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Effect of clump density/spacing on the productivity and nutrient uptake in *Bambusa pallida* and the changes in soil properties

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Abstract—A trial was conducted on *Bambusa pallida Munro.* with three densities (278, 204 and 156 clumps/ha) of planting in square geometry over a period of 12.5 years. Planting density significantly influenced the circumference of clumps and the characteristics of culms i.e., number of internodes, mean height, girth, tapering rate, hollowness and dry weight of a culm. Total biomass productivity decreased from 341 t/ha at 278 clumps/ha to 234 t/ha at 156 clumps/ha. Accumulation of nutrients (N, P, K, Ca, Mg, Cu, Zn, Mn and Fe) in the above ground biomass followed the same trend. Total nutrient accumulation was 5 t/ha at 278 clumps/ha at the highest biomass producing density of 278 clumps/ha. Harvested culms drained nutrients from the plantation site to the tune of 469 kg/ha per year over the last six years, while floor litters enriched the plantation site by adding 79 kg nutrient/ha per year during last 10 years of study. Floor litters returned 15, 21 and 31% of the total nutrient uptake to the surface soil at the planting densities of 278, 204 and 156 clumps/ha, respectively. Mn and Fe accumulated by the bamboo biomass in the acid soil condition were largely (61–73%) returned through floor litters to the soil. In general, there was positive nutrient balance under three densities of planting. Under the bamboo plantation, surface soil (0–20 cm) electrical conductivity and soil pH improved and the soil was enriched with organic matter, Ca, Mg and Zn, but it was depleted in available P, exchangeable K and Fe in proportion to the density of clumps.

Key words: Clump densities; culm characteristics; biomass productivity; nutrient balance sheet; soil chemical properties.

INTRODUCTION

Bambusa pallida is a slender, feminine caespitose bamboo with thick clumps. It is a medium-tall, medium-prolific species, sparsely branched at lower nodes and conspicuous due to smaller leaves with white ventral surface. It has been found growing in cultivated to semi-wild conditions in Sikkim, Assam, Meghalaya,

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Arunachal Pradesh, Nagaland and Tripura states of northeastern India. The bamboo grows up to 1070 m altitude in the hills of Arunachal Pradesh. *B. pallida* is one of the six major species contributing 4% to total growing stock of bamboo in India [1]. The species is widely used for construction of housing making roofing and walls particularly indoor walling of bamboo made houses, as posts, poles, furniture, pulping material for paper, light decorative work and edible young shoots. Optimum clumps density has to be standardized for a bamboo plant species to harvest maximum number of culms and achieve highest biomass production in a bamboo plantation. Therefore, a study was done to find out optimum clump density of *B. pallida* for maximum productivity.

MATERIALS AND METHODS

The study was conducted at Basar, West Siang district of Arunachal Pradesh, India (27°95′N latitude and 94°1′E longitude at an elevation of 660 m above mean sea level) during July 1988 to 2000. The experimental site experiences a humid subtropical climate, with a mean annual rainfall of 2370 mm during a period of 149 days. Most of the rainfall occurred during the southwest monsoon (April to October). The mean maximum temperature ranges from 12.7°C (January) to 39°C (July to September) and mean minimum temperature varies from 3.3°C (February) to 28.3°C (August). The natural vegetation comprises of wet evergreen and tropical moist deciduous forests. The area represents an 'Udic' soil moisture regime and *hyperthermic* soil temperature regime. The experiment was conducted on 25% hill slope, having clay loam soil. Initial soil physico-chemical properties have been described in Table 6. The experiment was conducted in a randomized block design with three planting densities and eight replications. The planting of seedlings of *Bambusa pallida* was done during monsoon (July, 1988) in square geometry (6 m $\times$ 6 m, 7 m $\times$ 7 m and 8 m $\times$ 8 m) to achieve three planting densities of 278, 204 and 156 clumps/ha. Planting was done in the pits of 60 cm $\times$ 60 cm $\times$ 60 cm size. Characteristics of seedlings of *B. pallida* used for planting have been given in Table 1. The large coefficient of variation in number of roots per plant was probably due to separation of soils from the collected seedlings during washing into water stream before transporting to the experimental site, causing breaking of some of the roots. Seedlings of *B. pallida* were collected from flowering areas near Doje

Table 1.
Characteristics of 1-year-old seedlings of *B. pallida* used for planting

Plant characteristics	Mean	Coefficient of variation (%)
Plant height (cm)	96.48	19.76
Number of roots/plant	24.13	57.82
Root length (cm)	15.51	32.30
Length of internode (cm)	16.13	1.7

and Kamki in the West Siang district of Arunachal Pradesh and planted in a nursery for hardening before planting in the field. In 1988, flowering was observed in three distinct patches of 50–200 clumps in the West Siang district. In 1989, gap filling was done for only six plants in the experiment. Observations on various parameters like culm characteristics, production of culms and biomass in different parts of the culm, were taken at harvest. Observations on clump characteristics and floor litters were taken from third years after planting. Harvesting of culms commenced from the sixth year onwards after planting. Total nutrient uptake was computed after determining concentration of nutrients (N, P, K, Ca, Mg, Cu, Zn, Mn and Fe) in various plant parts and multiplying them by dry matter in the leaves, branches and culms. Additions of nutrients through floor litters were similarly computed by multiplying dry matter and nutrient concentration in the floor litters.

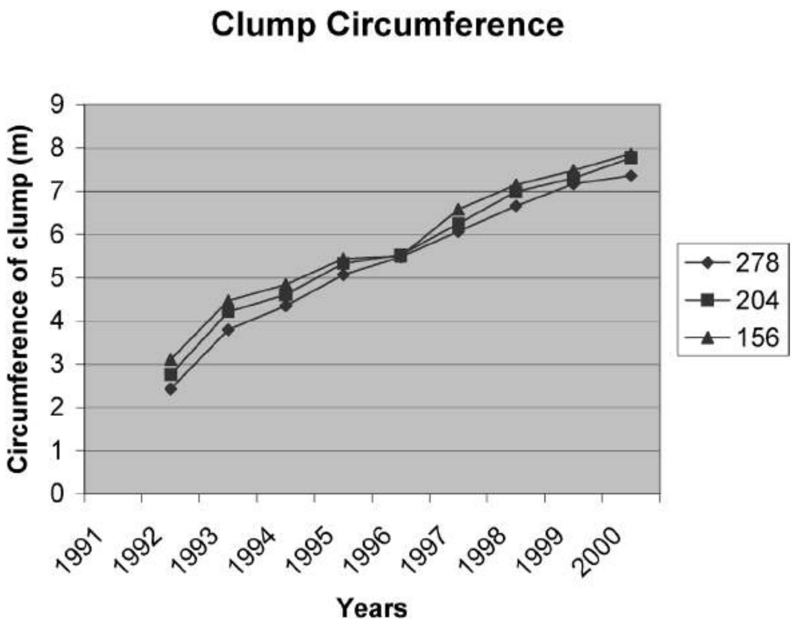
Surface (0–20 cm) soil samples from three treatments were sampled, dried in sunshine, processed and analysed for different soil chemical properties before layout of experiment and after 12.5 years. Soil pH, organic carbon, available P (Bray's P_2) exchangeable Ca, Mg and K were estimated by standard procedures [2]. N, P, K, Ca and Mg in plant samples were determined to compute nutrient uptake. Atomic absorption spectrophotometer was used to determine Cu, Zn, Mn and Fe in the samples of plant and soils.

RESULTS AND DISCUSSION

Characteristics of clumps and culms

Expansion of circumference of the clumps and cumulative culm production per clump were found to increase linearly over a period of 12.5 years (Figs 1 and 2). In *B. bambos*, linear growth in biomass had also been reported [3]. Expansion of circumference was found to be more (8 m) with the wider spacing (8 m $\times$ 8 m and 7 m $\times$ 7 m) than with the narrow spacing (6 m $\times$ 6 m) of planting in *B. pallida* (Table 2, Fig. 1). However, the number of culms produced in a clump did not vary with density of planting. The spacing between two culms at the fifth node in a clump was also not changed by different densities of planting. The spacing between two culms facilitates extraction of bamboo from the clump.

Observations on characteristics of culms produced with three densities of planting revealed significant differences in number of internodes in a culm, mean height and girth of the culm, tapering rate, hollowness and dry weight of the culm. However, not any differences were noticed in rind thickness (thickness of the wall of internodes) and mean length of internodes under three densities of planting. Close spacing (6 m $\times$ 6 m) produced culms with larger length, girth, tapering rate (1.5 cm/m) and hollowness inside the internodes but with same rind thickness and mean length of individual internode than the wide spacing (8 m $\times$ 8 m) of planting. The differences between 278 and 204, as well as and 204 and 156 clumps/ha were also noticed for these characters. Higher plant height under high density of planting



	1992	1993	1994	1995	1996	1997	1998	1999	2000
278	2.43	3.8	4.35	5.07	5.48	6.07	6.66	7.17	7.36
204	2.76	4.21	4.61	5.33	5.53	6.25	6.99	7.3	7.77
156	3.11	4.47	4.84	5.44	5.5	6.58	7.15	7.48	7.87

Figure 1. Circumference (in m) of clumps planted at 278, 204 and 156 clumps/ha.

might be due to etiolating effect under close spacing of planting than the lower plant height under low density of planting. The wider spacing in the lowest density of planting facilitated the emergence of a higher number of leaves of bigger size, higher weight and more branches than the leaves and branches obtained under highest density of planting. Thus leaves and branches constituted all together 33% of total biomass in low density of planting and 29% under highest density of planting.

Productivity

Productivity of culms differed significantly when *B. pallida* was planted at three densities (Table 3). Total number of culms produced over 12.5 years was higher (63 000/ha) under high density of 278 clumps/ha than the number of culms obtained at low density of 156 clumps/ha (35 000/ha). About 69–72% of total culms produced within 12.5 years were harvested during last six years. The difference in productivity of culms was solely due to differences in number of clumps per unit area. This was because number of culms produced in a clump did not differ significantly due to three densities of planting. Planting at the densities of 278 clumps/ha produced 80% more number of culms than the number of culms produced at the low density of 156 clumps/ha.

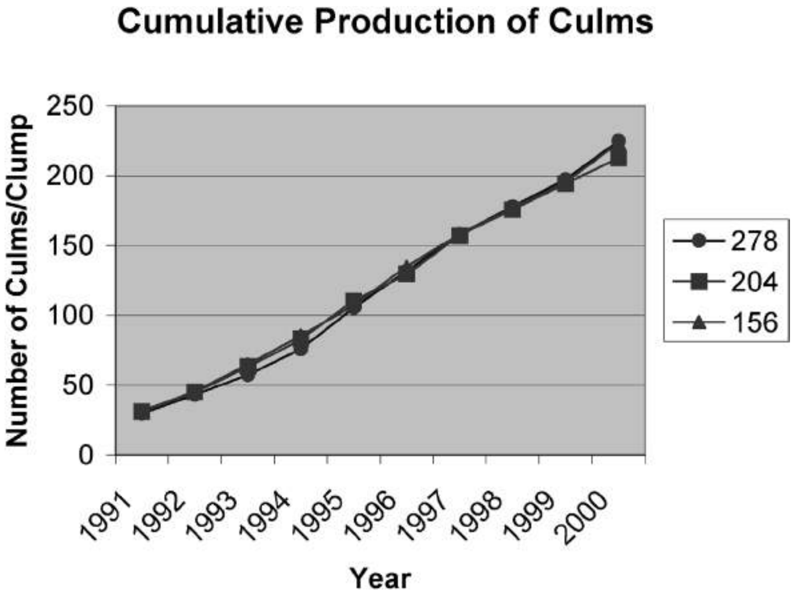
Table 2.
Effects of clump densities on the characteristics of clumps and culms in *B. pallida*

Parameter	Clump density (No/ha)			CD $P = 0.05$
	278	204	156	
Total number of culms per clump in 12.5th year	197.5	194.4	196.2	NS
Circumference of clump (m)	7.36	7.77	7.87	0.26
Spacing between two culms at fifth node (cm)	29.0	28.7	30.0	NS
Number of internodes in a culm	31.8	29.2	27.4	0.75
Mean height of culms (m)	14.00	13.60	13.20	0.59
Mean girth of culms (cm)	11.34	10.2	9.60	1.08
Taper rate (cm/m)	1.49	1.43	1.41	0.05
Mean dry weight of culm without leaves and branches (kg)	4.12	4.59	4.49	0.27
Mean dry weight of whole culm (kg)	5.80	6.44	6.69	0.36
Mean length of internodes (cm)	43.3	42.9	43.8	NS
Mean rind thickness (cm)	0.42	0.38	0.40	NS
Mean hollowness diameter inside internodes (cm)	3.21	2.86	2.65	0.33
Leaf length (cm)	18.32	19.56	21.24	0.62
Leaf width (cm)	1.30	1.55	1.67	0.21
Dry weight of leaves per culm (kg)	1.35	1.40	1.72	0.19
Dry weight of branches per culm (kg)	0.338	0.461	0.478	0.02
Leaves in whole culm (%)	23.24	21.70	25.72	—
Branches in whole culm (%)	5.82	7.15	7.15	—

Total biomass produced was 319 t/ha with net primary productivity of 26 t/ha/year at the highest density (278 clumps/ha) over 12.5 years (Table 3). Biomass productivity of 287 t/ha had been reported in case of *B. bambos* in the 10th year after planting [4]. In general the biomass productivity of bamboo had been reported to be 7–30% higher than any fast-growing tree species [4]. The net primary productivity reduced significantly at planting densities of 204 and 156 clumps/ha. The net primary productivity found in *B. pallida* was higher than reported in *Phylostachys edulis* (9 t/ha per year) [5]. About 79–82% of total biomass produced over 12.5 years was harvested between the 7th and 12th years after planting. The culms constituted 71% of harvested biomass at highest densities of 278–204 clumps/ha and 67% at the lowest density of planting of 156 clumps/ha. The returns of biomass to the site in the form of floor litters were 3.6 t/ha per year at 278 clumps/ha over the last 10 years, which decreased with decreasing densities of planting.

Nutrient balance sheet

Over a period of 12.5 years, the total nutrient (N, P, K, Ca, Mg, Cu, Zn, Mn and Fe) uptake amounted to 5331 kg/ha at the planting density of 278 clumps/ha, which decreased with decreasing densities of planting (Table 4, Fig. 3). Overall, total nutrient uptake in different plant parts followed the pattern culms>leaves>branches at higher densities of planting (278 and 204 clumps/ha). At the lowest density of



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
278	29.78	3.8	43.18	57.36	75.88	105.56	131.9	158.3	197.45	225
204	31.14	45.15	63.32	83.31	110.13	129.8	156.9	175.7	194.32	212.75
156	31.51	46.01	65.03	85.56	107.66	134.7	157.9	176.81	196.19	223.72

Figure 2. Culm production in clumps planted at 278, 204 and 156 clumps/ha.

planting (156 clumps/ha) the pattern changed to leaves>culms>branches (Table 4, Fig. 3). Densities of planting also changed the pattern of different nutrients uptake. At high density of planting (278 clumps/ha), uptake of N, Ca, Mg and Cu was higher in the culms followed by leaves and branches, while at 204 and 156 clumps/ha N and Cu uptake was higher in the leaves than the uptake of N and Cu by the culms. Occurrences of such pattern of nutrient uptake were attributed to differences in dry matter production in different parts of plant, which were influenced by different density of planting. Each harvest of culms had annual nutrient drain of 469 kg/ha per year at the planting density of 278 clumps/ha from the plantation site, which decreased at low densities of planting by 41–61% during the last six years (Table 5). Among the different nutrients, the quantum drain of nutrients was in the order N>K>Ca>Mg>P>Fe>Zn>Cu. However, nutrient drain in harvested culms was reported to follow the order K>N>Mg>Ca>P in *Dendrocalamus hamiltonii* [6] and K>N>Ca>Mg>P in *D. hamiltonii, Neohoujeau dulloa* and *B. khasiana* [7] in secondary succession bamboo following slash and burn agriculture. Addition of nutrients through floor litters was 79 kg/ha per year at the planting densities of 278 clumps/ha, which decreased with decreasing densities of planting, showing a slower turnover to enrich the soils under *B. pallida* plantation. The nutrient composition of floor litters revealed that at high density of 278 clumps/ha, 15%

Table 3.
Productivity of *B. pallida* as influenced by clump densities

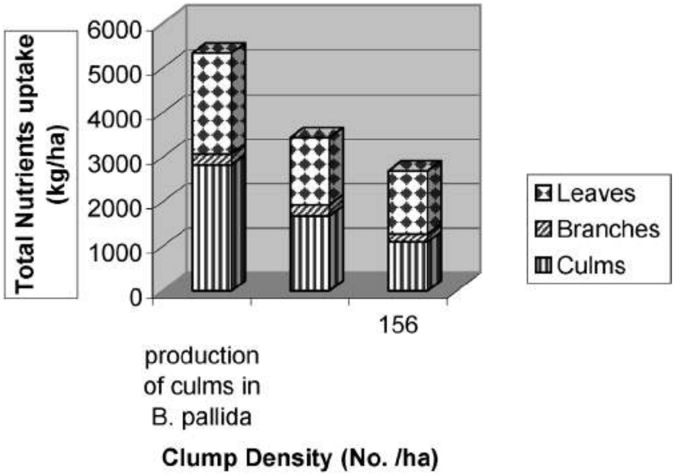
Plant part	Clump density (No/ha)			CD
	278	204	156	$P = 0.05$
Number of culms harvested over 6 years	45.1	30.6	24.2	2.68
Number of culms in the stand in 12.5 years	17.7	12.8	10.7	1.21
Total number of culms produced	62.8	43.4	34.9	3.86
Standing biomass				
Leaves	13.23	12.63	11.04	1.49
Branches	3.52	4.17	3.06	NS
Culms	40.45	41.46	28.78	2.86
Total Live biomass	57.00	58.26	42.88	4.03
Harvested biomass				
Leaves	60.69	42.76	41.67	1.59
Branches	15.69	14.10	11.56	1.58
Culms	185.54	140.39	108.67	4.14
Total harvested biomass	261.47	197.25	161.90	5.84
Total biomass				
Leaves	73.93	55.40	52.71	8.33
Branches	18.57	18.27	14.62	3.45
Culms	226.03	181.85	137.45	7.26
Total biomass	318.53	255.51	204.78	8.33
Floor litter over 10 years	35.82	34.60	32.91	1.91

The number of culms is the number of culms $\times 10^{-3}$/ha, and biomass is t/ha.

of the total nutrient uptakes were returned to the site through floor litters which increased to 21 and 25% of the total nutrient uptake at 204 and 156 clumps/ha, respectively. Further, 61–73% of the Mn and Fe taken up by the bamboo plants were returned to the bamboo plantation site through floor litters. About 10% of the nutrients present in the standing biomass was reported to be recycled to the soil through floor litters in *B. bambos* [8]. The uptake of total nutrient was faster and storage of essential nutrients in standing, as well as harvested biomass was larger than return to the soils [7]. In a 12.5-year-old bamboo plantation, accounting of nutrients in standing biomass, addition to the soil through floor litters (excluding contribution of fine roots) and drain of nutrients through harvested culms in last six years, showed an over all positive nutrient balance of 3309 kg/ha at the highest density of 278 clumps/ha, which decreased to 2464 and 2268 kg/ha at 204 and 156 clumps/ha, respectively. Inclusion of nutrients in fine roots biomass to the nutrient balance sheet could have shown higher quantum of nutrient balances. It has been reported that bamboo played an important nutrient conservation role in a bamboo plantation ecosystem [7].

Table 4.
Nutrient uptake (in kg/ha) in different components of biomass as influenced by clump densities in *B. pallida*

Element	278 clumps/ha (6 m × 6 m)			204 clumps/ha (7 m × 7 m)			156 clumps/ha (8 m × 8 m)		
	Leaves	Branches	Culms	Leaves	Branches	Culms	Leaves	Branches	Culms
Nitrogen	1389.7	98.4	1604.5	880.7	106.0	745.6	806.5	73.1	398.6
Phosphorus	66.5	16.2	119.8	46.5	9.5	83.7	40.6	6.9	42.6
Potassium	301.6	83.1	422.6	224.9	87.1	371.0	221.2	63.9	325.7
Calcium	310.5	31.6	406.8	221.6	28.7	329.2	241.4	20.0	236.4
Magnesium	110.9	13.6	176.3	72.6	13.3	87.3	61.2	9.7	50.9
Macro elements	2179.2	242.9	2730.0	1446.3	244.6	1616.8	1376.9	175.6	1034.2
Copper	0.296	0.074	0.452	0.277	0.002	0.182	0.323	0.012	0.138
Zinc	4.58	0.85	6.33	3.54	0.59	5.09	3.58	0.44	3.99
Manganese	66.5	1.49	4.07	47.97	0.84	3.28	30.47	0.62	2.75
Iron	15.37	4.01	75.03	5.43	6.38	50.92	5.38	5.21	29.10
Trace elements	86.75	6.43	85.88	57.22	7.81	59.47	39.75	6.28	35.98
Total	2265.95	249.33	2815.88	15035.2	252.31	1676.28	1416.65	179.88	1090.18



		204	156
Culms	2815.9	1676.3	1090.2
Branche	249.33	252.3	179.9
Leaves	2266	1503.52	1416.7

Figure 3. Effect of clump densities on nutrient uptake in different components of *B. pallida* over a period of 12.5 years.

Soil physico-chemical properties

Planting of *B. pallida* at three densities significantly changed the properties of surface soil (0–20 cm soil depth) over a period of 12.5 years (Table 6). Soil pH, electrical conductivity, organic matter, Ca, Mg and Zn cat ion increased but available P, exchangeable K and Fe depleted in the surface soils as compared to initial soil status. Changes in the soil properties also reflected the effects of clump densities. Cu and Mn contents in the soils showed marginal reduction. The soil under highest density of 278 clumps/ha, recorded an increase of 0.82 units in soil pH compared to their initial soil status. Higher soil pH under the plantation of *B. pallida* than the soil under the plantation of *B. balcoa* had been reported [9]. The increase in soil pH might be attributed to the build up of organic matter due to return of 11–16% of the total biomass to the site through floor litters at different planting densities, excluding fine roots ramified in the surface soil. The build of soil organic matter was also in proportion to floor litter added to the soil surface under different densities of planting. Increase in soil organic matter due to floor litters and contribution of fine root biomass had been reported in bamboo plantations of *B. pallida* [9], *Melocanna baccifera*, *Oxytenanthera nigrociliata*, *B. longispiculata*, *D. giganteus* [10], *Gigantochloa* spp. and *B. vulgaris* [11].

Biogeochemical characteristics of bamboo, i.e., rapid biomass accumulation, the accumulation of its floor litters and the extremely high biomass of fine roots might have helped to build up organic matter in the soil under *B. pallida* plants. Ca content

Table 5.
Nutrient cycling under different densities of planting in *B. pallida* over 12.5 years

	Total uptake by total biomass produced (kg/ha)			Drain of nutrient from the site by harvested culms (kg/ha)			Enrichment of surface soil by floor litters (kg/ha)		
	278	204	156	278	204	156	278	204	156
Nitrogen	3092.6	1732.3	1278.2	1604.5	745.6	398.6	386.9	339.1	329.1
Phosphorus	202.5	139.7	90.1	119.8	83.7	42.6	21.5	15.2	16.5
Potassium	807.3	683.0	616.8	422.6	371.0	325.7	45.2	46.1	45.4
Calcium	748.9	579.5	497.8	406.8	329.2	236.4	179.1	160.2	150.1
Magnesium	300.8	173.2	121.8	176.3	87.3	50.9	48.7	41.9	37.2
Macro elements	5152.1	3307.7	2604.7	2730.0	1616.8	1054.2	681.4	602.5	578.3
Copper	0.822	0.461	0.473	0.452	0.182	0.138	0.143	0.208	0.264
Zinc	11.76	9.22	8.01	6.33	5.09	3.99	1.72	2.01	1.95
Manganese	72.06	52.09	33.84	4.07	3.28	2.75	52.30	46.85	37.93
Iron	94.41	62.73	39.69	75.03	50.92	29.10	57.89	56.40	52.65
Trace elements	179.052	124.501	82.013	85.88	59.47	35.98	112.05	105.47	92.80
Total	5331.2	3432.2	2686.7	2815.9	1676.3	1090.2	793.5	708.0	671.1

Total biomass does not include root biomass.

Table 6.
Effect of planting of *B. pallida* on the physicochemical properties of the surface soil

Soil property	Initial soil status	Soil status after 12.5 years			CD $P = 0.05$
		278 clumps/ha	204 clumps/ha	156 clumps/ha	
Soil pH	4.24	5.06	5.00	5.00	NS
Electrical conductivity (millimhos/cm)	101	137	130	125	06
Organic Carbon (%)	2.75	4.33	3.95	3.57	0.35
Available P (ppm)	4.50	1.00	0.60	0.60	NS
Exch. K (ppm)	105	70	72	70	NS
Calcium (ppm)	101	309	305	292	09
Magnesium (ppm)	77	93	91	84	05
Copper (ppm)	1.20	1.12	1.18	1.16	0.04
Zinc (ppm)	1.23	1.48	1.40	1.60	0.10
Manganese (ppm)	44.6	43.1	41.1	41.4	NS
Iron (ppm)	153	41	39	40	NS
Soil texture	Clay loam	Clay loam	Clay loam	Clay loam	

in the surface soils increased three times and Mg content increased 1.2 times under different densities of planting, as compared to their initial soil status. This build-up of Ca and Mg in the surface soils was largely due to floor litters which had added 113–131 kg/ha Ca and 29–33 kg/ha Mg, which were taken up by bamboo plants largely from the deeper layers of the soils. A return of about 10% of total N, K, Ca and Mg uptake to the soil in the form of floor litters in *B. bambos* had been reported [8]. Thus, the nutrients being mined from deeper layers of the soil by bamboo plantation enriched surface soil after return of leaves and branches in the form of floor litters. Cu and Mn content showed a marginal decline (7–8%) compared to their initial soil status. However, the bamboo plantation significantly depleted available P, exchangeable K and Fe over 12.5 years. The effects of clump densities showed that depletion of available P was found more at low densities of 156–204 clumps/ha as compared to 278 clumps/ha. Available P was as such low in the acidic soils of the plantation site and a good amount (43–120 kg P/ha) either remained locked in stem portion or exported out of the site due to harvesting of culms. Only a low amount of 11–14 kg P/ha was returned through floor litters to the surface soil. Decrease in available P and increase in Ca and Mg contents of the surface soils under bamboo plantation of *B. nutans* had also been reported in Sikkim (Eastern Himalaya) [13]. Graminaceous plants easily took up monovalent K in excess quantity than divalent cat ion. This might be the reason for depletion of exchangeable K in the soils under the bamboo plantation. *D. hamiltonii* acted as accumulator of K and depleted the soil in first 0–10 years of plantation but improved available K in the soil after 15 years age in acidic soils [6]. A major amount of Fe of the total uptake by bamboo plantation was either exported due to harvest of culms or remained sequestrated in standing culms. Hence, there was depletion of Fe in the soils of *B. pallida* without any effect of different densities of planting.

CONCLUSIONS

Closer (6 m $\times$ 6 m) spacing of planting of *Bambusa pallida* produced the maximum number of culms having more length and girth but lighter in weight than wider (7 m $\times$ 7 m; 8 m $\times$ 8 m) spacing of planting. The rind thickness of internodes of culms did not show any difference under three spacings of planting. In general, the bamboo plantation showed positive nutrient balance. In *B. pallida* plantation, soil pH, electrical conductivity, organic matter, Ca, Mg and Zn cat ion in the surface soil increased but available P, exchangeable K and Fe cat ion depleted over a period of 12.5 years. Quantum changes in the positive nutrient balances and the soil chemical properties decreased with increasing spacing of planting.

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