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LITTER FALL AND NUTRIENT RETURN IN *QUERCUS CERRIS* L. VAR. *CERRIS* FORESTS IN THE CENTRAL BLACK SEA REGION OF TURKEY

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Abstract

Litter fall and nutrient return in a deciduous *Quercus cerris* L. var. *cerris* forest which constitutes the "étage supra-mediterranéen pré-pontique" vegetation layer in the Central Black Sea Region of Turkey were investigated. Total annual input of litter was 681.90 g m^{-2} of which 64% was leaf litter fall, followed by 27, 7 and 2% wood, reproductive and miscellaneous litter fall, respectively. The annual nutrient return through litter fall was 42.70 kg ha^{-1} N, 2.62 kg ha^{-1} P, 44.37 kg ha^{-1} K, 85.78 kg ha^{-1} Ca and 15.54 kg ha^{-1} Mg. High turnover rate was found in the present study. However, turnover time was lower than other *Quercus* forests.

Introduction

Litter is an important factor affecting community organization and dynamics far beyond its commonly recognized role as a transitory bank of nutrients (Facelli & Pickett, 1991). Understanding the dynamics of forest litter is a prerequisite for the study of the energy flow and nutrient cycling in forest ecosystems (Proctor, 1983; Vitousek, 1984). Litter on the forest floor affects the moisture status, run-off pattern and nutritional characteristics of the soil (Garkoti & Singh, 1995). Litter fall also increases the water holding capacity and contributes to the development of the soil structure (Dündar, 1988). Litter fall represents the key process for transferring nutrients from aboveground biomass to the soil. The changes in litter nutrient concentrations over time decisively affect plant nutrition (Vitousek 1982; Chapin & Kedrowski, 1983; Vitousek, 1984).

Quercus cerris L. var. *cerris* (Turkey oak) is one of the most important deciduous tree species in the "étage supra-méditerranéen pré-pontique" in Northern Anatolia (Quézel *et al.*, 1980). *Q. cerris* var. *cerris* forms pure stands in the area and these forests represent the potentially natural vegetation of the bioclimatic zone (Akman, 1995). The objectives of this study were: (i) to quantify the annual litter fall and the related nutrient flux in a *Q. cerris* var. *cerris* forest and (ii) to compare the results with those of other deciduous forests in the Mediterranean and temperate regions.

Materials and Methods

Study Area

This study was carried out in the Central Black Sea Region, in the northern part of Turkey (36° 10' 45'' E, 41° 22' 30 ''N) near the town Bafra in an area covering approximately 35 km^2. The study area comprises one *Q. cerris* var. *cerris* forest with 60 years old trees and includes the full site variability of *Q. cerris* var. *cerris* forests. Outside of the study area *Q. cerris* var. *cerris* forests are extremely degraded and converted into shrub communities. Mediterranean climate exists in the study area. According to the method of Emberger (Daget, 1977) Q, M and m values (Q = precipitation - temperature index; M= maximum temperature; m= minimum (temperature)

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are 129.3, 23.2°C and 4.0°C, respectively. The studied Turkey oak forest occurs on grey-brown podsolic soils which is derived from marl and sandstone bedrock (Kutbay & Kilinç, 1995). Some data on the soil properties of the local *Q. cerris* var. *cerris* forests are given in Table 1. Details of the soil were presented in Kutbay & Kilinç (1995). Bulk density, horizon thickness and coarse fragment content were used to transform the concentrations of soil nutrients per unit mass of sieved soil to pool sizes (kg/ha). As shown in Table 1 the studied oak forest occurs on soils that are rich in nitrogen but low in phosphorus. Locally, the *Quercus* forests also occur on soils that are relatively high in phosphorus. pH values range between 5.55 (acid) and 7.70 (slightly alkaline). Most Turkey oak forests occur on non-calcerous and non-saline soils, but sometimes calcium carbonate concentrations may be high. Organic matter values are usually high (Kutbay & Kilinç 1995).

Table 1. Some properties of the study area and range values for some soil properties.

Altitude (m)	350
Tree age (years)	60
Aspect	NW
Slope (%)	25
Tree density (trees/ha)	390
Stem basal area (m^2/ha)	39.9
Texture	Clay loam
C/N	12.01-14.53
Total nitrogen(kg/ha)*	640-2240
Total phosphorus (kg/ha)	32.4-65.0
Total potassium (kg/ha)	18.0-153.0
Cation exchange capacity (meq/100 g)	19.43-35.78
$CaCO_3$ (%)	0.16-4.23
Total salinity (%)	0.03-0.09
Organic matter (%)	1.34-5.53
pH (w:v; 1:1 soil:water extract)	5.55-7.70

*An impact sampler was used to obtain bulk density. Horizon thickness and coarse fragment content were also taken into account. In the bottom of each pit where limiting factors (i.e. water or bedrock) were absent, bucket auger samples to a depth of 4 m. from the soil surface were used to check for the presence of roots.

Litter input to the forest floor was measured for three years from 1993 to 1995 by using 9 litter traps which were randomly placed on the forest floor. The traps were 50x50 cm wide with 15 cm high wooden sides with a nylon net bottom. They were placed on northwest facing slopes. Monthly estimation of litter fall was made by collecting the litter from these traps and then sorting it into leaves, twigs, reproductive and miscellaneous matter and their oven dry weights (80°C) were determined (Singh, 1992). The miscellaneous litter consisted of mosses, epiphytic ferns, debris from bark and reproductive parts etc. These monthly samples were pooled together in proportion to their mass to get annual samples. These composite samples were grounded and analysed for nutrients.

Litter samples were digested in a mixture of nitric and perchloric acids with the exception of samples for N analysis which were digested with sulphuric acid and selenium catalyst. Nitrogen concentration was determined with the micro-Kjeldahl method. Phosphorus and potassium concentrations were analysed by the ammonium molybdate-stannous chloride method and a Petracourt PFP-1 flame photometer, respectively. Calcium and magnesium concentrations were determined with a Perkin Elmer 2280 atomic absorption spectrophotometer (Allen *et al.*, 1986). The nutrient concentrations were multiplied by the weight of annual litter fall to compute the amounts of nutrients transferred to the forest floor. The nutrient use efficiency (NUE) was calculated as the ratio of mass fall to nutrient in mass fall of a forest (Garkoti & Singh, 1995a).

The turnover rate (K) of litter was calculated indirectly according to Olson (1963): $K=A/A+F$ where 'A' is the annual increment of litter, i.e. annual litter fall and 'F' is the annual averages across months. Turnover time (t) is the reciprocal of the turnover rate $t=1/K$.

Results

The total annual litter fall measured in litter traps was 681.9 g m^{-2} in the studied *Q. cerris* var. *cerris* forest. The percentage contribution of wood, reproductive and miscellaneous falls were 27, 7 and 2%, respectively. The dominant fraction was leaf litter with 64% (Table 2).

Table 2. Annual litter fall values of *Quercus cerris* var. *cerris* forests (g m^{-2}±1 SE). Values in parentheses are the percentage of the total litter fall.

Component	Litter fall measured in litter traps	CV*
Leaf	433.63 ± 10.55 (64)	10.48
Wood	185.72 ± 2.99 (27)	14.36
Reproductive	45.38 ± 3.84 (7)	20.22
Miscellaneous	17.17 ± 0.96 (2)	7.22
Total	681.90 ± 14.35	8.74

*Coefficient of Variation

The leaf fall was concentrated during October-December with the peak value occuring in November and it was fairly staggered in time encompassing about 9 months of the annual cycle. Leaf fall ceased from May to July. The peak value for wood litter fall was obtained in November in parallel to leaf fall. Wood and miscellaneous litter fall followed quite irregular patterns (Fig. 2 and 4).

Monthly leaf fall ranged from 7.67 to 106.93 g m^{-2}, wood fall from 7.69 to 30.85 g m^{-2}. Extreme values for reproductive litter were 5.50 (minimum) and 9.14 g m^{-2} (maximum), and 0.25 and 3.01 g m^{-2} for miscellaneous litter. Reproductive litter fall occurred during June-October. Reproductive and miscellaneous litter fall also was obtained at low rates in the winter months. Monthly variability of litter fall (t ha^{-1}) during the 3 years of study are shown in Fig. 5. Litter fall fluctuated from 1993 to 1995. Litter fall values for various litter components remarkably fluctuated in 1993 and to a lesser degree in 1994 and 1995.

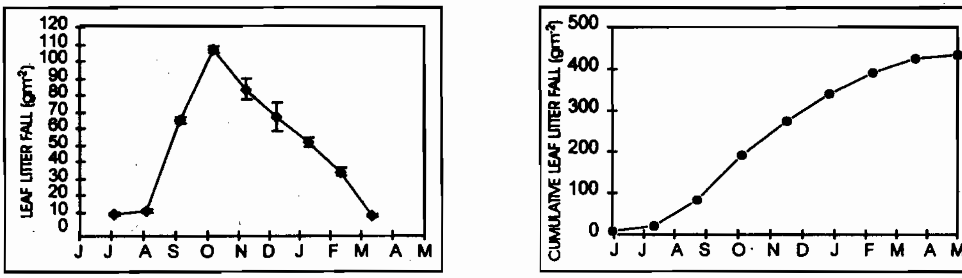

Fig 1.a) The monthly variation in leaf litter fall (Standard deviation indicated) and b) Cumulative leaf litter fall.

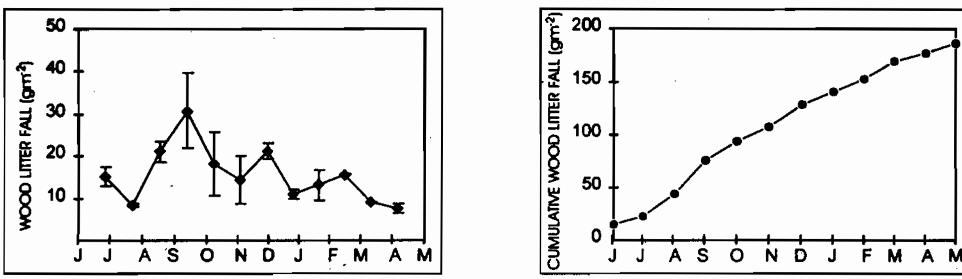

Fig 2.a) The monthly variation in wood litter fall (Standard deviation indicated) and b) Cumulative wood litter fall.

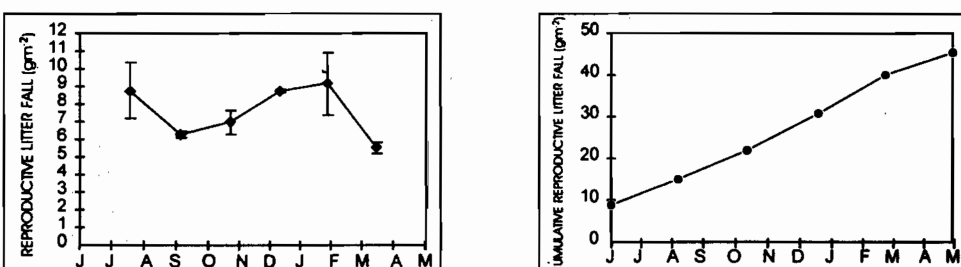

Fig 3.a) The monthly variation in reproductive litter fall (Standard deviation indicated) and b) Cumulative reproductive litter fall.

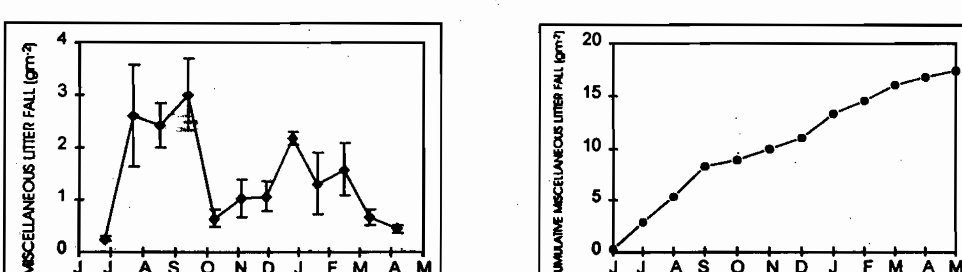

Fig 4.a) The monthly variation in miscellaneous litter fall (Standard deviation indicated) and b) Cumulative miscellaneous litter

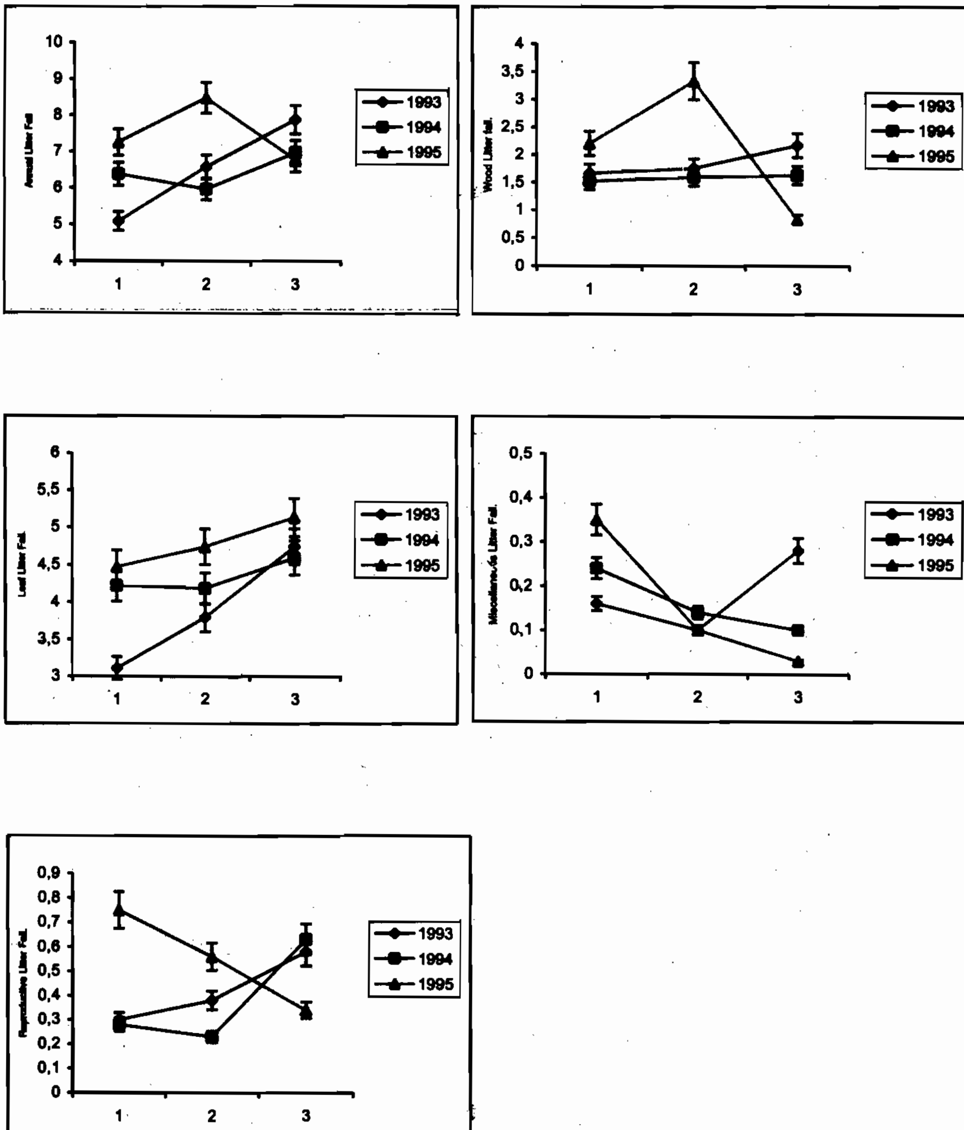

Fig 5. Monthly amount of litter fall (t ha-1) during the 3 years of study.

Nutrient concentrations in the biomass could usually be ranked in the order reproductive > leaves > miscellaneous > wood although it was different for N with a maximum in the leaf fraction (Table 3). The annual flux of nutrients transferred to the forest floor was highest for the leaf litter fraction and lowest for miscellaneous litter. Leaf litter constituted 54-77% of the total amount of nutrients transferred to the forest floor in the case of N, P, K and Ca (Table 3).

Table 3. Mean nutrient concentrations in different litter fractions and nutrient fluxes with litter fall (mean ± 1 SE). CV* values are given in parenthesis.

Component	N	P	K	Ca	Mg
	Concentrations (%)				
Leaf litter fall	0.76±0.14	0.046±0.01	0.72±0.43	1.07±0.61	0.043±0.003
	(6.57)*	5 (23.91)	(26.38)	(52.33)	(19.76)
Wood litter fall	0.38±0.07	0.019±0.00	0.30±0.08	1.56±0.28	0.17±0.031
	(23.68)	5 (42.63)	(60.00)	(19.23)	(73.52)
Reproductive litter fall	0.43±0.08	0.049±0.02	1.32±0.77	1.83±0.26	0.25±0.04
	(26.74)	0 (53.06)	(30.30)	(9.83)	(32.40)
Miscellaneous litter fall	0.44±0.09	0.034±0.00	0.93±0.32	1.24±0.22	0.061±0.007
	(13.63)	5 (44.11)	(52.68)	(29.03)	(39.34)
	Fluxes (kg ha^{-1} yr^{-1})				
Leaf litter fall	32.95±1.25	1.99±0.14	31.22±3.5	46.39±2.5	1.86±0.12
	(12.86)	(31.68)	5 (31.75)	7 (43.71)	(26.73)
Wood litter fall	7.05±0.23	0.35±0.06	5.57±1.81	28.97±1.4	12.44±0.34
	(33.33)	(32.35)	(73.72)	5 (33.35)	(74.84)
Reproductive litter fall	1.95±0.27	0.22±0.04	5.99±0.95	8.30±2.37	1.14±0.17
	(13.22)	(73.91)	(14.40)	(22.07)	(15.74)
Miscellaneous litter fall	0.75±0.04	0.06±0.02	1.59±0.73	2.12±0.80	0.10±0.08
	(20.00)	(35.71)	(56.52)	(26.54)	(36.00)
Total return	42.70	2.62	44.37	85.78	15.54
Nutrient use efficiency (NUE)	159	2599	153	79	438

*Coefficient of Variation

The contribution of leaf litter fall to the total return of the elements was 77% (N), 76% (P), 70% (K), 54% (Ca) and 30% (Mg). The contribution values for wood litter fall were 17% (N), 14% (P), 13% (K), 34% (Ca) and 50% (Mg). The corresponding values for reproductive litter fall were 5% (N), 8% (P), 14% (K), 10% (Ca) and 18% (Mg). The contribution of miscellaneous litter fall to the total nutrient return was negligible and varied between 1% (Mg) and 4 (%) K. The turnover rate calculation indicated that about 80% of the forest floor is replaced each year with a turnover time of 1.25 years.

Discussion

The annual litter fall value of the studied Turkey oak forest was 6.81 t ha^{-1}. This value is somewhat higher than the values reported from most other deciduous forests (Table 5). The annual wood litter fall value (1.85 t ha^{-1}) was particularly high and exceeded the world mean for temperate forests reported by Bray & Gorham (1964), or corresponding values from Central Himalayan high altitude forests (Garkoti & Singh, 1995b).

With 64% percentage contribution of leaf fall to the total annual litter fall was comparable to the values reported by Singh (1992) for dry deciduous forests of India. This value is also similiar to global averages (70% for leaf litter) reported by Meentemeyer *et al.*, (1982) and it is within the range of 40-85% given for temperate forests around the world by Rodin & Bazilevich (1967).

Table 4. Nutrient concentrations within each litter fraction.

Leaves	Ca>N>K>P>Mg
Wood	Ca>N>K>Mg>P
Reproductive	Ca>K>N>Mg>P
Miscellaneous	Ca>K>N>Mg>P

Table 5. Annual litter fall values (t ha^{-1}) of some temperate and Mediterranean forests (all fractions).

Forest type	Location	Litter fall	Reference
TEMPERATE			
Quercus petraea	England	3.86	Carlisle *et al.*, (1966)
Q. petraea	Netherlands	6.31	van der Drift (1981)
Q. robur	Sweden	5.28	Anderson (1970)
Q. floribunda Q.lanuginosa, Q.leucotrichophora	India	4.7-7.8	Rawat & Singh (1989)
Q. cerris var. *cerris*	Northern Turkey	6.81	Present study
Q. pyrenaica	Salamanca, Spain	5.62	Gallardo *et al.*, (1989)
North American oak forests	Minnesota, USA	4.57	Reiners & Reiners (1970)
Quercus-Acer	USA	4.89	Vitousek (1982)
Quercus-Betula	USA	3.70	Witkamp&van der Drift (1971)
Acer-Fagus-Quercus	Indiana, USA	5.23	Vitousek *et al.*, (1982)
Alnus rubra	Oregon, USA	4.49-9.90	Zavitkovski & Newton (1971)
A. rubra	USA	7.80	Turner *et al.*, (1976)
Castanea sativa	Salamanca, Spain	6.18	Gallardo *et al.*, (1989)
Fagus sylvatica	Southern Sweden	5.70	Nihlgård (1972)
MEDITERRANEAN			
Quercus coccifera	Southern France	2.30-2.60	Rapp (1969)
Q. ilex	Southern France	3.80-7.00	Rapp (1969)
Q. ilex	France	4.22	Lossaint & Rapp (1978)
Q. ilex	Etna, Italy	3.57	Leonardi & Rapp (1981)
Q. ilex	Spain	2.28	Bellot *et al.*, (1992)
Q. ilex	Northern Spain	3.1	Mayor & Rodá (1992)
Q. suber	Iberian Peninsula	2.88-4.33	Robert *et al.*, (1996)

Leaf litter fall in this forest of the supra-Mediterranean stage peaked during November-January and thus occured somewhat later in the year than leaf fall in deciduous forests of the cool temperate zone of the Northern hemisphere (Witkamp & van der Drift, 1971). Leaf and wood litter were dominated by Ca and N. However there is a little difference in the rank of K in reproductive and miscellaneous litter fall (Table 4). Reproductive litter fall usually has high K values (Gallardo *et al.*, 1989; Bellot *et al.*, 1992). The order of nutrients were also in agreement with Peterson & Rolfe (1982) and Robert *et al.*, (1996).

Wood litter fall usually has lower nutrient concentrations, except for Ca and Mg concentrations as compared to leaf litter fall (Table 3). This may be attributed to non-photosynthetic: photosynthetic-tissue ratios and tissue longevity (Sharma & Pande, 1989). However, Ca and Mg concentrations in woody material were higher than those of leaves (Chapin, 1980; Attiwill *et al.*, 1978). The mean fluxes of nutrients returned with annual litter fall were highest for leaf litter except for Mg. Leaf litter was followed by wood and reproductive litter, respectively (Table 3).

Table 6. Annual nutrient return with litter fall in kg hg^{-1} for various forests of the temperate and Mediterranean region.

Forest type	Location	Element	Nutrient return	Reference
Betula sp.	USSR	N	66.00	Ovington (1965)
Betula sp.	Denmark	N	33.50	Thamdrup (1973)
Acer cappadocicum	India	N	56.07	Garkoti & Singh (1995a)
Betula utilis	India	N	34.07	Garkoti & Singh (1995a)
Rhodedendron campanulatum	India	N	25.53	Garkoti & Singh (1995a)
Quercus leucotricophora	India	N	74.50	Rawat & Singh (1989)
Q. floribunda	India	N	83.0	Rawat & Singh (1989)
Q. lanuginosa	India	N	124.60	Rawat & Singh (1989)
Q. cerris var. *cerris*	Northern Turkey	N	42.70	Present study
Q. leucotricophora	India	P	4.36	Rawat & Singh (1989)
Q. floribunda	India	P	3.20	Rawat & Singh (1989)
Q. lanuginosa	India	P	12.30	Rawat & Singh (1989)
Acer cappadocicum	India	P	5.38	Garkoti & Singh (1995a)
Betula utilis	India	P	3.26	Garkoti & Singh (1995a)
Rhododendron campanulatum	India	P	2.03	Garkoti & Singh (1995a)
Q. cerris var. *cerris*	Northern Turkey	P	2.62	Present study
Acer cappadocicum	India	K	23.29	Garkoti & Singh (1995a)
Betula utilis	India	K	12.22	Garkoti & Singh (1995a)
Rhododendron campanulatum	India	K	9.94	Garkoti & Singh (1995a)
Q. cerris var. *cerris*	Northern Turkey	K	44.37	Present study
Quercus leucotricophora	India	Ca	83.90	Rawat & Singh (1989)
Q. floribunda	India	Ca	73.20	Rawat & Singh (1989)
Q. lanuginosa	India	Ca	129.40	Rawat & Singh (1989)
Q. cerris var. *cerris*	Northern Turkey	Ca	85.78	Present study

A review of litter fall data for a number of temperate and Mediterranean forests is given in Table 5. In an earlier review Madge (1965) found annual litter mass values between 3.6 and 39.9 t ha^{-1} in the temperate region. Annual litter fall values of evergreen Mediterranean-type *Quercus* forests were lower than those of temperate deciduous *Quercus* forests including the studied Turkey oak forest.

Annual variability in litter fall values varied between 7.22 and 20.22% in the different fractions (Table 2 & 3). Average coefficient of variation (CV) of total litter fall in the present study were lower reported for a deciduous *Quercus pyrenaica* (26.2%) and a *Q. barcalis* (30.8%) forest (Gallardo *et al.*, 1989; Bray & Gorham, 1964). Similarly CV' s of total litter fall values of evergreen *Q. ilex* (11.8-20.8%) forests were also higher than the CV values presented in this study (Lossaint & Rapp, 1978; Leonardi & Rapp, 1981; Bellot *et al.*, 1992). Average CV' s of nutrient fluxes varied between 6.57 to 74.84% and average CV values of reproductive and miscellaneous litter fractions were higher than the other litter fractions because they follow quite irregular pattern (Fig. 3 and 4). For deciduous forests the average CV was 25.2% (ranges 11-32%). However for coniferous and broadleaved evergreens the average CV was 11.2 (ranges 4-20%) and this difference may be explained on the basis of deciduous species have a higher inter-annual variability than broadleaved evergreens and coniferous species probably due to climatic fluctuations (Bellot *et al.*, 1992).

Annual nutrient return in litter fall has been considered as an index of the availability of nutrients. The comparison of the data obtained in the present study and other forests in terms of nutrient return (kg ha^{-1} yr^{-1}) are shown in Table 6. *Q. cerris* var. *cerris* forest showed lower N return as compared to a *Betula* sp., forest (66.0) of USSR (Ovington,

1965) and a Central Himalayan high altitude forest (25.53-56.07) (Garkoti & Singh, 1995a), with higher N return as compared to a *Betula* sp., forest (33.5) of Denmark (Thamdrup, 1973). P return was towards the lower end of the other forest. P return for *Quercus leucotrichophora, Q. floribunda* and *Q. lanuginosa* was 4.36, 3.2 and 12.3, respectively (Rawat & Singh, 1989). P return of *Acer cappadocicum, Betula utilis* and *Rhododendron campanulatum* forest was 5.38, 3.26 and 2.03, respectively (Garkoti & Singh, 1995a). K return in the present study was higher than the other forests. For example K return in *A. cappadocicum, B. utilis* and *Rh. campanulatum* forests varied between 9.94 and 23.29 (Garkoti & Singh, 1995a). Ca return usually coincided with the values reported for other *Quercus* forests (Rawat & Singh, 1989).

Annual nutrient return with litter fall values for the studied *Q. cerris* var. *cerris* forest were usually higher or towards the upper end of the range than the other forests (Table 6) and these high values cause higher turnover rates as reported by Rode (1993) for an oak forest at the later stages of succession. The turnover rate in the present study was 0.80. The turnover rate in an evergreen oak forest is reported to be 0.68 (Rawat & Singh, 1988) and turnover rate in the present study was higher than the values reported by Rawat & Singh (1988) and Rode (1993). High turnover rates were explained on the basis of high sclerophyll indices (Garkoti & Singh, 1995a). *Q. cerris* var. *cerris* has high sclerophyll indices during the growing season (Kutbay & Kilinç, 1994). Turnover time of litter in an evergreen oak forest was 1.47 years. Reiners & Reiners (1970), Rochow (1975) and Lang & Formann (1978) have reported replacement times of 14.1, 2.7 and 2.7 years for the litter on the forest floor. Turnover time in the present oak forest was usually lower (1.25 yr) as compared to other studies and the forest floor of *Q. cerris* var. *cerris* forest is more dynamic than the other evergreen and temperate forests.

The contribution values for different litter fractions to the total return are similar to the reports of Rawat & Singh, (1989). Of the total annual nutrient input through litter fall, leaf fall generally accounts for 75-85% and wood fall for 10-35% (Rawat & Singh, 1989; Garkoti & Singh, 1995). The litter dry matter / N ratio varied between 60-200 among a large number of forests (Vitousek, 1982). The litter dry matter / N ratio in *Q. cerris* var. *cerris* forests is 159 and this value is within the average values (Garkoti & Singh, 1995a).

Annual litter fall and nutrient input to the forest floor values in *Q. cerris* var. *cerris* forests were usually similar to the other temperate broad leaf forests. However some differences were observed and they may be due to the influence of oceanic climate at the study area, because the study area has a climate intermediate between oceanic and Mediterrarean climates. Thus, the differences between turnover values reported for the present oak forest as compared to the other evergreen and temperate forests may be explained on the basis of the transitional state of the study area.

NUE values were higher than those reported by Rawat & Singh (1989) in *Quercus floribunda, Q. lanuginosa* and *Q. leucotrichophora* forests and by Garkoti & Singh (1995a) in some deciduous plant communities in Central Himalayan high altitude forests. NUE values reported by Rawat & Singh (1989) varied between 58 and 65 (N), 1017-1420 (P) and 222-233 (K), respectively. However these values were reported as 112-140 (N), 1310-1704 (P) and 269-348 (K) by Garkoti & Singh (1995a). *Q. cerris* var. *cerris* forests seem to be more efficient in nutrient use except K as compared to other *Quercus* forests and deciduous forests.

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