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Fine root biomass production and turnover in evergreen forests of Central Himalaya, India

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Abstract. Fine root biomass, net primary production and turnover in two evergreen Central Himalayan forests viz., *Quercus leucotrichophora* and *Pinus roxburghii* forest are described here. The fine root biomass and fine root net primary production decreased with increasing soil depth. The total annual fine root biomass was 2,071 kg ha^{-1} in chir pine forest and 3,236 kg ha^{-1} in banj oak forest. The fine root net production was 3,428 kg ha^{-1} yr^{-1} in oak forest which was higher then the fine root production of pine forest (2,459 kg ha^{-1} yr^{-1}). In banj oak forest the fine root turnover rate (0.826) was maximum at 40-60 cm soil depth and in chir pine forest the turnover rate was maximum at 0-20 cm soil depth (0.730).The percent contribution of live root biomass to total root biomass ranged from 63-68 percent. The maximum fine root biomass and net primary production was recorded in rainy season followed by summer and winter season in both the forests. The nitrogen (%) concentration decreased with increasing soil depth and ranged from 0.48-0.68% in chir pine forest and 0.60-0.76% in oak forest.

Key-words: root biomas, production, *Quercus leucotrichophora*, *Pinus roxburghii*, Central Himalaya

Introduction

Fine root production is an important component of both dry matter and nutrient cycling in forest ecosystems (Vogt *et al.* 1986 b; McClaugherty *et al.* 1984; Singh 1983). Data from numerous studies have shown that the greatest proportion of the root system of many forests is located in the upper soil horizon (Vogt *et al.* 1983). The roots near the soil surface undergo much more rapid changes than the deep roots (Hendrick and Pregitzer).

The role of small diameter roots and mycorhiza in total forest biomass dynamics were underrated (Caldwell 1979, Herman 1977, Santantonio *et al.* 1977). In many previous studies rough estimates of belowground turnover were accepted as an alternative to having no estimate at all (Harris *et al.* 1977, Leith 1968) what control the death and replacement of fine root in forest ecosystems is a matter of conjecture (Caldwell 1979, Harman 1977, Persson 1982, Sutton 1980). Investigators of production ecology and nutrient cycling in forests face a major gape in their understanding of system process because little is known about production and turnover of fine roots (Jarvis and Leverenz 1983, Santantonio and Grace 1987). Methodological difficulties, i.e., lack of uniform investigatory techniques together with varying environmental conditions make it practically impossible at present to draw a general conclusion from available data in literature. The most commonly used method of estimating fine root production and mortality involves periodic measurements of live and dead fine root biomass. Production and mortality rates are based on changes in fine root biomass (Persson 1978, McClaugherty *et al.* 1982). Soil cores have been accepted as a suitable means of sampling, but a standard method to quantify fine roots in soil cores remains unidentified. Fogel (1983,1985) and Persson (1983) have discussed many technical difficulties. Methods vary widely and only a few data are directly comparable.

This present study is an attempt to understand the fine root production and turnover rates in Himalayan forests and to compare these estimates with similar studies in other part of the world.

Material and methods

Site description

The study was conducted in Nainital district of Uttar Pradesh, India 79°15' to 79°38'E) in 1,600 m to 2,150 m altitude. The year is divisible into three main seasons viz. rainy (mid June to September), winter (October to March) and summer season (April to mid June). Of the annual rainfall of 1,963 mm 90% encountered in the rainy season (Usman 1993). The mean daily temperature ranges between 7°C and 19.3°C. The annual value (119.4) of P.E, index (precipitation effectiveness) indicate that it fells within the humid climate regime. However, April and November are dry months (Fig. 1).

In *Quercus leucotrichophora* site rocks are black carbonaceous and pyritous locally oxidised to as grey colour within characteristic oxidation rings on parting planes. Rocks in the pine site are quartzite consisting of variegated purple, brown, fawn, grey and white quartzarenite and sublitharcenite interbedded with purple perruginous.

In both of the forest soils were sandy clay in texture. However significant differences were observed in soil pH, bulk density, total nitrogen, carbon, phosphorus, and potassium between the soil of banj oak and chir pine forests (Table 1). The two species differ greatly in tissue N concentration and its retranslocation from leaves during senescence. Both of the forests had similar tree density, but the total basal area of banj oak forest (6,592 cm^2 100m^2) was

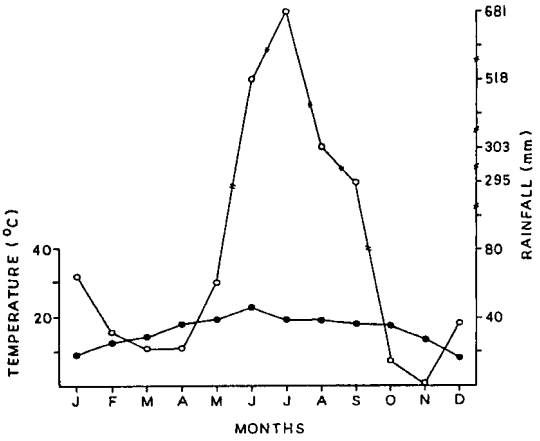

Fig. 1. Climatic diagram for the study area.

greater than that of chir pine (3,474 cm^2 $100m^2$) forest. Investigators of production ecology and nutrient cycling in forest face a major gap in their understanding of systems process because little is know about production and turnover of fine roots (Jarvis and Leverenz 1983, Santantonio and Grace 1987).

Methods

Fine root biomass

Fine root biomass (≤ 1mm diameter in both the forest stands (i.e. *Quercus leucotrichophora* and *Pinus roxburghii*) was determined seasonally by sorting fine roots from the soil cores taken during mid-June, mid-September and mid-December. Sampling was done in three directions of the sample tree and the sampling point were located 1/2, 1/4th and 1/8th distance from the centre of neighbouring trees. Soil cores were obtained by driving a sharp edged steel tube (8.5 cm inside) sliced into 0-20, 20-40, and 40-60 cm soil depth.

Seventy-one soil cores were taken for each depth class. Individual cores were placed in polythene bags and returned to the laboratory for sorting.

In the laboratory, roots were separated from the other organic material by passing the soil cores through a sequence of fine sieves with the hole size ranging from 12.7 to 2 mm. Live and dead root material was hand sorted from the residue remaining on each sieve. Live and dead roots were distinguished on the basis of colour and texture. Dead roots were dark and spongy living roots were pinkish and firm. In case of doubt roots were cut with a sharp razor and examined under magnification for colour and cohesion between the cortex. Fine roots are generally defined as non-woody small diameter and mycorhizae. Upper values for fine root diameter vary among published studies and generally ranged from <1 to <5 mm. Definition of fine root vary among studies because its morphology and size vary among species and even within species across site (Fitter 1985).

In the laboratory roots were separated (up to ≤ 1 mm diameter) with the help of forceps and attached organic material soil particles were removed by washing through running tap water. These samples were oven dried at 80°C till constant weight. The over dried root samples were pooled depth wiss powdered and placed in plastic bags and sealed for chemical analysis. The total fine root nitrogen was determined by microkjeldhal method (Jackson 1958).

Parameters	Q.l.	P.r.
Bulk density (g cm^{-3})	0.89	0.98
Texture (%)		
Sand	56.1	61.9
Silt	25.0	20.4
Clay	18.6	17.6
pH	6.4	5.8
Total n(%)	0.26	0.21
Organic C(%)	3.06	2.54
Available P(%)	0.016	0.008
Total K(%)	0.10	0.06

Table 1. Comparative account of physico-chemical properties of soil in *Quercus leucotrichophora* (Q.l.) and *Pinus roxburghii* (P.r.) forest.

Fine root production

Fine root production was calculated through maximum minimum method. The maximum-minimum method changes in fine root biomass in volumetric soil samples are considered to estimate fine root production. This method is simpler then the other method in that it uses only the difference between annual minimum and maximum fine root biomass to estimate FRP (Singh and Yadava, 1974; McClaugherty *et al.* 1982; Aber *et al.* 1985).

Fine root turnover

The turnover rate of belowground biomass was calculated by the method proposed by Dahlmand and Kučera (1965):

$$\text{Turnover} = \frac{\text{Fine root net production}}{\text{Maximum fine root biomass}}$$

Results

Fine root biomass and fine root production

The fine root biomass (FRB) represents a varying proportion of the total accumulated organic matter of the forests stands.

Marked seasonal variation in the fine root biomass were observed in both the forests. Seasonal live fine root biomass very from 24-972 kg ha^{-1} (across different soil depth) in banj oak forest and from 26-749 kg ha^{-1} (across different soil depth in chir pine forest. The live fine root biomass (all soil depths) was at its maximum in the rainy season. In oak forest, it was 972 kg ha^{-1}, 572 kg ha^{-1}, and 142 kg ha^{-1}, and in pine forest it was 749 kg ha^{-1}; 401 kg ha^{-1}, and 89 kg ha^{-1}, respectively at 0-20, 20-40 and 40-60 cm soil depth. Fine root necromass (dead root biomass) also changed seasonally in both the forests (Table 2). This appeared to be related to the seasonal changes in fine root biomass. At different soil depths the fine root necromass ranged from 46 kg ha^{-1} (winter) - 1,974 kg ha^{-1} (rainy) in banj oak and from 46 kg ha^{-1} (winter)

Seasons Depth (cm)	*O.leucotrichophora* (kg\ha) Live	Dead	Total	*P. roxburghii* (kg\ha) Live	Dead	Total
Rainy						
0-20	972±626	1974±656	2946±1184	740±550	1338±202	2087±253
20-40	572±199	1097±211	1668±390	401±139	693±94	1094±177
40-60	142±44	265±101	407±133	89±20	151±27	240±42
Summer						
0-20	617±100	1310±212	1927±246	370±53	729±79	1099±110
20-40	338±36	657±60	995±63	204±66	364±35	568±77
40-60	100±20	189±31	289±42	61±7	104±27	165±32
Winter						
0-20	309±52	677±95	986±139	186±29	377±51	563±50
20-40	142±36	277±41	419±168	114±28	213±23	327±41
40-60	24±9	46±11	70±39	26±8	46±18	72±12

Table 2. Standing fine root biomass (<1 mm diameter) in banj oak and chir pine (kg ha $^{-1}$) forests.

Forest site	Soil depth (cm)	Production (kg\ha.yr)	Turnover
O. leucotrichophora			
	0-20	1960	0.665
	20-40	1249	0.749
	40-60	219	0.826
	Total	3428	
P. roxburghii			
	0-20	1524	0.730
	20-40	767	0.700
	40-60	168	0.700
	Total	2459	

Table 3. Annual fine root production and turnover at different soil depth.

- 1,338 kg ha^{-1} (rainy) in pine forest. In both the forests the fine root biomass was more then twice as much as live mass. The bulk of fine root biomass was concentrated to a depth of 20 cm (63%) of the total fine root biomass. For both study sites the proportion of dead fine root (necromass in total fine root biomass) showed a narrow range across the season (62-66%). The total annual fine root biomass was 2,071 kg ha^{-1} in chir pine forest and 3,236 kg ha^{-1} in banj oak forest. Large variation in the amount of fine roots (FRB+FRN) were found in both stands (Fig 2).

The total fine root production was 3,428 kg ha^{-1} yr^{-1} in oak forest which was higher than the fine root production of pine forest (2,459 kg ha^{-1} yr^{-1}). At different soil depths the rate of turnover ranged from 0.67-0.83 y^{-1} in oak and from 0.70-0.73 yr^{-1} in pine forest respectively (Table 3).

Fine root N concentration:

The N concentration of fine root also showed seasonal pulses. In oak forest at 0-20 cm soil depth the maximum N was found in rainy season (0.76%) followed by summer (0.73%) and winter (0.71%). Similar seasonal patterns were observed for all soil depths (i.e. 20-40 and 40-60 cm soil depth). Across the seasons the N concentration of fine roots was higher in banj oak forest (0.76% at 0-20 cm) compared to pine forest (0.68% at 0-20 cm soil depth - Table 4).

Discussion

Most investigations of root tips in temperate regions show that there is a concentration of root tips in the upper 20 cm of soil (Meyer and Gottsche 1971; Meyer 1967; Farrell and Leaf 1974). An estimate made on root tips count showed that about 80% of the root tips were in the upper 20 cm of the soil in both the forests across three seasons. It seems that the higher concentration of nutrients in upper soil permits higher concentration of fine root tips, and it decreases towards deeper soil as soil nutrients decrease.

The fine root biomass value of the present study lies with in the range reported for various temperate forests. (Table 5).

In the present study both oak and pine forests showed similar seasonal patterns of fine root biomass (live and dead). In both the forests the fine root

Season	Soil depth	Banj Oak	Chir Pine
Rainy	0-20	0.76±0.012	0.68±0.03
	20-40	0.70±0.015	0.55±0.01
	40-60	0.62±0.017	0.49±0.17
Winter	0-20	0.71±0.023	0.64±0.01
	20-40	0.68±0.008	0.51±0.01
	40-60	0.59±0.020	0.47±0.01
Summer	0-20	0.73±0.015	0.65±0.02
	20-40	0.69±0.012	0.53±0.01
	40-60	0.60±0.010	0.48±0.02

Table 4. Percent N-concentrations of fine roots in dependence on soil depth (cm).

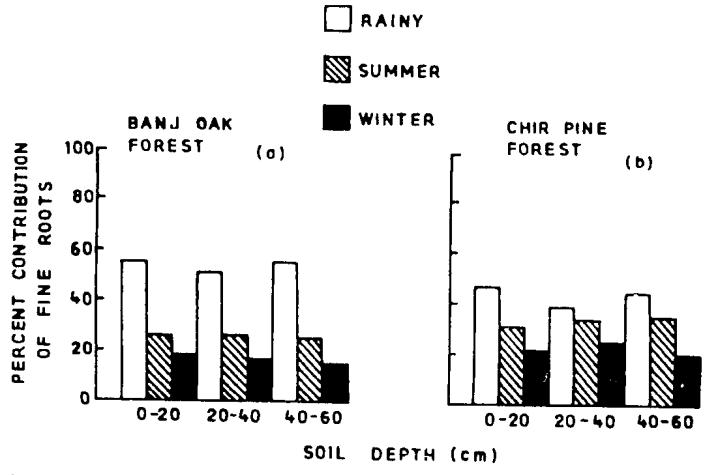

Fig. 2. Seasonal contribution of fine roots (%) in different soil depths of banj oak (a) and chir pine (b) forests.

Forest type	Location	Diameter Class (mm)	Root Standing Crop kg ha^{-1}	References
Dry Deciduous forest	Varanasi, India	<6	4000-5500	Singh and Singh (1981)
Evergreen forests	Western Ghats	<2	3,420	Parthasarathy (1988)
Semi-evergreen	Western Ghats	<2	3,500	Parthasarathy (1988)
Mixed deciduous	Kalakad Western Ghats	<2	1,830	Parthasarathy (1988)
Tropical rain forest	Ivory Coast	<5	8,800-9,600	Huttel (1969)
Mixed tropical forest	Ghana	<5	8,000-10,000	Jenik (1969)
Moist semi-deciduous forest	Ghana	<5	56,000-124,000	Lowson *et al.* (1970)
Terra firma forest	Latosol of Amazonia	<6	16,100	Klinge (1973)
Terra firma forest	Podzol of Amizonia	<6	10,900	Klinge (1973)
Central Amazon. rain forest	Brazil	<2	8,430	Klinge (1973)
Tropical wet forest	Costa Rican	<5	3,690-6,620	Gower (1987)
Mixed hardwood forest	SE Virginia &NE N.Carolina	<2-<5	18,870	Powell and Day (1991)
Tropical dry deciduous	Chamela	<0.5->2	31,000	Castellanous *et al.* (1991)
Tropical dry deciduous	Chamela	<0.5->2	45,000	Murphy and Lugo (1986b)
Psedotsuga menziesii	Chamela	<0.5->2	17,000	Hellman & Gassell (1963)
Quercus leucotrichophora	Nainital, India	<1	3,236	Usman (1993)
Pinus roxburghii	Nainital, India	<1	2,072	Usman (1993)

Table 5. Fine root standing crop in various forests of the world. For references see Usman (1993).

biomass peaked during rainy season. McClaugherty *et al.* (1982) have made similar observation in red pine forest. In both the forests percent concentration of fine root biomass was higher (about 53 and 55%) during rainy season followed by summer (32 and 33%) and winter (15 and 16%) respectively in oak and pine forests. Similar seasonal patterns of root biomass were also observed by Keyes and Grier (1981) for a spruce and sub-alpine fir forest in British Columbia. Similarly in both the forests, with a increase in fine root biomass, the fine root necromass (dead fine root) was decreased slightly, presumably because of low death rate and faster rate of fine root decomposition. This was consistent with the findings of Keyes and Grier (1981). The percent contribution of fine root necromass to total fine root was fairly stable across seasons and both forest sites (64-66%). Santantonio and Santantonio (1987) also reported similar values for *P. radiata* plantation in New Zealand.

Consistent with the findings of Moir & Bachelard (1969) the average contribution of root biomass in both forests were 63%, 31%, and 7%, respectively in 0-20, 20-40 and 40-60 cm soil depth. Santantonio and Santantonio (1987) and Castellcanson *et al.* (1991) observed that about 90% of total fine root biomass occurred up to 40 cm soil depth, and fine root biomass declined below 15 cm depth in the mineral soil.

McQueen (1968) and Kimmins and Hawks (1978) found that the concentration of fine root in the upper soil in mixed pine beech forest and white spruce sub-alpine fir forest were correlated with high concentration of organic matter and nutrients with favourable physical soil conditions. The vertical distribution of fine root in our study correlated with the vertical distribution of nutrients along soil depth. (Table 4).

The root biomass was inversely proportional to the bulk of soil depth (Nambiar and Sand 1992) According to Nambiar and Sand (1992) when bulk increases, soil strength increases, and aeration decreases leading to an adverse effect on root growth consistent with the fine root biomass the nitrogen concentration was also higher during rainy season followed by summer and winter seasons. Also the nitrogen concentration of fine roots decreased with increase in soil depth. These results are consistent with the findings of Charles *et al.* (1982) for hardwood forest.

Fine root production and dieback are seasonal and can result in seasonal changes in fine root biomass which is a factor that can limit comparison of studies undertaken at different time of the year. Ovington *et al.* (1963) found that in an oak wood ecosystem in central Minnesota the fine root biomass increased from 12.9 t ha^{-1} to 20.7 t ha^{-1} in the period from April to July and then decreased again to 10 t ha^{-1} by December. Similar seasonal patterns of fine root biomass were observed for both of the present sites. In the banj oak forest it increased from 3.2 t ha^{-1} to 5.2 t ha^{-1} from summer to rainy season and declined to 1.4 t ha^{-1} in winter season. In the case of the chir pine forest, fine root biomass increased from 1.8 t ha^{-1} in summer to 3.4 t ha^{-1} in rainy season and decline 0.9 t ha^{-1} in winter season.

Estimates of fine root production derived from the maximum-minimum method are generally well below the upper limit to FRP as derived from ingrowth method for the same study area (Usman 1993). In the present study the fine root derived from the maximum-minimum up to 60 cm soil depth was 3.4 t ha^{-1} in oak and 2.5 t ha^{-1} in chir pine forest however, for similar forest sites FRP by ingrowth method was 5.2 and 3.7 t ha^{-1} in oak and pine forests, respectively (Usman 1993), so this maximum minimum method can be used to define a lower limit to FRP at a site. This method underestimates FRP, however, at sites where fine root biomass is not seasonally variable, where roots are short lived, or where period of production and mortality overlap (Aber *et al.* 1985, Kurz and Kimmins 1987, Nadelhoffer and Reich 1992).

The turnover rate of belowground biomass was calculated by the method proposed by Dahlman and Kučera (1965). Turnover rate shows that in banj oak forest maximum amount of biomass was replaces by the lower soil layer (i.e. 40-60 cm soil depth) and minimum by upper soil layer (67%). About 75% of root

biomass was replaced by 20-40 cm soil depth. However, in chir pine forest the maximum amount of fine root biomass was replaced by upper soil layers (i.e. 0-20 cm soil depth) 73% as compared to middle soil layers (20-40 cm soil depth) as well as lower soil layers (40-60 cm soil depth).

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