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Biomass and production of fine and coarse roots during regrowth of a disturbed subtropical humid forest in north-east India

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Abstract

Seasonal variation and depthwise distribution of dry matter in roots of different diameter classes and their annual production were studied using sequential core sampling. The investigations were carried out in three stands of a subtropical humid forest of north-east India representing different stages of regrowth after tree cutting. The mean annual standing crop of fine (<2 mm in diameter) and coarse (2–15 mm diameter) roots increased gradually from 5.4 Mg ha^{-1} and 0.7 Mg ha^{-1} in 7-yr old regrowth to 9.4 Mg ha^{-1} and 2.8 Mg ha^{-1} in 16-yr old regrowth, respectively. The contribution of fine roots to the total root mass declined from 88% in 7-yr old regrowth to 77% in both 13 and 16-yr old regrowths, while that of coarse roots increased from 12 to 23%. A major portion of fine roots (59–62%) was present in 0–10 cm soil layer, but the coarse roots were concentrated in 10–20 cm soil depth (38–48%). In all the three stands, biomass of both fine and coarse roots followed a unimodal growth curve by showing a gradual increase from spring/pre-rainy season to autumn/post-rainy season. Biomass to necromass ratio increased from 2.5 in the 7-yr old to 3.2 in the 16-yr old stand. The annual fine root production increased from 5.9 Mg ha^{-1} to 7.7 Mg ha^{-1} and total root production from 7.6 Mg ha^{-1} to 14.7 Mg ha^{-1} from 7-yr to16-yr old regrowth.

Introduction

Recent studies on fine roots conducted in a variety of temperate and tropical forests have established their importance in the functioning of these ecosystems (Vogt *et al.* 1986, 1991). Fine roots enrich the soil with organic matter and nutrients by rapid turnover and help in growth of vegetation by efficient absorption of nutrients. They also conserve nutrients by preventing leaching losses from the ecosystem. The role of fine roots in the process of vegetation regrowth following major disturbances such as cutting of trees is not fully understood in forest ecosystem. Nevertheless, some data are available on the growth and development of fine roots and their dynamics in successional tropical forests on fallow agricultural land (Uhl *et al.* 1982), in tree fall gaps (Sanford 1989) and in a humid tropical forest following disturbance caused by a hurricane (Parrota & Lodge 1991).

The subtropical humid forest which represents a climax vegetation of north-east India between 1500 and 2000 m altitude (Champion & Seth 1968) is often disturbed by clear cutting or by selective felling of trees for timber and fuelwood requirements. The disturbed forest stands are then left for natural recovery, the duration of which may vary between 5 and 20 years depending on the availability of land and population pressure. The recovery of such disturbed forest ecosystems depends among other things on soil fertility, which is drastically reduced in disturbed forests due to accelerated nutrient losses from the soil during periods with high rainfalls and a hilly terrain. The objectives of the present study were to analyse the temporal and spatial variation in standing crop of roots of different diameter classes and to determine their role in organic matter input in soil during regrowth of disturbed subtropical humid forest ecosystem. Seasonal and depthwise variations of root mass accumulation

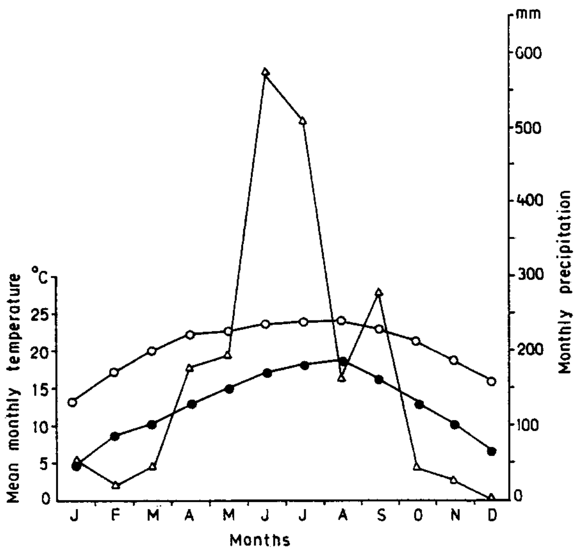

Fig. 1. Climatic diagram based on the data collected during 1993. Temperature curves-maximum (○) and minimum (●), precipitation curve (△).

in different diameter classes (<1–15 mm) of roots and their annual production were estimated in three disturbed stands of a subtropical humid forest in Meghalaya, north-east India.

Study site

The study was carried out in a subtropical humid forest (latitude 25° 34′ N, longitutde 91° 56′ E, altitude 1900 m asl) near Shillong, the capital of Meghalaya, India. The area is characterised by high annual rainfall (2500 mm), 80% of which is confined mainly between May and mid-October (rainy season) (Fig. 1). Annual mean minimum and maximum temperatures are 16 °C and 22 °C. Winters during mid-November to February are cold and dry (Fig. 1). The mean minimum and maximum temperatures during winter are 3 °C and 16 °C, respectively, and frost occurs occasionally. The short transitional periods from mid-October to mid-November and from March to mid-May represent autumn and spring, respectively.

Three adjacent stands of a subtropical humid forest representing different stages of vegetation recovery (7-, 13-, and 16-yr old regrowths) after selective tree cutting were chosen for the study during December 1993. As a consequence, the forest regrowth was interspersed with a few older trees scattered over the forest stands. The 7-yr old regrowth was dominated by early successional species like *Eupatorium adenophorum, Litsea elongata, Pinus kesiya* and sprouting stumps (10–25 cm DBH) of *Quercus dealbata, Castonopsis kurzii* and *Schima khasiana.* In the 13-yr old regrowth, where the DBH of the trees ranged between 10 and 30 cm, *Q. dealbata* and *C. kurzii* were the dominant tree species. In this stand, the ground vegetation was thin and devoid of early successional weeds and grasses. *Rhododendron arboreum* and *Q. dealbata* were dominant in 16-yr old regrowth where the DBH of the tree species varied between 10 and 40 cm. In this stand the forest floor had a dense growth of shade-tolerant herbs, pteridophytes and mosses.

Methods

In all the three stands, samplings for root mass were done during winter (January), spring (April), rainy (July) and autumn (October) seasons during 1993. In each stand, ten randomly located soil cores (6.5 cm diameter, 30 cm depth) were taken with a long tubiform steel corer and sliced into three sections, each measuring 10 cm in length, starting with the soil surface. The cores were taken to the laboratory in polythene bags and stored in a deep freeze at −20 °C before root separation. Roots were retrieved from the soil cores by wet-sieving method outlined by Bohm (1979) and processing of all samples was completed within 21 days as suggested by Parrotta & Lodge (1991).

The roots were separated into five diameter classes: <1, 1–2, 2–5, 5–10 and 10–15 mm. Live and dead roots were distinguished on the basis of pliability and degree of cohesion between cortex and periderm. Living roots were much more resistant than dead ones and did not break easily when bent. Dead roots were often wrinkled and dark in colour in contrast to the smooth and light coloured live roots (Persson 1979, 1983). Fine roots (<1 plus 1–2 mm diameter classes) as well as coarse roots (2–5, 5–10 and 10–15 mm diameter classes) were washed twice to ensure removal of all external mineral matter and soil particles adhered to the roots. The clean root samples were dried to a constant weight at 70 °C and weighed.

Annual root production by diameter class was determined by summing up the positive increments in live root mass (biomass) and concurrent increment, if any, in dead root mass (necromass) in successive samplings in a given diameter class (Uma Shankar *et al.* 1993).

In all the three stands, vegetation analysis was done during the rainy season in ten randomly placed 10 m × 10 m quadrats for woody species and 1 m × 1 m quadrats for herbaceous vegetation. Nomenclature of the plant species follows Hooker (1872–1897). Density, frequency, abundance, basal cover and importance value of the woody and herbaceous species were determined according to Misra (1968). In each stand, soil samples of three different depths (0–10, 10–20 and 20–30 cm) were also collected from each of the ten quadrats used for the vegetation study. They were mixed thoroughly according to depth, air-dried and used for the determination of texture, pH, water holding capacity (WHC), organic-C, total Kjeldahl nitrogen (TKN) and available-P by standard procedures (Allen *et al.* 1974).

Results

Composition of vegetation and soils of study sites

Dominant and co-dominant species identified on the basis of importance value indices of the tree, shrub and herbaceous components of vegetation are given in Table 1. Density of woody vegetation increased significantly from 680 plants ha^{-1} in 7-yr old regrowth to 1440 plants ha^{-1} in 16-yr old regrowth. Average DBH per tree showed a marked increase from 7- to 13-yr old regrowth, after which it did not register any increase. However, the total tree basal cover registered about 15-fold increase from 7- to 16-yr old regrowth.

The soil of the area is oxisol (latosol) derived from precambrian igneous rocks. At the study site the soil was sandy loam to clay loam and acidic (pH 5–5.2). The WHC, organic-C, TKN and available-P in soil increased gradually from the 7-yr old stand to the 16-yr old stand (Table 1).

Temporal variation in root mass

Fine-root (<2 mm diameter) standing crop was maximum during October in 7-yr old regrowth and during January in 13- and 16-yr old regrowths and minimum during July in all the three stands (Fig. 2). Maximum coarse-root (2–15 mm diameter) mass was recorded during October in all the three stands and minimum during January in 16-yr old regrowth and during April in 7- and 13-yr old regrowths (Fig. 2). The ratio of biomass to necromass of fine and coarse roots was minimum (2.1–2.6) during January and maximum (3.4–4.1) during April except for the 16-yr old regrowth where the peak occurred in July.

The mean annual standing crop of fine roots increased from 5.4 to 9.4 Mg ha^{-1} and that of the coarse roots increased from 0.7 to 2.8 Mg ha^{-1} with the progression of vegetation recovery (Table 2). Two-way ANOVA of root mass data revealed significant ($p < 0.01$) differences due to season and diameter class.

The total standing crop of roots peaked during October in all stands and then declined gradually until April in 16-yr old regrowth and July in 7- and 13-yr old regrowths. The increase in mean annual total root mass from 7-yr to 13-yr old regrowth was significant ($p < 0.01$), but the difference between 13- and 16-yr old regrowth was not significant.

Root biomass was significantly higher ($p < 0.01$) than necromass in all four seasons; it was maximum during October in all the stands and minimum during April in the 16-yr old stand and during July in the 7- and 13-yr old stands. The necromass varied between 1.1 and 4.2 Mg ha^{-1}, showing peak during autumn in the 7-yr old stand and during winter in the 13- and 16-yr old stands. Its minimum value was recorded during rainy season in the 7-yr old stand and during spring in the 13- and 16-yr old stands. The biomass:necromass ratio fluctuated through seasons and was highest (3.3–4.3) during spring and lowest (2.1–2.7) during winter in the 7- and 16-yr old stands and during rainy season in the 13-yr old stand (2.2). The ratio between mean annual biomass and necromass of roots increased from 2.5 in 7-yr old stand to 3.2 in 16-yr old stand.

Vertical distribution of root mass

Up to 62% of the fine roots were present in 0–10 cm soil layer and their proportion declined to 13% in 20–30 cm soil layer (Fig. 3). In contrast, the proportion of coarse roots (2–15 mm diameter) gradually increased from 35–44% in 0–10 cm soil layer to 38–48% in 10–20 cm and then declined to 9–26% in 20–30 cm soil depth. Two-way ANOVA showed a significant ($p < 0.05$) decline in the fine- and coarse-root mass with increasing soil depth. The biomass and necromass in the 0–10 cm soil layer was significantly ($p < 0.01$) higher than the subsurface soil layers. Generally, the accumulation of total root mass in the upper soil layer increased with the increase in age of the stand, but the difference between the 13- and 16-yr old stands was not significant.

Table 1. Vegetation and soil characteristics of the study sites. Values for soil parameters are the means of three soil depths (0–10, 10–20 and 20–30 cm) and four seasons across the year ($n = 12$)

	Forest regrowth stage		
	7-yr old	13-yr old	16-yr old
Vegetation			
Dominant species			
Trees	*Pinus kesiya*	*Quercus dealbata*	*Rhododendron arboreum*
	Schima khasiana	*Castonopsis kurzii*	*Quercus dealbata*
Shrubs	*Litsea elongata*	*Litsea elongata*	*Litsea elongata*
	Osbeckia stellata	*Symplocos spicata*	*Viburnum foetidum*
Ground vegetation	*Imperata cylindrica*	*Pteridium aquilinum*	*Lycopodium clavatum*
	Eupatorium adenophorum	*Smilax blumeii*	*Commelina benghalensis*
Density of the woody vegetation (Plants ha^{-1})			
Trees	180±21	480±13	1140±24
Shrubs	500±11	780±19	300±9
Total	680	1260	1440
Basal area of the woody vegetation (m^2 ha^{-1})			
Trees	3.10±0.36	19.85±0.54	44.21±0.93
Shrubs	0.31±0.01	0.62±0.02	0.43±0.01
Total	3.41	20.47	44.64
Average DBH (cm)			
Trees	14.81±1.33	22.95±1.85	22.22±1.29
Shrubs*	2.80±0.19	3.18±0.23	4.25±0.31
Soil			
Textural class	Sandy loam	Sandy clay loam	Clay loam
WHC (%)	50.5±2.1	56.5±3.1	66.1±6.3
pH	5.2±0.2	5.0±0.1	5.0±0.2
Organic-C (%)	2.9±0.1	3.9±0.1	5.8±0.6
TKN (%)	0.3±0.0	0.4±0.0	0.5±0.0
Available-P (μg g^{-1})	5.4±1.6	6.1±1.9	7.0±2.3

* Basal diameter.

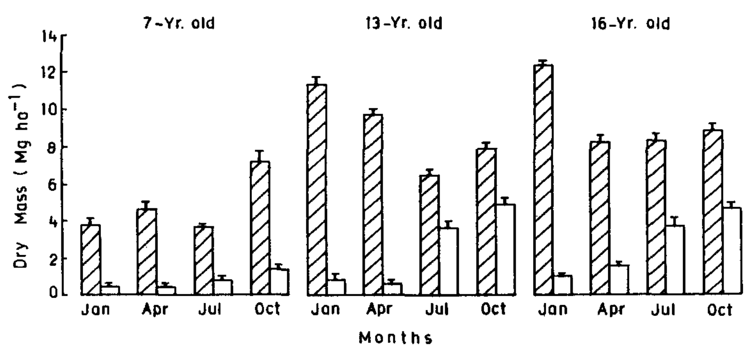

Fig. 2. Seasonal variation in fine (<1–2 mm diameter) and coarse (>2–15 mm diameter □) root standing crop in forest regrowths of different ages.

Table 2. Standing crop of roots (dry mass, Mg ha^{-1}) of different diameter classes in forest regrowths of different ages in the humid subtropics. (BM – Biomass, NM – Necromass, and – absent)

Forest regrowth stage	Soil depth (cm)	Root diameter class (mm)									
		<1		1–2		2–5		5–10		10–15	
		BM	NM	BM	NM	BM	NM	BM	NM	BM	NM
7-yr old	0–10	1.8	0.6	0.6	0.2	0.2	0.1	0.2	--	--	--
	10–20	0.5	0.2	0.3	0.2	0.1	0.1	0.2	0.03	--	--
	20–30	0.3	0.1	0.3	0.1	0.05	0.01	--	--	--	--
	Total	2.7	1.0	1.2	0.5	0.3	0.2	0.2	0.03	--	--
13-yr old	0–10	2.7	0.7	1.7	0.5	0.5	0.4	0.1	--	--	--
	10–20	1.1	0.2	0.6	0.3	0.5	0.3	0.3	--	0.2	--
	20-30	0.4	0.2	0.3	0.2	0.1	0.1	--	--	0.07	-
	Total	4.1	1.2	2.6	1.0	1.1	0.7	0.4	--	0.3	--
16-yr old	0–10	3.0	0.7	1.4	0.5	0.6	0.2	0.1	--	0.06	--
	10–20	0.09	0.4	0.8	0.3	0.4	0.1	0.2	0.09	0.2	--
	20–30	0.5	0.2	0.5	0.2	0.06	0.2	0.3	--	0.2	--
	Total	4.5	1.2	2.7	1.0	1.1	0.6	0.6	0.09	0.5	--

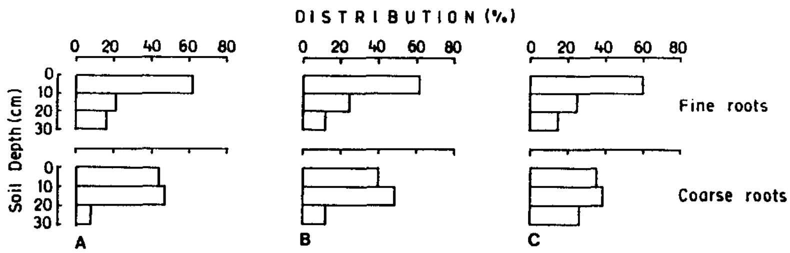

Fig. 3. Depthwise distribution (%) of fine and coarse roots in forest regrowths of different ages, (**A**) 7-yr old, (**B**) 13-yr old and (**C**) 16-yr old.

Root production

The estimates of annual net production for different diameter classes show that the fine roots contributed to 77, 57 and 53% of the total root production in 7-, 13- and 16-yr old regrowths, respectively. Since both fine- and coarse-root production increased with the increase in age of the stand, the total root production was maximum (14.7 Mg ha^{-1}) in the 16-yr old regrowth and minimum (7.6 Mg ha^{-1}) in the 7-yr old regrowth. Generally, production declined with the increase in soil depth and root diameter (Table 3).

Discussion

The mean standing crop of fine roots in the 7-yr old regrowth is close to the value reported from a dry deciduous forest (Singh & Singh 1981), while those obtained in the 13- and 16-yr old regrowths are higher than the majority of estimates in the tropical and temperate forests (Table 4). Several studies on vertical distribution of tree roots have shown that most of the roots colonize the upper 50 cm of soil and majority of the fine roots are confined within the top 30 cm of the soil profile (Hermann 1977; Kozlowski 1971; Persson 1983). In the present study, the top 20 cm layer of the soil profile had 84–87% of the fine-root mass, the bulk of which was confined to 0–10 cm depth. The total fine-root stock in the upper 10 cm soil layer falls within the range reported for a secondary forest in Puerto

Table 3. Root production (Mg ha^{-1} yr^{-1}) in the 7-, 13- and 16-yr old regrowths

Category	Forest regrowth stage		
	7-yr old	13-yr old	16-yr old
Diameter class (mm)			
<1	3.2	3.4	3.9
1– 2	2.7	3.8	3.9
2– 5	1.1	3.6	3.1
5–10	0.6	1.3	1.9
10–15	–	0.6	1.9
Total	7.6	12.7	14.7
Soil depth (cm)			
0–10	4.0	6.2	6.4
10–20	2.0	4.6	4.6
20–30	1.6	1.9	3.7

– absent.

Rico (Cuevas *et al.* 1991), premontane forest in Costa Rica (Berish 1982), and in a hurricane-disturbed subtropical wet forest in Puerto Rico (Parrotta & Lodge 1991).

The fine-root mass in forests changes both seasonally and annually. The seasonal periodicity of fine-root growth is known in both temperate and tropical forests (Harris *et al.* 1977; Parthasarathy 1987; Persson 1978; Srivastava *et al.* 1986). At our study site, fine roots followed a unimodal growth pattern with a trough in summer and a peak either in autumn (7-yr old regrowth) or in ensuing winter season (13- and 16-yr old regrowths). Autumn peak of the belowground biomass obtained in grassland ecosystems has been attributed to the translocation of large amount of organic matter from shoot to the belowground parts (Sims & Singh 1978). This seems to be true in case of the 7-yr old regrowth which looked like a savanna due to abundance of perennial grasses such as *Imperata cylindrica* and *Arundinella benghalensis* in open spaces between sparsely growing young regenerating trees of pine, *Quercus dealbata, Castonopsis kurzii* and *Schima khasiana.* In the other two stands, where woody elements were abundant, the peak in fine roots coincided with the period of tree leaf senescence and fall. Low spring biomass corresponded to the period of active shoot growth due to gradual increase in temperature from the preceding winter season.

The seasonal changes in the amount of fine roots also reflect the variation in production and decomposition processes through seasons (Ford & Deans 1977; Khiewtam & Ramakrishnan 1993; Srivastava *et al.* 1986). For instance, a low fine-root standing crop occurred in July when decomposition is most rapid due to high temperature and humid conditions. Higher standing crop values for fine roots was recorded during post-rainy season when the rate of decomposition declined due to a decrease in soil moisture and atmospheric temperature.

Evidence from most fine-root production studies suggests that a large flux of organic matter takes place through this component. Fine-root production which accounted for 77–53% of the total root production in the three stands, is higher than those reported by Harris *et al.* (1977) from a mixed temperate deciduous forest, and Persson (1978) from Scots pine stands. The relatively higher proportion of fine root production in the young stand may be attributed to the dominance of perennial grasses and evergreen *Pinus kesiya* saplings, both of which have the tendency of accumulating more organic matter in the belowground parts. In the present study, the greater production of fine roots in the surface soil layer (0–10 cm) than in the deeper layers (10–20 and 20–30 cm) seems to be related to high soil nutrient concentration and greater moisture retention (Table 1). Similar observations were made by Ford & Deans (1977) in Sitka spruce *(Picea sitchensis)* plantations, by Srivastava *et al.* (1986) in teak *(Tectona grandis)* plantations and by Khiewtam and Ramakrishnan (1993) in a mature subtropical broadleaved forest. Studies in temperate forest ecosystems reveal that low availability of water, light and nutrients promote contribution of roots rather than the foliage in detrital cycling (Vogt *et al.* 1986, 1991). However, our results do not agree with these findings, because root production gradually increased as the WHC, organic-C, TKN and available-P increased in soil during forest regrowth (Table 1). Thus, a gradual increase in fine- and coarse-root production with concomitant increase in soil nutrient level, from the 7-yr old to 16-yr old regrowth, suggests that a significant proportion of organic matter and nutrients are being added to the soil system through roots in general, and fine roots in particular.

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Table 4. Fine-root mass in different temperate and tropical forests of the world

Vegetation	Location	Sampling depth (cm)	Root diameter class (mm)	Root mass (Mg ha^{-1})	Authors
Temperate forests					
Pinus sylvestris forest					
18-yr old stand	Sweden	10	<2	2.5	Persson (1979)
120-yr old stand	Sweden	10	<2	4.6	Persson (1980)
Pinus sylvestris forest	Sweden	10	<2	1.8	Persson (1982)
Picea sitchensis forest	Scotland	15	<2	3.5	Deans (1981)
Abies amabilis forest					
23-yr old stand	USA	30	<2	3.7–10.6	Vogt *et al.* (1981)
180-yr old stand	USA	30	<2	8.7–17.7	Vogt *et al.* (1981)
Tropical/Subtropical forests					
Dry deciduous forest	India	50	<2	4–5	Singh & Singh (1981)
Teak forest	India	10	<2	1.8	Parthasarathy (1987)
Mixed deciduous forest	India	10	<2	1.8	Parthasarathy (1987)
Moist deciduous forest	Ghana	50	<2	8–10	Jenik (1969)
Premontane wet forest					
1-yr old stand	Costa Rica	85	<2	1.0	Berish (1982)
8-yr old stand	Costa Rica	85	<2	3.1	Berish (1982)
70-yr old stand	Costa Rica	85	<2	3.4	Berish (1982)
Semi evergreen forest	India	10	<2	3.5	Parthasarathy (1987)
Semi evergreen forest					
7-yr old regrowth	India	30	<2	5.4	Present study
13-yr old regrowth	India	30	<2	8.9	Present study
16-yr old regrowth	India	30	<2	9.4	Present study
Semi evergreen climax forest	India	30	<3	4.6	Khiewtam & Ramakrishnan (1993)
Evergreen forest	India	10	<2	3.4	Parthasarathy (1987)
Evergreen forest	Puerto Rico	10	<2	4.2	Parrotta & Lodge (1991)
Evergreen forest	Puerto Rico	20	<1	4.1	Kangas (1992)

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