agronomy Journal,* 37(10), 839–847. https://doi.org/10.2134/agronj1945.00021962003700100007x.

Xiong, Y. M., Xia, H. P., Li, Z. A., & Cai, X. A. (2007). Effects and mechanisms of plant roots on slope reinforcement and soil erosion resistance: A research review. In *Chinese Journal of Applied Ecology* 18 (4) ,pp. 895–904.

Yang, L., Wu, S., and Zhang, L. 2010. Fine root biomass dynamics and carbon storage along a successional gradient in Changbai Mountains, China. *Forestry,* 83(4), pp.379–387. https://doi.org/10.1093/forestry/cpq020.