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Litter fall, Fine Root Biomass and Soil Nutrient Returns in Van Panchayat Forest of Uttarakhand

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Abstract

The litter fall and fine root biomass is needed to quantify the annual return of elements and organic matter to the soil. The tree species that covers the largest area in the present studied community managed forest are the common banj oak and chir pine. The mean annual litter fall in Anriyakot Van Panchayat forest was 6.25±0.26 t ha^{-1}. The mean litter fall value was higher in the summer season (2.86±0.39 t ha^{-1}) and minimum in winter season (1.53±0.04 t ha^{-1}). The soil organic carbon percentage of the Anriyakot Van Panchayat ranged from 1.00±0.29% to 2.73±0.51%. The total fine root biomass ranged from 4.33 t ha^{-1} to 6.65 t ha^{-1}. The fine root biomass was higher during the rainy season (59.2%) followed by summer and winter seasons (26% and 14.8%, respectively). Soil organic carbon percent ranged from 1.00±0.29 to 2.73±0.51%. Fine root and litter fall affect the levels of nutrient returns in soil and acts as a medium for transfer of atmospheric carbon into the soil in the form of carbon containing compounds.

Key words: Community managed forest**,** Van panchayat, Litter fall

Introduction

Litter fall and fine root biomass are important vectors of nutrient recycling in forest ecosystems (Gill and Jackson 2000; Sayer 2006) and their turnover depend on a variety of factors such as weather conditions, season, vegetation type, soil conditions, species composition, age groups, canopy cover, biotic factors and density of the forest stand (Rawat et. al., 2009). Litter fall collection is a standard non destructive technique of assessing dynamics of aboveground biomass in forests. Evaluation of litter fall production is important for understanding nutrient cycling, forest growth, successional pathways, biological and physicochemical properties of topsoil and interactions with environmental variables in forest ecosystems (Zhou et. al., 2007). Knowledge of litter production was also important when estimating nutrient turnover, C and N fluxes in different ecosystems. Due to its influence on humus characteristics, tree growth and nutrition return litter production was used as a parameter to characterize forest ecosystems. A major part of the annual gain of energy and matter by plants is shed as litter, which enters into decomposition subsystem as detritus and plays a crucial role in the ecosystem structure and function (Christensen, 1975). Fine roots exert a significant influence on the soil profile development and contribute substantially to the soil organic pool through their turnover (Persson, 1982).

Fine root biomass is constantly renewed, and its productivity often exceeds aboveground productivity despite the fact that living fine root biomass constitutes only a small fraction of the total stand biomass (Helmisaari et. al., 2002). The distribution of fine roots in different soil layers is assumed to be related to climate and site characteristics, such as soil structure, compactness and aeration, and differs between different plant species. The rate of growth of fine roots is affected by the availability of nutrients and environmental factors such as soil temperature and moisture contents. Fine roots of trees and understory vegetation play an important role in the carbon and nutrient dynamics of forest soils.

The litter and fine root biomass is needed to quantify the annual return of elements and organic matter to the soil. The tree species that covers the largest area in the present studied community managed forests are the common banj oak and chir pine. However, in the present scenario the banj oak in reserve forests are highly degraded due to strong anthropogenic influence. In order to preserve and recover these forests, the ecology of the oak forests need to be known.

Material and Methods

The selected sites are located in the Van Panchayat forests of Anriyakot and Bhatkholi in Almora district (29º 32.98′ to 29º 34.32′ N latitudes and 79° 41□□' to 79° 43.2' E longitudes). The climate of the study area is influenced by the monsoon rhythm of rainfall. The monsoon strikes this area from June to the September and sometimes to late October. The average annual rainfall varied from 274.5 mm to 463.2 mm. The parent material forming the soils in the study area mainly comprises of schist, micaceous quartizimeta morphism, plutonic bodies of granodiorites and granites (Rawat, et. al., 2010). The vegetation type mainly comprises Himalayan moist temperate oak forest and subtropical pine forest. The dominated tree species of both the Van Panchayats are *Quercus leucotrichophora, Pinus roxburghii, Rhododendron arboreum* and *Myrica esculenta*. Majority of forest soils in the present study is residual, shallow and slightly acidic in reaction and the texture is more or less clay loam. Four aspects at both the Van Panchayats were identified with in each aspect forest floor litter mass were collected from 10, (0.5X0.5m) quadrats placed randomly following Rawat and Singh (1988).

All the herbaceous live and dead shoots at ground level were harvested. Litter were categorized into fresh leaf litter, partially decomposed litter, wood litter including seed, miscellaneous litter consisting of material other than above. The collection would be brought to the laboratory and the oven dried weight was determined (Rawat and Singh, 1988). Fine root biomass (< 1 mm in diameter) was estimated following the ingrowth core method. The soil cores were obtained by driving a sharp edged steel tube (8.5 cm internal diameter) in to the soil up to a depth of 1m (0-20, 20-40, 40-60, 60-80, 80-100 cm soil depths). A total of 360 soil samples were taken for each depth class in three seasons (winter, summer and rainy). Fine roots were excavated from the soil core with the help of a steel tube and the hole refilled afterwards with soil. Samplings were carried out in three directions from the measured trees and a sample point was located at 1/2m, 1/4m and 1/8m of the distance away from the neighbouring trees. Root samples collected from different directions and different depths were kept in separate polythene bags and brought to the laboratory. Roots were separated from other organic material by passing the soil core through a sequence of sieves.

Soil samples were collected from 5-6 pits dug to 100 cm depth in different locations for each site. From each pit 300 to 500 g soil samples were collected from 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, 70-80 cm, 80-90 cm and 90-100 cm soil depths. Soil texture was determined after removing the gravel particles, air drying the soil samples and passing through a series of sieves following Jina et. al., (2009). Soil moisture was determined on fresh weight basis following Jackson (1958). Soil carbon content was based on rapid titration method of Walkey and Black following Jackson (1958). For total Nitrogen (N), available Phosphorus (P) and available Potassium (K), three composite samples at different soil depths (0-30, 30-60, 60-100 cm) were taken. The total nitrogen content (%) was determined by micro-Kjeldahl assembly (Peach and Tracey, 1956). Soil phosphorous and potassium were extracted by wet ashing of 1 g soil material in acid mixture consisting of 10 ml H_2SO_4 +3 ml HNO_3 + ml $HClO_4$ (Jackson, 1958). Soil potassium was determined using a flame Photometer, and phosphorous was determined using spectrophotometer following Jackson (1958).

To determine soil bulk density, soil samples were collected by means of a special metal core-sampling cylinder of known volume from different layers considered for soil carbon estimation for different soil depths. Samples of soil were brought to the laboratory and oven dried at 60°C till constant weight and soil bulk density was calculated following Misra (1968). Analysis of variance (ANOVA) and Standard errors were calculated by using SPSS version 16 software.

Results

Site I

The total annual litter fall at this site was 6.83 t ha^{-1}. The maximum seasonal litter fall was recorded for summer season (3.21 t ha^{-1}) and the minimum for winter season (1.48 t ha^{-1}, Fig. 2). Among different forest litter type fresh leaf contribute maximum to the total litter (3.03 t ha^{-1}). The total fine root biomass at this site was 6.15 t ha^{-1}. It was maximal in the rainy season (3.93 t ha^{-1}) followed by summer and winter seasons (1.56 t ha^{-1} and 0.65 t ha^{-1}, respectively, Fig. 1). Fine root biomass declined with depth. The top soil layer (upto 40 cm) contributed approximately 67.4% to the total fine root biomass; 38.5% was observed in the 0-20 cm interval, 28.9% in the 20-40 cm interval, 16.6% in the 40-60 cm interval, 8.8% in the 60-80 cm interval and 7.2% was recorded in the 80-100 cm interval (Fig. 1). The soil organic carbon percent varied from 1.34±0.19 to 2.23±0.31 across all the soil depths (Fig. 3). Contrary to this, the soil bulk density followed a reverse trend and varied from 1.18±0.03 g cc^{-3} to 1.44±0.22 g cc^{-3} across different soil depths. Soil nitrogen, phosphorus and potassium value varied from 0.18 to 0.22%, 0.0008 to 0.0018% and 0.0072 to 0.0108%, respectively across different soil depths (Fig. 4).

Site II

The total annual litter fall at this site was 5.61 t ha^{-1}. The maximum annual seasonal litter fall was recorded in summer season (2.38 t ha^{-1}), while the minimum in winter season (1.59 t ha^{-1}). The contribution of the fresh leaf litter to the total litter fall was maximum (3.91 t ha^{-1}, Fig. 2). The total fine root biomass at this site was 6.65 t ha^{-1}. It was maximal in the rainy season (4.00 t ha^{-1}) followed by summer and winter seasons (1.64 t ha^{-1} and 1.01 t ha^{-1}, respectively, Fig. 1). Fine root biomass declined with depth. The top soil layer (upto 40 cm) contributed approximately 85% to the total fine root biomass; 50.3% was observed in the 0-20 cm interval, 20.9% in the 20-40 cm interval, 13.7% in the 40-60 cm interval, 8.2% in the 60-80 cm interval and 6.9% was recorded in the 80-100 cm interval (Fig. 1). The organic soil carbon percent varied from 1.38±0.09 to 1.65±0.13 across all the soil depths (Fig. 3). The soil bulk density varied from 1.17±0.01 g cc^{-3} to 1.36±0.03 g cc^{-3} across all the soil depths. Soil nitrogen, phosphorus and potassium value varied from 0.22 to 0.42%, 0.0006 to 0.0013% and 0.0056 to 0.0083%, respectively across various soil depths (Fig. 4).

Site III

The total annual litter fall at this site was 6.12 tha^{-1}. The maximum total annual seasonal litter fall was recorded in rainy season (t ha^{-1}), while minimum in winter season (1.60 t ha^{-1}). The contribution of the fresh leaf litter to the total litter was maximum (3.05 t ha^{-1}, Fig. 2). The total fine root biomass at this site was 4.33 t ha^{-1}. It was maximal in rainy season (2.18 t ha^{-1}) followed by summer and winter seasons (1.25 t ha^{-1} and 0.90 t ha^{-1}, respectively). Fine root biomass declined with depth. The top soil layer (upto 40 cm) contributed approximately 84.4% to the total fine root biomass; 67.4% was observed in the 0-20 cm interval, 17% in the 20-40 cm interval, 5.9% in the 40-60 cm interval, 5.5% in the 60-80 cm interval, and 4.2% was recorded in the 80-100 cm interval (Fig. 1). The organic soil carbon percent varied from 1.03±0.71 to 1.97±0.17 across all the soil depths (Fig. 3). The soil bulk density varied from 1.15±0.006 g cc^{-3} to 1.30±0.01 g cc^{-3} across all the soil depths. Soil nitrogen, phosphorus and potassium values varied from 0.11 to 0.20%, 0.0008 to 0.0010% and 0.0055 to 0.0068%, respectively across various soil depths (Fig. 4).

Site IV

The total annual litter fall at this site was 6.43 t ha^{-1}. The maximum total annual seasonal litter fall was recorded in summer season (3.78 t ha^{-1}), while minimum in rainy season (1.23 t ha^{-1}). The contribution of the fresh leaf litter to the total litter was maximum (2.98 t ha^{-1}, Fig. 2). The total fine root biomass at site IV over the whole year was 5.30 t ha^{-1}. It was maximal in rainy season (3.14 t ha^{-1}) followed by summer and winter seasons (1.39 t ha^{-1} and 0.77 t ha^{-1}, respectively). Fine root biomass declined with depth. The top soil layer (upto 40 cm) contributed approximately 88.89% to the total fine root biomass; 54.4% was observed in the 0-20 cm interval, 24.4% in the 20-40 cm interval, 10.1% in the 40-60 cm interval, 6.4% in the 60-80 cm interval, and 4.7% was recorded in the 80-100 cm interval (Fig. 1). The organic soil carbon percent varied from 1.00±0.29 to 2.73±0.51 across all the soil depths (Fig. 3). The soil bulk density follows an inverse trend and varied from 1.09±0.07 g cc^{-3} to 1.42±0.01 g cc^{-3} across all the soil depths. Soil nitrogen, phosphorus and potassium value varied from 0.11 to 0.18%, 0.0006 to 0.0018% and 0.0035 to 0.0065%, respectively across various soil depths (Fig. 4).

Analysis of variance (ANOVA) test showed that fine roots biomass varied significantly ($P<0.05$) between season, forest site, soil depth. The combined effects of season x forest site and season x soil depth, soil organic carbon, site and soil depth also varied significantly at $P<0.05$. ANOVA test showed significant variation at $P<0.05$ across aspects, seasons and types of litter also the combined effects of seasons x litter types, seasons x aspects varied significantly at $P<0.05$. However, in case of site x aspects, sites x seasons, sites x litter types and aspects x litter types did not show significant variation

Discussion

Mehra et. al., (1985) studied the annual total litter fall in six central Himalayan forests. The value ranged from 2.1 to 3.8 t c ha^{-1}, of which 54-84% was leaf litter, 9-20% wood litter and 6-14% other litter. The forest floor biomass was 12.7-167.7 t ha^{-1} for temperate, 14.2 t ha^{-1} for tropical and 3.4 t ha^{-1} for sal Central Himalayan forests, 5.7 - 7.7 t ha^{-1} for Central Himalayan *Quercus* spp. (Table 2). The total annual litter fall in the present study across different aspects ranged between 5.12 to 7.47 t ha^{-1}. The present values of litter fall are within the range reported earlier by Chaturvedi and Singh (1987), Rawat and Singh (1989), Singh (2009), Raikwal (2009) for the central Himalayan pine and oak forests (1.3 to 6.2 t ha^{-1} and 5.8 to 7.7 t ha^{-1}, respectively) and lower than those of temperate forests (Table 2).

This is due to the fact that the present studied forest was situated in a montane sub-tropical belt where temperatures are never too low to inhibit faunal and microbial activity (Upadhyay and Singh, 1985), but not as high as in the tropics. The system represents an intermediate situation between temperate and tropical conditions (Pandey and Singh, 1981a). In the present study fresh leaf litter accounted maximum amount (4.58 to 5.94 t ha^{-1}). Gloaguen and Touffet (1976) also reported that annual leaf production considered as the main litter fraction in most cases is favoured by relatively high temperatures and high precipitation during summer.

Compared to mean values of 0.7 to 2.2 (arctic), 2.5-3.0 (cool temperate), 3.5-3.6 (warm temperate) and 6.6-6.8 t ha^{-1} (equatorial forests) as reported by O'Neill and DeAngelis (1980) the annual average wood litter fall was 1.89 t ha^{-1}. This value lies within the range of 0.6-1.9 t ha^{-1} yr^{-1} reported for different forest types in Central Himalaya (Chaturvedi and Singh, 1987). Release of nutrients not only depends upon litter composition but also upon soil type, microbial communities and soil properties (Kutsch and Dilly, 1999). Being evergreen, the present forests exhibit year round litter fall. The pattern of litter fall in the present study was comparable to tropical ecosystems of India (Singh, et. al., 1999). Maximum amount of litter fall in the present study was recorded during summer season (3.78 t ha^{-1}) and minimum litter fall was recorded in winter season (1.15 t ha^{-1}).

The maximum litter falls observed in the summer may be due to warm and drier conditions prevailing during the summer period. The seasonal litter fall pattern was mainly controlled by community characteristics and environmental factors (Kavvadias, et. al., 2001; Pedersen and Hansen, 1999). The biotic agents, *Presbytis entellus*, *Semnopithecus entellus*, *Solenarctos thibetanus* and Himalayan black beer are active particularly in early summer. They cause severe damage to the twigs and branches due to which the probability of litter fall in the present study increase (Rawat and Singh, 1989). Such a pattern with peak leaf fall in summer has also been observed for other central Himalayan forest (Pandey and Singh, 1981a; Rawat and Singh, 1989; Singh, 2009;

Raikwal, 2009). According to Henery (1977) the nutrient content in the leaf varies considerably among species and even in the same species from different localities. The age, density of the forest which determines the quantity of litter fall and differences in soil nutrient levels may affect the nutrient return (Duvigneaud and Denaeyer, 1970). Different soil nutrients in the present study varied among different aspects and Van Panchayats (Table 1 and Fig. 4). The return of the major nutrients (C, N, P, and K) through litter fall in this study was similar to that reported by Singh (1968) for *Shorea* and *Tectona* forest of central India. The soil organic carbon percentage in the present study ranged from 1.00±0.29% to 2.97±0.46%. Soil organic carbon plays a significant role in the global carbon cycle. On an average, the percentage of carbon in the top 20cm, relative to that in the first meter soil column, is 50% of that in the first meter (Jobbagy and Jackson, 2000). Generally the surface layer soil is more affected by climate and litter types.

Reference

Carlisle, A., Brown, A.H.F, & White, E.J. (1966) "Litter fall, leaf production and effects of defoliation by T*ortrix viridiana* in a sessile oak (*Quercus petraea*) woodland" *J. Ecol* Vol.54, pp. 65-85.

Chaturvedi, O.P, & Singh, J.S. (1987) "The structure and function of pine forest in Central Himalaya. I. Dry matter dynamics" *Annals of Botany Vol.* 60, pp.237-252.

Christensen, T. (1975) "Wood litter fall in relation to abscission", environmental factors and the decomposition cycle in Danish Oak forest, *Oikos ,Vol.* 26: pp. 187-195.

Duvigneaud, E & Denaeyer-DeSmet, S. (1970) "Biological cycling of minerals in temperate deciduous forests". In: Reichle, D. E. (Ed.), Analysis of temperate forest ecosystems, pp. 199-225. Springer-Verlag, New York.

Gill, R.A. & Jackson, R. (2000) "Global patterns of root turnover for terrestrial ecosystems", New Phytol., pp.147, 13-31.

Gloaguen, J.C. & Touffet, J. (1976) "Litter production and mineral elements inputs to soil in some conifer forests of Bretagne". Ann. For. Sci.Vol 33: pp.87–107.

Golley, F B., McGinnis, J. T., Clements, R. G., Child, G. I & Duever, M. J. (1975) Mineral cycling in a tropical moist forest ecosystem. Athens, Georgia, Univ. of Georgia Press.

Helmisaari, H.S., Makkonen, K., Kellomaki, S., Valtonen, E., Malkonen, E. (2002) Below and aboveground biomass, production and nitrogen use in Scots pine stands in eastern Finland. *Forest Ecology and Management* Vol.165:pp.317-326.

Henery, D.G. (1977) Foliar nutrient concentrations of some Minnesota forest species, Minn, For. Res., Note, USA.

Jackson, M.L. (1958) Soil chemical analysis, Prentice Hall Inc., USA, 498p.

Jina, B.S., Bohra, C.S., Sah, P. (2009) Pedology of Oak and Pine Forests in Indian Central Himalaya, *Nature and Science,* Vol.7 No.7: pp.113-115.

Jobbagy, E.G & Jackson, R.B. (2000) The vertical distribution of soil organic "carbon and its relation to climate and vegetation," *Ecological applications*, Vol.10: pp.423-436.

Kavvadias, V.A., Alifragis, D., Tsiontsis, A., Brofas, G & Stamatelos, G. (2001) "Litter fall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece", *Forest Ecol. Manag,*Vol. 144: pp.113–127.

Kutsch, W.L & Dilly, O. (1999) "Ecophysiology of plant and microbial interactions in terrestrial ecosystems, pp. 74–84 in Beyschlag, W. and Steinlein, T. (Eds.) *Okophysiologie pflanzlicher Interaktionen. Bielefelder ¨ Okologische Beitrage* 14.

Mehra, M. S., Pathak, P. C & Singh, J. S. (1985) "Nutrient movement in litter fall and precipitation components for Central Himalayan forests, Ann". Bot.,Vol. 55:pp. 153-170.

Misra, R. (1968) Ecology workbook, Oxford and IBH Publishing Co. Calcutta, 224p.

O'Neill, R. V & DeAngelis, D. L. (1980) "Comparative productivity and biomass relations of forest ecosystems". In Reichle, D. E. (Ed.), Dynamic properties of forest ecosystems, pp.411-449.Cambridge University Press, Malta.

Ovington, J.D., Hetkamp, D., Lawrence, D.B. (1963) "Plant biomass and productivity of Prairie, Savana oak wood and maize field ecosystem in central Minnesota", *Ecology*, Vol.44: pp.52-63.

Pandey, R.R., Sharma, G., Tripathi, S.K & Singh, A.K. (2007) "Litter fall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in northeastern India", *Forest Ecol. Manag,Vol.* 240: pp.96-104.

Pandey, U & Singh, J. S. (1981a) "A quantitative study of the forest floor, litter fall and nutrient return in an oak-conifer forest in Himalaya". I - Composition and dynamics of forest floor, *Oecol Gener,*Vol 2: pp.49-61.

Pandey, U & Singh, J.S. (1981 b) "A quantitative study of the forest floor, litter fall and nutrient return in oak-conifer forest in Himalaya". II -pattern of litter fall and nutrient return, *Oecol Gener,*Vol. 2: pp.83-99.

Peach, K & Tracey, M.V. (1956) "Modern methods of plant analysis". Vol. I, Springer-Verlag, Berlin.

Persson, H. (1982) Changes in the tree and dwarf shrub fine roots after clear cutting in a mature Scots pine stand, Swedish Coniferous Forest Project, Technical Report 31.

Pedersen, L.B, & Hansen, J. B. (1999) "A comparison of litterfall and element fluxes in even aged Norway spruce, sitka spruce and beech stands in Denmark", *Forest Ecol. Manag*, Vol.114: pp.55–70.

Raikwal, D. (2009) Effect of leaf litter removal on soil nutrients in Central Himalayan banj oak and chir pine forests with relation to carbon sequestration. Ph.D. Thesis submitted to Kumaun University, Nainital.

Rawat, N., Nautiyal, B.P., Nautiyal, M.C. (2009) "Litter production pattern and nutrients discharge from decomposing litter in an Himalayan alpine ecosystem", *New York Science Journal*, Vol.2 No.6: pp.54-64.

Rawat, V. S., Tewari, A & Rawat, Y.S. (2010) Local level Community Forest Management an effective tool in conserving forest biodiversity, *Russian Journal of Ecology*, Vol42 No.5:pp. 388-394.

Rawat, Y.S & Singh, J.S. (1988) "Structure and function of forest in central Himalaya". II. dry matter dynamics, R. (1968). Ecology workbook, A*nnals of botany,* Vol.62:pp. 413-427.

Rawat, Y.S & Singh, J.S. (1989) "Forest floor biomass, litter fall and nutrient return in central Himalayan oak forests", *Vegetatio*, Vol82: pp.113-125.

Sayer, E.J. (2006) "Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems". Biol Rev Camb Philos Soc Vol81: pp.1–31.

Singh, J.S & Singh, S.P. (1987) Forest vegetation of the Himalaya, *Botanical Review, Vol.* 1: pp.81-192.

Singh, J & Ramakrishnan, P.S. (1981) "Biomass and nutrient movement through litter in *Shorea robusta* Gaertn. F. plantations in Meghalaya, *Proc". Indian Natl. Sci. Acad,Vol.* 47 B: pp.852-860.

Singh, K.P. (1968) "Litter production and nutrient turnover in deciduous forests of Varanasi. In: Misra R, Gopal B (eds) Advances in tropical ecology Part II. Proceedings of symposium on recent advances in tropical ecology". Banaras Hindu University, India, pp 655–665.

Singh, K.P., Singh, P.K., Tripathi, S.K., (1999) "Litter fall, litter decomposition and nutrient release patterns in four native tree species raised on coal mine spoil at Singrauli. India, *Biol". Fertil. Soils,* Vol29, pp.371–378.

Singh, S.P., Singh, V & Skutsch, M. (2010) "Rapid warming in the Himalayas: Ecosystem responses and development options". Climate and Development.Vol. 2: pp.221-232.

Singh, V. (2009) Biomass stock and Carbon Sequestration rates in banj oak (*Quercus leucotrichophora*, A. Camus.) forest under different disturbance regimes in Central Himalaya. Ph.D. Thesis, Kumaun University, Nainital.

Upadhyaj, V. P & Singh, J. S. (1985) Decomposition of woody branch litter on an altitudinal transect in the Himalaya, Vegetatio,Vol. 64: pp.49-53.

Zhou, G., Guan, L., Wei, X., Zhang, D., Zhang, Q., Yan, J., Wen, D., Liu, J., Liu, S., Huang, Z., Kong, G., Mo, J., Yu, Q. (2007) "Litter fall production along successional and altitudinal gradients of subtropical monsoon evergreen broadleaved forests in Guangdong, China". Plant Ecol Vol188: pp.77–89.

Table 1: Comparison of annual litter fall from different forests of the World

Forest type	Location	Litter fall (t ha $^{-1}$)	Reference
Pinus stand	Temperate	12.7- 167.7	Ovington (1965)
Riverine forests	Tropical	14.2	Golley *et al.* (1975)
Quercus petraea	England	3.86	Carlisle *et. al.*, (1966)
Quercus lanuginosa	India	7.7	Singh and Singh (1987)
Quercus floribunda		6	
Quercus leucotrichophora		5.8	
Oak conifer forests	India	5.50	Pandey and Singh (1981 b)
Quercus forest	India	4.7-7.8	Rawat and Singh (1989)
Sal forest	East Himalaya	3.4	Singh and Ramakrishnan (1981)
Natural oak forest and managed plantation	North India	4.20-5.48	Pandey *et. al.*, (2007)
Quercus leucotrichophora	India	6.1	Singh (2009)
Pinus roxburghii dominant forest of Toli Van Panchayat of Uttarakhand	India	7.28	Singh *et. al.*, (2010)
Quercus leucotrichophora dominant forest of Dhaili Van Panchayat of Uttarakhand	India	8.94	Singh *et. al.*, (2010)
Oak Pine mixed Van Panchayat forest	**India**	**5.12-7.47**	**Present study**

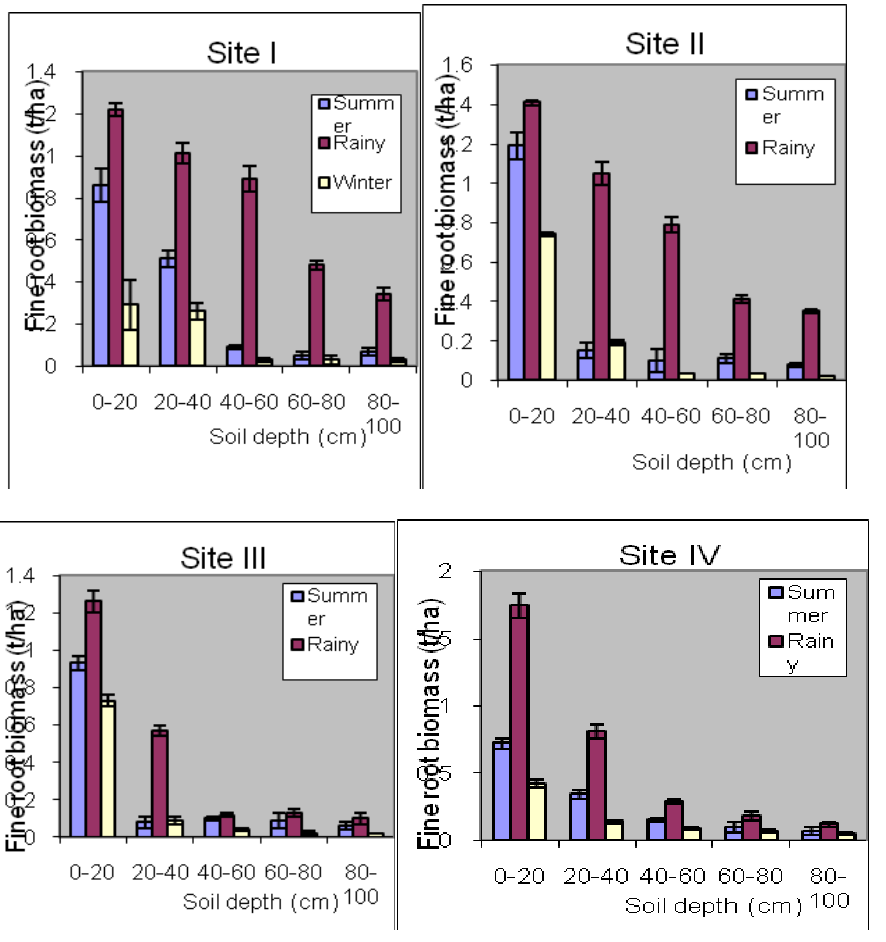

Fig. 1- Fine roots biomass (t ha $^{-1}$) of Anriyakot Van Panchayat across different sites and seasons

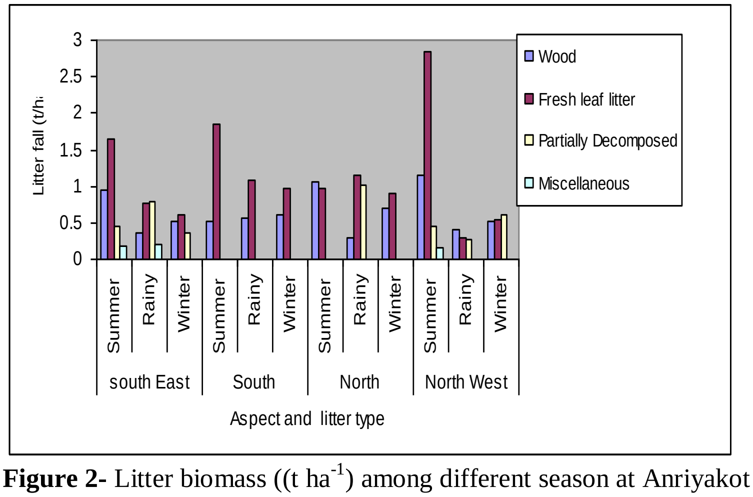

Figure 2- Litter biomass ((t ha^{-1}) among different season at Anriyakot Van Panchayat

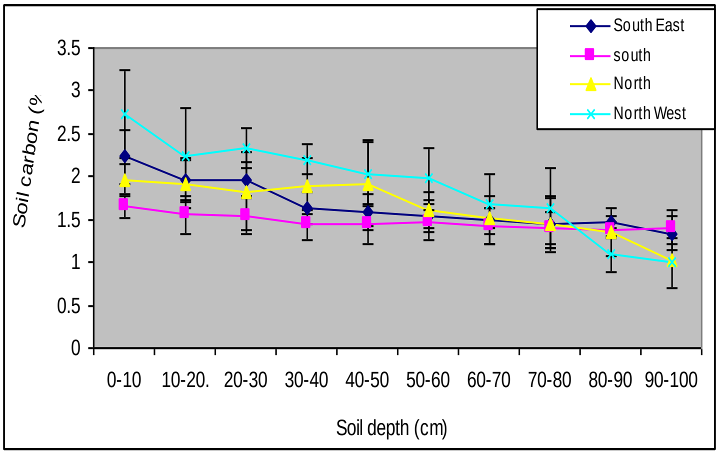

Figure 3- Soil organic carbon percent of Anriyakot Van Panchayat along different soil depth and sites

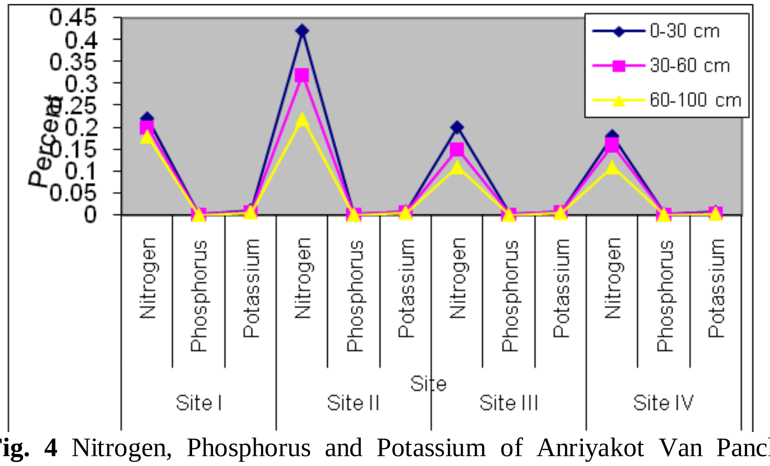

Fig. 4 Nitrogen, Phosphorus and Potassium of Anriyakot Van Panchayat along different soil depths and sites.