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Soil Macro Nutrient Status in Teak (*Tectona grandis*) and Bamboo (*Dendrocalamus strictus*) Plantations in Vertisols of Nagpur, India

Bhargavrami Reddy[1*], K.S. Bharath Kumar[2], and V.S. Reddy Kiran Kalyan[3]

[1]Department of Soil Science and Agricultural Chemistry, KVK, Kalikiri, India
[2]Department of Soil Science and Agricultural Chemistry, College of Agriculture Nagpur, India
[3]Department of Soil Science and Agricultural Chemistry, DAATTC, Chittoor, India
**Corresponding author*

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A B S T R A C T

The potential contribution of trees to soil improvement is one of the major assets of agroforestry in general and more specifically agroforestry lands. Agroforestry systems are often mentioned as type of sustainable agriculture. However, long term studies on the sustainability of this land use do not exist. The study was conducted at Agroforestry Research Farm, Nagpur to know the soil nutrient status of teak and bamboo plantations and to evaluate the soil nutrient status in agroforestry research farm which was compared with cultivable land. Soil samples were taken from different depths 0-15 cm and 15-30 cm of 8-19 year old teak, 14-19 year old bamboo plantations and farm land, respectively. Samples were analyzed for pH, organic carbon, inorganic carbon, available N, P, K, S and Exchangeable Ca and Mg. Soil pH was significantly lower in the teak (1994, 3X3m) followed by other plantations and higher pH was observed in cultivable land. Bamboo plantations had significant higher organic carbon, inorganic carbon, available potassium, sulphur and exchangeable calcium and magnesium concentrations than teak plantations and farm land. Available nitrogen was significantly higher in teak plantations than bamboo and farm land, available phosphorus was significantly higher in Teak (1994 3X3m) followed by bamboo plantations and cultivable land. Teak and Bamboo plantations with carefully evaluated agroforestry species could be employed as productive soil ameliorations in arid and semiarid soil of India.

Introduction

Agroforestry a dynamic, ecologically based, natural resource management system that integrates trees on agricultural landscape, diversify and sustain production for increased social, economic and environmental benefits for land users at all levels, seems to hold promising potential. Agroforestry is quite useful system because this is not only utilizes water efficiently but meets the basic requirements of fodder, fuel, pulp and green manure for agricultural crops (Sanchez, 1997). Agroforestry system would be capable of meeting the demand of raw materials of several agricultural and forest based industries.

To assure forest ecosystem rehabilitation on site were natural succession is not an option, due to site and time constraints, managers' may turn to plantations as rehabilitative tools (Lugo, 1992a, b; Parrotta, 1992). There is an ample literature on the productive potential and ecological functions of agroforestry systems (Smith *et al.*, 1995; Dubais *et al.*, 1996), among which soil conservation is often most important, maintenance of soil fertility requires preservation of its organic matter, physical properties and nutrient levels. Several studies showed the usefulness of tree plantations in the restoration of soil attributes and biological attributes and biological diversity on degraded land (Fisher, 1995; Lugo, 1997) trees that influence soil chemical and physical properties has been used in agricultural applications through agroforestry and forest fallow for some time (Nair, 1993). There are different ways that a tree can ameliorate soil conditions at a given site, these include N-fixation, surface soil nutrient enrichment through litter fall and root turnover, increase in soil organic matter through additional litter and root inputs, changes in above and below ground microclimate (moisture and temperature extremes aeration, etc.) and trough the increase in organism activities within the rhizosphere of perennial roots, therefore tree plantations is an important consideration for maintaining or enhancing of soil properties. The nature and amount of organic matter produced after decomposition of the litter depends on the dominating tree species present and the site characteristics of the area which regulate the physical and chemical properties of the soil. Different forest trees species are known to exert varied influence on soil properties (Singh and Suri, 1987).

Teak is a valuable exotic timber species and enjoys worldwide reputation as a quality timber on a account of its remarkable physical and mechanical properties, particularly for retention of shape and durability, hence used for ship building, furniture and carving (Kaosa-ard, 1981). Bamboo is a predominant under-story species in several Asian forest ecosystems. Bamboos occur extensively in the managed ecosystems of India, both as plantations (Chandrashekara, 1996) and in agroforestry (scattered clumps, hedgerows on farm boundaries etc., Kumar, 1997; Divakara *et al.*, 2001). It has a long history as an exceptionally versatile and widely used resource. Important traditional uses include paper and pulp, fuel, food, feed, house construction, scaffolding, making several articles of everyday use (Sharma, 1987), controlling soil erosion and facilitating on-site nutrient conservation (Christanty *et al.*, 1996). In a rapidly changing world, however, households develop a myriad of livelihood options and in several cases bamboos are considered to be an important livelihood strategy of rural people. Coincidentally, bamboo is being elevated from a raw material known as the "*poor man's timber",* to the status of the "*timber of the 21st century*" (http://agricoop.nic.in/bamboo/bamboomission .htm). However, by all these considerations the present study was conducted with an objectives were comparative study and to evaluate the physicochemical properties and nutrient status of nutrients nitrogen, phosphorus, potassium, sulphur, calcium and magnesium in all teak and bamboo plantations of different ages, including the cultivable land under the similar site conditions were assessed.

Materials and Methods

Site description

The study was undertaken at Futala farm under Dr. Panjabrao Deshmukh Krishi Vidhyapeeth College of Agriculture, Nagpur, Maharashtra from September 2011 through April 2012. Sites were located bound in the north compound wall of maintenance command in the east by Futala tank in the south by national highway No. 6 and the south village Dhaba, a 278 ha restoration project owned by Dr. Panjabrao Deshmukh Krishi Vidhyapeeth College of Agriculture, Nagpur and funded by All India Coordinated Research Project (AICRP) on Agro-Forestry. The area is located 21^{O}8" to 21^{O} 9" north latitude 79^{O}0" to 79^{O}3" east longitude in the physiographic unit *i.e.* eroded valley with the elevation of 320 meters above mean sea level and receives an annual rainfall of approximately 1200 mm, falling primarily from June to October. Nearby temperatures fluctuate daily from a low of 18.5 ^{o}C to a high of 35.6 ^{o}C throughout the year. The sites used in this study included Teak and Bamboo plantations which were planted in different years with different spacing (Table 1). The cultivable land was selected to provide reference of comparison for agroforestry plantations.

The soils were situated on nearly level to very gentle sloping topography (1-2 % slope) and classified as Vertisols under the fine Montmorollinitic, hyper thermic. The study sites had soil texture clay developed in the basaltic alluvium deposition and color of soils were dark brown to very dark grayish brown.

The teak and bamboo plantations were established by AICRP on agroforestry initiative in 1992. Teak plantations were planted with native species at spacing of 3m × 3m, 8m × 2m, 8m × 4m, 12m × 2m and 12m × 4m. Bamboo plantations were planted with spacing of 6m × 8m, 5m × 5m and 8m × 8m, cleared of competing vegetation for 4 years. At the time of study plantations were 8, 14, 17 and 19 years old. The details of planting of two plantations were listed in table 1.

Sampling and soil chemical analysis

Site maps were created by taking longitude and latitude coordinates with a handheld Global Positioning system (GPS) unit along the plantation perimeters. The soil sampling was carried out in a plantation after subdivision into three plots (replicates). In each plot a composite sample were collected in 0-15cm and 15-30 cm layer, which represented greater uniformity. The samples were air dried and sieved in a 2 mm sieve.

Soil pH, OC, IOC, available N, P, K, S, exchangeable Ca and Mg were determined following the methods generally used. The soil pH was determined in H_2O in a soil water ratio of 1:2.5; OC was determined by chromic acid titration method by Walkely and Black (1934), IOC was analyzed by rapid titration method using phenolphthalein indicator by Piper (1966), soil available N was determined by alkaline potassium permanganate method (Subbiah and Asija 1956). Available P was determined by Olsen method (Olsen *et al.*, 1954). K, Ca and Mg were analyzed after extraction using 1nutral normal ammonium acetate at pH 7.0. Readings for Ca and Mg in the extracts were analyzed by versenate titration and K was determined by flame photometry (Jackson 1973). Available S was measured using 0.15% calcium chloride ($CaCl_2$) solution as an extractant (Tabatabai, 1996).

Statistical analysis

The experimental design used was a factorial randomized block, with eleven treatments (different plantings), two factors (soil depth and plantations) and three replicates. Means were compared with the T-test, at 5% of probability.

Results and Discussion

Soil chemical attribute

The soils chemical analysis in teak and bamboo over a range of 10-19 years old plantations comparison with cultivable land yielded significantly differed pH among the plantations. The decrement in pH among the plantations can be attributed to litter fall, which on decomposition are known to produce the organic acids (Sing and Totey, 1985; Nandi *et al.*, 1991). The phenomenon of lowering pH might be related to several mechanics that release H^+ ions, such as cation uptake by biomass, decomposition of organic matter to organic acids and Co_2, root respiration and nitrification. The increased accumulation of above ground biomass and associated cation uptake by the tree component of agroforestry systems is possibly one of the causes for decreased pH in the soil. The pH (Table 2) of the cultivable land, teak and bamboo plantations were ranged from 6.53±0.22 to 7.97±0.17, the teak pH of the soils were in the order of Teak (1994, 3x3m) recorded lower values followed by teak (1992, 8x2m), teak (1992, 12x2m), bamboo (1992, 6x8m) and the highest values were recorded in cultivable land when compared with the teak and bamboo plating systems. The electrical conductivity was also determined and it ranged from 0.092±0.023 dS m^{-1} to 0.680±0.319 dS m^{-1} with an average of 0.353±0.19 dS m^{-1} surface soil and 0.224±0.1 dS m^{-1}subsurface soil whereas electrical conductivity was differed significantly among the depth but the distribution of soluble salts showed non-significant among the plantations. The uptake of nutrients by agroforestry plantations may contribute to differential values of soil Vadiraj and Rudhrappa, 1990 and observed the electrical conductivity did not differ significantly among the soil under different plantations. The results pertaining to calcium carbonate ($CaCo_3$) in the soils of the cultivable land, teak and bamboo plantations, the $CaCo_3$ found to be higher in the bamboo plantations were followed by teak and cultivable land. The $CaCo_3$ content in the experimental site (Table 2) was in the order of bamboo (1992, 6x8 m) 12.3±0.61 per cent followed by bamboo (1994, 5x5 m) 7.93±0.17 per cent, teak (2004, 3x3 m) 7.01±0.035 per cent further the lowest values was recorded in teak (1992, 8x2 m) 4.74±0.35 per cent among the agroforestry plantations whereas the cultivable land yielded 6.17±0.47 percent compared with agroforestry plantations. In this investigation relative lesser $CaCo_3$ percent was found among the teak plantations and higher $CaCo_3$ percent in bamboo plantations this might be due to Ca content in the litter fall added to surfaces soil under the teak and bamboo3.

Maintaining the amount of soil organic carbon (SOC) in the Agro ecosystems is desirable for maintenance or rehabilitation of soil fertility Craswell and Lefroy, 2001 note that an important aspect of organic matter management is the mimic natural systems that have constant input of C of varying quality. The soil organic carbon differed significantly among the cultivable land, teak and bamboo plantations and depth of the soil of experimental site. The SOC among the plantations and cultivable land ranged from 3.3±0.03 g kg^{-1} to 10.7 ±0.089 g kg^{-1}(Table 2). The mean organic carbon content (0-30 cm) of the experimental site took the order of bamboo (1992, 6x8 m) 9.7± 0.07 g kg^{-1}, bamboo (1994, 5x5 m) 8.9± 0.04g kg^{-1}, teak (1994, 3x3 m) 8.6 ± 0.04 g kg^{-1} and at lastly the cultivable land recorded lowest SOC (3.9±0.03 g kg^{-1}) when compared with teak and bamboo panting systems. Increase in soil organic carbon was due to litter fall and magnitude of buildup. The organic carbon varied among the teak and bamboo plantations varied with the biomass production. The SOC recorded increasing trend with increasing in the biomass production and litter fall. Contractor and Badanur, 1996 reported that organic carbon content in soil accounted that rate of quantity of litter fall and the rate if their decomposition. Variations in organic carbon content in soils under various tree sp. Is attributed to the age of plantation and amount of litter fall, their biochemical composition and rate of their decomposition (Narain *et al.,* 1990), Guomo zhou *et al.,* 2011 reported higher organic carbon content in bamboo plantation soil.

Available nutrients

The available nutrients and exchangeable captions (calcium and magnesium) were determined in the experimental site. The available N content in the teak, bamboo plantations and cultivable land varied with the age of plantations and decreased with the increase in depth of soil. The mean available N content at depth (0-15cm) and (15-30 cm) was shown in table 3 in an experimental site was significantly differed among the planting system with range of 192.96 ± 1.53 kg ha^{-1} – 246.04±2.18 kg ha^{-1} which took in the order of teak (1994, 3x3 m) 246.04±2.18 kg ha^{-1} followed by teak (1997, 3x3m) 236.28±2.36 kg ha^{-1} where as the bamboo plantations occupied 7^{th} position among the planting systems when compared with cultivable land (152.96±1.53 kg ha^{-1}). The available N content in soils of cultivable land and crop land was less compared to the soils under teak and bamboo plantations, obviously due to the low organic matter content (Swift., 1994 and Ashok., 1998). The low content of available N in bamboo may be due to immobilization of nitrogen by un decomposed organic matter Sanchez, 1987. Available P were significantly differed among the teak, bamboo plantation and cultivable land and varied with the ages of the plantations. The mean available P content in soils yielded with a range of 9.45±0.12 kg ha^{-1} to 25.25±0.21 kg ha^{-1} the available P significantly recorded higher under teak (1994, 3x3 m) 25.25±0.21 kg ha^{-1} followed with an order bamboo (1992, 6x8 m) 23.75±0.76 kg ha^{-1}, bamboo (1994, 5x5m) 22.87±0.23 kg ha^{-1} and the last rank was occupied by the teak (2004, 3x3m) 16.07±0.16 kg ha^{-1} yielded higher when compared with cultivable land 9.45±0.12 kg ha^{-1}. Available P in soil was medium to moderately high in the soils of experimental site. The increase in available P with agroforestry plantations soils attributed to the litter fall and subsequent mineralization of organic P in soils revealed by Cahvan *et al.,*1995 and Osman *et al.,* 1995). The available potassium was found to increase in soils under the agroforestry cover. The mean coverage (0-30cm) content of available K in soil under teak, bamboo and cultivable land was ranged from the 246±4.06 kg ha^{-1} to 370±5.16 kg ha^{-1} kg ha^{-1}. The mean average (0-30cm) content of available K was recorded maximum in the bamboo (1992, 6x2m) 370±5.16 kg ha^{-1} and took an order bamboo (1994, 5x5 m) 362±3.51 kg ha^{-1}, bamboo (1997, 8x8 m) 352±3.51 kg ha^{-1} teak (1994, 3x3m) 324 ±4.97 kg ha^{-1} and the lowest rank was observed under the teak (2004, 3x3m) 252±2.52 kg ha^{-1} was higher when compared with the cultivable land. Mulugeta *et al.,* 2004 reported that available K were high under the plantation of *C. lusitanica* and *P.patula* than the mechanized farming, tradition farming. It is predicted that trees on capable of absorbing potassium from the unweathred minerals and potassium is rapidly and efficiently cycled in established forest stands and very little potassium appears to be leached from surface root mat in undisturbed soil (Prictchet, 1979).

Exchangeable calcium and magnesium of agroforestry cover was increased in the soil as result of incorporation of leaf litter from the plantations. The soils under bamboo (1992, 6x8 m) showed higher exchangeable Ca and Mg followed by bamboo (1994, 5x5 m), bamboo (1997, 8x8 m), teak (1994, 3x3 m) and the lowest rank was attained by teak (2004, 3x3 m). High Ca content of leaf litter is the cause for Ca becoming a dominant cation in the soils of teak and bamboo plantations. The difference among the trees sp. May be attained to the variation in the rate of decomposition of leaf litter. High concentration of exchangeable Ca and Mg have be found under naturally growing teak forests (Yadav and Sharma, 1968) and teak plantation (Singh *et al.*, 1985) than under the natural forest plantations in India. Teak is calciolous tree species that take up Ca rapidly (Sing *et al.*, 1985). Due to high Ca concentration in teak leaves, especially at peak leaf fall teak return more Ca to the soil than any other nutrient (Nwoboshi, 1970). Our study found increased concentration of Ca in the Bamboo plantation over teak plantation and cultivable land due to high concentration of Ca in leaf litter of bamboo. Available sulphur was differed among the plantations, the available sulphur (Table 3) record higher under the bamboo (1992, 6x8m) 32.70±0.32 mg kg^{-1} and took the order by teak (1994, 3x3 m) 32.21±0.74 mg kg^{-1}, bamboo (1994, 5 x5 m) 30.73±0.30 mg kg^{-1} with a lowest data was recorded under the teak (2004, 3x3m) 22.58±0.33 mg kg^{-1} among the planting systems when compared with cultivable land. High available S content was recorded in bamboo followed by teak this may be differential performance of the element by the tree sp as represented by Ashok, 1928.

Fertility

The results of the fertility equation suggests a shift of increasing fertility in both surface and subsurface soils form the cultivable land, with the teak and bamboo planting have high to moderately high fertility classes.

Table.1 Details of different Agroforestry plantations under taken for studying soil characteristics

Name of the species	Botanical name	Year of plantation	Spacing	Latitude	longitude
1.Teak	*Tectona grandis*	1994	3 × 3m	$21^0 09^{'} 23.04$”	$79^0 01^{'} 47.26$”
		1992	8 × 2m	$21^0 09^{'} 22.79$”	$79^0 01^{'} 48.05$”
		1992	12 × 2m	$21^0 09^{'} 23.55$”	$79^0 01^{'} 48.39$”
		1992	8 × 4m	$21^0 09^{'} 22.62$”	$79^0 01^{'} 50.33$”
		1992	12 × 4m	$21^0 09^{'} 23.16$”	$79^0 01^{'} 51.60$”
		1997	3 × 3m	$21^0 09^{'} 22.38$”	$79^0 01^{'} 53.07$”
		2004	2 × 2m	$21^0 09^{'} 69.82$”	$79^0 01^{'} 04.51$”
2. Bamboo	*Dendrocalamus strictus*	1992	6 × 8m	$21^0 09^{'} 26.16$”	$79^0 01^{'} 52.08$”
		1994	5 ×5m	$21^0 09^{'} 27.76$”	$79^0 01^{'} 59.06$”
		1997	8 × 8m	$21^0 09^{'} 22.04$”	$79^0 01^{'} 03.20$”
3. Open field				$21^0 09^{'} 22.79$”	$79^0 01^{'} 48.82$”

Table.2 Showing Mean (±S.D.) of some chemical and nutrient properties in the 0-15 and 15-30 cm soil layers under agroforestry planting systems and cultivable land

Soil properties	Depth (cm)	Cultivable land	Teak (1992, 8x2m)	Teak (1992, 12x2m)	Teak (1992, 8x4m)	Teak (1992, 12x4m)	Teak (1994, 3x3m)	Teak (1997, 3x3m)	Teak (2004, 3x3m)	Bamboo(1992, 6x8m)	Bamboo (1994, 5x5)	Bamboo (1997, 8x8m)
pH	0-15	7.71±0.09	6.81±0.07	7.04±0.22	7.07±0.22	7.16±0.35	6.53±0.22	7.04±0.46	7.35±0.12	7.03±0.02	7.09±0.03	7.54±0.12
	15-30	7.97±0.17	7.15±0.52	7.28±0.35	7.39±0.25	7.41±0.16	7.28±0.09	7.48±0.37	7.67±0.14	7.31±0.17	7.66±0.04	7.82±0.15
	Mean	7.84±0.12	6.98±0.29	7.16±0.28	7.23±0.23	7.28±0.25	6.90±0.15	7.26±0.41	7.51±0.13	7.17±0.09	7.38±0.03	7.68±0.13
EC (dS m^{-1})	0-15	0.300± 0.010	0.092±0.023	0.680±0.319	0.458±0.309	0.457±0.413	0.498±0.307	0.168±0.059	0.513±0.320	0.273±0.077	0.146±0.038	0.302±0.257
	15-30	0.176±0.059	0.100±0.006	0.143±0.074	0.136±0.079	0.105±0.033	0.376±0.360	0.242±0.107	0.281±0.018	0.465±0.215	0.226±0.075	0.215±0.123
	Mean	0.24±0.03	0.10±0.01	0.41±0.20	0.30±0.19	0.28±0.22	0.44±0.33	0.21±0.08	0.40±0.17	0.37±0.15	0.19±0.06	0.26±0.19
$CaCo_3$ (%)	0-15	5.99±0.58	3.57±0.39	5.96±0.61	5.61±0.45	6.16±0.19	6.24±0.55	6.63±0.65	6.51±0.37	11.66±1.00	6.49±0.12	6.18±0.57
	15-30	6.35±0.36	5.91±0.30	6.85±0.40	6.36±0.21	6.48±0.27	6.71±0.91	6.75±0.87	7.50±0.33	13.00±0.22	9.37±0.21	6.82±0.25
	Mean	6.17±0.47	4.74±0.35	6.40±0.51	5.98±0.33	6.32±0.23	6.47±0.73	6.69±0.76	7.01±0.35	12.33±0.61	7.93±0.17	6.50±0.41
Soil C (g kg^{-1})	0-15	0.45±0.03	0.86±0.04	0.81±0.06	0.82±0.05	0.75±0.04	0.94±0.05	0.81±0.03	0.58±0.04	1.07±0.08	0.96±0.05	0.87±0.03
	15-30	0.33±0.03	0.60±0.02	0.56±0.02	0.55±0.01	0.51±0.04	0.78±0.04	0.62±0.04	0.49±0.04	0.86±0.05	0.81±0.03	0.71±0.06
	Mean	0.39±0.03	0.73±0.03	0.68±0.04	0.68±0.03	0.63±0.04	0.86±0.04	0.72±0.04	0.54±0.04	0.97±0.07	0.89±0.04	0.79±0.05
Available N (kg ha^{-1})	0-15	195.36±1.95	264.42±2.64	261.54±2.62	263.42±2.63	259.45±2.59	273.54±2.17	264.42±2.64	210.7±2.11	238.34±2.38	225.78±2.26	220.52±2.21
	15-30	110.56±1.11	205.28±2.05	201.12±2.03	203.16±2.01	198.12±1.98	218.54±2.19	208.15±2.08	175.68±1.76	200.7±2.01	195.23±1.95	175.32±1.75
	Mean	152.96±1.53	234.85±2.34	231.33±2.32	233.29±2.33	228.78±2.29	246.04±2.18	236.28±2.36	193.19±1.94	219.52±2.19	210.50±2.11	197.92±1.98
Available P (kg ha^{-1})	0-15	11.90±0.12	24.16±0.24	22.26±0.22	23.77±0.24	20.24±0.20	28.21±0.28	24.25±0.24	19.64±0.20	26.32±1.27	25.64±0.26	23.77±0.23
	15-30	7.01±0.11	19.06±0.20	16.27±0.28	18.34±0.18	13.12±0.13	22.30±0.14	15.54±0.16	12.50±0.13	21.17±0.25	20.10±0.20	18.10±0.20
	Mean	9.45±0.12	21.61±0.22	19.27±0.25	21.05±0.21	16.68±0.16	25.25±0.21	19.90±0.20	16.07±0.16	23.75±0.76	22.87±0.23	20.94±0.22

Table.3 Showing Mean (±S.D.) of Available nutrient properties in the 0-15 and 15-30 cm soil layers under agroforestry planting systems and cultivable land

Soil properties	Depth (cm)	Cultivable land	Teak (1992, 8x2m)	Teak (1992, 12x2m)	Teak (1992, 8x4m)	Teak (1992, 12x4m)	Teak (1994, 3x3m)	Teak (1997, 3x3m)	Teak (2004, 3x3m)	Bamboo(1992, 6x8m)	Bamboo (1994, 5x5)	Bamboo (1997, 8x8m)
Available K ($kg\ ha^{-1}$)	0-15	258±4.51	338±3.51	320±3.51	323±2.52	318±3.51	343±6.43	326±3.51	270±2.52	384±3.51	375±3.51	360±3.51
	15-30	235±3.61	300±6.81	294±2.52	296±2.52	290±2.52	305±3.51	298±2.52	235±2.52	356±6.81	350±3.51	345±3.51
	Mean	246±4.06	319±5.16	307±3.01	309±2.52	304±3.01	324±4.97	312±3.01	252±2.52	370±5.16	362±3.51	352±3.51
Available S ($kg\ ha^{-1}$)	0-15	20.38±0.23	19.47±0.20	16.31±0.14	18.40±0.18	16.20±0.16	20.80±0.91	15.54±0.19	12.80±0.13	36.91±1.18	34.96±1.07	32.72±0.55
	15-30	23.50±0.20	22.26±0.12	20.30±0.20	22.10±0.22	21.17±0.80	24.50±0.25	19.60±0.20	16.22±0.48	46.23±1.76	45.09±0.74	41.81±1.03
	Mean	21.94±0.22	20.87±0.16	18.31±0.17	20.25±0.20	18.69±0.48	22.65±0.58	17.57±0.20	14.51±0.30	41.57±1.47	40.02±0.91	37.27±0.79
Exchangeable Ca (C mol (p+) kg^{-1}	0-15	13.40±0.10	11.20±0.11	9.40±0.09	10.50±0.11	8.40±0.08	12.40±0.12	8.88±0.09	7.40±0.07	16.96±1.08	12.71±0.50	10.44±0.19
	15-30	15.60±0.20	13.60±0.14	10.80±0.11	12.40±0.12	10.40±0.10	15.40±0.15	10.80±0.11	9.40±0.09	23.19±0.69	22.00±0.63	20.17±0.61
	Mean	14.50±0.15	12.40±0.13	10.10±0.10	11.45±0.11	9.40±0.09	13.90±0.14	9.84±0.10	8.40±0.08	20.08±0.88	17.36±0.57	15.31±0.40
Exchangeable Mg (C mol (p+) kg^{-1}	0-15	23.89±0.26	29.28±0.32	28.12±0.28	28.74±0.46	27.15±0.64	34.17±0.36	32.16±0.32	24.16±0.24	34.16±0.31	32.48±0.35	28.11±0.30
	15-30	20.64±0.52	25.49±0.65	25.36±0.25	24.83±0.92	23.68±0.13	30.25±1.13	28.12±0.28	21.01±0.41	31.25±0.33	28.97±0.24	25.32±0.23
	Mean	22.27±0.39	27.39±0.48	26.74±0.27	26.78±0.69	25.42±0.39	32.21±0.74	30.14±0.30	22.58±0.33	32.70±0.32	30.73±0.30	26.71±0.26

An increase in fertility in both surface and subsurface soils indicates not only in soil surface inputs (e.g. Litter fall) but also in subsurface (e.g. Root sloughing and nutrient leaching). Although these results are only an indication of one decade of growth, the increased soil fertility, especially in the teak plantation is a resource that could be utilized by implementing understory crops.

In conclusion, in this study the soils of the agroforestry systems maintained the improvements of their chemical characteristics especially with repeat to increased levels of exchangeable Ca and Mg, available potassium while maintaining stable level of organic carbon when compared with cultivable land. However, available N fall to extremely low levels and available P fall to moderately low levels.

The increased soil fertility in both plantations, especially teak plantations would be beneficial for agricultural crops or agroforestry systems that can co-exist with the plantation. Further soil analysis would have to occur to determine if the increased fertility remains after the full rotation of the plantation, especially if agricultural crops will follow timber harvest. Thus, plantations with carefully evaluated agroforestry species could be employed as productive soil ameliorations in arid and semiarid soil of India.

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