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Organic Matter, N and P Dynamics of Fine and Coarse Roots in a Humid Subtropical Forest Ecosystem Exposed to Disturbance in Meghalaya, Northeast India

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ABSTRACT

Standing fine (<2mm diameter) and coarse (>2mm diameter) root mass production, N And P accumulation, and turnover rate were studied in two pairs of protected and disturbed stands of a subtropical humid forest to examine the response of below-ground parts to mild disturbance caused by above-ground vegetation by humans. Disturbance of mild intensity caused significant reduction in biomass accumulation and production of fine and coarse roots. The fine root (540-754 gm^{-2}) and coarse root (307-387 gm^{-2}) mass was higher in the protected stands, declining (fine root: 422-466 gm^{-2}, coarse root: 247-305 gm^{-2}) significantly in the disturbed stands. The total annual root production was also higher in the protected stands (1102 -1242 gm^{-2}) than in the disturbed stands (890-940 gm^{-2}). Live roots (biomass) showed a higher N and P concentration than the necromass (dead root mass). Nutrient concentration was higher in the fine roots compared to the coarse roots. N and P accumulation in the roots was high (N = 99 - 132 kg ha^{-1}, P =5 - 8 kg ha^{-1}) in the protected stands and low (N = 76 - 85 kg ha^{-1}, P= 4 -7 kg ha^{-1}) in the disturbed stand. The total input of N to the soil by roots ranged from 121-132 kg ha-1 in the protected stands to 96-100 kg/ha in the disturbed stands, whereas P input was 5 to 7 kg ha^{-1} in all the stands. The study reveals that roots play a significant role in maintaining the organic matter, Nitrogen and P status of the soil and is influenced by soil conditions and vegetation characteristics. Soil and vegetation are affected due to disturbance, which in turn affects mass, production, N and P concentration and their accumulation in the roots. These results are discussed in the present paper and the information should help further understanding of the fragility of subtropical humid forest ecosystems.

Keywords: Fine and coarse root, biomass and production, N and P concentration, accumulation, subtropical humid forest, disturbance

INTRODUCTION

Fine roots play a more important role in the dynamics of organic matter, nitrogen and phosphorus in the soil than the coarse roots in forest ecosystems. Though fine roots comprise only a small proportion of the total root biomass in ecosystems (Vogt *et al*. 1986; 1991), they account for 40-50% of the total N (Vogt *et al*.

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1983; Hendrick and Pregitzer 1993) and 45-75% of total phosphorus (Vogt *et al*. 1983; Arunachalam *et al*. 1997) return to the soil by a rapid turnover rate. A dense network of fine roots in humid tropical forests not only conserves nutrients through efficient absorption but also prevents leaching losses and enriches the soil with organic matter and nutrients by a rapid turnover. The amount of fine roots is influenced by stand age (Arunachalam *et al*. 1996; John *et al*. 2001) and they undergo rapid change due to perturbations in the ecosystem (Hendrick and Pregitzer 1993). Studies on fine roots dynamics following major disturbances in humid subtropical forest caused by anthropogenic activities (Arunachalam *et al*. 1996) reveal their increase with an increase in stand age whereas, the conversion of tropical forests into forestry plantations (Sundarapandian *et al*. 1999) decreases root mass and production.

The humid subtropical forests are found between 1000-1800 m asl in the state of Meghalaya, northeast India, where average annual rainfall is >2500 mm and mean temperature ranges from 5° to 28°C. Though most of the forests are disturbed by human activities of a varied kind, small forest patches ranging from 0.1 ha to >400 ha areas are still found in an intact state due to religious beliefs of the indigenous tribes. These patches of forests popularly known as 'sacred forests' represent the remnants of the climax vegetation of the area. However, these forest patches are also being gradually encroached upon for small timber and fuel wood requirements of the local people as well as for grazing of domesticated animals. Therefore, an understanding of the functioning of the ecosystem in relation to fine roots due to human disturbance is a pre-requisite for evolving conservation strategies. The objective of the present study was to examine the impact of disturbance on dry matter production of fine and coarse roots as well as their importance in N and P accumulation and turnover in soil of a humid subtropical forest ecosystem.

MATERIALS AND METHODS

Study Site

The study was conducted in two forests, one located near Ialong village (latitude 25° 28' N, longitude 92° 16' E, altitude 1350 m) and the other near Raliang village (latitude 25^0 30' N and longitude 92^0 28'E, altitude 1300 m) in Jaintia Hills district of Meghalaya in North-east India. Both the forests are sacred forests representing the climax forest vegetation of a subtropical wet hill forest of Meghalaya (Champion and Seth 1968), and are owned and managed by the local tribal communities. In order to correlate the fine and coarse root organic matter, N and P dynamics with disturbance regime in each forest, two distinct stands differing in degree of disturbance were identified and termed as protected and disturbed stands. No product is extracted from the protected stands, while the disturbed stands are exposed to disturbance of mild intensity because of collection of fuel wood and small timber.

The climate of the area is influenced by monsoon winds with distinct warm-wet and cold-dry seasons. The wet season extends from April to October followed by a short dry period from November to March. During the wet season, 95% of the total rainfall occurs with the monthly rainfall ranging from 131 mm to 1557 mm,

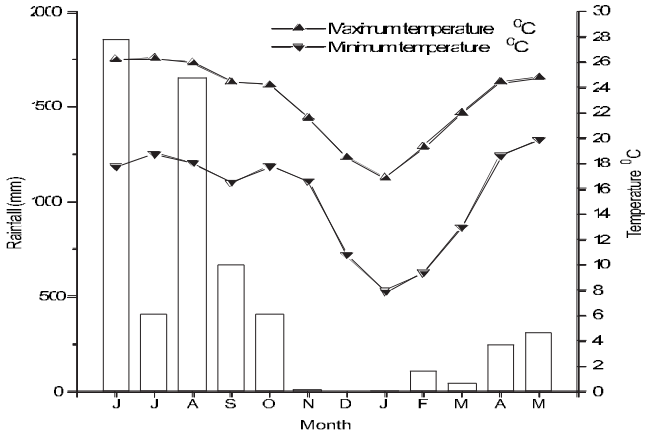

Fig. 1: Monthly variation in rainfall (mm), mean maximum and minimum temperature (^{0}C) during the study period (June 2000 – May 2001)

while in the dry period it is usually < 50 mm per month. The annual rainfall was 5691mm during the study period (2000-2001). The mean monthly temperature varies from a maximum of 260C in the month of April to a minimum of 50C in January (*Fig. 1*).

The density and basal area of woody species (≥5 cm dbh) were determined by laying fifty 10 x 10m quadrats each in the protected and disturbed forest stands. Tree saplings (<5 cm dbh and >1 m height) were studied in fifty 5 x 5 m quadrats, and seedlings (<1 m height) as well as herbaceous species in the ground layer were studied in fifty 1 x 1 m size quadrats. The latter quadrats were nested within the 10 x 10 m quadrats. The calculation of density and basal area followed Misra (1968) and Mueller *et al*. (1974).

The composite soil samples for each of the four stands representing 0-20 cm soil depth were prepared during each season by mixing the soils collected from 10 random locations in each stand. The soils were sieved through a 2-mm mesh screen and were used for analysis. Soil texture was determined by Bouyoucos hydrometer method (Allen *et al*. 1974) and soil organic carbon (SOC) was determined by rapid titration method (Allen *et al*. 1974). The total Kjeldahl nitrogen (TKN) was estimated by digesting the air dried soil samples with H_2SO_4 followed by distillation and titration (Allen *et al*. 1974). Ammonium nitrogen (NH_{4+}-N) was determined by indo-phenol blue method after extracting fresh soil sample with M NaCl (6%) and nitrate nitrogen (NO_3^--N) by phenol di-sulphonic acid method, after extracting with deionised water. Available phosphorous was determined by molybdenum blue method after extracting the air dried soil with 0.5 M $NaHCO_3$ (Allen *et al*. 1974).

Root Sampling and Analysis

Monthly sampling of roots was done during June 2000 to May 2001 in each stand of the two forests by the soil core method (Bohm 1979). On each sampling date,

ten cylindrical cores (n=10) were taken with a steel corer (length 20 cm and inner diameter 6.3 cm). The samples were transferred to the laboratory in polythene bags and stored in deep freeze at -20^{0}C until the roots were separated. The roots were retrieved by wet-sieving method (Bohm 1979) and processing of all the samples was completed within 21 days as recommended by Parrotta and Lodge (1991). The separated roots were categorised into two diameter class viz., fine (< 2 mm) and coarse (2-15 mm). The roots were further classified as live (biomass) and dead (necromass) on the basis of pliability and the degree of cohesion between the cortex and periderm. Live roots were often smooth and light coloured compared to the dead roots that were wrinkled and dark in colour (Persson 1979; 1983).

Root mass was determined after drying the sample at 800C to a constant weight. Annual fine and coarse root production was determined by summing up the positive increments in live root biomass in each diameter class and concurrent increment, if any, in the dead root mass in a given diameter class during successive sampling (Persson 1978). The annual root production was calculated by considering the increase in root mass between the first sampling month, that is, June 2000 and the 13th month, that is, June 2001. However, the last sampling under the study was done in the month of May 2001 because of logistic constraints. Hence, the data for June 2000 was used for June 2001 for calculating the annual root production. This was done based on the assumption that the studied stands are old growth forests and are unlikely to exhibit a significant difference between June 2000 and June 2001.

The data on root mass were pooled to obtain average values for winter (December to February), spring (March to May), rainy (June to August) and autumn (September to November) seasons. The dried root samples were ground to powder in a Cyclotec-Tecator Grinder and were used for N and P analysis. Total Kjeldahl nitrogen (TKN) was determined by digestion and distillation method (Allen *et al*. 1974). Total P in the roots was colorimetrically determined following molybdenum blue method after digesting the samples with tri-acid mixture (nitric acid, perchloric acid and sulphuric acid in a ratio of 1:10:2 respectively) (Allen *et al*. 1974). N and P accumulation in live and dead roots was calculated by multiplying the mean dry mass of fine and coarse roots with their respective element concentrations. Turnover rate (K) was calculated using the model: $K=P/X_m$, where P = annual root production and X_m = mean annual dry weight. Similarly, the N and P turnover was calculated by substituting the dry mass with the values of mineral elements. Turnover time (T) was calculated as the reciprocal of turnover rate, that is, $T=1/K$ where T= time in year (Reiners and Reiners 1970).

Statistical Analysis

In order to assess the impact of disturbance on soil physico-chemical properties, litter quality, root biomass, necromass, as well as accumulation of organic matter, N and P in fine and coarse roots and the respective values in protected and disturbed forest stands were subjected to t-test both in Ialong and Raliang forests (Zar 1974). Three-way Analysis of Variance (fixed effect model) was performed using the monthly data to examine the variation in dry mass, and N and P concentration and accumulation in fine and coarse roots in the two selected forests due to disturbance

(protected and disturbed), season (rainy, autumn, winter and spring) and root mass (biomass and necromass) using SYSTAT Version 10.0 (SPSS Inc. 2000).

RESULTS AND DISCUSSION

Vegetation and Soil Characteristics

The density of woody species decreased in the unprotected stand at Ialong (1476 to 1340/ ha) but increased at Raliang (938 to 1308 / ha). The density of tree seedlings, saplings and ground vegetation was lower in the disturbed stands than in the protected stands (Table 1).

The soil texture varied from loamy sand to sandy loam and the pH of the soil was acidic in the four stands. The soil moisture content (SMC), soil organic carbon (SOC), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4^+-N), nitrate nitrogen(NO_3^--N)and available phosphorous concentration was significantly higher in the protected stands than in the disturbed stands (Table 2). The litter quality assessed based on nitrogen, phosphorous and potassium concentration in the leaf litter was better in the protected stands compared to the disturbed stands.

Biomass and Production of Roots

The mean annual dry weight of fine and coarse root biomass and necromass varied significantly (t-test, $P<0.01$) between the protected and disturbed stands both at Ialong and Raliang. The mean annual fine root biomass was significantly higher ($p< 0.001$) in the protected stands at Raliang (624 g m^{-2}) and Ialong (463 g m^{-2}) than their corresponding disturbed stands (Table 3). A similar pattern of coarse root mass was observed with significantly higher values in the protected stands of both the forests ($p<0.01$). Three-way ANOVA revealed that the fine and coarse root mass varied significantly ($p<0.01$) between the stands and seasons (*Fig. 2* and Table 4). The fine root biomass was higher during the wet (rainy) season while the necromass was higher during the dry winter season. The coarse root biomass also peaked during the rainy season in all the stands except in the Raliang protected stand where it was higher during autumn. However, the coarse root necromass was high in both the protected and disturbed stands during autumn at Ialong and during winter at Raliang (*Fig. 2*). The biomass values of both fine and coarse roots were significantly ($P<0.01$) higher than the necromass values in all the stands (Tables 3 and 4).

TABLE 1
Vegetation characteristics in protected and disturbed forest stands at Ialong and Raliang.

Parameters	Ialong		Raliang	
	Protected	Disturbed	Protected	Disturbed
Density of woody species (ha^{-1})	1476	1340	938	1308
Density of tree saplings (100 m^2)	46	41	76	57
Density of tree seedlings (100 m^2)	1410	955	2300	775
Density of ground vegetation (100 m^2)	2474	2075	1997	1887
Tree basal area (m^2 ha^{-1})	57.46	49.64	71.44	36.52

TABLE 2
Soil physico-chemical characteristics and leaf litter quality in protected and disturbed forest stands at Ialong and Raliang. Values of soil moisture content (SMC), soil organic carbon (SOC), total Kjeldahl nitrogen (TKN) and available –phosphorous (P) are the means of four seasons across the year (n=12) for 0-20 cm depth

Parameters	Ialong		Raliang	
	Protected	Disturbed	Protected	Disturbed
Sand (%)	82.9 [a] (0.36)	81.0 [a] (1.50)	48.1[c] (1.0)	77.2[d] (1.04)
Clay (%)	5.75 [a] (0.50)	6.20 [a] (0.70)	21.55 [c] (0.80)	9.65[d] (1.0)
pH	4.7 [a] (0.05)	5.0 [b] (0.06)	4.6[c] (0.07)	4.8[c] (0.08)
SMC (%)	38.50[a] (3.80)	36.35 [b] (3.30)	47.35[c] (2.55)	29.25[d] (1.30)
SOC (%)	4.63 [a] (0.08)	3.92 [b] (0.03)	4.62[c] (0.08)	4.01[d] (0.17)
TKN (%)	0.41[a] (0.003)	0.35 [b] (0.05)	0.45[c] (0.02)	0.35[d] (0.01)
Available- P ($\mu g g^{-1}$)	13.98[a] (1.52)	12.17[a] (0.86)	15.61[c] (2.01)	11.28 [d] (0.93)
NH_4^+-N ($\mu g g^{-1}$)	11.23[a] (0.06)	6.04 [b] (0.55)	14.21[c] (1.21)	7.78[d] (1.24)
NO_3^-- N ($\mu g g^{-1}$)	11.95[a] (1.45)	9.72 [a] (0.86)	18.49 [c] (1.92)	12.92[d] (2.08)
Leaf litter quality				
TKN (%)	1.99 [a] (0.03)	1.49 [b] (0.02)	1.73[c] (0.02)	1.51[d] (0.05)
P (%)	0.07 [a] (0.001)	0.05[a] (0.001)	0.07[c] (0.002)	0.06[d] (0.003)
K (%)	1.75 [a] (0.01)	1.27[b] (0.06)	1.38[a] (0.01)	1.07[d] (0.01)

Values in parentheses are the SE. Values with dissimilar superscript (Ialong:a and b, Raliang: c and d)) are significantly different (P<0.01) between protected and disturbed stands at Ialong and Raliang.

TABLE 3
Mean standing crop of biomass, necromass and annual root production of fine (< 2mm) and coarse (2-15mm) roots in protected and disturbed forest stands

Stands	Root category	Biomass ($g\ m^{-2}$)	Necromass ($g\ m^{-2}$)	Biomass/ Necromass ratio	Production ($g\ m^{-2}\ yr^{-1}$)
Ialong					
Protected	< 2mm	462.60[a] ± 41.28	76.89[a] ± 5.13	6.01[a]	534.78
	2-15mm	276.32[c] ± 35.29	30.71[c] ± 6.24	8.99[c]	568.52
Disturbed	< 2mm	324.43[b] ± 42.84	97.17[b] ± 15.44	3.34[b]	472.20
	2-15mm	222.75[d] ± 49.86	29.55[c] ± 8.56	7.54[c]	466.34
Raliang					
Protected	< 2mm	623.64[e] ± 56.03	130.77[e] ± 10.36	4.77 [e]	568.60
	2-15mm	364.15[g] ± 32.19	33.80[g] ± 6.59	10.77[g]	673.10
Disturbed	< 2mm	349.96[f] ± 31.54	115.49[f] ± 9.17	3.03[f]	424.32
	2-15mm	244.67[g] ± 47.34	60.66[h] ± 6.85	4.03[h]	466.04

Values with dissimilar superscript (Ialong a, b, c, d and Raliang e, f, g, h) are significantly different (P<0.01) between protected and disturbed stands at Ialong and Raliang for fine (a, b and e, f) and coarse (c, d and g, h) roots.

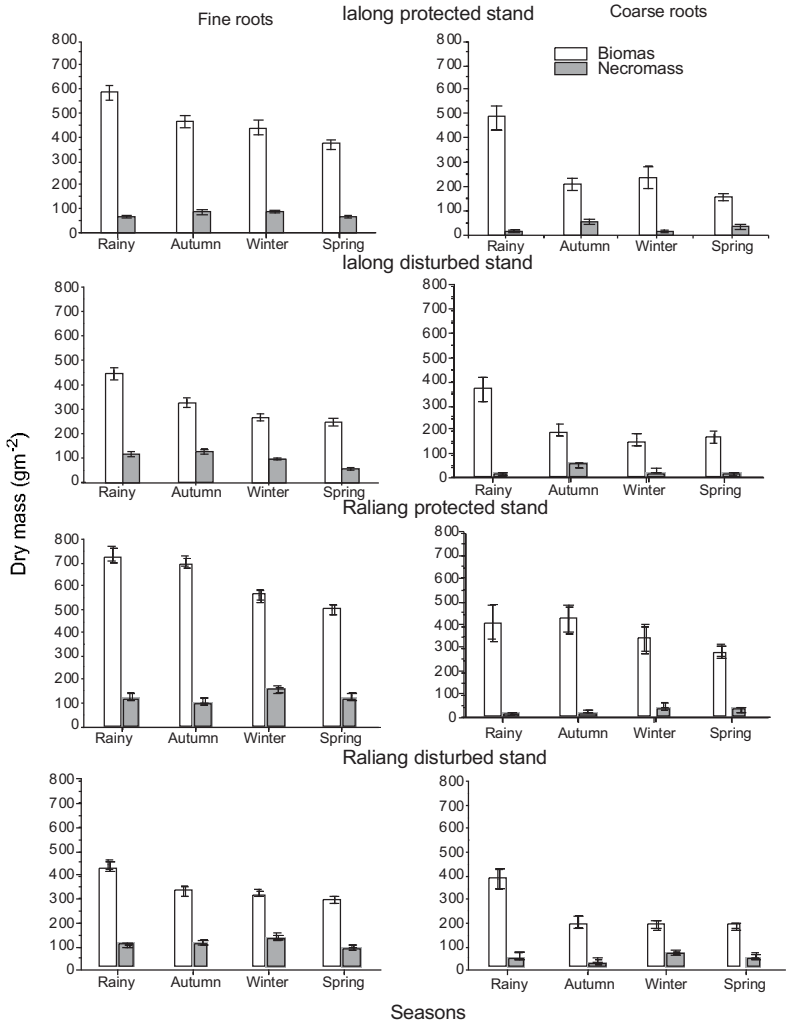

Fig. 2: Seasonal variation of fine (<2mm) and coarse (2-15mm) root biomass and necromass in 0-20 cm soil layer in protected and disturbed stands

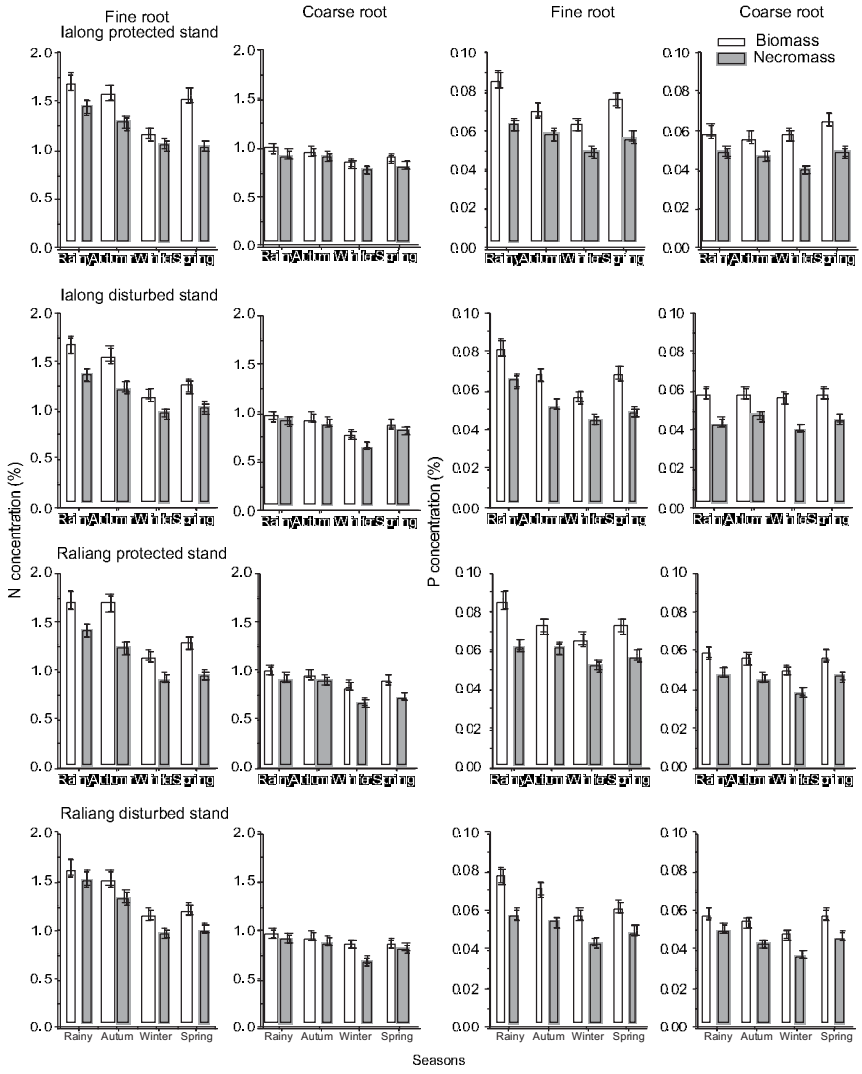

Fig. 3: Seasonal variation in N and P concentration in fine and coarse root biomass and necromass in protected and disturbed stands

The seasonal variations in fine root mass as observed in the present study have been established by a number of workers in both temperate and tropical forests (Srivastava *et al*. 1986; Parthasarathy 1988; Khiewtam and Ramakrishnan 1993; Sundrapandian *et al*. 1999). The seasonal change in root biomass could be due to changes in the environment such as soil moisture, soil temperature and root turnover as reported by Hook *et al*. (1994). The higher root biomass during the rainy season corresponds to the most favorable period for vegetation growth of plants and better nutrient availability through fast decomposing litter and high moisture content in the soil. The low fine root mass during spring, which marked the beginning of new shoot growth after a dormant phase could be due to their slow growth in the preceding winter season, that is, December to February and the upward translocation of reserve food from the root system (Singh and Coleman 1997). A similar seasonal trend in fine root biomass has been reported from dry tropical and humid subtropical forest ecosystems (Srivastava *et al*. 1986; Sundrapandian and Swamy 1996; John *et al*. 2001).

The variation in fine root mass in the protected and disturbed stands could be attributed to the differences in site quality and species composition (Aerts *et al*. 1992; Sundrapandian *et al*. 1999). The higher fine root biomass in the protected stands could be due to high density of seedlings, saplings and ground vegetation and the undisturbed condition prevailing in the forest (Upadhaya 2002). Selective removal of trees, collection of firewood and movement by cattle and humans coupled with low organic matter, TKN, NH_4^+-N, NO_3^--N and available P concentration might be the factors for the low root mass in the disturbed stands of both the forests. Further, the greater fine root biomass in protected stands of both the forests corresponds to higher nutrients in the soil.

The total annual root production was higher in the protected stands (Raliang: 1242 g m^{-2} Ialong: 1103 g m^{-2}) than their corresponding disturbed stands (Raliang: 890 g/m^{-2}, Ialong: 939 g m^{-2}) (Table 3). The fine roots contributed 46 to 50% of the total annual root production in all the stands.

The annual fine root production obtained at the present study sites is within the range (178 - 591 gm m^{-2}) as reported from dry tropical forest (Roy and Singh 1994), evergreen (476 g m^{-2}) and deciduous (527 g m^{-2}) tropical forests (Sundrapandian *et al*. 1999) and (160-591 g m-2) temperate forest (Nadelhoffer 1985). The low annual production of fine roots obtained in the disturbed stands of both the forests could be the effect of disturbance that might have facilitated the loss of organic matter and nutrients like TKN and available P from the soil. The low root production in nutrient poor soil has also been reported by Ford and Deans (1977) and Persson (1983). Yang *et al*. (2004) also observed higher fine root biomass in a natural forest where soil fertility, productivity and species diversity is high as compared to monocultures.

Nitrogen and Phosphorous Accumulation

In both the protected and disturbed stands at Ialong and Raliang forests, N concentration in the roots was low in winter and high during the rainy season (*Fig*. 3 and Table 4). The biomass had significantly ($P<0.01$) higher N concentration than the necromass. Similarly, the fine root biomass (<2 mm) had a higher

TABLE 4
Results of Analysis of Variance showing variation in dry mass, and N and P concentration and accumulation in fine and coarse roots in two forests due to disturbance, season and root mass

Parameters	Source of variations	df	Ialong				Raliang			
			Fine root		Coarse root		Fine root		Coarse root	
			F value	P	F value	P	F value	P	F value	P
Dry mass	Disturbance regime	1	51.40	0.00	4.75	0.03	281.03	0.00	8.01	0.00
	Season	3	36.48	0.00	21.06	0.00	21.45	0.00	3.816	0.01
	Root mass	1	1389.49	0.00	305.40	0.00	1784.37	0.00	247.27	0.00
	Disturbance x Season	3	0.715	0.54	1.01	0.38	2.84	0.03	2.044	0.10
	Disturbance x Root mass	1	92.85	0.00	4.36	0.03	224.78	0.00	20.012	0.00
	Season x Root mass	3	22.25	0.00	24.69	0.00	27.29	0.00	5.573	0.00
	Disturbance x Season x Root mass	3	1.05	0.37	1.33	0.26	6.65	0.00	1.16	0.32
Nitrogen concentration	Disturbance regime	1	6.19	0.01	15.07	0.00	0.48	0.48	2.52	0.11
	Seasons	3	176.23	0.00	149.32	0.00	329.13	0.00	129.65	0.00
	Root mass	1	230.78	0.00	89.11	0.00	328.89	0.00	233.89	0.00
	Disturbance x Seasons	3	0.32	0.81	5.64	0.00	0.82	0.48	1.17	0.32
	Disturbance x Root mass	1	1.09	0.29	0.37	0.54	31.0	0.00	21.63	0.00
	Season x Root mass	3	5.34	0.00	2.04	0.11	3.57	0.01	9.14	0.00
	Disturbance x Season x Root mass	3	0.51	0.67	0.62	0.60	3.42	0.02	3.56	0.02
Phosphorous concentration	Disturbance regime	1	37.03	0.00	8.20	0.01	74.86	0.00	1.34	0.25
	Season	3	97.51	0.00	18.26	0.00	72.98	0.00	47.15	0.00
	Root mass	1	435.34	0.00	452.0	0.00	392.79	0.00	238.54	0.00
	Disturbance x Season	3	1.91	0.13	4.71	0.00	1.32	0.27	1.24	0.29
	Disturbance x Root mass	1	0.12	0.79	0.07	0.78	0.05	0.82	0.01	0.96
	Season x Root mass	3	6.75	0.00	2.87	0.04	5.91	0.00	0.39	0.75
	Disturbance x Season x Root mass	3	0.34	0.79	1.45	0.23	0.54	0.23	0.45	0.72
Nitrogen accumulation	Disturbance regime	1	14.98	0.00	9.98	0.00	107.45	0.00	27.68	0.00
	Season	3	26.67	0.00	48.33	0.00	38.32	0.00	21.98	0.00
	Root mass	1	375.87	0.00	521.62	0.00	723.69	0.00	817.41	0.00
	Disturbance x Season	3	0.04	0.99	2.37	0.89	4.67	0.01	6.08	0.01
	Disturbance x Root mass	1	20.85	0.00	8.79	0.01	102.45	0.00	66.63	0.00
	Season x Root mass	3	15.76	0.00	51.60	0.00	27.29	0.00	23.63	0.00
	Disturbance x Season x Root mass	3	0.54	0.65	2.72	0.06	6.26	0.00	3.51	0.02
Phosphorous accumulation	Disturbance regime	1	14.71	0.00	10.62	0.01	18.03	0.00	16.91	0.00
	Season	3	14.99	0.00	38.43	0.00	3.15	0.00	5.70	0.00
	Root mass	1	285.70	0.00	591.95	0.00	100.11	0.00	281.94	0.00
	Disturbance x Season	3	0.07	0.97	2.07	0.12	0.18	0.41	3.50	0.03
	Disturbance x Root mass	1	19.35	0.00	9.85	0.01	13.74	0.00	15.41	0.00
	Season x Root mass	3	10.67	0.00	43.43	0.00	2.94	0.00	11.53	0.00
	Disturbance x Season x Root mass	3	0.17	0.91	2.17	0.11	0.26	0.24	1.88	0.15

concentration than the coarse roots (2-15 mm). Three-way ANOVA revealed significant differences ($P<0.01$) in N concentration between the biomass and necromass fractions in different seasons both at Ialong and Raliang (*Fig.3* and Table 4). A similar seasonal fluctuation in P concentration was also observed in the biomass and necromass fractions of fine and coarse roots. In all the stands, P concentration in fine root was significantly higher ($P<0.01$) than in coarse roots. N and P concentration that ranged from 0.92 to 1.72% and 0.044 to 0.086% in the fine roots declined from 0.67 to 1% and 0.038-0.066% in the coarse root (*Fig.3*).

The observed difference in the nutrient concentration in fine root between protected and disturbed stands seems to be strongly dependent on the species composition. The proportion of fast growing secondary colonising species increased in the disturbed stands and produced litter with low nutrient content (Upadhaya 2002). This could be one of the reasons for the low soil nutrient status in the disturbed stands. Since renewal and death of fine roots takes place simultaneously (Persson 1983), they continuously add nutrients to the soil system. The fine root biomass had higher N and P content than the coarse root biomass. This is in conformity with the findings of Vogt *et al*. (1991) who argued that nutrient concentration in roots is strongly influenced by their diameter. The decrease in nutrient content with the increase in root diameter reflects the increase in dead woody tissues, which contain lesser amount of nutrients. In the present study, marked seasonal increase of N and P content during rainy season is similar to that found by Khiewtam and Ramakrishnan (1993), and can be attributed to intense absorption of these elements from decomposing litter. The reabsorption of nutrients from the young live roots during senescence and maturation could be one of the possible reasons for the low N and P concentration in the root necromass as well as in the older roots.

Nitrogen accumulation in fine and coarse roots varied significantly ($P<0.01$) between the stands. The protected stands of both Ialong and Raliang forests had higher N accumulation than the unprotected stands. The fine and coarse root biomass showed a marked seasonality in N accumulation pattern with higher values during the rainy season and lower values in spring (*Fig. 4* and Table 4). The mean N accumulation in root mass was 99 kg ha-1 and 132 kg ha^{-1} at Ialong and Raliang protected stands whereas the corresponding values for the disturbed stands were 76 kg ha^{-1} and 85 kg ha^{-1}, respectively (Table 5). The pattern of P accumulation in fine and coarse roots was similar to that of N accumulation with a higher accumulation in protected stands than in the disturbed stands of both the forests. Seasonal pattern of P accumulation is shown in *Fig. 4.* The mean P accumulation in root mass was higher at Raliang (8 kg ha^{-1}) and Ialong (5.4 kg ha^{-1}) protected stands, whereas in the disturbed stand of both the forests, it ranged from 4 to 7 kg ha-1 (Table 5). About 65-74% of the total N and P accumulation was by fine roots alone and only 26-35% was contributed by coarse roots.

The total input of N to the soil by roots was a maximal (121-132 kg ha^{-1}) at Ialong and Raliang protected stands and a minimum (96-100 kg ha^{-1}) was observed in the disturbed stand. However, the P input was much lower than that of N and the values were 7.12, 6.48, 5.26 and 4.8 kg ha^{-1}, respectively, in the protected and disturbed stands (Table 5). The turnover rate of fine roots 0.75 - 1.01 yr^{-1} was

TABLE 5
Mean accumulation and input of organic matter, N and P in fine (<2mm) and coarse (2-15mm) roots in protected and disturbed stands at Ialong and Raliang

Parameters	Ialong				Raliang			
	Protected		Disturbed		Protected		Disturbed	
	<2	2-15	<2	2-15	<2	2-15	<2	2-15
Accumulation (kg ha^{-1})								
Organic matter	5394.9^{a}	3070.3^{c}	4216^{b}	2523^{d}	7544.1^{e}	3979.5^{g}	4654.5^{f}	3053.3^{h}
Nitrogen	71.21^{a}	27.32^{c}	53.96^{b}	21.69^{d}	97.32^{e}	34.62^{g}	60.50^{f}	26.56^{h}
Phosphorous	3.51^{a}	1.62^{c}	2.57^{b}	1.29^{d}	4.98^{e}	1.98^{g}	2.74^{f}	1.49^{h}
Annual production/ input (kg ha^{-1})								
Organic matter	5437.8^{a}	5675.2^{c}	4722^{b}	4663.4^{d}	5686^{e}	6731^{g}	4243.2^{f}	4660.4^{h}
Nitrogen	70.59^{a}	50.50^{c}	60.44^{b}	40.10^{d}	73.34^{e}	58.56^{g}	55.16^{f}	40.54^{h}
Phosphorous	3.47^{a}	3.01^{c}	2.88^{b}	2.38^{d}	3.75^{e}	3.37^{g}	2.50^{f}	2.50^{h}

Values with dissimilar superscripts (Ialong a, b, c, d and Raliang e, f, g, h) are significantly different (P<0.05) between the stands at Ialong and Raliang for fine (a, b and e,f) and coarse (c, d and g, h) roots.

Table 6
Turnover rate and time of organic matter, N and P in fine (<2mm) and coarse (2-15mm) roots in the protected and disturbed stands at Ialong and Raliang.

Parameters	Ialong				Raliang			
	Protected		Disturbed		Protected		Disturbed	
	<2	2-15	<2	2-15	<2	2-15	<2	2-15
Turnover rate (year^{-1})								
Organic matter	1.01	1.85	1.12	1.85	0.75	1.69	0.91	1.53
Nitrogen	0.99	1.85	1.12	1.85	0.75	1.69	0.91	1.53
Phosphorous	0.99	1.86	1.12	1.84	0.75	1.70	0.91	1.68
Turnover time (year)								
Organic matter	0.99	0.54	0.89	0.54	1.33	0.59	1.09	0.65
Nitrogen	1.01	0.54	0.89	0.54	1.33	0.59	1.09	0.65
Phosphorous	1.01	0.54	0.89	0.54	1.33	0.59	1.09	0.59

lower than that of coarse roots (1.53 - 1.85 yr^{-1}). The turnover time for fine roots varied from 0.89 -1.33 yr^{-1}, whereas for coarse roots, it was low (0.59 - 0.65 yr^{-1}) in all the stands (Table 6).

N and P content in roots is governed by their concentration in the roots and the root mass. However, the latter seems to play a much greater role in determining the nutrient accumulation pattern in the below ground parts than the former (John *et al*. 2002). The maximum accumulation of N and P in the protected stands of Ialong and Raliang forests is due to greater root mass in these stands. The higher accumulation of N and P in fine and coarse root biomass during the rainy season corresponds not only to root mass but could be due to rapid uptake of nutrients that are released at a faster rate due to fast decomposition of litter during this period of the year (Khiewtam and Ramakrishnan 1993). The N and P accumulation in roots obtained in the present study is close to those reported (N = 37.18 – 65 kg ha^{-1} and P = 2.49 – 7.02 kg ha^{-1}) from different forest types (McClaugherty *et al*. 1982; Arunachalam *et al*. 1997; John *et al*. 2002). In all the stands, the amount of N accumulation in roots was greater than that of P. This finding is similar to those

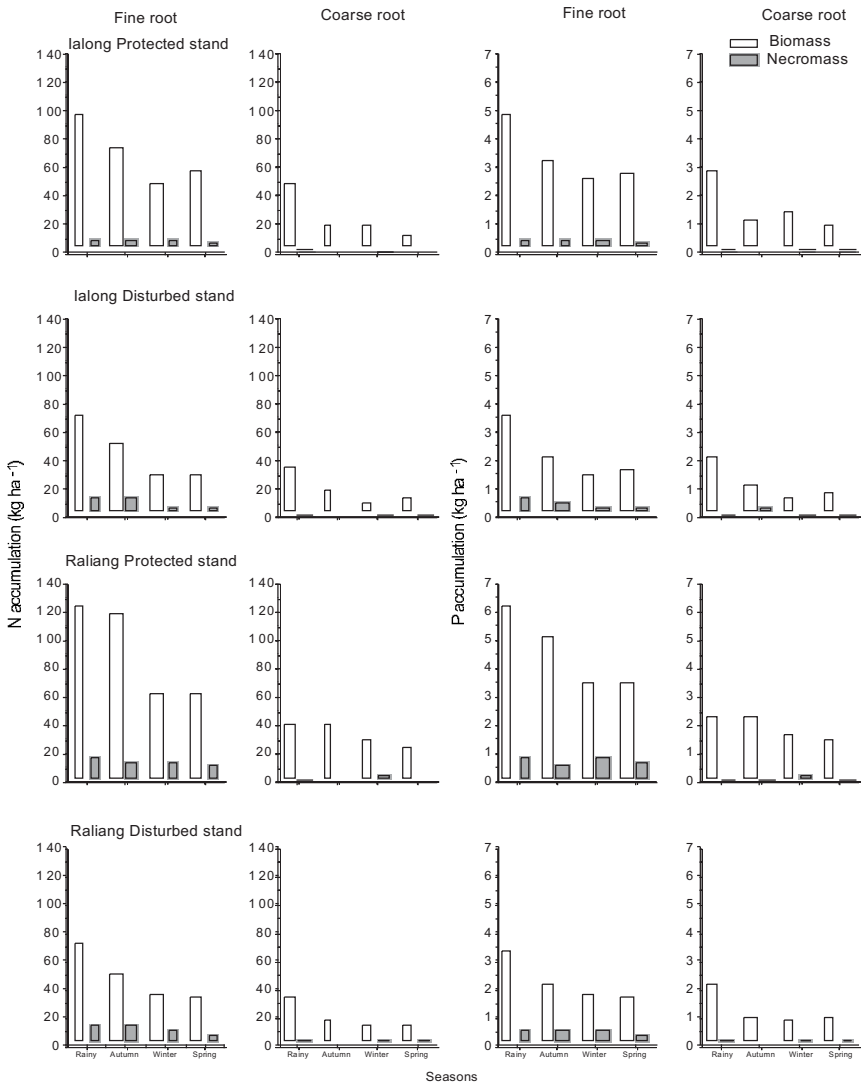

Fig. 4: Mean seasonal variation in N and P accumulation in fine and coarse root biomass and necromass in protected and disturbed stands

reported by Nambiar (1987), Khiewtam and Ramakrishnan (1993) and John *et al*. (2002). Annual N and P input to the soil are also related to production. According to Gill and Jackson (2000), fine root turnover rates from different forest types are in the range of 0.02 to 2.64 yr^{-1} with an average of 0.56 yr^{-1}. The present estimate is well within the range.

CONCLUSION

Fine roots play an important role in organic matter and nutrient dynamics in the studied stands where they accumulated for 69 - 72% of the total N and 65 - 72% of the total P storage in the below ground parts. Mild disturbance in the form of collection of fuelwood, selective logging for timber and movement by humans led to a significant reduction in the fine root mass and annual production in the disturbed stands and is attributed to the change in the dominant tree species and decrease in stand basal area as well as a decrease in density of tree saplings, seedlings and ground vegetation. Besides vegetation change, disturbed stands had low soil N, P and organic matter content. The dynamics of fine roots on the forest floor in relation to different degrees of disturbance should therefore receive more attention for a better understanding and management of the forest ecosystem.

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