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Root characteristics of tea [C*amellia sinensis* (L.) O. Kuntze] and silver oak [*Grevillea robusta* (A. Cunn)] in a mixed tea plantation at Munnar, Kerala

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Abstract

Rooting characteristics of tea (*Camellia sinensis*) and silver oak (*Grevillea robusta*) were evaluated in a mixed plantation of these species in the Western Ghats in Munnar, Kerala employing three techniques viz., root excavation, measurement of starch concentration, and root cation exchange capacity (CEC) determination. Root systems of three representative trees of *G. robusta* and three tea bushes were exposed by systematically removing the soil both in the vertical and horizontal planes. While a majority of tea feeder roots (47%) were found in the surface (0 to 22.5 cm) and sub-surface (22.5 to 45.0 cm) layers of the soil, *G. robusta* had only a relatively smaller proportion (33%) of their fine roots in these layers. The feeder roots of *G. robusta* (67%) were mostly found in the soil layers below 45 cm implying complementarity in resource use by tea and *G. robusta*. *G. robusta* roots also penetrated deeper into the soil profile (2.4 m) compared to that of tea bushes, which were confined within a limit of 1.5 m. Starch concentrations of coarse roots (> 2 mm diameter) of *G. robusta* and tea, analyzed at monthly intervals as a measure of nutrient demand, suggest that *G. robusta* had lower starch levels than tea roots and an inverse relationship existed between the two species. *G. robusta* trees, however, had higher root CEC than tea plants, which again signifies that interspecific competition for plant nutrients like N and K in such systems, may not be substantial.

Keywords: Feeder roots, Mixed species plantations, Rooting pattern, Root starch reserves, Root cation exchange capacity

Introduction

Agroforestry is often more productive than either monospecific crop or tree production systems, especially when the trees and crops exhibit some degree of spatial complementarity in resource use (van Noordwijk et al., 1995). Woody perennials are generally known to use their extensive root system for uptake of nutrients from the lower horizons of the soil profile (Kumar, 2006), besides enriching the topsoil through leaf litter (Kumar, 2007). Yet, certain tree-crop combinations have been found to be competitive too (George et al., 1996; Newaj et al., 2000). Knowledge about the root distribution pattern of different tree species used in mixed species production systems could lead to selection of those species that do not compete with agricultural crops when grown in association (Toky and Bisht, 1992). It would also be useful for fine-tuning the cultural operations and rationalizing the use of costly inorganic inputs.

In the tea [*Camellia sinensis* (L.) O. Kuntze] estates of southern India, silver oak [*Grevillea robusta* (A. Cunn)] has been the shade tree of choice. Although some previous studies from East Africa (McCulloch et al., 1993) have indicated that tea bushes were able to exploit the soil more effectively than the roots of shade trees, this aspect has not been validated in the tea – *G. robusta* systems of southern India. Furthermore, in the perennial shaded systems, the extent of tree-crop interactions may be dependent on factors such as soil and climate. Yet root interactions of tea and the associated shade trees have been seldom evaluated in the peninsular Indian context. Although excavation of tree root systems is widely regarded as an ideal method to assess root

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interactions, it is often cumbersome. Therefore, alternate methods have been suggested for root studies. In particular, measurement of starch concentration in roots can lead to better assessment of productivity in terms of photosynthetic efficiency and nutrient uptake patterns (Jeyaramraja et al., 2002). A knowledge of root CEC is also useful in understanding the dynamics of plant nutrition and compatibility of plants in mixed plantations (Ranganathan and Narayanan, 1979). The results obtained from such diverse approaches are, however, variable. An attempt was made to assess the complementary/competitive nature of *G. robusta* shade trees in tea plantations by studying their root distribution pattern and variations in the temporal pattern of root starch reserves and root CEC, besides assessing the degree of concordance among the three approaches.

Materials and Methods

The study was conducted in tea fields of Tata Tea Limited at Madupatty Estate, previously known as Kanan Devan Hills, located in the Western Ghats in Central Kerala (10°5' N 77°4' E; 1550 m above mean sea level) during the period April 2002 to March 2004. The site situated on the eastern side of the slope received an annual rainfall of 1940.7 mm for the period from April 2002 to March 2003 and 2127.2 mm for the period from April 2003 to March 2004. Mean annual minimum and maximum temperatures were 12°C and 22°C respectively. The soil of the experimental site was predominantly lateritic (Oxisols) with a pH range of 4.0 to 5.5.

Tea has been grown in this locality for a long time with *G. robusta* as the shade tree. *G. robusta* is normally planted at a spacing of 6 x 6 m in new tea clearings to provide shade to young tea plants. However, once the tea plants are established (within 10 years) the shade trees are routinely thinned by removing alternate trees in the north-south direction maintaining a spacing of 12 x 6 m. The trees are also pollarded at 9 m height leaving one branch in each direction. Annual lopping of the pollarded *G. robusta* is carried out during April/May to regulate light reaching the tea canopy. While lopping, 20% of the foliage is left on the crowns by retaining the lateral spreading branches and removing only the erect growing branches.

Root excavation

Three 10 year-old *G. robusta* trees and tea bushes each in the same plot were excavated during the month of April 2003. The trees and bushes, which corresponded to the mean height, diameter at breast height, collar diameter, and crown spread of the stand were selected for excavation. The top portion of trunk of *G. robusta* was cut and removed and the tree trunk cum root systems were anchored to retain their normal positions throughout the process of digging the soil and exposing the roots. In order to assess the spread of roots both vertically and horizontally, the rhizosphere was divided into different zones vertically (0 to 22.5, 22.5 to 45.0, 45.0 to 67.5, and 67.5 to 90.0 cm) and horizontally (0 to 50, 50 to 100, and 100 to 150 cm). First, the soil in the zone corresponding to 0 to 22.5 cm vertical depth and 0 to 50 cm lateral distance was removed carefully by thin pointed iron rods and were kept separately for retrieval of roots, if any, at a later stage. Then the soil from 0 to 22.5 cm vertical depth and 50 to 100 cm lateral distance was removed and kept similarly. The process of removing soil from different zones as defined by vertical and lateral distances of the rhizosphere continued till the whole root system of the marked trees/bushes was fully exposed in all directions. Following this, the vertical distance to which the roots penetrated was measured. The number of tap, primary, secondary, and tertiary roots were also counted from the exposed root systems. Soil from each "zone," which was kept separately, was washed to separate the roots from soil. The roots were counted and categorized as fine (<2 mm diameter), thin (2 to 5 mm), medium (5 to 15 mm), and coarse (>15 mm). The whole root mass excavated was oven-dried at 65 ± 1° C and weighed.

Determination of starch concentrations

Ten year-old tea field interspersed with *G. robusta* shade trees of same age was used for determination of root starch reserves. Three plants each of *G. robusta* and tea were selected based on the criteria mentioned above.

After removing the soil covering root system, coarse roots (roots having >2 mm diameter) were cut, washed with distilled water to remove extraneous matter adhering to the roots, and dried overnight at 80°C until constant weights. The roots were treated with 80% ethanol to remove sugars and then starch was extracted with 52% perchloric acid. In the hot acidic medium, starch hydrolyses to glucose and forms hydroxymethyl furfural. This compound gives a green coloured product with anthrone, which was estimated colorimetrically following Sadasivam and Manickam (1992).

Measurement of root cation exchange capacity (CEC)

Root CEC was determined as per the method described by Crooke (1964). As it is known that root CEC decreases and stabilizes after reaching maturity, four plants each of *G. robusta* and tea for each age group varying from 1 to 25 years were selected based on the criteria mentioned under root excavation study. Root samples (feeder roots with less than 2 mm diameter) were collected by loosening and lifting a soil block containing as much as possible of the root system of these plants and freeing the roots from the bulk of the soil by jets of water. The final separation was achieved by placing roots on sieve under running water and using a combination of gentle agitation and floatation. The root samples were dried overnight at 80ºC and ground to pass through 0.7-1.0 mm sieve. After thorough mixing, sub samples of 0.1 g were taken in a 400 ml beaker, moistened with few drops of distilled water, and allowed to become thoroughly wet to prevent root debris floating on the surface during the next stage. To this, 200 ml of 0.01N HCl was added and stirred intermittently for 5 min. The root material was filtered through Whatman No. 1 filter paper and washed with distilled water until the washings were free of chloride. The filter paper was pierced and the root material was washed into 250 ml beaker using 200 ml M KCl (pH adjusted to 7.0). The pH of root-KCl suspension was determined and titrated against 0.01 N KOH solution with intermittent stirring to restore the pH of 7.0, which was maintained for at least 5 min. The CEC of roots was expressed in $cmol\ kg^{-1}$ of root material.

Statistical analysis

The species-wise data from the root excavation study were analyzed following ANOVA for split plot design with vertical depth as the main plot and lateral distance as the sub-plot factors. The individual trees of each species constituted replicates and the treatment means were compared using Least Significant Difference (LSD). In starch concentration and root CEC studies, the period of sampling and age of the plant were taken as treatments respectively and the treatment means were compared using Duncan's multiple range test, following ANOVA.

Results and Discussion

For a given soil depth, there was significant difference in weight of roots obtained in different lateral distances, irrespective of size. Root distribution of *G. robusta* was characterized by the occurrence of less number of feeder (fine) roots and an abundance of coarse roots near the soil surface. The bulk of root mass for *G. robusta* (67% of <2 mm, 66% of 2 to 5 mm roots and 94% of 5 to 15 mm roots) was found at a depth of 45.0 to 67.5 cm. In contrast, the majority of the fine roots of tea were found in the 0 to 45 cm depth (47% on weight basis; Table 1; Figures 1 and 2). Such spatial segregation of coarse and fine roots of trees is consistent with the findings of van Noordwijk et al. (1995) who concluded that as the distribution of feeder roots of a crop and associated tree is complementary, and competition for water and nutrients is likely to be less between them. While the fine roots constituted only a small fraction of total root mass in the case of *G. robusta* (0.48%), it contributed 9.81% of the total root weight in the case of tea. The share of roots of >15 mm size is more in the case of *G. robusta* (96.4%) compared to tea (69.6%). Our results are consistent with that of earlier studies on the root distribution in tea-*G. robusta* system in East Africa (McCulloch et al., 1993).

G. robusta roots also penetrated deeper into the soil (2.4 m as against 1.5 m for tea roots; Table 2). Both genetic characters and soil conditions (Toky and Bisht,

Table 1. Size class distribution of *Grevillea robusta* and tea roots at different soil depths and lateral distances in the Oxisols of Munnar, Kerala (*n* = 3) .

Soil depth (cm)	Lateral distance (cm)	*G. robusta* roots (g)					Tea roots (g)				
		Root size classes (mm)									
		< 2	2–5	5–15	>15	Total	< 2	2–5	5–15	>15	Total
0–22.5	0–50	n/a	n/a	n/a	7489 (38.42)	7489	29 (1.70)	22 (1.25)	114 (1.70)	69 (3.68)	234
	50–100	12 (0.47)	28 (0.94)	9 (1.41)	3709 (73.81)	3758	82 (2.36)	69 (2.16)	137 (3.74)	139 (6.16)	427
	100–150	9 (0.47)	11 (1.25)	n/a	1604 (46.23)	1624	9 (0.47)	9 (0.47)	36 (2.49)	557 (18.84)	611
LSD (0.05)		2.47	5.80	5.24	353	357	10.91	9.41	17.82	74.73	73.46
22.5–45.0	0–50	n/a	n/a	n/a	n/a	n/a	43 (2.05)	22 (0.94)	82 (2.49)	929 (32.14)	1076
	50–100	4 (1.25)	11 (0.82)	12 (0.94)	1296 (4.50)	1323	11 (0.47)	10 (0.82)	65 (3.30)	948 (27.07)	1034
	100–150	n/a	n/a	n/a	76 (3.27)	76	44 (1.70)	27 (0.82)	34 (1.70)	267 (7.26)	372
LSD (0.05)		4.62	3.03	3.49	20.60	27.96	10.04	5.53	16.58	158.06	159.37
45.0–67.5	0–50	11 (1.25)	10 (0.27)	24 (1.89)	129 (3.09)	174	36 (0.82)	32 (0.94)	52 (3.86)	149 (8.73)	269
	50–100	40 (0.94)	86 (1.25)	290 (6.02)	754 (2.49)	1170	43 (2.05)	28 (0.94)	19 (3.09)	172 (5.10)	262
	100–150	n/a	n/a	n/a	n/a	n/a	110 (3.30)	87 (2.05)	66 (2.83)	n/a	263
LSD (0.05)		5.80	8.20	23.38	14.72	46.83	14.72	9.08	21.12	37.48	NS
67.5–90.0	0–50	n/a	n/a	n/a	n/a	n/a	58 (1.63)	22 (1.63)	40 (6.18)	61 (3.09)	181
	50–100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	100–150	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LSD (0.05)		-	-	-	-	-	6.05	6.05	22.92	11.46	16.85

n/a – not available; values in parenthesis are standard errors of mean.

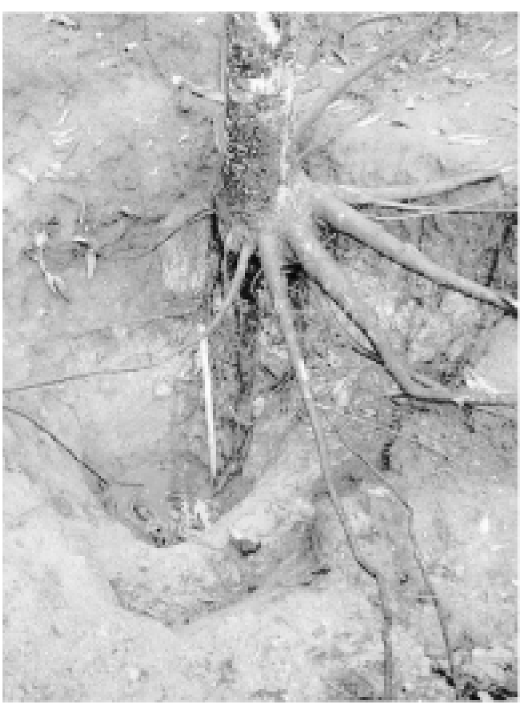

Figure 1. Root distribution pattern of a 10 year-old representative *Grevillea robusta* tree grown for shade purposes in a tea plantation in the Oxisols of Munnar, Kerala.

1992) are responsible for the distribution of root system through space and time. This would also enable the trees to capture nutrients that would have been leached from the upper horizons of the soil profile; thus increasing efficiency of nutrient use ("safety net hypothesis": Divakara et al., 2001).

The data in Table 3 reveal significant differences in starch concentration during different months in both *G. robusta* and tea. The starch concentration in tea roots was higher than that of *G. robusta* irrespective of the period of sampling. Moreover, the magnitude of change in starch concentration of *G. robusta* was relatively narrow. In particular, it was low during the period June-August and peaked during October (131.3 mg g^{-1}). Conversely, starch concentration in tea roots was relatively high during the period June-August and then it decreased and reached the lowest during October (71.9 mg g^{-1}). The inverse relationship between starch reserves in tea and *G. robusta* can be explained by the nature of growth of tea bushes in south Indian conditions. For instance, tea growth is characterized by two distinct peaks: April-May and

Table 2. Stand and root characteristics of 10-year-old *Grevillea robusta* and tea plants (*Camellia sinensis*) in the Oxisols of Munnar, Kerala.

Parameter	*G. robusta*	Tea
Stand density (number per ha)	140	10000
Diameter at breast height (cm)	17.7	10.0
Height (m)	12	0.9
Number of tap roots	3	1
Number of primary roots (originating from main root, irrespective of size)	15	12
Number of secondary roots (originating from primary roots)	345	378
Number of tertiary roots (originating from secondary roots)	763	1036
Maximum length of vertically growing root (m)	2.4	1.5

October-November. According to Selvendran and Selvendran (1972) as tea leaves are harvested intensively during these peaks, reserve carbohydrates present in the roots, mainly as starch granules get depleted. The tea leaf production, however, is relatively low during the months of July and August under southern Indian conditions, leading to accumulation of photosynthates in the roots. As photosynthesis is influenced by an adequate supply of nutrients from the soil, it is likely

Figure 2. Root distribution pattern of 10 year-old representative tea plant from a tea- *Grevillea robusta* mixed species production systems in the Oxisols of Munnar, Kerala.

Table 3. Monthly variations in root starch concentration of *Grevillea robusta* and tea (*Camellia sinensis*) in the Oxisols of Munnar, Kerala (*n*=3).

Month	Root starch concentration (mg g^{-1})	
	G. robusta	Tea
Apr 2002	91.8^{bcdef} (5.28)	$133.3^{bcdefgh}$ (1.45)
May 2002	94.7^{bcde} (3.56)	137.4^{bcdef} (1.72)
Jun 2002	84.3^{bcdefg} (1.85)	146.6^{bcde} (2.83)
Jul 2002	84.3^{bcdefg} (1.76)	220.3^{a} (2.30)
Aug 2002	$85.3^{bcdefgh}$ (3.35)	163.5^{bc} (2.14)
Sep 2002	89.5^{bcdefg} (5.68)	112.0^{cde} (4.04)
Oct 2002	131.3^{a} (2.44)	$71.9^{cdefghij}$ (4.23)
Nov 2002	79.8^{bcdefg} (2.74)	136.3^{bcdefg} (2.34)
Dec 2002	$85.3^{bcdefgh}$ (3.98)	106.5^{cde} (2.10)
Jan 2003	95.4^{bcd} (5.39)	113.4^{cde} (3.20)
Feb 2003	$60.9^{cdefghi}$ (2.46)	158.9^{bcd} (1.99)
Mar 2003	102.4^{bc} (2.04)	$123.0^{bcdefghi}$ (1.96)

Values in parenthesis indicate standard error of mean; Means were compared using Duncan's multiple range test at the 5% significance level; Mean values with the same superscript do not differ significantly.

that nutrient uptake will also follow a similar trend as starch reserves (Jeyaramraja et al., 2002). The inverse relationship between starch concentration in roots of *G. robusta* and tea suggests possibility of lack of competition for nutrients between these plants.

Table 4. Root cation exchange capacity of *Grevillea robusta* and tea (*Camellia sinensis*) at different growth stages of growth in the Oxisols of Munnar, Kerala.

Age of plants (yr)	Root cation exchange capacity (cmol kg^{-1})	
	G. robusta	Tea
1	28.59[a] (1.15)	25.57[a] (1.68)
2	28.40[ab] (1.43)	23.94[a] (1.35)
3	28.20[abc] (1.13)	22.84[a] (3.06)
4	26.45[abc] (1.96)	22.05[a] (1.87)
6	23.87[abc] (1.99)	21.54[a] (3.03)
7	23.28[abc] (2.56)	20.97[a] (1.39)
8	22.30[abc] (1.76)	20.69[a] (2.78)
9	22.47[abc] (2.21)	20.48[a] (1.27)
10	22.10[abc] (2.44)	20.39[a] (2.07)
11	22.20[abc] (1.06)	19.59[a] (3.40)
12	22.20[abc] (1.29)	18.15[a] (1.82)
13	21.70[abc] (2.53)	17.77[a] (0.38)
14	20.90[bcd] (1.45)	17.58[a] (1.80)
15	20.90[bcd] (0.77)	17.54[a] (1.73)
17	20.80[bcd] (1.20)	17.29[a] (0.87)
25	20.75[bcd] (1.55)	16.18[b] (0.88)

Means were compared using Duncan's multiple range test at the 5% significance level; Mean values with the same superscript do not differ significantly. Values in parenthesis indicate standard error of mean.

There was significant difference in root CEC between plants of different maturity. This was observed in both *G. robusta* and tea plants. For a given age, *G. robusta* possessed a higher root CEC than the tea plants and a progressive decrease in the root CEC for both *G. robusta* and tea with age were noticed (Table 4). Root CEC is a useful parameter in the compatibility study of plants in an ecosystem and can be used as a possible explanation for the differential uptake of mono- and divalent cations by different plants (Blaser and Brady, 1950; Mouat and Walker, 1959). In a base deficient medium, the availability of cations is determined by the competition for exchange by the roots of different plants. In tea cultivation, the roots of shade trees (*G. robusta*) can compete with tea plants for nutrients. However, *G. robusta* roots with high CEC are essentially surrounded by more of divalent cations like Ca^{2+} and Mg^{2+} and less of monovalent cations like NH_4^+ and K^+. Due to higher root CEC, *G. robusta* trees may find it difficult to compete with tea plants for N and K as these two major nutrients are assimilated in monovalent forms. Our study points to the possibility of complementary sharing of soil resources like nutrients and soil moisture between tea and *G. robusta*. Furthermore, there is reasonable concordance among the three methods as they all denote temporal or spatial segregation of the resource acquisition capacities of tea and its preferred shade tree. Therefore, the utility of *G. robusta* as a desirable shade tree for tea gardens in Western Ghats, is confirmed as it possesses a spatially segregated root system in relation to tea plants.

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