J. Biosci., Vol. 19, Number 1, March 1994, pp 103-116. © Printed in India.

Fine root dynamics in two tropical dry evergreen forests in southern India

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MS received 12 April 1993; revised 11 November 1993

Abstract. Seasonality in fine root standing crop and production was studied in two tropical dry evergreen forests viz., Marakkanam reserve forest (MRF) and Puthupet sacred grove (PSG) in the Coromandel coast of India. The study extended from December 89 to December 91 in MRF and from August 90 to December 91 in PSG with sampling at every 2 months. Total fine interval. Mean fine root standing crop was 134 g m^{-2} in MRF and 234 g m^{-2} in PSG. root production was 104 g m^{-2} yr^{-1} in MRF and 117 g m^{-2} yr^{-1} in PSG. These estimates lie within the range for fine roots reported for various tropical forests. Rootmass showed a pronounced seasonal pattern with unimodal peaks obtained during December in the first year and from October-December in the second year in MRF. In PSG greater rootmass was noticed from June-October than other times of sampling. The total root mass in MRF ranged from 114 to 145 g m^{-2} at the 13 sampling dates in the three sites.

The live biomass fraction of fine roots in MRF ranged from 46 to 203 g m^{-2} and in PSG it ranged from 141 to 359 g mm $^{-2}$ during the study periods. The dead necromass fraction of fine roots ranged from 6 to 37 g m^{-2} in MRF and from 12 to 66 g m^{-2} in PSG. Fine root production peaked during December in both the forest sites. The necromass fraction of newly produced roots was negligible.

Total N was slightly greater in PSG than in MRF. Whereas total P level was almost similar in both the sites. The study revealed that season and site characteristics influenced fine root system.

Keywords. Dry evergreen forest; soil monoliths; fine-root production; biomass; necromass; seasonality.

1. Introduction

Roots are the link between soil and plants. Seasonal periodism in root growth is common in woody plants (Hermann 1977; Santantonio *et al* 1977; Vogt *et al* 1981) and is reported for various tropical and temperate zones. Fine roots exert a significant influence on the soil profile development and when dead contribute substantially to the organic pool of the soil (Persson 1978, 1979, 1982, 1983a, b). Also the knowledge of Hine root biomass is important for understanding energy flow and nutrient cycling (Aerts *et al* 1992; Khiewtam and Ramakrishnan 1993). It was not until the 1970s that root studies were carried out in context of ecosystem functioning. These studies included estimates of the rate of change in the amount of fine root fractions, both in terms of dry weight and in mineral nutrient content (Persson 1990). Only in the last two decades have there been some attempts to understand roots as part of the entire forest system (Hermann 1977; Santantonio *et al* 1977). Data from numerous studies have shown that the greatest proportion of the root

systems of many forests is located in the upper soil horizons (Vogt *et al* 1983). The roots near the soil surface undergo much rapid changes than the deep roots (Hendrick and Pregitzer 1992).

Root productivity is one of the most difficult ecosystem parameters to measure (Jordan and Escalante 1980) and studies on root production have been partly hindered by the lack of simple and feasible techniques (Hamzah *et al* 1983). Fine root production is regulated by the nutrient availability in forest litter accumulation (Cuevas and Medina 1988; Aerts *et al* 1992). In an integrated study on vegetation, soil, root biology, mycorrhizae and litter dynamics in two tropical dry evergreen forests in India as no research work is available on these aspects. This communication reports the fine root dynamics. The aim of this study was two fold: (i) Assessing the seasonal dynamics of fine root mass and (ii) determining fine root production by the new ingrowth techniques and their nutrient levels in two tropical forests in India.

2. Materials and methods

2.1 *Study area*

The study was conducted in two dry evergreen forest formations in the Coromandel coast of India: (i) Kurumbaram section of Marakkanam reserve forest (MRF), situated about 40 km north of Pondicherry (long. 79° 55′E and lat. 12° 11′ N) and the second site Puthupet sacred grove (PSG) located 15 km north of Pondicherry (long. 79° 52′ E and lat. 12° 03′ N) off the Pondicherry-Madras coastal road. MRF originally contained three dry forest formations in three places namely Kurumbaram, Agaram and Marakkanam with total areas of 246, 243 and 26 ha respectively. Of these the latter two areas had already been converted to plantations of *Casuarina* and *Eucalyptus* and Kurumbaram alone remains with natural vegetation. This is situated 10 km from the seashore. The terrain is more or less flat with slight depressions, formed due to soil erosion. Soils are red ferralitic belonging to the Miocene Cuddalore sand stone geological formation (Bourgeon 1988). The mean annual rainfall for the 21 years (1971-91) is 1254 mm with bulk of the rainfall received during October, November and December, moderate during January and February and none during April in the past two years (figure 1).

Soil samples were taken from ten places randomly in each of the 1 ha plots. They were pooled plot-wise and composite soil was taken for analysing further soil properties. Soil temperature was measured in the field using a soil thermometer. pH was measured in the laboratory taking 1:5 soil suspension by adding 100 ml of water to 20 g of soil and pH was read in a digital pH meter by inserting an electrode in the suspension. Moisture content was determined taking 10 g soil and oven drying it at 105°C for 48 h. Soil organic carbon, nitrogen and phosphorus were determined as detailed in root chemical analyses. The annual mean soil temperature was 28·2°C, moisture content 5·9%, water holding capacity 32·9% pH varied from 6·8–7·6. Seasonal variation in rainfall, temperature and moisture are shown in figure 1. Soil organic carbon content was determined by Kalembasa and Jenkinson (1973) and total nitrogen and phosphorus was determined as detailed for root analyses and the values are given in table 1.

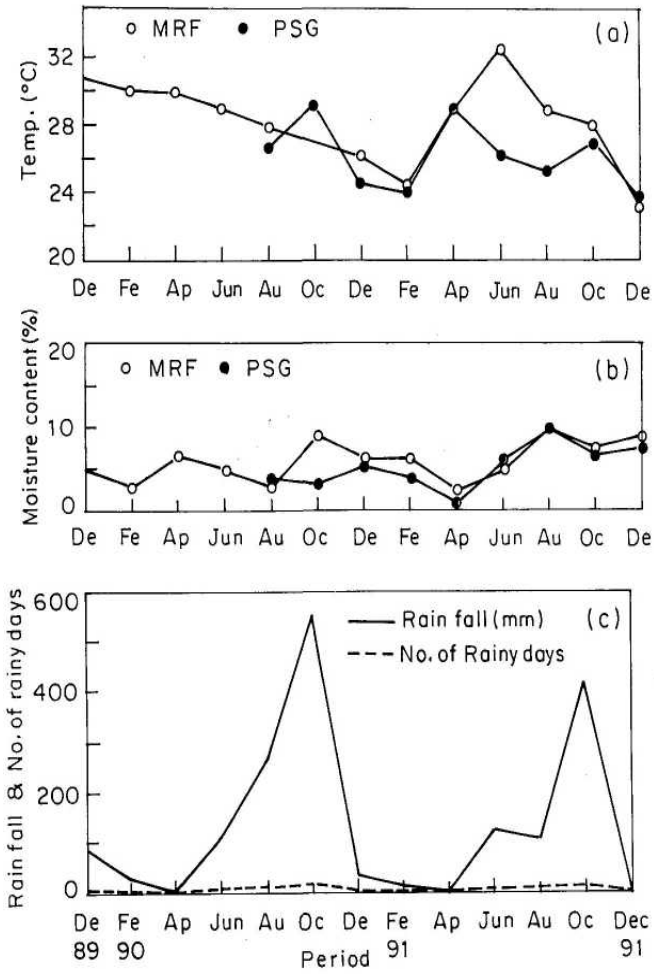

Figure 1. Soil temperature **(a)** and moisture **(b)** in MRF and PSG sites and **(c)** rainfall data of Pondicherry from Dec. 89 to dec 91.

Table 1..site chracterstics of threee MRF and two PSG sites.

	Vegetation		Litter		Soil		
Forest site	Stand density (no ha^{-1})	Stand basal area (m^2 ha^{-1})	Litter production (t ha^{-1} yr^{-1})	Standing crop of litter (t ha^{-1})	Organic carbon (%)	Total nitrogen (%)	Total phosphorus (μg g^{-1})
MRF 1	200	9·34	6·1	2·2	1·35	0·26	18·6
MRF 2	410	19·54	4·9	2·3	1·47	0·28	16·7
MRF 3	230	4·51	4·3	1·8	1·17	0·23	16·0
PSG 1	1250	40·10	10·1	2·8	1·04	0·19	13·9
PSG 2	1010	33·58	12·2	3·5	0·93	0·19	12·9

The dominant species at the MRF site were *Albizia amara, Azadirachta indica, Canthium dicoccum, Carissa spinarum, Chloroxylon swietenia, Dalbergia paniculata, Dodonaea viscosa, Garcinia spicata, Ixora pavetta, Mallotus rhamnifolius, Manilkara hexandra, Memecylon umbellatum, Mimosa intisia, Pterolobium hexapetalum, Pterospennum canescens, Syzygium cumini* and *Ziziphus oenoplea.* Vegetation characteristics such as stand density and stand basal area of both the forests are provided in table 1.

The second site, PSG is a temple forest protected on account of religious belief and occupies an area of 17·8 ha. This area is relatively undisturbed with a dense vegetal cover. Soil is of alluvial, sandy loam in texture. Annual rainfall would be the same as at Pondicherry (1254 mm). The major species occurring in this area are *A. amara, A. indica, C. dicoccum, C. spinarum, Flacourtia indica, Eugenia bracteata, G. spicata, Lepisanthes tetraphylla, M. umbellatum, Pongamia pinnata P. canescens* and *S. cumini.* The common lianas include *Plecospermum spinosum, Combretum albidum, M. intsia* and *Strychnos colubrina.* Three 1 ha plots were marked in MRF and two 1 ha plots in PSG for periodical sampling.

2.2 *Methodology*

2.2a *Sampling of fine roots :* Fine root sampling was carried out in ten places randomly in each of the three 1 ha permanent plots in MRF, during December 89 to December 91 and in the two 1 ha plots in PSG from August 90 to December 91 regularly at 2 months intervals. Collections were facilitated by using a metal quadrat frame, 10 cm on each side, which was placed on the ground. Roots inside the frame were cut by a scissors. The soil matter within the frame was removed digging down to 10 cm depth with a small shovel and these 10 cm^3 soil monoliths containing the standing crop of roots were transported to the laboratory in polythene bags.

2.2b *Sampling of new ingrowths* : For root productivity studies, soil monoliths of 10 cm^3 were removed from ten places in each of the five 1 ha permanent plots using a metal frame. The fine roots were extracted from the soil by hand-sorting and the root-free soil was then returned to their original position in to the pits, trying to maintain as far as possible the same compactness. It was assumed that any new root ingrowths in the soil blocks represented root production. The ingrowths were monitored at bimonthly intervals. The ingrowth pits were marked with bamboo sticks tied with plastic leaf at top (to appear as a seedling, to prevent any human disturbance) at all the four corners of the soil block.

2.2c *Root mass estimation* : Fine roots were extracted from the soil monoliths by hand-sorting. The adhering soil particles were removed by washing in a fine jet of water. The live biomass and the dead necromass fractions were hand separated based on their degree of cohesion between cortex and periderm, colour and resilience. No species-wise classification of roots was attempted. The live and dead roots were air-dried and then ovendried at 80°C for 48 h and the biomass and necromass were determined using a digital top pan balance. The roots recovered from ingrowth pits

were also processed similarly as outlined for standing crop root mass, oven dried (80°C) and weighed. Root estimates of ten pits were averaged to obtain mean root mass for 10 cm^2 area and it was extrapolated to mm^{-2} value.

The oven dried root samples were pooled plot-wise, powdered and stored in plastic vials in a desiccator until analysis. Root total N was determined by Microkjeldahl method (Hessey 1971) and total P by molybdenum blue method (Fiske and Subbarow 1925) using a spectrophotometer (Milton and Roy Model-1201).

2.2d *Statistical analyses* : Two way ANOVA was calculated to find out whether there is a significant difference between plots and between seasons as well as for interaction. Root data were analysed for Pearsons linear correlations.

3. Results

3.1 *Seasonality in standing crop of fine roots*

3.1a *Total root mass* : Seasonal fluctuation in the standing crop of fine roots is presented in figure 2. In MRF the total root mass (TRM) during the 13 study periods ranged from 114 to 145 g mm^{-2} for the 3 sites. TRM was greater in December in all the 3 plots in the first year and during the second year it was greater in December in MRF1 and in October in MRF2 and MRF3. The initial estimate of TRM in December 89 was 80 g m^{-2} , 58 g m^{-2} and 53 g m^{-2} in MRF1, 2 and 3 respectively. It increased slightly in February and April and dropped to 68, 63 and 67 g m^{-2} in June. From August 90 onward there was a gradual increase, with a peak in December. In the second year from the initial estimate of 239, 237 and 195 gm^{-2} in December 90 it gradually declined in February and April, with low estimate coupled with the peak dry period of June. From August onward it gradually increased peaking in October and December 91 (figure 2a).

In PSG the mean total root mass ranged from 195 to 273 g m^{-2} among the 9 study periods. It peaked in December in the first year and in October in the second year in PSG1 and in October in the first year and in June in the second year in PSG2. There was a marked seasonal fluctuation in TRM during the period August 90 to December 91. In PSG1 from August 90 the TRM values gradually increased till December 90 and declined in February and April 91 followed by a slight increase in June, again a decline in August and a peak in October 91 (figure 2b). In PSG2 from an initial estimate of 174 g m^{-2} in August 90 it increased in October then declined from December 90 to April 91 and a sharp increase in June 91 up to 401 gm^{-2} and then declined in every alternate periods till December 91. The mean annual TRM was greater in PSG2 (268 g m^{-2}) than in PSG1 (197 g m^{-2}). Two way ANOVA for the MRF sites revealed that there existed a significant difference between the sites (F = 3·79) at 5% level and between the seasons (F = 8·14) at 1% level. In PSG the TRM variations with sites (F = 39·8), date (F = 83·5) and site X date (F = 3·78) were significant at 1% level.

3.1b *Biomass and necromass fraction of fine roots* : The live fine root biomass component(FRB) in MRF ranged from 46 to 203 g m^{-2} in three sites in the 13

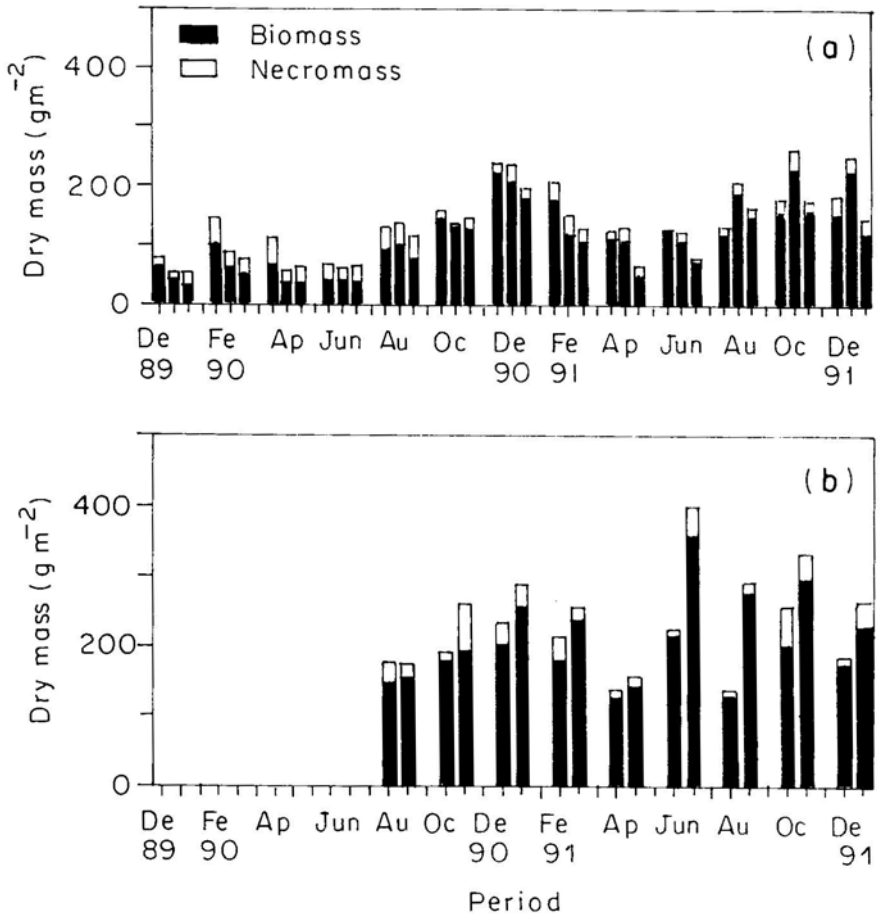

Figure 2. Seasonality in standing crop of fine roots (gm^{-2}) monitored from Dec. 89 to Dec. 91 in the upper 10 cm soil profile in MRF **(a)** and PSG **(b)** sites.

collection periods. Biomass fraction was highest in December during the first year in all plots and in February in MRF1, in October in MRF2 and MRF3 during the second year (figure 2a). The mean FRB was more in MRF1 and 2 with 144 and 145 g m^{-2}, compared to 114 g m^{-2} in MRF3. FRB declined gradually from February to June and increased from August to December in both the years. A marked fluctuation was noticed among the three plots (F = 11·9) and also among the seasons (F = 27·6) at 1% level.

In PSG, FRB ranged from 125 to 216 g m^{-2} in PSG1 and from 141 to 359 g g m^{-2} in PSG2 during the 9 periods. Biomass fraction peaked to 202 g m^{-2} during December in the first year and during October in the second year in PSG1 and in PSG2, it peaked to 299 g m^{-2} during October in the first year and 401 g m^{-2} during June in the second year. Seasonal dynamics in FRB were significant between the two plots (F = 47·2) and between the seasons (F = 11·0) and for interaction (F = 3·52) at 1% level.

In MRF, necromass ranged from 6 to 37 g m^{-2} during the 13 sampling dates (figure 2a). Necromass was greater during August in 1990 and in February in 1991. There was a gradual decline in necromass during February through June then increased in August and October (figure 2a). Statistically there existed a significant difference for necromass between the seasons ($F = 9{\cdot}45$) at 1% level.

In PSG, necromass fluctuated from 11 to 56 g m^{-2} in PSG1 and from 12 to 66 g m^{-2} in PSG2. There was a gradual increase in October 90, December 90 and February 91 (11, 31 and 38 g m^{-2}) in PSG1 and in PSG2 it dropped from October 90 till April 91 (figure 2b). There existed a significant difference in necromass level between the plots ($F = 7{\cdot}85$) and between the seasons ($F = 5{\cdot}43$) as well as interaction ($F = 6{\cdot}34$) at 1% level.

3.1c *Fine root production* : Fine root production levels in the top soil of MRF and PSG sites are presented in figures 3. In MRF 1, 2 and 3, the mean bimonthly root production was 16, 16 and 19 g m^{-2} respectively during the 12 study periods.

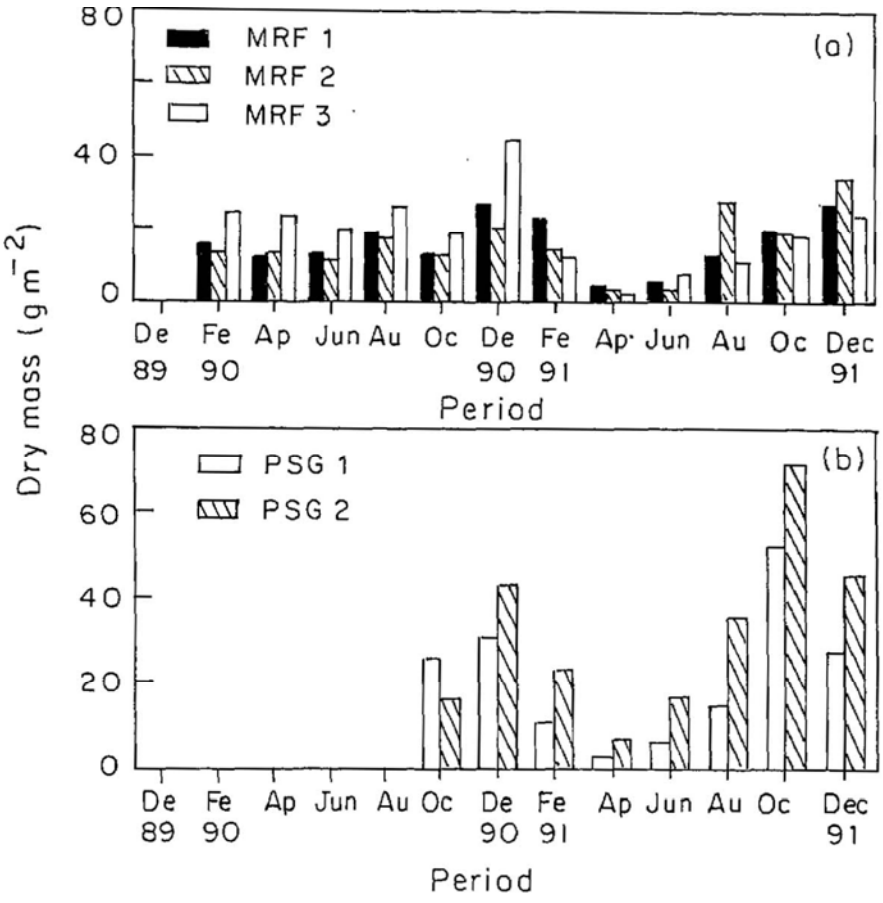

Figure. 3. Seasonality in fine root production in MRF(a) and PSG (b) sites.

From an initial production of 16, 13 and 25 g m^{-2} in MRF 1, 2 and 3 respectively in February 90, root productivity declined through June, then increased slightly in August 90, dropped in October, and peaked to 27, 20 and 50 g m^{-2} in December. In the second year from February through June it dropped sharply, then increased gradually from August peaking in December 91, except in MRF2 which showed a decline in October 91 (figure 3a). The necromass fraction of newly produced roots was negligible and ranged from 0 to 0·87 g m^{-2}.

In PSG, the estimated bimonthly fine root production ranged from 3 to 52 g m^{-2} in PSG1 and 7 to 72 g m^{-2} in PSG2. A maximum root production of 31 g m^{-2} in PSG1 and 43 g m^{-2} in PSG2 was obtained in December in the first year and in the second year the production was 52 g m^{-2} in PSG1 and 72 g m^{-2} in PSG2 in October. The collection period of February through June recorded low production (figure 3b). The necromass fraction of new ingrowths ranged from 0 to 1·6 g m^{-2}.

Two way ANOVA indicated that there existed a significant difference in total fine root production between the plots (F = 14·1), between the seasons (F = 59·8) and for interaction (F = 12·0) at 1% level in MRF and in PSG, there was a significant difference between the sites (F = 131·4) and between the seasons (F = 182·3) and for interaction (F = 14·1) at 1% level. There existed a negative correlation between soil temperature and total root mass and fine root biomass. Fine root necromass showed a weak negative correlation with temperature (–0.301) in MRF whereas in PSG a weak positive relation (0·149) was obtained. The new ingrowths showed a negative relation with soil temperature. With soil moisture the standing crop of roots, root biomass and root production showed a positive relation, whereas fine root necromass was negatively correlated to soil moisture.

3. Id *Nutrient concentration of fine roots:* Nitrogen concentration of fine root fraction (table 2) showed that the mean N concentration of all the 3 seasons was 1·54, 1·59, and 1·34% in MRF1, 2 and 3 and it was 1·60 and 1·59 in the 2 sites

Table 2. Total nitrogen (%) and phosphorus (μg g^{-1}) content of standing crop of root biomass in MRF and PSG.

Forest site	Summer (April 91)		Rainy season (October 91)		Mild winter (December 91)		Mean for 3 seasons	
	N	P	N	P	N	P	N	P
MRF 1	1·261	29·6	1·782	35·0	1·583	55·0	1·542	39·9
MRF 2	1·394	20·2	1·564	39·8	1·801	48·8	1·586	36·3
MRF 3	1·431	52·5	1·109	42·1	1·488	64·0	1·343	52·9
Mean for 3 sites	1·362	34·1	1·485	39·0	1·624	55·9	–	–
PSG 1	1·327	38·1	1·773	37·5	1·706	63·5	1·602	46·4
PSG 2	1·602	24·8	1·564	34·0	1·612	37·5	1·593	32·1
Mean for 2 sites	1·465	31·5	1·669	35·8	1·659	50·5	–	–

in PSG. Mean N level was as low as 1·36% in MRF site and 1·47% in PSG site during summer and increased to 1·62% during mild winder in MRF and to 1·67% during rainy season in PSG. Mean total P content for the 3 seasons was 39·9, 36·3and 52·9 μg g^{-1} in MRF1, 2 and 3 and it was 46·4 and 32·1 μg g^{-1} in PSG1 and PSG2 respectively. Low P concentration was noticed during summer in MRF1 and 2 and in PSG2, whereas root P accumulation was greater during mild winter in all the sites. P level increased in the following order mild winter > rainy > summer in both the forest sites.

4. Discussion

Fine roots are the important below ground components carrying out vital functions of water and nutrient absorption. The root mass of various tropical forest ecosystems are compared (table 3). Evidently root mass estimates varied greatly with respect to sampling depth and diameter class under consideration besides the forest types and their locations across the tropics. The total annual fine root production Was 1036 kg ha^{-1} yr^{-1} in MRF and 1171kg ha^{-1} yr^{-1} in PSG. The root standing crop was 1344 kg ha^{-1} in MRF and 2343 kg ha^{-1} in PSG. These estimates lie within the range reported for various tropical forests. The root standing crop value is comparable to those of mixed deciduous forest of Kalakad reserve forest in southern western ghats (Parthasarathy 1988) and also the tropical forests of Costa Rica (Sanford 1989). Whereas the root mass of PSG is comparable to the evergreen and semi-evergreen forests of Kalakad (Parthasarathy 1988) and the tropical forest of Costa Rica (Sanford 1989). Root mass showed a pronounced seasonal pattern with unimodal peaks obtained during December in the first year and from October to December in the second year in MRF. In PSG higher root mass was noticed from June to October. During the summer month of April root mass was least probably as a result of lower root production and root decomposition in both the forests due to low soil moisture and higher temperature. This is in conformity with the data of southern Western Ghats (Parthasarathy 1988).

Fine root production also varies succinctly with site quality and species composition (Aerts *et al* 1992; Fogel 1983; Persson 1982; Shaver and Billings 1975). The greater fine root mass in PSG compared to MRF can probably be attributed to a relatively low soil temperature, high tree density as well as stand basal area and relatively undisturbed condition prevailing in this forest. Besides the vicinity of the southern end of the Kaliveli lake, would possibly account for higher soil humidity which may favour the root growth. The low estimate of fine roots in MRF can be attributed to shallow, stony soil structure containing pebbles at a depth of 5 to 8 cm, in most of the spots where fine roots were sampled. Further the lateritic soil on exposure to dryness hardens considerably which is unfavourable for fine root growth. The low stand density and basal area of trees and frequent fire wood collection, in addition grazing and browsing by cattle might also affect the fine root production. Y_in *et al* (1989) stated that forest removal would significantly influence fine root biomass production and mortality. Hence both vegetation and physical environment are responsible for the control of fine root biomass (Persson 1985). Moreover the root system of different species may ramify the soil in different fashion, influenced by their requirement for microclimate, competitive ability apart from their genetic behaviour (Parthasarathy 1988).

Table 3. Fine root standing crop and productivity in various tropical forests.

Forest type	Location	Sampling depth (cm)	Diameter class (mm)	Root standing crop (kg ha^{-1})	Root production (kg ha^{-1} yr^{-1})	Source
India						
Tropical dry evergreen forest	Marakkanam RF, Coromandel Coast	10	≤2	1344	1036	Present study
Tropical dry evergreen forest	Puthupet Sacred Grove, Coromandel Coast	10	≤2	2343	1171	Present study
Dry deciduous forests	Varanasi	50	≤6	4000–5500	2412–2785	Singh and Singh 1981
Evergreen forest	Kalakad RF, Western Ghats	10	≤2	3420	–	Parthasarathy 1988
Semi-evergreen evergreen forest	Kalakad RF, Western Ghats	10	≤2	3500	–	Parthasarathy 1988
Mixed deciduous forest	Kalakad RF, Western Ghats	10	≤2	1830	–	Parthasarathy 1988
Teak forest	Kalakad RF, Western Ghats	10	≤2	980	–	Parthasarathy 1988
Scrub jungle	Kalakad RF, Western Ghats	10	≤2	960	–	Parthasarathy 1988
Tropical deciduous forests	Orissa	50	>1	324–1902	–	Behera *et al* 1990
Other tropical areas						
Moist deciduous forest	Ghana	50	<6·4	5000	–	Greenland and Kowal 1960

Table 3. (*Contd.*)

Forest type	Location	Sampling depth (cm)	Diameter class (mm)	Root standing crop (kg ha^{-1})	Root production (kg ha^{-1} yr^{-1})	Source
Tropical rain forest	Ivory coast (auger samples)	130–250	< 5	8,800–9,600	–	Huttel 1969
Mixed tropical forest	Ghana	50	< 5	8,000–10,000	–	Jenik 1969
Moist semi-deciduous forests	Ghana	122	< 5	56,000–124,000	–	Lawson *et al* 1970
Terra firme forest on latosol	Amazonia	107	< 6	16,000	–	Klinge 1973
Terra firme forest on podzol	Amazonia	89	< 6	10,900	–	Klinge 1973
Central Amazonian rain forest	Brazil	18	≤ 2	8430	–	Klinge 1973
Amazonian rain forest	Venezuela	10	All diam classes	–	1170–2010	Jordan and Escalante 1980
Tropical wet forests	Costa Rica	50	< 5	3,690–6,620	–	Gower 1987
Tierra firme forest	Venezuela, South America	10	All diam classes	–	11170	Cuevas and Medina 1988
Tall cattinga forest	Venezuela	10	All diam classes	–	1200	Cuevas and Medina 1988
Bana forest	Venezuela, South America	10	All diam classes	–	2350	Cuevas and Medina 1988
Tropical forests	Costa Rica					Sanford 1989
i. Intact forest		15	≤ 2	1399	–	
ii. Tree fall gap zones		15	≤ 2	897	–	
Deciduous dry forest	Chamela, Mexico	10	≤ 1	–	4230	Kummerow *et al* 1990
Mixed hardwood forest	South-eastern Virginia and north eastern North Carolina	40	< 2 – > 5	18,870	3540–9890	Powell and Day 1991

Fine root production is also regulated by the nutrient availability in forest litter (Cuevas and Medina 1988). Jordan and Escalante (1980) reported that the growth of fine roots was greater in the surface root mats when fresh litter was present. The leaf litter forms a shelter for the surface roots by providing a moist microclimate for the developing new roots. This is evident in the PSG site where numerous fresh roots were found intermingled with the litter layer.

Fine roots exert a greater influence on their environment by accumulating litter and redistributing nutrients in to the soil profile (Persson 1990). The nutrients that are released from the litter are not leached down to the soil but are transferred directly to the surface roots which are growing intermingled with the decaying matter (Richards 1952; Sioli 1973; Walter 1971; Went and Stark 1968). However in PSG eventhough the surface litter is more, root nutrient concentration is comparatively lower than that of MRF sites (table 2) . Further the lower root nutrient concentration in PSG may be due to the alluvial nature of the soil where the nutrient leaching may be more and the sandy loam soil possibly may not hold much nutrients due to their low water holding capacity or alternately get accumulated in thicker roots or in the above ground parts by translocation, as fine roots are short-lived.

Fine roots may also contain a high proportion of N, P and K compared to other ecosystem components (Vogt *et al* 1982). The mean N concentration in the three sites of MRF was 1·54, 1·59 and 1·34% and it was 1·60 and 1·59% in the two sites of PSG. These values are higher than those of the seven forest sites in Kalakad RF, where it ranged from 0·53 to 1·11% (Parthasarthy 1986) and also in the tropical forests of Africa and South America where it ranged from 0·47 to 1·01% (Klinge 1976). The scrub jungle of Kalakad RF showed still lower value (0·62 to 0·75%) (Parthasarathy 1986).

The level of root P was 39·9, 36·3, and 52·9 μg g^{-1} in the three plots in MRF and it was 46·4 and 32·9 μg g^{-1} in two plots in PSG. This value is lower when compared to the nutrient levels of fine roots in Kalakad RF, where it ranged from 45 to 144 μg g^{-1} (Parthasarathy 1986) as well as the values of 200 to 10,000 μg g^{-1} in Africa and South America (Klinge 1976). Fine roots are the principal abodes for mycorrhizal fungi (Wilcox 1967). The association of vesicular- arbuscular mycorrhizal fungi (VAMF) with plant roots is an important connecting link between the plant and the soil and is responsible for increased uptake of nutrients to the host through their hyphal connection. The fine roots especially the new ones were heavily infected with arbuscules in MRF which might also account for increased P content in roots (Visalakshi 1993). The present study reveals that fine root standing crop and root production varied greatly with respect to the season, soil and vegetation.

Acknowledgements

I am grateful to Dr V M Meher-Homji, French Institute, Pondicherry for his valuable guidance and encouragement and Dr N Parthasarathy for encouragement and perusal of the manuscript.

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