Soil fertility status of 20 seed production areas of *Tectona grandis* Linn. f. in Karnataka, India

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ABSTRACT: The seed production area (SPA) is an improved plantation managed for production of quality seeds for a large-scale plantation programme. The soil nutrient is one of several factors affecting seed production among SPAs. The status of soil nutrients and their effect on seed production are poorly understood. Hence, the present study was undertaken in 20 seed production areas located in different seed zones of Karnataka, South India. Results showed that there was a greater variation among SPAs in various soil properties like soil pH, organic carbon, available NPK (nitrogen, phosphorus and potassium). Some of the studied parameters recorded significant variations among three different depths: 0–20 (top), 20–40 (middle) and 40–60 cm (bottom). For instance, organic carbon and available potassium showed significant variations at different depths, where the highest content was recorded in the top layer, followed by middle and bottom layers. Considering associations between soil properties and tree growth, organic carbon was positively associated with dbh (diameter at breast height; $r = 0.500$), stem roundness ($r = 0.351$) and stem volume ($r = 0.250$). Similarly, available nitrogen positively influenced the stem volume ($r = 0.250$). Though the fruit yield varied among SPAs, none of the studied soil parameters showed a significant influence on fruit yield indicating that some other factors like genetic ones, phenology, rainfall overlapping with peak flowering might control it. Data on site quality showed that all existing SPAs studied were growing in poor site conditions, however, this could be one of the factors affecting overall seed yield among SPAs. Hence, it is recommended to undertake a few important silvicultural interventions like application of fertilizer/organic manure, soil working, spraying of floral hormone and others to improve the existing seed production level.

Keywords: soil properties; seed production area; fruit production

Teak, *Tectona grandis* Linn. f. (family: *Verbenaceae*), is one of the major plantation tree species of the world, which is naturally distributed in Southeast Asia. It is a unique species whose timber is the most aristocratic amongst the timbers of India. Though the teak plantations account for 5–8% of the total forest area in the tropics (Ball et al. 1999), about 90% of the quality hardwood plantations for timber production belongs to teak only (Granger 1998). As estimated, India has 1.5 million ha of teak plantations with the annual planting target of 50,000 ha (Subramanian et al. 2000).

State Forest Departments are raising quality nursery stock using improved seeds from Clonal Seed Orchards (CSOs) and Seed Production Areas (SPAs). It is reported that clonal seed orchards produce very low fruit yield and this may be due to various factors like asynchronous flowering, flowering coincided with heavy rainy days, soil fertility and others (Gunaga, Vasudeva 2005). The soil is one of the factors that influence tree growth and fruit yield. Reviews showed that a plenty of available studies on soil properties are aimed at tree (stand) growth and development, but not at fruit yield among tropical tree species. Moreover, the site quality is another important factor that decides on the quantity of timber as well as on fruit production in any seed stands. However, the site quality of a stand is determined by various features like soil depth, soil texture, profile characteristics, mineral composition, steepness of slope, aspect, microclimate, species and others (Alexander et al. 1987).

Hence, the study of soil features and site quality of seed stand in relation to the quantity of seed production is very important. Such studies among seed production areas of teak in the country are very limited. Therefore, the present study was undertaken to characterize the soils of existing seed production areas of teak in Karnataka, South India, in relation to fruit yield.

MATERIAL AND METHOD

For the present study, 20 seed production areas (SPAs) of teak distributed in four seed zones: Dandeli, Yallapur, Shimoga and Madikeri of Karnataka, South India, were considered (Fig. 1). The age of the particular SPAs varied from 40 to 79 years and the average stocking (tree density per ha) ranged from 112 to 266 trees·ha^{-1}. Details of individual SPA regarding SPA code, locality, range, division, extent, sampled area and percentage of total area sampled are presented in Table 1.

All these SPAs were located in the Western Ghats part of Karnataka having the major soil group of laterite and lateritic soils (Ferralsols and Dystric Nitisols). The major limitations posed by these soils include deficiency of phosphorus (P), potassium (K), calcium (Ca), zinc (Zn) and boron (B), high acidity and toxicity of aluminium (Al) and manganese (Mn; FAO 2005).

Fig. 1. Map of 20 seed production areas of teak selected for the present study

In each SPA, three sample plots (with sampling intensity of about 2%) of 40 × 40 m^2 in size were laid out randomly during November 2005. For the soil sample collection, one pit per sample plot (pit size of 0.30 m in width × 1.0 m in length) was dug up to the depth of 60 cm using implements such as spade, pick-axe and crow bar. Soil samples were collected from three different layers, 0–20, 21–40, and 41–60 cm from each soil pit. For each SPA, one composite sample from each layer was prepared by properly mixing the soils from three sample plots. Then, these samples were labelled and transported to the laboratory for further soil analyses. Soil properties such as pH, electrical conductivity (EC), organic carbon, available nitrogen, phosphorus and potassium were analysed by the following standard methods (Tandon 1995) at the Soil Laboratory of Krishi Vigyana Kendra (KVK) of Sirsi Campus of University of Agricultural Sciences, Dharwad, Karnataka:

Station No.	Soil properties	Methods/source
1	soil pH	digital pH meter
2	electrical conductivity	conductometry method
3	organic carbon	walkley-Black wet oxidation method
4	available nitrogen	alkaline permanganate method using Kal Plus Distyl EM instrument
5	available phosphorus	bray's method
6	available potassium	flame photometer method

For evaluating variability with respect to physical and chemical soil properties, three working samples (replications) from composite samples of each layer (depth) were used for the particular SPA [20 SPAs × three layers (layer-wise composite samples from three sample plots) × three replications]. Further, the soil data were subjected to statistical analysis using mStat-C package and analysis of variance (ANOVA) was constructed.

Simple Pearson's correlation analysis was done using soil properties (organic carbon, available nitrogen, phosphorus, potassium, soil pH and electrical conductivity) and tree parameters (mean values of tree height, bole height, diameter at breast height, stem straightness, roundness, tree volume) with fruit production. This analysis was done using three replicated values of all the 20 seed production areas (N = 60 values derived from 3 sample plots

Table 1. Details of seed production areas of teak with respect to location, area, year of establishment, forest ranges and geo-coordinates

SPA Code	SPAs	Extent (ha)	Year of establishment	Research range	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)
D	Dandeli seed source						
D1	Hudsa	20.0	1927	Gund	15°08.647'	74°31.780'	510
D2	Bhagavati	50.0	1928	Bhagavati	15°09.889'	74°43.738'	422
D3	Janata Colony	20.0	1950	Dandeli	15°13.219'	74°36.856'	513
D4	Kulagi	10.0	1950	Kulagi	15°09.708'	74°38.241'	538
D5	Veerampalli Plot 1	8.8	1951	Dandeli	15°13.216'	74°35.766'	599
D6	Veerampalli Plot 2	11.2	1952	Dandeli	15°13.421'	74°35.924'	562
D7	Virnoli	20.0	1957	Dandeli	15°13.219'	74°36.856'	513
M	Madikeri seed source						
M1	Moovakal 1	34.4	1930	Thithimatti	12°15.233'	75°59.708'	899
M2	Moovakal 2	27.0	1931	Thithimatti	12°15.242'	75°59.219'	918
M3	Moovakal 3	30.0	1932	Thithimatti	12°15.240'	75°59.486'	870
M4	Devamachi 1	25.0	1936	Thithimatti	12°16.141'	75°59.176'	933
M5	Devamachi 2	25.0	1937	Thithimatti	12°16.209'	75°59.095'	921
S	Shimoga seed source						
S1	Sannivasa	13.0	1941	Anandapura	14°04.913'	75°19.211'	696
S2	Gaddemane	23.0	1956	Anandapura	14°05.132'	75°16.818'	655
S3	Konehosur	22.0	1959	Anandapura	14°05.345'	75°17.393'	711
S4	Halkuni	24.0	1963	Anandapura	14°05.793'	75°21.014'	638
Y	Yallapur seed source						
Y1	Gunjavati 1	21.0	1937	Yallapur	14°59.377'	74°54.408'	500
Y2	Gunjavati 2	20.0	1937	Yallapur	14°59.122'	74°54.037'	508
Y3	Kanderayana Koppa 1	15.0	1941	Kiravatti	15°00.520'	74°51.777'	585
Y4	Kanderayana Koppa 2	15.0	1964	Kiravatti	15°00.451'	74°51.838'	585

used as replications × 20 seed production areas used as treatments = 60 values).

RESULTS AND DISCUSSION

The teak is a deciduous tree species occurring on a variety of geological formations usually in acidic soils, but it grows up to the soil pH of 8.5 and beyond this it suffers from poor growth (Balagopalan, Jose 1991; Tewari 1992). In the present study, a significant variation among Seed Production Areas (SPAs) for soil pH was recorded and it varied from 5.04 (S3) to 5.81 (S4) with an overall mean of 5.41 (Table 2). It revealed that the soils of all studied SPAs are acidic in nature. Further, Aparanji (2000) reported that teak plantations located at different bio-climatic zones of Karnataka showed significant variation in respect of bulk density (1.15–1.6 $g\cdot cm^{-1}$) and soil pH (6.2–8.2). Banerjee et al. (1986) reported the good growth of teak even under the soil pH of 4. Akinsanmi (1985) showed a significant association between the volume increment of teak and soil pH. Ezenwa (1988) reported that soil pH is positively correlated with tree heights and basal area.

Among 20 SPAs, soil organic carbon significantly varied from 0.72 (M1) to 1.44% (D2 and S2). Available nitrogen ranged from 164.22 (D3) to 206.22 $mg\cdot kg^{-1}$ (S3) with an overall mean of 191.68 $mg\cdot kg^{-1}$. Only two SPAs recorded the lowest value of available nitrogen and the remaining SPAs recorded more available nitrogen (> 180 $mg\cdot kg^{-1}$).

Table 2. Variations in different properties of soil among twenty Seed Production Areas of teak in Karnataka

SPA Code	Teak SPA	pH	EC (dS·m^{-1})	OC (%)	N (mg.kg^{-1})	P (mg.kg^{-1})	K (mg.kg^{-1})
D1	Hudsa	5.25	0.192	0.99	198.89	6.96	355.11
D2	Bhagavati	5.35	0.162	1.44	199.33	6.25	181.78
D3	Janata Colony	5.47	0.147	0.92	164.22	6.18	192.22
D4	Kulagi	5.30	0.138	1.38	206.22	6.58	300.89
D5	Veerampalli 1	5.51	0.154	1.30	197.56	6.53	265.33
D6	Veerampalli 2	5.43	0.185	1.41	188.00	4.96	392.89
D7	Virnoli	5.06	0.175	1.08	183.78	6.26	416.00
M1	Moovakal–1930	5.50	0.182	0.72	175.33	3.84	482.67
M2	Moovakal–1931	5.80	0.219	1.13	180.89	4.19	328.22
M3	Moovakal–1932	5.74	0.187	1.43	203.33	5.52	309.33
M4	Devamachi–1936	5.47	0.168	1.28	204.67	7.96	156.89
M5	Devamachi–1937	5.57	0.173	1.19	188.22	4.56	294.89
S1	Sannivasa	5.16	0.163	1.03	191.11	4.44	334.44
S2	Gaddemane	5.42	0.119	1.44	206.00	2.52	353.11
S3	Konehosur	5.04	0.147	1.32	193.33	2.94	334.44
S4	Halkuni	5.81	0.156	1.20	189.33	3.93	215.33
Y1	Gunjavati 1	5.20	0.168	1.11	187.33	6.46	243.11
Y2	Gunjavati 2	5.27	0.153	1.24	189.78	6.34	225.11
Y3	Konderayana Koppa 1	5.43	0.146	1.20	189.33	6.43	252.67
Y4	Konderayana Koppa 2	5.47	0.162	1.36	196.89	6.07	319.78
	Mean	5.41	0.165	1.21	191.68	5.45	297.71
	SEm (±)	0.09	0.020	0.12	5.97	0.65	25.90
	CD at 5% *P*	0.25	NS	0.33	16.99	1.85	73.76
	CV (%)	2.85	20.87	16.04	5.39	20.68	18.07

NS – not significant

In the case of available potassium, it ranged from 2.52 (S2) to 7.96 mg·kg^{-1} (M4). Among 20 SPAs, 10 SPAs recorded a higher level of available potassium (> 6 mg·kg^{-1}; Table 2).

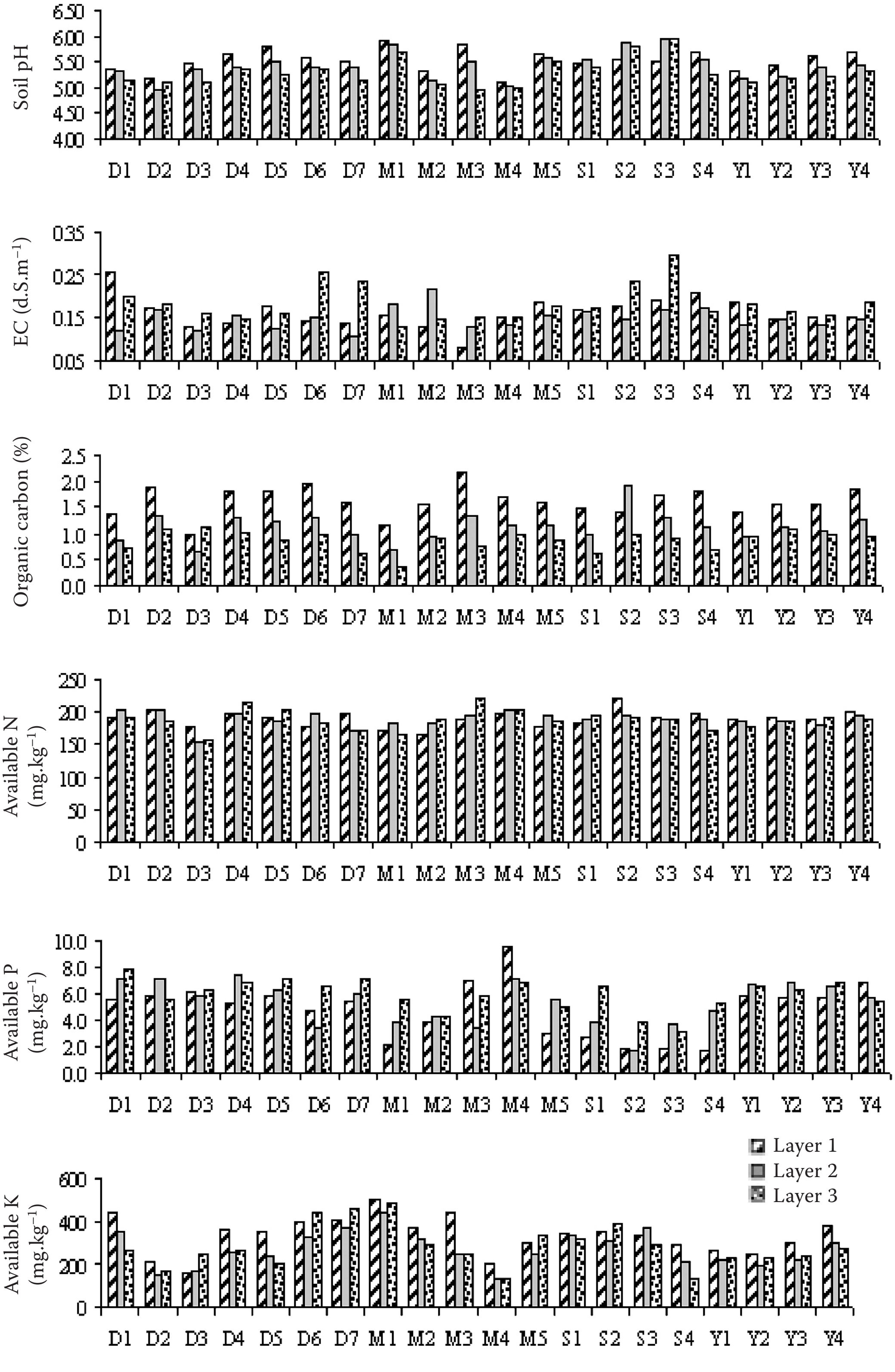
Most of SPAs that belonged to Dandeli and Yallapur seed zones of Karnataka recorded higher values of available potassium than the other seed zones indicating the influence of seed zone on soil rich in potassium.

A wide range of variation was also recorded among SPAs for available phosphorus, where it ranged from 156.89 (M4) to 482.67 mg·kg^{-1} (M1) with an overall mean of 297.7 mg·kg^{-1}. 11 out of 20 SPAs showed the highest available phosphorus of more than 300 mg·kg^{-1} soil. Further, the soil of SPAs D4 and D1 was found to be rich in available nitrogen, phosphorus and potassium. Similarly, the soil of other SPAs like D5, M4 and S2 also showed superiority with respect to available NPK with organic carbon (Table 2).

Significant variation among the three soil layers of 20 SPAs was also recorded in the present study ($P \geq 0.05$; Fig. 2).

Organic carbon and available nitrogen were found to be on a higher level in the top layer (0–20 cm), followed by middle (21–40 cm) and bottom (40 to 60 cm) layers in most of the SPAs. However, this trend was not seen in the other soil parameters in different SPAs.

Such observations of different soil nutrients among teak plantations were recorded by Tewari et al. (1994), where nitrogen varied from 0.13 to



	pH	EC	Organic carbon	Available N	Available P	Available K
CV (%)	2.22	10.06	31.54	0.61	17.04	11.04
F-ratio	12.07	4.81	71.91	0.29	2.47	10.75
P level	< 0.01	< 0.01	< 0.01	NS	NS	< 0.01

Fig. 2. Variation in chemical properties of soil across three layers among twenty SPA's of teak in Karnataka

Table 3. The influence of soil chemical properties on tree growth and fruit production in SPAs of teak in Karnataka

Variables	Organic carbon	Available			pH	EC
		nitrogen	phosphorous	potassium		
Tree height	0.173	0.156	–0.204	–0.168	0.092	0.083
Bole height	0.060	0.007	–0.138	–0.192	0.043	–0.029
dbh	**0.480****	0.215	**–0.252***	–0.121	0.152	–0.074
Crown diameter	–0.132	–0.056	–0.073	–0.105	–0.174	0.128
Straightness	0.217	0.048	–0.235	–0.137	–0.062	–0.134
Roundness	**0.342****	–0.135	–0.074	0.126	**0.298***	0.078
Tree volume	**0.495****	**0.259***	**–0.294***	–0.112	0.122	–0.067
Fruit yield	–0.006	0.163	–0.128	–0.058	–0.012	0.034

*Significance at P = 5% (Pearson's correlation value r = 0.250)

**Significance at P = 1% (Pearson's correlation value r = 0.350)

0.072% on the surface and decreased in the subsoil from 0.0056 to 0.05% at about 100 cm depth, while available phosphorus ranged from 2 to 21 mg.100 g^{-1} and it was reverse in total potassium content, where more potassium was recorded in subsurface soil (0.54 to 1.80%) and less in surface soil (0.40 to 1.13%). However, high leachability was noticed in surface soil.

The study of correlations showed a few strong associations of soil properties with tree growth characters. Organic carbon was positively associated with tree diameter (r = 0.500), stem roundness (r = 0.351) and stem volume (r = 0.502; Table 3).

Available nitrogen showed a significant positive influence on tree volume (r = 0.250), whereas available phosphorus was negatively correlated with tree diameter at breast height (r = –0.268) and stem volume (r = –0.282; Table 3). This relationship could largely be due to an ameliorative function of these nutrients which directly control the soil fertility. Such trends were also reported by Aparanji (2000) among different teak plantations of Uttara Kannada district of Karnataka, India, where major nutrients such as available NPK showed a positive association with stand growth and tree volume. Further, Prabhu (2007) recorded that SPAs of Kerala did not show a significant influence of soil properties (like organic carbon, total N, available P and K) on fruit yield. Further, he also mentioned that SPAs located in the Parambikulam seed zone recorded higher fruit yield as influenced by higher contents of organic carbon, available P, Ca, Mg and total nitrogen with high water-holding capacity. Kumar et al. (2009) recorded the nutrient status of dry biomass in a teak plantation where the total wood biomass contained 165.47 kg·ha^{-1} of N, 20.96 kg·ha^{-1} of P and 35.06 kg·ha^{-1}. This indicates that the NPK level in soil is around 3 times higher than that of N, about four times higher than that of K and about 8 times higher than that of K as compared to the NPK level in dry wood biomass.

It followed from the study that even though a significant variation was recorded for various soil properties as well as fruit yield among SPAs, none of these soil nutrients significantly correlated with fruit yield indicating that the soil degradation might be one of the causal factors for this (Chauhan 1972; Nair et al. 1996; Vimal et al. 2003). Hence, soil enrichment is necessary to improve the fruit production level in a seed stand. Further, it is shown that fruit yield in teak is affected by several factors other than the soil properties like phenology, rainfall coincided with peak blooming period, crown exposed to light, pollinator activity during blooming and genetic factors (Gunaga, Vasudeva 2005; Indira 2005; Gunaga 2008).

The site quality is one of the potential indicators of stand that determines the production of timber as well as fruit yield. Krusche and Melchior (1977) reported that trees growing in fertile soil produced more flowering than trees growing in poor or infertile soil. Similarly, Tewari (1992) also reported a significant role of site quality where trees growing in site quality classes I and II produced a higher volume of wood than the site with quality classes IV and V, which recorded the lowest tree volume. Hence, determination of site quality is important to manage the stand whether for higher volume or fruit yield. In the present study, sixteen out of the twenty SPAs, nearly 80%, were growing in areas with site quality classes IV and V and the remaining SPAs were under site class III. Interestingly, none of the studied SPAs belonged to category I or II. This could be another reason for the low fruit yield among seed production areas (Gunaga 2008). Therefore, it is recommended to improve the nutrient status of soils in the studied SPAs using inorganic fertilizers or organic manures (Tewari 1992; Balagopalan, Chacko 2001).

CONCLUSION

It is concluded that the existing seed production areas showed a significant variation in various soil properties. Some of these properties showed a strong positive association with stand growth, but not with fruit yield. The results indicated that most of the SPAs of Karnataka are growing in poor site quality classes indicating the soil degradation occurring in the stand, which needs several silvicultural interventions like application of fertilizer, organic manure, bio-fertilizer, canopy manipulation, soil working, hormonal spraying and others to enhance the seed production.

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