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Soil physicochemical and enzymatic properties in bamboo plantation entisol soil of sub-montane zone of Maharashtra

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Abstract
Bamboo, recognized for its ecological significance and diverse applications, plays a crucial role in influencing ecosystems globally. Bamboo can act as a backbone of ecosystem as it provides the microhabitats for myriad of species (Janzen, 1976). As we delve deeper into ecosystem of bamboo it goes beyond its terrestrial importance and could help in dealing with climate change, preserving biodiversity, and producing renewable energy. Bamboo is proven to be excellent source of renewable energy. It can be used for the production of ethanol which is used in flex-fuel engines as a biofuel. The study, conducted at the Zonal Agricultural Research Station in Kolhapur, Sub-montane Zone of Maharashtra during 2022-23, aimed to assess the comparative impact of six bamboo species on soil physical, chemical, and biological properties after 12 years of plantation in entisols with the slope ranging from 5 to 6.5%. Physical properties like bulk density and maximum water holding capacity remained unaffected in both soil depths. Soil pH, EC, and $CaCO_3$ showed no significant changes. However, nutrient content varied, with *Dendrocalamus strictus* exhibiting the highest N (345 and 234 kg ha^{-1}), P (15.7 and 11.4 kg ha^{-1}), and K (150 and 140 kg ha^{-1}) in surface and subsurface soil layers, respectively. Soil organic carbon remained consistent, with a slight increase in *Dendrocalamus strictus*. Available nutrient content and organic carbon decreased with soil depth. Enzyme assays indicated significant variations, with *Dendrocalamus strictus* showing the highest dehydrogenase activity (2.71 and 2.17 µg TPF g^{-1} soil hr^{-1}) and phosphatase activity (acid phosphate: 88.16 and 65.80 µg PNP g^{-1} soil hr^{-1}; alkaline phosphate: 63.18 and 48.97 µg PNP g^{-1} soil hr^{-1}) in surface and subsurface layers, respectively. It was showed that the *Dendrocalamus strictus* emerged as a significant contributor to enhanced nutrient levels and enzyme activities in Sub-montane zone of Maharashtra.

Keywords: *Dendrocalamus strictus,* exhibiting, highest

Introduction
Bamboo, a resilient and fast-growing plant with diverse applications, has long been acknowledged for its ecological significance and socio-economic contributions. As we delve deeper into the ecosystem of bamboo, it becomes evident that bamboo plays a crucial role in various ecosystems across the globe. It thrives in diverse climates, ranging from tropical to temperate regions, spanning Asia, America, and Africa (Ahmad *et al*., 2021) [4, 2] . There are a total of 1500 identified bamboo species worldwide, with India alone being home to approximately 148 bamboo species. This rich diversity extends across wild and cultivated varieties, encompassing 29 genera. The Northeastern hilly states of India stand out for their unique bamboo landscape, hosting nearly 90 species, 41 of which are exclusive to this region.

Bamboo is well-known for its traditional uses, such as construction material and furniture. In addition to these uses, bamboo also significantly impacts the physical, chemical, and biological aspects of soil. Scientists have conducted extensive research to unravel the intricate interactions between various bamboo species and the soil environment. This exploration aims to shed light on the effects of bamboo cultivation on soil health and sustainability.

Bamboo's intricate root system plays a pivotal role in shaping the physical properties of the soil. It has been observed that bamboo roots contribute to improving soil structure by enhancing soil aggregation and reducing erosion (Kaushal *et al*, 2020) [3].

The extensive rhizome network of bamboo helps in stabilizing soil, preventing landslides, and promoting water retention. Additionally, bamboo has a significant impact on soil chemistry, showing exquisite effects on nutrient cycling and soil fertility. The decomposition of bamboo litter releases organic matter and nutrients, fostering nutrient-rich soil conditions. Furthermore, bamboo has the ability to uptake heavy metals, contributing to soil remediation efforts in contaminated areas (Emamverdian *et al*, 2018) [2, 4].The biological dimension of soil is also significantly affected by the presence of bamboo. The rhizosphere of the bamboo plant acts as a hotspot for microbial activity, enhancing microbial diversity and positively influencing soil microbial communities. Additionally, bamboo exhibits allelopathic effects, influencing the composition of soil microbial populations and affecting plant growth

The increasing global interest in sustainable agriculture and land management practices has prompted a closer examination of bamboo's influence on soil physical, chemical, and biological properties. This exploration provides crucial insights into the potential contributions of bamboo to ecosystem resilience and resource sustainability. As the demand for alternative materials and environmentally friendly solutions continues to rise, investigating the diverse effects of bamboo on soil aligns with the broader objective of promoting eco-friendly practices and unlocking the full potential of this versatile plant.

In the specific context of Maharashtra, the region's topography characterized by flat surfaces and gentle slopes creates an ideal environment for bamboo cultivation. The preference for these mild slopes not only ensures land stability but also minimizes the risks of soil erosion, positioning bamboo as an environmentally sustainable choice for land-use practices in the area. The unique soil composition of the sub-montane zone of Maharashtra further enhances the suitability of this region for research. This distinctiveness makes it an ideal location for analyzing the impact of various bamboo species on soil properties, particularly in Entisols. By focusing on the physical, chemical, and biological aspects of the soil, this research aims to provide valuable insights into the potential benefits and challenges associated with different bamboo species in the sub-montane zone of Maharashtra.

Material methods

Experimental site and location

The field experiment on the carbon sequestration potential of various Bamboo Species in Entisols of Sub-montane Zone of Maharashtra was conducted at the Zonal Agricultural Research Station, Shenda Park, Kolhapur which is located at the south-west of Maharashtra having an elevation of 561 m above mean sea level.

Experimental details

In order to evaluate the soil physical, chemical and biological properties as influenced by different bamboo species A field experiment on bamboo plantation was initiated in September 2010 having six different species *viz. Bambusa tulda, Bambusa balcooa, Bambusa bambos, Dendrocalamus asper, Dendrocalamus strictus,* and *Melocanna baccifera*. The Randomized Block Design (RBD) was utilized to laid out the experiment with each treatment replicated four times. The field selected having the slope ranging 5.0 to 6.5%. The planting distance was standardized at 5.0 × 5.0 m.

Soil sampling

Soil samples were collected from the root zone of six distinct bamboo species, each replicated four times, at two depths 0-15 cm and 15-30 cm from a total of 24 plots. The collected soil samples underwent air-drying, grinding with a wooden mortar and pestle to pass through a 2 mm sieve for laboratory analysis, and a 0.5 mm sieve for Soil Organic Carbon (SOC) analysis. These samples were stored in a cloth bag. Analysis of the soil samples under the selected bamboo species included assessments of chemical, physical, and biological properties. The samples were then analyzed within two weeks from sampling for the determination of dehydrogenase and acid and alkaline phosphatase enzyme activity.

Table 1: Standard methods used for analysis of soil properties

Sr. No.	Parameters	Methods Used	References
I)	**Physical properties**		
1.	MWHC	Keen's Box method	Keen and Raczkowski (1921) [6]
2.	Bulk density	Core method	Page *et al*. (1982) [7]
II)	**Chemical Properties**		
1.	Organic carbon	Wet oxidation	Nelson and Sommer (1982) [8]
2.	pH (1: 2.5)	Potentiometric	Jackson (1973) [9]
3.	EC (1: 2.5)	Conductmetric	Jackson (1973) [9]
4.	$CaCO_3$	Acid neutralization	Allison and Moodier (1965) [10]
5.	Available N	Alkaline permanganate	Subbaih and Asija (1956) [11]
6.	Available P	0.5 M $NaHCO_3$ (pH 8.5)	Olsen *et al*. (1954) [12]
7.	Available K	1N NH_4OAc	Knudsen *et al*. (1982) [12]
III)	**Biochemical properties (Soil enzyme assays)**		
1.	Dehydrogenase	Triphenyltetrazolium chloride (TTC)	Lenhard (1956) [14]
2.	Acid phosphatase	Spectrophotometry	Tabatabai and Bremmer (1969) [15]
3.	Alkaline phosphatase	Spectrophotometry	Tabatabai and Bremmer (1969) [15]

The recorded observations on soil chemical properties, such as pH, EC, $CaCO_3$, SOC, TOC, and available N, P, K. In soil physical properties for bulk density core sampler was used to collect the sample at two different depths and maximum water holding capacity were calculated by using the soil which is passed through 2 mm sieve. The standard methods were used to analyze the chemical physical and biological properties of which is displayed in the table 1.

Statistical Analysis

The data obtained from our experiment underwent thorough statistical analysis using the "Analysis of variance" (ANOVA) technique. This method, as outlined by Panse and Sukhatme (1985) [5], involved the construction of an ANOVA table. This statistical approach was crucial for examining the variations in the experimental data and drawing meaningful conclusions from the results. To ensure originality and avoid plagiarism, we adhered to the guidelines provided by Panse and Sukhatme (1985) [5] in the application of the ANOVA technique.

Results and Discussions

Soil Physical Properties as Influenced by Different Bamboo Species

Soil bulk density

The study investigated soil bulk density across six bamboo species (*B. tulda*, *B. balcooa*, *B. bambos*, *D. asper*, *D. strictus*, *and M. baccifera*) at two depths (0-15 cm and 15-30 cm) and represented in table 2 and fig. 1 *D. strictus* exhibited the lowest bulk density at 0-15 cm (1.31 Mg m-3), suggesting improved soil aggregation due to its fibrous root system. A similar trend was observed at 15-30 cm, with *D. strictus* again having the lowest bulk density (1.37 Mg m^{-3}). This decrease in bulk density in *D. strictus* may be attributed to increased fine root production, litter turnover, and enhanced microbial activity, aligning with previous studies of Kaushal *et al*., 2020; Mandal and Jayprakash, 2009 and Sirsat *et al*., 2021[3, 16, 17].

Maximum water holding capacity

The study examined maximum water holding capacity (MWHC) in soil under various bamboo species at depths of 0-15 cm and 15-30 cm which represented in table 2 and fig. 2 *Dendrocalamus strictus* showed the highest MWHC at both depths (38.59% at 0-15 cm and 28.47% at 15-30 cm), indicating a robust root system and biomass accumulation. *Bambusa bambos* also exhibited high MWHC. Conversely, *Dendrocalamus asper* had the lowest MWHC at both depths (37.63% at 0-15 cm and 27.32% at 15-30 cm).

Table 2: Soil physical properties as influenced by different bamboo species

Tr. No.	Treatment/ Bamboo species	Soil bulk density (Mg m^{-3})		MWHC (%)	
		0- 15 cm		15-30 cm	
T_1	*B. tulda*	1.34	1.39	37.74	27.42
T_2	*B. balcooa*	1.33	1.39	37.67	27.50
T_3	*B. bambos*	1.32	1.38	37.93	27.51
T_4	*D. asper*	1.34	1.40	37.63	27.32
T_5	*D. strictus*	1.31	1.37	38.59	28.47
T_6	*M. baccifera*	1.33	1.39	37.80	27.44
	General mean	1.33	1.39	37.89	27.61
	SEm $\pm$	0.01	0.01	0.29	0.26
	CD at 5%	NS	NS	NS	NS

The increase in MWHC within each species suggested improvements in the root system and biomass. This phenomenon may be attributed to root-soil interactions, influencing soil aggregate particle size and litter decomposition. Similar findings regarding MWHC variations among bamboo species were reported by Nath *et al*. (2015) [18].

Soil pH, EC and $CaCO_3$ content

Soil samples from different bamboo species, including *Bambusa tulda*, *Bambusa balcooa*, *Bambusa bambos*, *Dendrocalamus asper*, *Dendrocalamus strictus*, *and Melocanna baccifera*, were analyzed for soil pH, electrical conductivity (EC), and calcium carbonate ($CaCO_3$) content at depths of 0-15 cm and 15-30 cm which is represented in table 3 and fig. 3 for pH, fig. 4 for EC and fig. 5 for $CaCO_3$. After 12 years of plantation, no significant differences were observed in soil pH and electrical conductivity among the bamboo species. In the topsoil (0-15 cm), pH ranged from 6.9 to 7.0, with numerical variations but no statistical significance. Electrical conductivity values were consistent across bamboo species. $CaCO_3$ content remained stable, averaging 2.55% at 0-15 cm. At 15-30 cm depth, soil pH, EC, and $CaCO_3$ content also showed no significant variations among bamboo species. However, a slight numerical increase in soil $CaCO_3$ percentage was observed at the lower depth, averaging 2.71%. These variations in soil properties can be influenced by factors such as land use changes and long-term organic matter deposition.

Table 3: Soil pH, electrical conductivity and calcium carbonate content as influenced by different bamboo species

Tr. No	Treatment/ Bamboo species	pH(1:2.5)		EC		$CaCO_3$ content	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15 - 30 cm
				(dSm^{-1})		(%)	
T_1	B. tulda	7.0	7.1	0.14	0.15	2.54	2.59
T_2	B. balcooa	6.9	7.1	0.14	0.15	2.58	2.63
T_3	B. bambos	7.0	7.1	0.14	0.14	2.53	2.78
T_4	D. asper	7.0	7.1	0.14	0.15	2.53	2.71
T_5	D. strictus	6.9	7.1	0.14	0.15	2.58	2.75
T_6	*M. baccifera*	6.9	7.1	0.14	0.15	2.56	2.78
	General mean	7.0	7.1	0.14	0.15	2.55	2.71
	SEm $\pm$	0.07	0.08	0.003	0.002	0.26	0.24
	CD at 5%	NS	NS	NS	NS	NS	NS

The results align with previous findings by Gowthamchand *et al*. (2020) [19], indicating that soil properties are more influenced by land use systems than depth. Additionally, Dick and Wang (2000) [20] reported that soil chemical properties like pH, EC, and calcium carbonate content can be affected by organic amendments.

Soil available nutrients

The study assessed nutrient availability (nitrogen, phosphorus, and potassium) at two soil depths, presenting the data in Table 4 and graphically in Fig 6 Overall, there was a decrease in nutrient availability with increasing soil depth. *Dendrocalamus strictus* showed significantly higher nitrogen (345 kg ha^{-1}), phosphorus (15.7 kg ha^{-1}), and potassium (150 kg ha^{-1}) compared to other bamboo species, with *Bambusa tulda* having similar values (330, 15.3, and 147 kg ha^{-1}, respectively).

Table 4: Available nutrient status at 0-15 cm depth as influenced by different bamboo species

Tr. No	Treatment/ Bamboo species	Soil available nutrients content					
		N	P	K	N	P	K
		0-15 cm (kg ha^{-1})			15-30 cm (kg ha^{-1})		
T_1	*B. tulda*	330	15.3	147	220	11.0	138
T_2	*B. balcooa*	323	14.9	146	216	11.0	139
T_3	*B. bambos*	320	14.6	138	213	9.8	128
T_4	*D. asper*	314	14.7	135	213	9.6	128
T_5	*D. strictus*	345	15.7	150	234	11.4	140
T_6	*M. baccifera*	314	14.1	138	213	8.5	127
	General mean	324	14.9	142	218	10.2	133
	SEm $\pm$	6.1	0.52	2.90	6.38	0.38	3.49
	CD at 5%	18.5	1.57	8.74	19.22	1.13	10.5

Bambusa balcooa also had statistically similar potassium levels (146 kg ha^{-1}) to *D. strictus. Melocanna baccifera* exhibited the lowest nutrient status. At a lower depth, nutrient

availability decreased for all three nutrients. *D. strictus* had significantly higher values for nitrogen, phosphorus, and potassium, surpassing other species but statistically similar to *B. tulda* and *B. balcooa*.
The variation in nutrient content is attributed to organic matter differences between topsoil and subsoil. Higher nutrient content in topsoil aligns with findings by Tariyal *et al*. (2013) [21]. Bharat Kumar *et al*. (2016) [22] reported lower nutrient content in the lower soil depth influenced by different plantations. D. strictus consistently showed higher nitrogen content, possibly due to better root density. Increased phosphorus may be linked to enhanced root activity. Differences in potassium content may result from litter fall deposition. These results align with Tariyal *et al*. (2013) and Gaikwad *et al*. (2021) [21, 23, 25].

Soil organic carbon

Soil organic carbon (SOC) at 0-15 cm and 15-30 cm depths for various bamboo species are presented in Table 5 and graphically in Fig 7 at 0-15 cm, SOC values did not differ significantly among bamboo species, but there was a numerical increase in some. *Dendrocalamus strictus* had the highest SOC at 8.0 g kg^{-1}, while *Melocanna baccifera* had the lowest at 7.2 g kg^{-1}. At 15-30 cm, SOC values were numerically lower than the upper layer, indicating a general decline across all species. Although not statistically significant, *D. strictus* had the highest SOC at 6.0 g kg^{-1}, while *M. baccifera* had the lowest at 5.2 g kg^{-1}. The variation in SOC among bamboo species is attributed to differences in organic matter addition, litter fall, root density, and decomposition rates (Kaushal *et al*., 2020) [3].
Higher SOC values in *D. strictus* align with previous studies of Tariyal *et al*., 2013; Kaushal *et al*., 2020 and Gaikwad *et al*., 2022 [3, 21, 23, 25]. SOC content generally declined with soil depth, consistent with findings by Tariyal *et al*. (2013), Dick and Wang (2020), Bharat Kumar *et al*. (2016), and Kumari and Bhardwaj (2017) [20, 22, 24].

Table 5: Available nutrient status at 0-15 cm depth as influenced by different bamboo species

Tr. No.	Treatment/Bamboo species	Soil organic carbon	
		0-15 cm	15-30 cm
		(g kg^{-1})	
T1	*B. tulda*	7.7	5.6
T2	*B. balcooa*	7.4	5.3
T3	*B. bambos*	7.7	5.6
T4	*D. asper*	7.7	5.3
T5	*D. strictus*	8.0	6.0
T6	*M. baccifera*	7.2	5.2
	General mean	7.6	5.5
	SEm ±	0.3	0.2
	CD at 5%	NS	NS

Dehydrogenase activity

Differences in the accumulation rate of organic matter in soil across various bamboo species are linked to variations in dehydrogenase activity (DHA), as presented in Table 6 and graphically in Fig 8 DHA values significantly varied among bamboo species, with *Dendrocalamus strictus* exhibiting superior DHA (2.71 µg TPF g-1 soil hr-1), statistically comparable to *Bambusa* tulda (2.67 µg TPF g-1 soil hr-1), while Melocanna baccifera had the lowest DHA (1.79 µg TPF g-1 soil hr-1). These differences persisted at 15-30 cm depth, with D. strictus having the highest DHA (2.17 µg TPF g-1 soil hr-1)

Table 6: Dehydrogenase activity, Acid phosphatase and alkaline phosphatase activity as influenced by different bamboo species.

Tr. No.	Treatment/ Bamboo species	DHA		Acid phosphatase		Alkaline phosphatase	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
		µg TPF g^{-1} soil hr^{-1}		………….µg PNP g^{-1} soil hr^{-1}……………			
T1	*B. tulda*	2.67	1.89	84.46	62.20	54.31	44.64
T2	*B. balcooa*	2.13	1.88	70.20	60.60	56.28	47.19
T3	*B. bambos*	2.08	1.85	68.39	52.20	50.73	44.46
T4	*D. asper*	1.97	1.70	67.15	52.80	47.60	41.89
T5	*D. strictus*	2.71	2.17	88.16	65.80	63.18	48.97
T6	*M. baccifera*	1.79	1.14	66.17	41.61	42.25	30.45
	General mean	2.23	1.77	74.09	55.87	52.39	42.93
	SEm ±	0.10	0.12	3.53	2.92	3.45	2.88
	CD at 5%	0.29	0.36	10.63	8.79	10.41	8.68

The variations highlight the dynamics of dissolved organic carbon in soil under different bamboo species. Higher DHA in D. strictus suggests increased litter accumulation, creating a favorable microclimate. These findings align with Kaushal *et al*. (2020) and Sengupta *et al*. (2016) [3], emphasizing the influence of organic matter on DHA variation

Acid and alkaline phosphatase

Soil acid phosphatase and alkaline phosphatase activities at the 0-15 cm soil depth varied significantly among different bamboo species, as outlined in Table 6 and visually represented in Fig 9 *Dendrocalamus strictus* displayed the highest acid and alkaline phosphatase activities at 0-15 cm, at 88.16 µg PNP g-1 soil hr-1 and 63.18 µg PNP g-1 soil hr-1, respectively, statistically comparable to *Bambusa tulda*. *Melocanna baccifera* exhibited the lowest activities.
At 15-30 cm depth, phosphatase activities decreased, but differences persisted among species. *D. strictus* showed highest acid phosphatase activity, surpassing several species, while being statistically on par with others. For alkaline phosphatase, *D. strictus* had significantly higher activity compared to *Melocanna baccifera*, while being statistically similar to other species. These variations indicate distinct enzymatic dynamics under different bamboo species. The enhanced phosphatase activities in *D. strictus* suggest a higher presence of organic residues, consistent with findings by Dick and Wang (2000) [20]

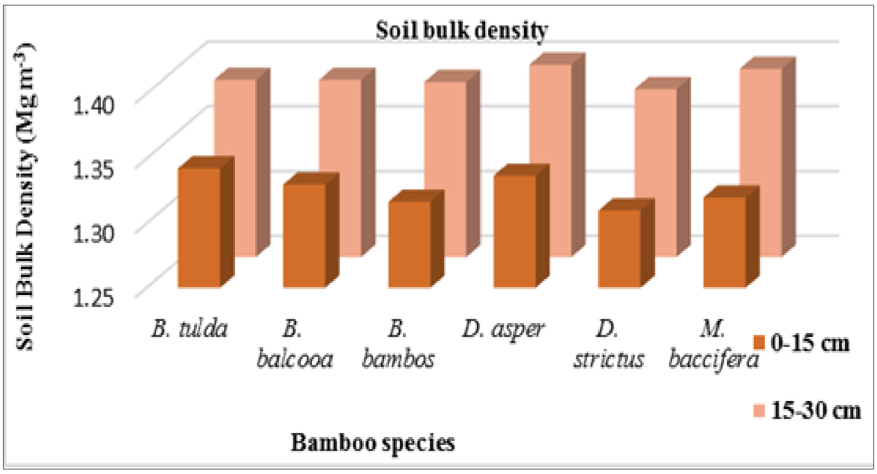

Fig 1: Bulk density as influenced by different bamboo species

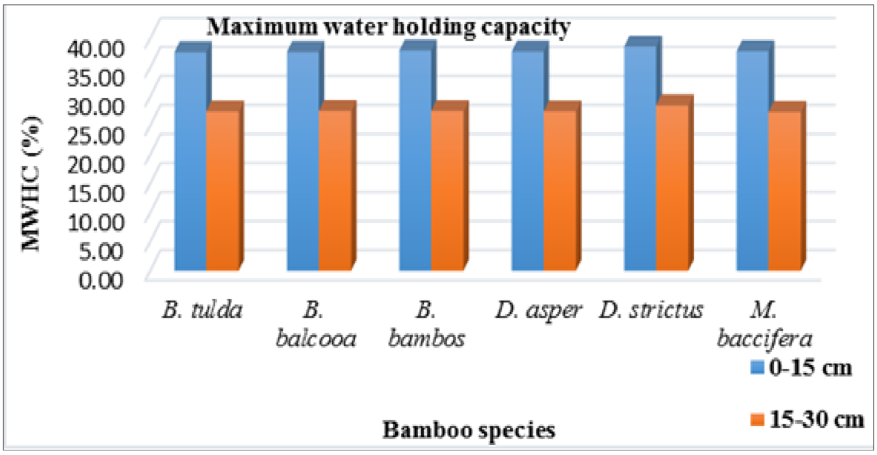

Fig 2: Maximum water holding capacity as influenced by different bamboo species

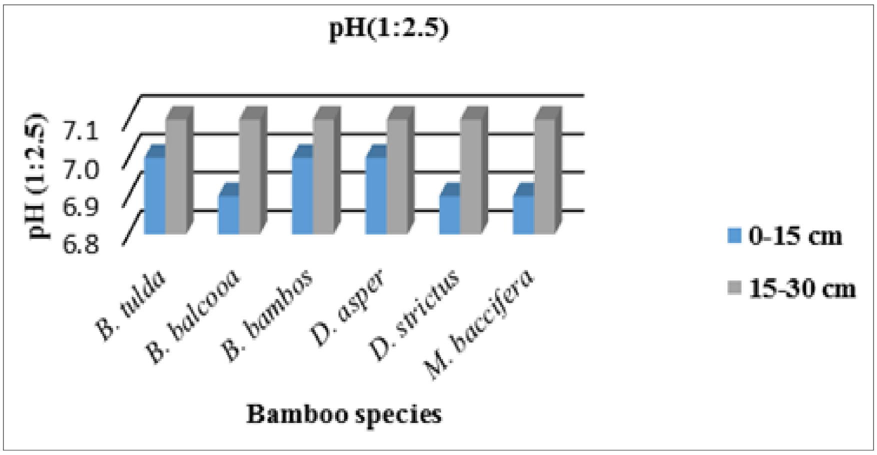

Fig 3: pH as influenced by different bamboo species

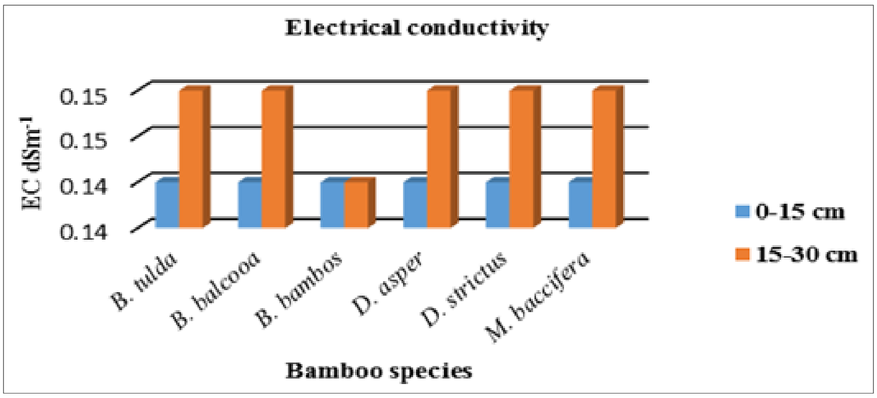

Fig 4: Electrical conductivity as influenced by different bamboo species

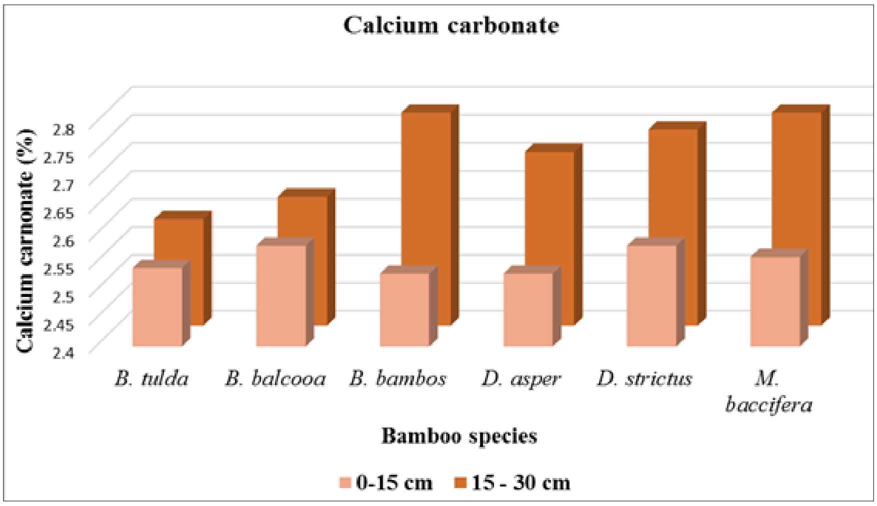

Fig 5: Calcium carbonate as influenced by different bamboo species

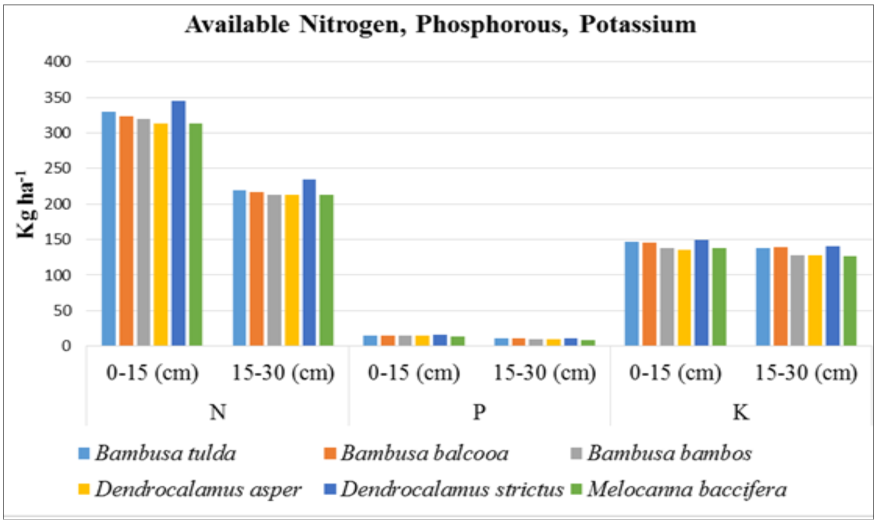

Fig 6: Available N, P and K as influenced by different bamboo species

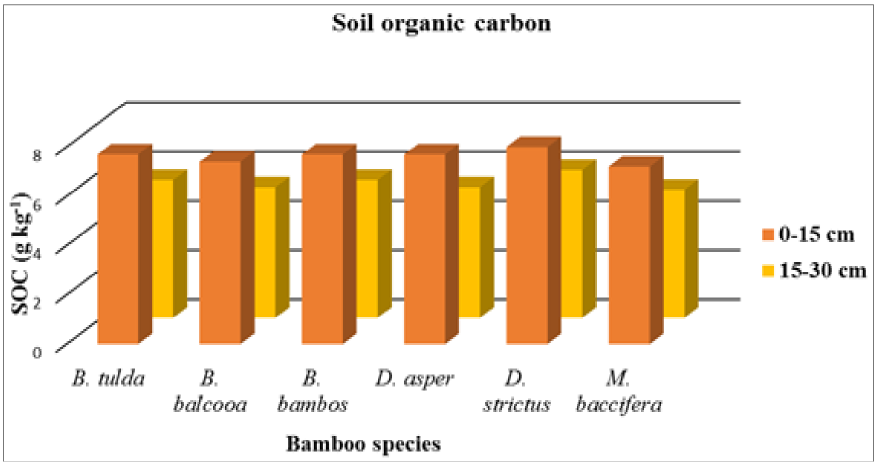

Fig 7: Soil organic carbon as influenced by different bamboo species

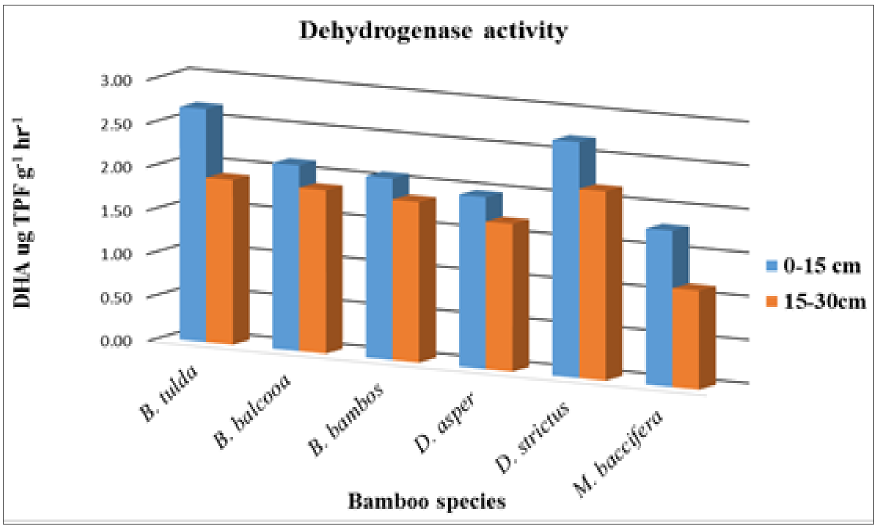

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Fig 8: Dehydrogenase activity as influenced by different bamboo species

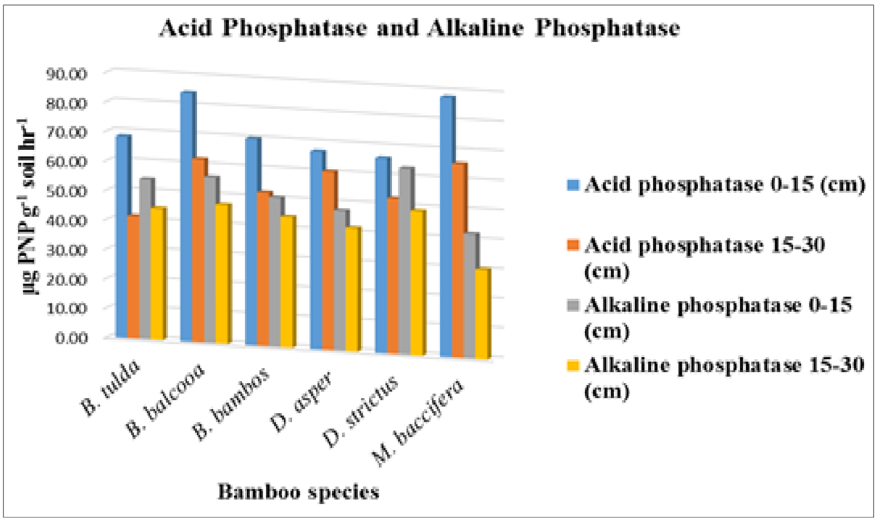

Fig 9: Acid and Alkaline Phosphataseas influenced by different bamboo species

Conclusion

The six bamboo species were analysed to study the impact of different bamboo species on soil physical, chemical and biological properties and the key values were identified across various soil parameters. *Dendrocalamus strictus* demonstrated its soil-enhancing attributes by consistently exhibiting the significantly lower bulk density at 0-15 cm and 15-30 cm depths, indicative of improved soil aggregation attributed to its fibrous root system. Notably, *D. strictus* displayed the highest maximum water holding capacity at both depths, underscoring its robust root system and effective biomass accumulation. The soil pH, electrical conductivity, and calcium carbonate content among bamboo species showed stability with minor numerical variations. *D. strictus* consistently presented significantly higher values for available nutrients (nitrogen, phosphorus, potassium) at both depths, emphasizing its positive influence on soil fertility. Furthermore, *D. strictus* exhibited elevated levels of soil organic carbon and dehydrogenase activity, indicating enhanced organic matter accumulation and microbial activity. In terms of phosphatase activities, *D. strictus* showcased the highest values for both acid and alkaline phosphatases, suggesting superior phosphorus cycling. These findings collectively highlight *Dendrocalamus strictus* as a species with multifaceted positive effects on various soil parameters, making it a promising candidate for sustainable soil management and bamboo cultivation practices.

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