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Litter Production and Nutrient Return in Three Different Aged Regenerating White Oak (*Quercus leucotrichophora* A. Camus) Forests in the Central Himalaya

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Abstract

The present study described forest floor biomass, patterns of litter fall and nutrient return in three regenerating white oak (*Quercus leucotrichophora*) forests (16, 27 and 34 years old). The study sites were earlier invaded by pine (*Pinus roxburghii*) and oak returned after fire killed the pine. The main objectives of the present study were to evaluate changes in litter dynamics of regenerating oak forests and to estimate the time of recovery these forests may require. Total annual litter fall was 258.5 g m^{-2}, 428.3 g m^{-2} and 561.7 g m^{-2}, respectively in the 16, 27 and 34 year old oak stands. The proportional contribution of the leaf litter fraction to the total litter fall decreased significantly with stand age. Litter nutrient concentration in the 16 year old oak stand was the lowest and generally highest in 34 year old stand. Relatively high leaf litter nutrient concentration and low nutrient retranslocation from senescing tissues, low litter dry matter: litter N ratio in the 34 year old forest indicate increase in soil nutrient pool. These estimates are similar to undisturbed mature oak forests of the region.

Key Words: Litter Fall; Forest Floor; Oak; Nutrient Retranslocation; Central Himalaya; Turnover.

INTRODUCTION

Litter fall is fundamental ecosystem process by which forest nutrient cycling is maintained (Meentemeyer et al. 1982, Kumar and Deepu 1992, Garkoti and Singh 1995, Pragasan and Parthasarthy 2005). It is closely related to the growth and productivity of forests (Garkoti 2008) and plays an important role in maintaining soil fertility (Maguire 1994, Tripathi et al. 2006, Garkoti and Singh 1994). Litter production and its role in regulating forest ecosystem processes like flow of energy, nutrient cycling and maintenance of soil fertility vary with forest age, tree density and basal area (Bray and Gorham 1964). As litter production and litter nutrients are important drivers of soil chemistry, dynamics of both have direct impact on recovery of soil fertility during forest regeneration (Lugo 1992, Read and Lawrence 2003) and ecosystem structure and functions.

Between 1200 and 3000 m above sea level (asl) elevations in the Indian central Himalaya, oak forests dominate the landscape. White oak (*Quercus leucotrichophora*) occurs between 1200 and 2200 m asl (Troup 1921) and covers approximately 12 % of land in the Indian central Himalaya. At lower elevations (between 900-1700 m asl) chir pine (*Pinus roxburghii*) shows pure monotonous distribution. White oak is socially more desired and ecologically more important than the chir pine (Singh and Singh 1992, Joshi and Negi 2011). It is a perennial source of fodder and fuelwood. Ecologically, it plays an important role in the conservation of soil and water, and hence, maintains water quality of springs, creeks and rivers (Singh and Singh 1992). Because of these ecosystem services, most human settlements have been concentrated below 2500 m asl. In the oak-pine ecotone zones, increased anthropogenic pressures (oak tree lopping and forest fire in the pine) allow encroachment of chir pine (an early successional species) into oak forest (a late successional species) (Singh and Singh 1992, Singh et al. 2012). However, in valley sites where soil moisture is high, removal of chir pine by fire during certain years (when environmental factors favour the white oak over chir pine) helps oak to reoccupy habitat (Garkoti personal observation). Although the size of the habitats reoccupied by oak seldom exceeds 2 ha, (range < 0.5 ha to 2 ha) reasonable numbers of such oak regenerating sites are available in the region. Due to its higher value in terms of fodder, fuel wood, conservation of soil and water, higher soil fertility and higher bio-diversity, white oak is the preferred species in the central Himalaya (Joshi and Negi 2011). Therefore, regenerating oak stands are traditionally conserved by local residents.

Patterns of litter fall and nutrients in forest communities along successional and elevational gradients have been studied by many ecologists (Odum 1960, Swift et al. 1981, Singh and Singh 1992, Garkoti and Singh 1995). However, there are limited data on dynamics of litter fall and nutrient return during forest regeneration (Hall and Okali 1979, Lodge et al. 1991, Singh and Singh 1992, Gairola et al. 2009). Inadequate information about the litter fall and nutrient dynamics during forest regeneration warrants a study which in turn may help to strengthen forest management.

Based on studies in mature mixed oak forests, the present study hypothesized that: (i) the annual litter production would increase with the age of the forest but the contribution of leaf litter to the total litter production would decline with age, (ii) litter nutrient concentration would increase with forest age, reflecting the increase in soil fertility under oak forest. To test these hypotheses this study was conducted with the objectives to compare litter production, nutrient return and litter quality in three different aged regenerating protected (by local community) oak forests and to assess the recovery time white oak requires.

STUDY AREA

The study was carried out in three regenerating oak forests in district Champawat in the Indian central Himalaya. The forest ages were 16 years (in Dabari, 29°20"11.6' N, 80°01"5.2' E), 27 years (in Sipty, 29°20"22.3' N, 80°00"45.7' E), and 34 years (in Chirabanj, 29°9"6.9' N, 80°01"26'E). All the three atudy sites were within 3k from each other. Until the last few decades all three sites were under chir pine forest with a few scattered remnant oak trees in oak-pine transition zones. Sites became dominated by oak (*Quercus leucotrichophora*) after forest fires eliminated the chir pine. On dry mountain ridges, forest fires that removed the chir pine and/or oak, not only helped chir pine to reoccupy the sites, but also resulted in chir pine encroachment into oak forests. In valley regions, however, the fire in certain years helped oak to regenerate (Garkoti, personal observation). Other associates of the oak joined the forest community at the latter stages after the site became favourable for them due to continuous occupancy of oak and consequent amelio-ration of habitat. Due to the awareness programmes at the local level and oak being a more useful species, people now protect regenerating oak forests from disturbances like forest fires and even lopping. The climate of the study area was monsoonal subtropical with an annual average rain fall of 1430 mm. The area has three distinct seasons, a cool and usually dry winter, a warm and dry summer, and a warm and humid rainy season. The mean monthly temperature was minimum in January (7 °C) and maximum in June (21.5 °C). The area consists predominantly of igneous and low grade metamorphic rocks (Valdiya 1980). The soil is residual colluvial on gentler slopes, consisting of sandy loam and soil water holding capacity changing with stand age (Table 1).

Tree density and basal area generally increased with age (Table 1), but due to confounding site with age, it is not possible to say whether age or site or both control the changes. In all three forest stands, most of the density and basal area was contributed by white oak (Table 1). Other associates of the *Q. leucotrichophora* were *Q. floribunda*, *Myrica nagi*, *Pyrus peshia*, *Symplocos chinensis*, and *Ficus* sp. in the 16 year old oak forest, *Q. floribunda*, *Myrica nagi*, *Pyrus peshia*, *Symplocos chinensis*, *Alnus nepalensis*, *Pinus roxburghii* and *Ficus* sp. in 27 years old forest and *M. nagi*, *Lyonia ovalifolia*, *Rhododendron arboreum*, *Pinus roxburghii* in the 34 years old oak forest.

METHODS

The forest floor litter biomass data was collected from 15, 1 m × 1 m random quadrats on each forest stand during each season, i.e., the summer, rainy and winter seasons. The litter input was measured every month from first week of February 2010 to last week of January 2011 in all the forest stands from 15 randomly placed litter traps. Each litter trap was 1 m × 1 m with 15 cm high wooden sides with a nylon net bottom. Sampling was always carried out around the same date of the months. Litter samples collected from each trap were brought to

Table 1. Vegetation and soil characteristics of three different age regenerating oak (*Quercus leucotrichophora*) forests of central Himalaya.

Categories	16 years old	27 years old	34years old
Elevation (m)	1849	1860	1653
Tree density (trees ha^{-1})	1280 (950)	1030 (430)	1100 (660)
Tree basal area (m^{-2} ha^{-1})	12.0 (10.4)	26.6 (15.3)	33.3 (28.3)
Soil temperature (^{0}C)	8.4±0.71	8.5±0.62	9.2±0.84
Soil temperature (%)	28.31±2.13	31.56±2.36	31.46±2.69
Soil bulk density (g cm^{-3})	0.741±0.05	0.677±0.08	0.631±0.12
Soil pH	5.77±0.21	5.89±0.49	6.21±0 .47
Water holding capacity (%)	65.9±5.34	71.0±7.06	74.7±5.69
Soil N (%)	0.41±0.04	0.47±0.03	0.48±0.03
Available P (%)	0.024±0.002	0.026±0.02	0.030±0.002

Values in parentheses are for *Q. leucotrichophora*, and those outside are total for the forest inclusive of all species.

the laboratory in polythene bags, and were sorted into leaf litter, fine woody litter (≤2 mm in diameter) and miscel-laneous litter (flower, fruits, bark and other plant detritus). The separated samples were oven dried at 80 °C to constant weight (Morillas et al. 2012). Annual litter input in each forest stand was determined by summing up the dry mass of the litter fall during the year. Monthly litter samples of a given category of the litter were pooled seasonally, ground and analyzed for nutrients. Nitrogen was determined with micro-Kjeldahl method in KEL PLUS automatic Nitrogen estimation system (Misra 1968), Phosphorus was estimated colori-metrically (Anderson and Ingram 1993) Potassium was determined by flame photometry (Jackson 1958). The concentrations of N, P and K, were multiplied with the respective litter fall dry mass samples to get N, P and K contents.

Litter turnover rate (k) was calculated using a mathematical model (Olson 1963):

$$K = \frac{A}{(A + F)},$$

where A is the annual litter fall and F is the residual litter biomass. Turnover time (t) is the reciprocal of the turnover rate: t = 1/k. Similarly, the nutrient turnover was calculated by substituting the dry mass values with nutrient content.

RESULTS

Litterfall

Litter fall at all the sites of the present study exhibited a marked seasonality (Figure 1). Seasonally litter fall varied between 22.96 g m^{-2} (winter) and 174.58 g m^{-2} (summer) in the 16 year old oak, 37.6 g m^{-2} (winter) and 289 g m^{-2} (summer) in the 27 year old oak and between 55.48 g m^{-2} (winter) and 375.01 g m^{-2} (summer) in the 34 year old oak forest (Table 2). Leaf and wood litter showed more or less similar seasonal patterns. Leaf litter constituted 79.4 %, 74.9 % and 69.6 % of the annual litter fall respectively, in the 16, 27 and 34 years old oak forests. The contribution of the leaf litter fall to the total litter fall has significantly decreased ($p < 0.05$) with forest age. Contrary to the leaf litter fall proportional wood litter fall was higher in the 34 year old oak stand (26.9 % of the total litter fall) followed by 27 year old oak forest (21.0 %) (Table 2). In all the forests, miscella-neous litter made a very small contribution (Table 2).

Peak litter fall in all the forests occurred in April (Figure 1). The monthly leaf litter fall ranged from 1.71 g m^{-2} (November) to 66.91 g m^{-2} (April) in the 16 year old oak, 2.23 (October) to 98.11 g m^{-2} (April) in 27 year old oak and 4.84 g m^{-2} (October) to 121.37 g m^{-2} (April) in the 34 year old oak forests (Figure 1). Although concen-trated leaf fall in all the sites were observed during summer, leaf shedding occurred year round (Figure 1). Monthly wood litter fall ranged from 1.21 to 6.2 g m^{-2},

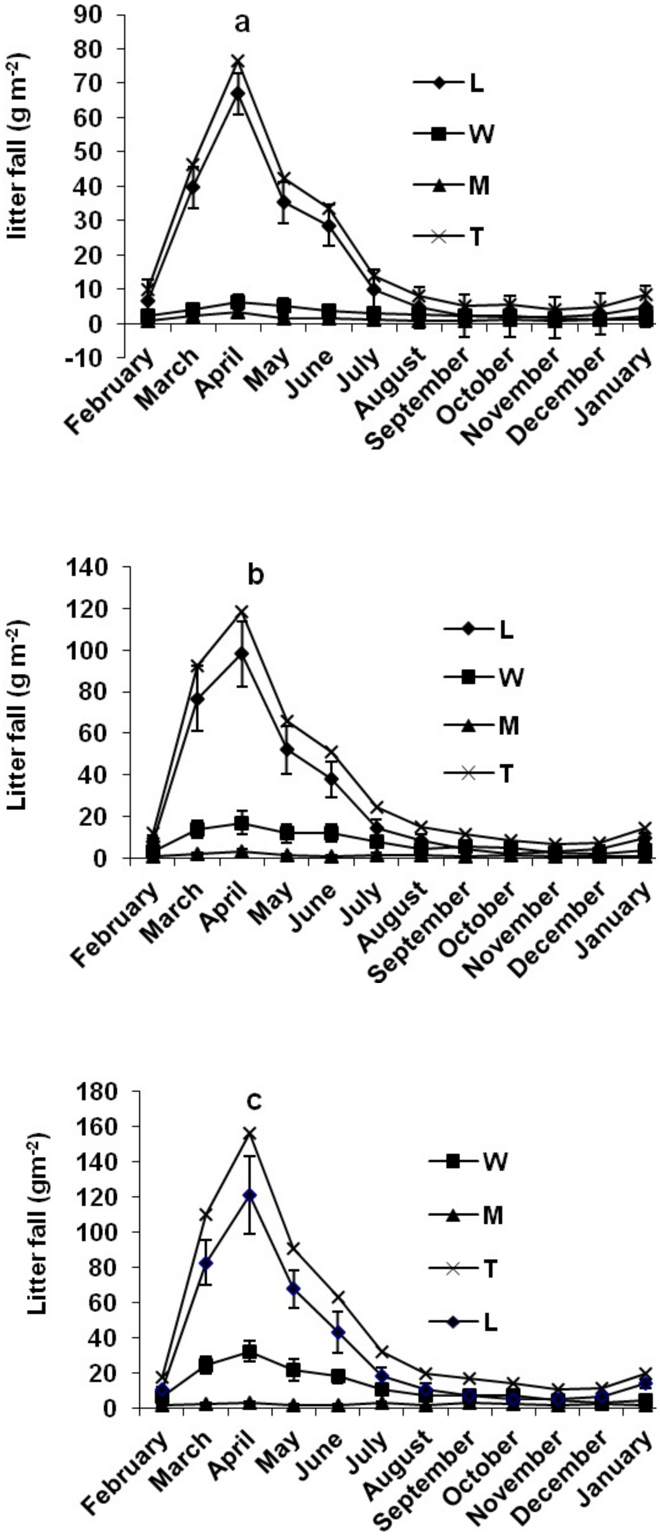

Figure 1. Monthly variations in litter fall components in three regenerating oak forests. (a) is the16 year old oak forest, (b) is the 27 year old oak forest ,and (c) is the 34 year old oak forest. L is leaf litter, W is wood litter, M is miscellaneous litter, and T is total litter (error bars are +/- 1 SE).

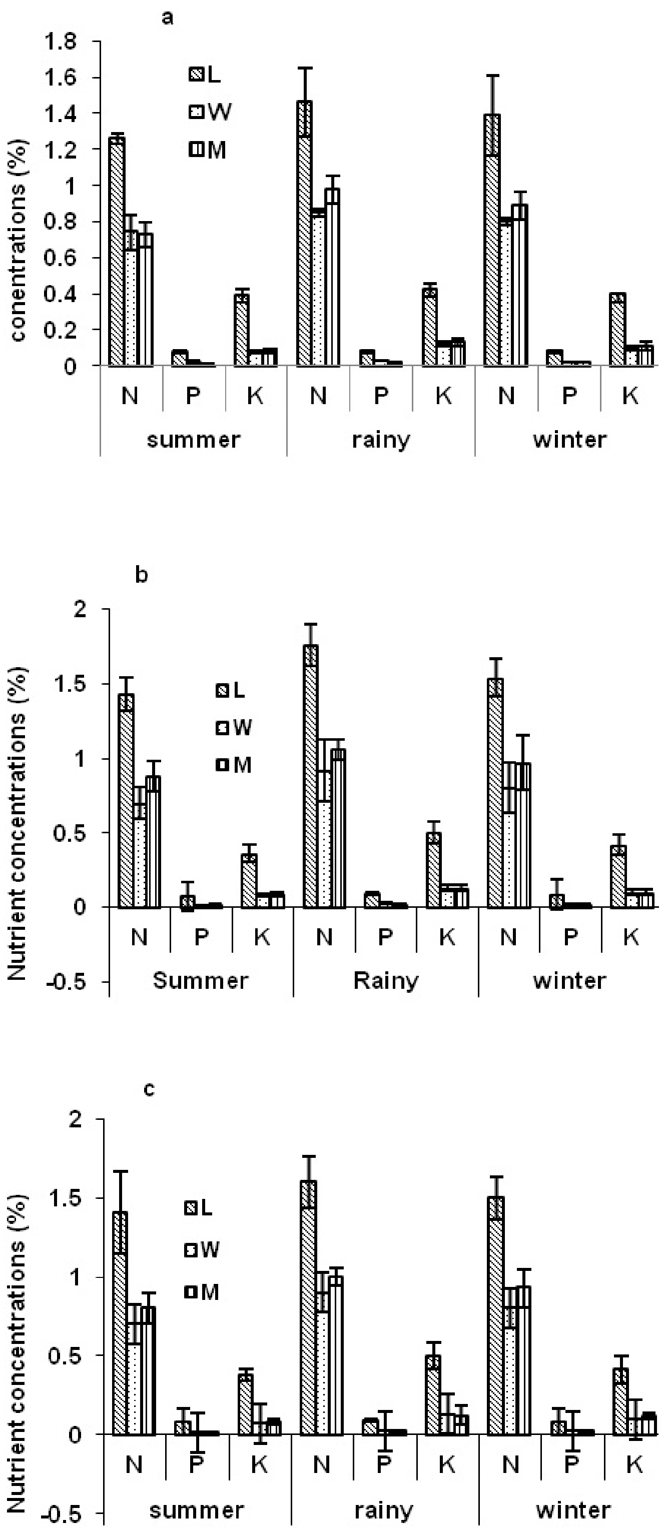

Figure 2. Seasonal variation in nutrient concentrations (% ±1SE) in litter fall components in three regenerating oak forests. (a) is the16 year old oak forest, (b) is the 27 year old oak forest, and (c) is the 34 year old oak forest. L is leaf litter, W is wood litter, and M is miscellaneous litter.

Table 2. Seasonal patterns of litter fall (g m-2) in three regenerating oak forests of Indian central Himalaya.

Litter categories	16 year old			27 year old			34 year old		
	Summer	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter
Leaf litter	148.56	45.3	11.29	235.05	65.87	19.97	292.09	84.88	30.05
Wood litter	17.67	11.57	7.16	45.9	30.48	13.3	58.51	37.35	18.22
Miscellaneous litter	8.35	4.07	4.51	8.05	5.36	4.33	8.41	8.94	7.21
Total litter	174.58	60.94	22.96	289	101.71	37.61	375.01	131.17	55.48

Table 3. Seasonal variation in forest floor components (g m^{-2} ± 1SE) in three regenerating community protected oak forests in Indian central Himalaya. FLL is Fresh leaf litter, PDL is partially and more decomposed litter, WL is Wood litter, ML is miscellaneous litter and TFFL is total forest floor litter.

Litter	16 year old forest			27 year old forest			34 year old forest		
	Summer	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter
FLL	31.7±6.9	9.8±1.7	3.9±04	39.92±5.6	14.67±2.8	8.9±1.6	47.1±8.4	19.3±3.8	8.9±1.6
PDL	249.6±37.7	198.5±26.4	139.2±22.4	347.62±49.4	293.48±40.1	247.6±37.4	518.±76.8	381.7±56.5	247.6±37.4
WL	33.9±7.2	29.5±6.2	21.5±6.6	43.7±6.35	38.7±6.8	38.7±7.2	63.1±7.6	51.3±7.9	38.7±7.2
ML	3.5±0.6	1.9±.09	2.1±0.2	3.9±0.4	2.6±0.3	3.1±0.1	4.1±0.2	2.6±0.16	3.1±0.1
TFFL	318.7	239.7	166.7	432.1	334.8	298.3	633	454.9	298.3

1.96 to 17.14 g m^{-2} and 2.89 to 32.3 g m^{-2} respectively, in the 16 year old, 27 year old and the 34 year old oak stands. In all the sites wood litter fall also peaked in April (Figure 1). Monthly miscellaneous litter fall ranged from 0.77 g m^{-2} to 3.42 g m^{-2} in the 16 year old oak forest, 0.82 g m^{-2} to 3.19 g m^{-2} in 27 year old oak forest and 1.36 g m^{-2} to 3.12 g m^{-2} in the 34 year old oak forest and was rather irregular (Figure 1).

Forest Floor Litter Biomass

Fresh leaf litter biomass varied from 3.9-31.7 g m^{-2} in the 16 year old, 6.2-36.9 g m^{-2} in the 27 year old and 8.9-47.1 g m^{-2} in the 34 year old oak forests (Table 3). Differences in standing crop of the fresh leaf litter reflected the variable leaf fall in different seasons. Amounts of the partially and more decomposed litter varied from 139.2-249.6 g m^{-2} in the 16 year old oak, 197.4-347.6 g m^{-2} in 27 year old oak, and 247.6- 518.7 g m^{-2} in the 34 year oak (Table 3). Wood litter biomass ranged from 21.5-33.9 g m^{-2} in the 16 year old forest, 38.7-43.7 g m^{-2} in 27 year old oak forest and 38.7-63.2 g m^{-2} in the 34 year old oak forest. The miscellaneous litter which consists of debris from shrubs, herbs, mosses and ferns, varied from 2.1-3.5 g m^{-2} in the 16 year old oak, 2.6-3.9 g m^{-2} in 27 year old oak and 3.1-4.1 g m^{-2} in the 34 year old oak forests. In present study for all the litter categories, the highest values occurred in summer followed by rainy and winter seasons (Table 3).

Nutrient Input

Concentrations of all the nutrients were higher in leaf litter compared to wood litter and miscellaneous litter (Figure 2). Among the forests in general leaf litter nutrient concentration in the 34 year old oak was the highest. The 34 year old oak forest returned highest amounts of N, P and K followed by 27 and 16 year old oak forests (Figure 3). Leaf litter returned highest amounts of all the nutrients compared to wood and miscellaneous litter.

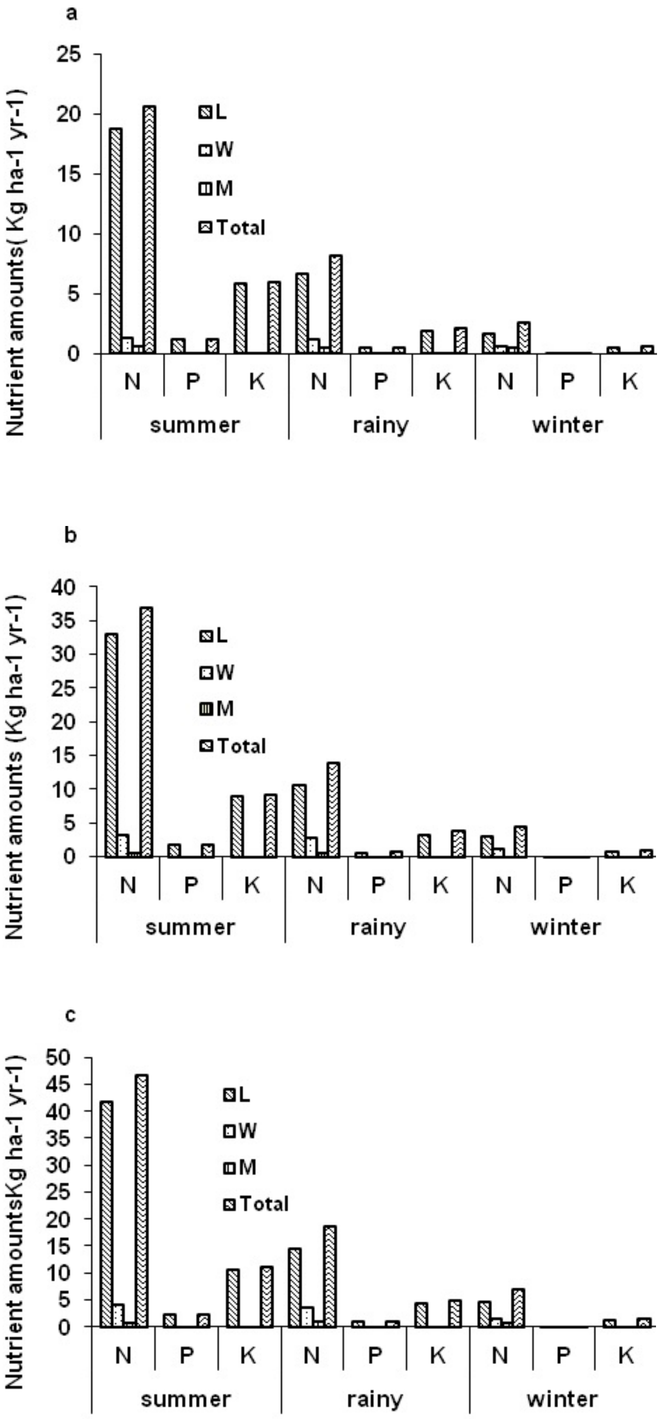

Figure 3. Seasonal variations in nutrient return through tree litter fall (kg ha-1) in three regenerating oak forests. (a) is the16 year old oak forest, (b) is the 27 year old oak forest ,and (c) is the 34 year old oak forest. L is leaf litter, W is wood litter, M is miscellaneous litter, and T is total litter (error bars are +/- 1 SE).

DISCUSSION

Since white oak is evergreen, regenerating forests exhibited year round litter fall. However, maximum leaf fall in all the sites occurred during the dry and warm season of the year, from March to June (summer). In addition to leaf phenology of the oak, low soil and air moisture associated with increased temperature seem to be the reason for the high proportion of litter fall during summer. Decline in soil water potential may trigger synthesis of abscissic acid in foliage which may in turn stimulate senescence of foliage or other plant tissues (Moore 1980, Singh et al. 2006). Such a pattern with peak litter fall during dry months of the year has also been observed for other evergreen forests of the region (Pandey and Singh 1981, Rawat and Singh 1989, Garkoti and Singh 1995). Interestingly minimum litter fall occurred during winters when both soil moisture and temperature declined. Unlike deciduous species, these evergreen oaks in the central Himalaya seem to maintain physiological activities during low temperature and moisture regimes. Average mid day water potential in *Q. leucotrichophora* during winters did not go below -1.29 MPa and average leaf conductance was 137 m mol m^{-2} sec^{-1} (Singh et al. 2006) indicating that the white oak remains physiologically active during the cold winters.

Present estimates of total litter fall for the 16 year old oak (258.5 g m^{-2} yr^{-1}) are below the range and for the 27 year old oak (428.3 g m^{-2} yr^{-1}) and the 34 year old oak (561.7 g m^{-2} yr^{-1}) are within the range (300-670 g m^{-2} yr^{-1}) reported for Asian temperate broadleaved forests (Liu et al 2004). However, present litter production values are much lower than the range (684 -893 g m^{-2} yr^{-1}) reported for subtropical evergreen forests in Japan (Xu et al, 2000). Annual litter production in the present study was positively correlated ($r = 0.97$, $p \leq 0.05$) to the forest basal area (Table 1, Figure 1). However, due to lack of replications it is not possible to infer if changes in the litter production in present study were due to age or site or site and age interactions. Present litter production and forest age relations are similar to the findings of Arunachalam et al. (1998), Singh and Singh (1992). Annual litter production in the 34 year stand in the present study was in the lower side of the range (550 and 650 g m^{-2} yr^{-1}) reported by Singh and Singh (1992) for old growth oak forests in the central Himalaya, which indicates that these regenerating oak forests take about 34 years to get back to their original undisturbed state. The leaf fall accounted for 79.4 %, 74.9 % and 69.6 % of the total annual litter fall in the 16 year old, 27 year old and the 34 year old oak stands, respectively, which is within the range 40-85 %, reported for temperate forests (Rodin and Bazelevich 1967, Yang et al. 2004). Leaf litter fall for 34 year old oak forests were comparable with the world average 70 %, estimated by Meentemeyer et al. (1982). Contribution of leaf litter to the total annual litter fall has significantly declined from the 16 year old oak to the 34 year old oak stand. It seems that these forests initially divert larger proportions of the photosynthates to form the photosynthetic canopy which gradually declines with the age of the forest.

Annual wood litter fall in the 16 year old oak forest (36.4 g m^{-2} yr^{-1}) was lower and in the 34 year old oak (146.08 g m^{-2} yr^{-1}) was higher than the world mean of 90 g m^{-2} yr^{-1} for cool temperate forests. The wood litter fall values for the 34 year old oak were comparable with the values reported for other evergreen forests in the region (Singh and Singh 1992, Garkoti and Singh 1995). Contribution of wood litter fall to the total litter fall in the present study has increased with age of the forest stand and was 14.1 % in the 16 year old, 21.0 % in the 27 year old oak stands and 26.9 % in the 34 year old oak stands. These values approximate the values reported for mixed oak-conifer forests in central Himalaya (Pandey and Singh 1981, Rawat and Singh 1989). Proportions of the wood litter fall to the total litter fall in the present 27 and 34 year old oak sites were comparable with those reported by Bray and Gorham (1964) (21-23 %), and in lower side of the range reported by Christensen (1978) (19-36 %) and Fahey (1983) (17-46). Present wood fall estimates for 34 year old stand are similar to the values reported by Mehra et al. (1985) in central Himalayan mature mixed evergreen forests.

The present study reveals the year round occurrence of two distinct layers on the forest floor, an upper layer of fresh leaf litter and below it a layer of partially and more heavily decomposed litter. Present forest floor litter biomass values (Table 3) are near the lower limit of the range 360 -4000 g m^{-2}, reported for various temperate forests of the world (Jenny et al. 1949, Reiners and Reiners 1970), and evergreen forests of central Himalaya (Singh and Singh 1992, Garkoti and Singh 1995).

Litter dry matter turnover rate estimates indicated that 61 to 65 % of the forest floor is replaced each year in the study oak forests (Table 4). Thus the forest floor is characterized by a relatively high replacement rate of the annual litter fall reflecting an increased rate of movement to the soil solution and availability of plant nutrients for plant uptake during growing season. The turnover time of the litter was 1.64 years in the 16 year old oak and 1.54 years in both 27 and 34 year old forests. These litter turnover time estimates are lower than the range, 2.7-14.1 years reported by Rochow (1975), and Lang and Forman (1978) for temperate broad leaved forests. The absence of black amorphous of humus and high turnover rate of the forest floor litter makes these forests different from true temperate forests at higher latitudes. In fact the present study area lies latitudinally in the tropical belt and is influenced by monsoon rains, although altitudinally the area experiences temperate situations (e.g., low temperature, low radiation, winter snow fall etc.). Present estimates for litter turnover time for 27 and 34 year old oaks are comparable with those for undisturbed mature oak forests reported by Singh and Singh (1992).

Table 4. Turnover rate (k) (%) of litter mass and nutrients in the forest floor in three regenerating oak forests

Forest age	Litter mass	N	P	K
16 year old	0.61	0.59	0.59	0.59
27 year old	0.65	0.63	0.63	0.62
34 year old	0.65	0.64	0.63	0.63

Vitousek (1982) calculated that litter fall dry matter: litter fall N ratio varied from 60 to 200 among a large number of forests. In the present study the litter dry matter: litter N ratio showed a decline from 83 in the 16 year old oak to 78 in 27 and 34 year old oak stands. N concentration in all the litter components in general was higher in the 34 year old oak forest compared to the other two forests. Both, the low litter dry matter: litter N ratio and high N concentration in litter components indicate improved available soil N pool in the older oak forests. The litter dry matter: litter N ratio for 27 year old and 34 year old stands were within the range (61-78) reported by Singh and Singh (1992) for undisturbed mature oak forests in the region indicating that at about 27 years of stand age the soil fertility recovers to the original state of the oak forests. N concentration of the mature green leaves of the oaks was 1.81 %, 1.97 % and 2.05 %, respectively, in the 16 year and the 34 year old stands. The proportional absorption of N from the senescing leaves of *Q. leucotrichophora* was higher in the 16 year old oak stand (19.3 %) compared to the 27 year old (15.7%) and the 34 year old (14.2%) stands. High N concentration in green leaves and low retranslocation of N from the senescing leaves in the 34 year old stand shows increased use of nutrients indicating higher soil nutrient capital. The opposite is true in case of the 16 year old oak, where due to lower availability of soil nutrients, retranslocation of nutrients from the senescing leaves is relatively high which in part provides independence to the plants from soil nutrients when soil nutrient availability is low (Tripathi et al. 2006). Nitrogen rich forest floor attracts microbial population and increases microbial decomposition of litter (Singh and Singh 1992, Devi et al. 2014). This could probably explain the higher turnover rate of litter in 27 and 34 year old oak forests compared to the 16 year old. Swift et al. (1979) and Maithani et al. (1996) also showed a positive relationship between microbial biomass and litter decomposition rates. In addition to the litter quality, more favourable micro-environmental conditions under the closed canopy of the older oaks (e.g., increased moisture) may result in increased microbial activities which in turn may result in faster turnover of litter dry matter and litter nutrients.

The relative abundance of the nutrients in the litter fall was in order N>K>P which agreed with the findings from variety of different forest ecosystems (Rodin and Bazilevich 1967, Peterson and Rolfe 1982, Singh and Singh 1992, Garkoti and Singh 1995). The nutrient inputs in the present study were within the range reported for many temperate broadleaved forests in central Himalaya (Singh and Singh 1992, Garkoti 1992). In the present study forests, of the total nutrient input through litter fall, leaf fall accounted for 82.6% - 94.5 % and wood litter fall for 3.6% - 12.8 %. Present litter fall estimates are comparable with the general range for leaf (75- 85 %) and wood (10-35 %) litter reported by Klinge and Rodrigues (1968), Bernhard-Reversat (1972).

Concentrations of N, P and K in all litterfall components showed significant seasonal ($p < 0.05$) variations. Highest values for all three elements were observed during rainy season and the lowest during summer. Lowest nutrient concentrations during summers may be attributed to increased proportions of nutrient reabsorption from senescing tissues during the warm summer.

Wood litter in the present study forests has lower N, P and K concentrations than the leaf litter and did not show marked seasonal variations compared to leaf litter. These observations in the present study are in agreement with the reports of Gosz et al. (1972), Arunachalam et al. (1998) and Garkoti and Singh (1995).

CONCLUSIONS

In present regenerating oak forests irrespective of forest age, litter fall was unimodal. The annual litter production increased with the age of the forest however could be the result of site and age interaction. Stand basal area was positively related to annual litter fall of the litter components. Contribution of leaf litter to the total annual litter fall has decreased with stand age, reflecting allocation of increased proportion of photosynthates to perennial supporting and storage tissues as forest age. Nutrient concentrations and nutrient amounts returned to the forest floor showed an increase with forest age indicating improvement of soil fertility as forests mature. Comparisons of present results with the mature oak forests in the region indicate that, these forests may require about three decade’s time to reach the original undisturbed state. If one uses the estimates of litter production and nutrient return as surrogates for recovery of ecosystem services (i.e., supply of fodder, forest carbon sequestration, maintenance of soil fertility etc.), it seems that these forests take more than 27 years time to come back into the state they were probably at before disturbances. In the face of increased disturbances in the forest ecosystems due to increased human activities and consequent losses of soil and its fertility, larger areas of regenerating oak forests are required as future insurance against loss of ecosystem services. Further, we need to identify the suitable habitats for the species which may provide asylum in the face of climate change.

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