Original article

Litterfall and mineral return in two cork-oak forests in northeast spain

A Caritat[1], G Bertoni[2], M Molinas[1], M Oliva[1],
A Domínguez-Planella[1]

[1]Cork-oak Laboratory, University of Girona, Pl Hospital 6, 17071 Girona, Spain;
[2]Laboratoire de physiologie végétale, École nationale supérieure agronomique,
145, av de Muret, 31076 Toulouse, France

Summary – Seasonal trends in litterfall and potential mineral return were studied in two cork-oak forest sites in the northeastern Iberian peninsula. The estimated average litter production was 3.9 Mg.ha^{-1}.year^{-1} for one site and 4.6 Mg.ha^{-1}.year^{-1} for the other; these figures are similar to those reported for holm-oak (*Quercus ilex*) forests in the same area. Seasonal litterfall patterns were typical of Mediterranean forest ecosystems. Leaves accounted for 46 to 78% of the total dry matter. Their annual weighted-average mineral composition was low in macronutrients (N 8–9; K 4–5; Mg 0.8–1.3; Ca 9–10 and P 0.4–1 mg.g^{-1}) and relatively high in micronutrients such as Mn (2–2.2 mg.g^{-1}) or Fe (0.3–0.4 mg.g^{-1}). Minimum N and P concentrations were found during the growth period. Estimates of potential mineral return for an annual cycle were N 38–52, P 2.1–5.2, K 20–28, Ca 44–53 and Mg 5.4–5.0 kg.ha^{-1}, depending on the site biomass and fertility.

cork-oak / litterfall / nutrient cycling / Mediterranean forest ecosystems / *Quercus suber*

Résumé – Variations saisonnières de la chute de la litière et de leur teneur en minéraux dans une forêt de chêne-liège au nord-est de l'Espagne. *Les variations saisonnières de la chute de la litière et de leur teneur en minéraux ont été étudiées sur deux sites du nord-est de la péninsule ibérique. La production de litière est de 3,9 Mg.ha^{-1} à Quart et de 4,6 Mg.ha^{-1} à Sant Hilari, valeurs similaires à celles qui ont déjà été publiées pour le chêne vert dans la même région. Le type de variation observé est caractéristique des écosystèmes forestiers méditerranéens avec une chute maximale des feuilles au début de l'été. Les feuilles constituent la majeure partie de la litière et montrent de faibles teneurs en N, K,Ca, Mg et spécialement en P, et des teneurs élevées en Mn (2,0–2,2 mg.g^{-1}) et en Fe (0,3–0,4 mg.g^{-1}). Les variations saisonnières les plus nettes sont celles des teneurs en P et en N ; les concentrations les plus faibles sont observées au début de l'été et sont probablement dues à la retranslocation de ces éléments. Dans l'ensemble, les valeurs observées pour le chêne-liège sont comparables à celles qui ont été publiées pour d'autres chênes méditerranéens ; les quantités de litière et d'éléments minéraux qui retournent au sol dépendent donc plus de la fertilité du sol que de l'espèce de chêne considérée.*

chêne-liège / écosystème forestier méditerranéen / litière / *Quercus suber* / retranslocation

INTRODUCTION

The stability of an ecosystem depends on the efficiency of nutrient recycling. In forest ecosystems, litterfall is one of the main sources of aerial mineral return to soil and, moreover, the quality and quantity of litterfall are related to primary production. In fact, the recording and study of quantitative information on litterfall is one of the best available methods for estimating changes in the function of forest ecosystems (Armentano and Woodwell, 1976).

To adapt to water-deficit conditions, trees tend to shed old leaves in order to reduce the transpiration surface. This adaptive mechanism leads to a rapid substitution of old leaves by new shoots, which exert a high photosynthetic capacity and are more efficient in water regulation (Kummerow, 1983). In the Mediterranean area, water deficit is highest in summer, but a marked variability in water supply during the growing season leads tree species to show a certain plasticity in litterfall which, in turn, affects nutrient recycling. According to Escudero and Del Arco (1987), the relatively rapid leaf abscission in *Quercus suber* when compared with other evergreen trees is a response to premature water stress.

Several studies have reported litterfall, nutrient content and mineral return on Mediterranean forest ecosystems, which show important interspecific differences (Kruger et al, 1983; Specht, 1988). In the Mediterranean geographic area, these facts have been investigated most often in the holm-oak forest (*Quercus ilex* L and *Q rotundifolia* Lamk) and in the deciduous oak forest (*Q pyrenaica* Willd and *Q faginea* Lamk) (Rapp, 1971; Lossaint and Rapp, 1978; Cole and Rapp, 1981; Escarre et al, 1984; Ferrés et al, 1984; Escudero et al, 1985; Caritat and Terradas, 1990; Leonardi et al, 1992). In fact, as far as we know, studies of cork-oak litterfall are limited to those performed by our group (Oliva et al, 1992) and to those performed by Escudero

and Del Arco (1987) and Escudero et al (1992), which are focused on leaf abcission and nutrient retranslocation in several tree species, the cork oak being among them.

In this paper, data are presented concerning litterfall and nutrient cycling in two selected locations that present different environmental conditions typical of those in cork-oak forests in the northeastern Iberian peninsula. A comparison is made between the values obtained in our two plots and those reported in other Mediterranean forest systems.

FIELD STUDY SITES

Two cork-oak forest plots of 400 m^2, one located near the village of Quart and the other near Sant Hilari (Girona, Spain), were selected. The site in Quart (41°51'N, 2°57'E; UTM:31T DG94) is a lowland cork-oak wood in the Catalonian Littoral Range subject to a xheroteric Mediterranean climate. The site in Sant Hilari (41°53'N, 2°28'E, UTM:31T DG53) represents a highland cork-oak wood in the Catalonian Prelittoral Range, combining an axheroteric sub-Mediterranean climate with Atlantic tendencies (table I). The tree level is formed by *Q suber* on both sites. In Quart accompanying vegetation is typical of a Mediterranean scrub-oak forest. In the undergrowth we notice *Arbutus unedo*, *Viburnum tinus* and *Pistacia lentiscus*. In Sant Hilari the forest community consists of mixed sub-Mediterranean and Atlantic flora with a greater abundance of leguminous species. At shrub level we find *Sarothamnus scoparius*, *Genista pilosa*, *Corylus avellana* and *Osyris alba*. The trees in the Sant Hilari forest are of seedling origin and show greater biomass than in Quart (table I). On both sites soils are weakly acid but differ markedly in texture. In Sant Hilari the soil is sandy and thick, while in Quart it is silty (table II). Every 14 years both plots are subject to periodic brushwood clearance

Table I. Physical, topographical and structural characteristics for the two forest sites in Quart and Sant Hilari (Girona, Spain).

	Site	
	Quart	Sant Hilari
Physical characteristics		
Altitude (m)	240	850
Substratum	Schists	Granodiorite
Aspect	NW	SW
Slope (%)	25	35
Annual precipitation (mm)	659	858
Average annual temp (°C)	14–15	11.2
Forest structure		
Age of tree (years)	50	75
Stem diameters (cm)	9.3–29	24–57
Average height (m)	11.4	12.4
Density (n.ha^{-1})	875	575
Basal area (m^2.ha^{-1})	28	58
Biomass (Mg.ha^{-1})	159	328

and cork extraction (3 Mg.ha^{-1} in Quart and 9 Mg.ha^{-1} in Sant Hilari).

METHODS

Total soil nitrogen was analyzed by the Kjeldhal method (CMA, 1973). Soil exchangeable K was extracted with ammonium acetate and analyzed by flame photometry. Exchangeable Ca and Mg were determined by EDTA sodium valuation, and extractable P in ammonium fluoride was analyzed by colorimetry (Jackson, 1958).

For litterfall measurements, seven 0.25 m^2 conical traps were placed at random in each plot (Staaf, 1982). Collection took place monthly from July 1989 to December 1992. The samples were

Table II. General soil characteristics on the sites in Quart and Sant Hilari (Girona, Spain).

| Soil characteristics	Site			
	Quart		Sant Hilari	
Depth	0–4	4–23	3–17	17–54
Horizonts	H	A	A2	B
Gravel/stones (> 2 mm) %	86	88	37	49
Fine hearth (< 2 mm) %	14	12	63	51
Texture	Silty loam	Silty loam	Sandy loam	Loamy sand
pH–H$_2$O	6.4	6.1	5.8	5.1
pH–KCl	6.1	5.2	4.6	3.8
N%	1.0	0.3	0.2	0.1
OM%	35.1	12.3	4.0	0.9
C/N	19.6	21.6	11.7	5.0
Exch Ca (Cmol$_c$.kg^{-1})	20.7	13.3	12.14	10.34
Exch Mg (Cmol$_c$.kg^{-1})	8.5	9.5	7	5.5
Exch K (Cmol$_c$.kg^{-1})	0.8	0.8	0.8	0.7
P$_2$O$_5$ (mg.kg^{-1})	21.9	12.4	25.2	20.7

LITTERFALL
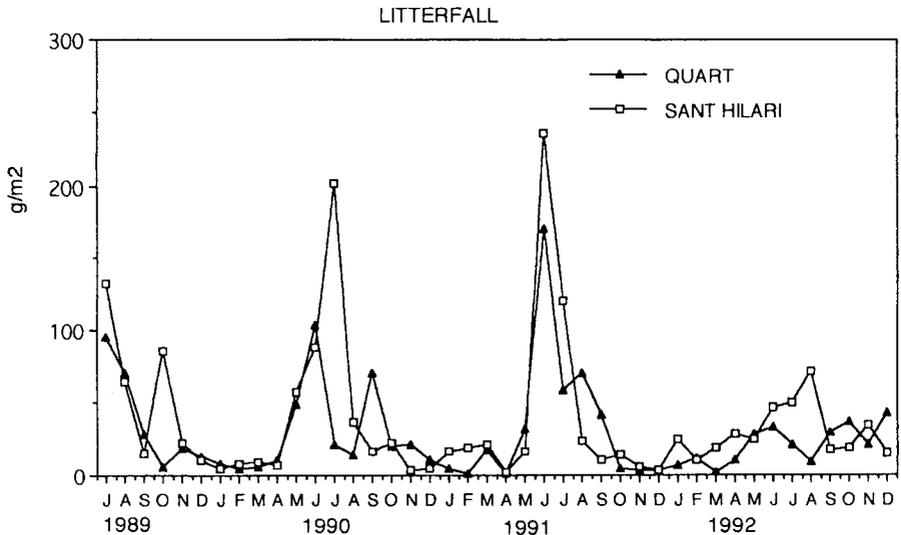
Fig 1. Seasonal patterns in the fall of litter in the cork-oak plot of Quart and Sant Hilari (Girona, Spain) from July 1989 to December 1992.

sorted into five components: leaves, twigs, male catkins, acorns and miscellaneous (including all nonidentifiable material). They were then dried at 80 °C for 48 h and weighed. Samples of components with insufficient individual amounts of dry matter were combined before analysis.

Monthly and annual litterfall amount and a coefficient of variation were estimated from the monthly collected litterfall in the seven traps on each plot. The interannual variation was also estimated from the interannual standard error of the amount of dry matter recovered each year on both sites.

Chemical leaf analysis was carried out on the dry matter after grinding. Nitrogen concentration was measured by colorimetry after mineralization by sulfuric acid in the presence of the catalyzer H_2O_2 (Lindner and Harley, 1942). All the other elements were determined in a HCl extract of the ash obtained at 550 C, employing the method used by Bonvalet et al (1986): P by colorimetry, K by emission spectrophotometry and Ca, Mg, Fe, Cu, Zn and Mn by atomic absorption.

The mineral return was calculated as the product dry weight of litter component by element concentration. The estimated total potential annual return is the sum of the different components taken between January 1990 and December 1990. The annual average concentrations of the different litter components are given in the form of weighted-average for the year 1990.

Monthly variations in the amount and mineral composition of the different litter fractions (leaves, twigs, acorns, male catkins and miscellaneous) were taken into account to estimate the average mineral content of the litterfall. Pondered estimates of the mineral content were obtained in the following way: for each fraction, annual content average is the sum of the content multiplied by the weight of the corresponding samples collected during the year, divided by the total weight of samples. Values shown correspond to the average (± standard error) of the two estimates of annual averages obtained, for each litter fraction, during the period of July 1989 to June 1991.

RESULTS AND DISCUSSION

Litterfall

The fall of cork-oak litter followed the seasonal pattern of many Mediterranean forest systems with maximum litterfall occurring at the end of spring (fig 1). Total dry matter

return-ranges recorded during the period studied were 3.6–4.3 Mg.ha⁻¹.year⁻¹ in Quart and 3.9–5.1 Mg.ha⁻¹.year⁻¹ in Sant Hilari, with respective average annual returns of 3.9 and 4.6 Mg.ha⁻¹ (table III). Coefficients of variation between the litterfall collected in different traps oscillated between 6 and 20%.

In the cork-oak the average return of litter was similar to that recorded by Cole and Rapp (1981) and Ferrés et al (1984) in a sclerophyllous Mediterranean holm-oak forest: 3.8 and 5.3 Mg.ha⁻¹.year⁻¹, respectively. However, in comparison with the holm-oak, the cork-oak showed a relatively short abscission period, also noted by Escudero and Del Arco (1987). According to these authors and to Kummerow (1983) a short abscission period may indicate the presence of a mechanism adaptive to water stress.

The seasonal litterfall variations and the distribution of the different litterfall components showed similarities in the two sites (fig 1 and table III). Leaves were the main litter component, representing 46 to 78% of the total litterfall weight, varying according to the site and year. The main leaf-fall period occurred in June, July or at the beginning of August (fig 1). Twigs were the second litter component (12–22% of total weight) with the maximum in summer and a smaller peak at the end of autumn or in winter. The twig fraction percentage was similar to that recorded in *Q pyrenaica* and *Q rotundifolia* (Escudero et al, 1985) but smaller than that recorded by Ferres et al (1984) in *Q ilex* (26%). Canopy structure differences found between cork- and holm-oaks could explain this lower proportion of twigs in the cork-oak litterfall. The male catkin contribution was in the range of 4–8% of the total litterfall weight, with a maximum in June or July. It has been found that favourable climatic conditions lead to a second flowering period. The proportion of acorns varied greatly depending on the year, oscillating between 2% (Quart 1991) and 31% (Quart 1992). We wish to draw attention to the fact that a large fall of acorns produced in 1992 was accompanied by a low fall of leaves (table III).

Mineral content of the litterfall fractions

In the leaf fraction the mineral composition was characteristic of senescent leaves (table IV) with a relatively low content of translocable elements (N, K, Mg and especially P), and high concentrations of Ca, Fe

Table III. Estimated amount of litterfall in Quart and Sant Hilari throughout three annual cycles (1990, 1991, 1992).

$g.m^{-2}$	Leaves	Twigs	Catkins	Acorns	Miscellaneous	Total
Quart						
1990	238	80	16	14	14	362
1991	340	52	23	7	11	433
1992	184	58	23	123	7	395
1990–1992	254 ± 46	63 ± 9	21 æ 2	48 ± 38	11 ± 2	396 ± 20
Sant Hilari						
1990	349	66	17	28	25	485
1991	345	73	39	32	25	514
1992	216	85	21	53	12	387
1990–1992	303 ± 43	74 ± 5	26 ± 6	38 ± 8	21 ± 4	462 ± 38

Mean values and standard error are provided. Litter has been divided into five separate components: leaves, twigs, male catkins, acorns and miscellaneous.

Table IV. Mineral composition of the litterfall components (mg.g⁻¹ of macronutrients; mg.kg⁻¹ of micronutrients) in the cork-oak plots in Quart (Q) and Sant Hilari (SH).

	Leaves		Twigs		Acorns		Catkins		Miscellaneous	
	Q	SH	Q	SH	Q	SH	Q	SH	Q	SH
$mg.g^{-1}$										
N	8.7 ± 0.5	9.1 ± 0.1	6.8 ± 0.4	7.6 ± 0.7	9.7 ± 1.4	9.5 ± 0.8	19.7 ± 1.4	17.9 ± 0.2	14.0 ± 1.8	12.2 ± 7
P	0.4 ± 0.1	0.9 ± 0.1	0.4 ± 0.1	1.1 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.5 ± 0.3	1.6 ± 0.1	1.1 ± 0.1	1.1 ± 0.7
K	4.5 ± 0.4	4.7 ± 0.1	3.3 ± 1.1	4.5 ± 0.1	8.0 ± 0.2	7.9 ± 0.1	12.3 ± 4.5	10.6 ± 0.5	5.4 ± 0.4	5.4 ± 2.7
Ca	9.5 ± 0.7	10.1 ± 1.2	18.1 ± 1.1	14.3 ± 0.3	4.1 ± 2.0	4.4 ± 0.1	4.8 ± 0.1	5.3 ± 0.1	7.3 ± 0.9	5.3 ± 2.8
Mg	1.3 ± 0.1	0.8 ± 0.1	1.2 ± 0.3	0.9 ± 0.1	1.3 ± 0.5	0.9 ± 0.1	1.7 ± 0.2	1.3 ± 0.1	1.4 ± 0.3	1.2 ± 0.3
$mg.kg^{-1}$										
Mn	2 224 ± 82	1 991 ± 209	388 ± 45	409 ± 10	811 ± 359	578 ± 4	832 ± 145	1 071 ± 457	736 ± 3	462 ± 290
Fe	357 ± 28	402 ± 21	433 ± 19	370 ± 23	111 ± 23	124 ± 45	446 ± 24	475 ± 111	830 ± 105	592 ± 400
Zn	22 ± 2	24 ± 4	24 ± 4	28 ± 1	17 ± 3	21 ± 5	23 ± 1	25 ± 1	35 ± 3	30 ± 10
Cu	5.1 ± 0.1	5.8 ± 0.4	7.4 ± 0.1	8.2 ± 0.2	8.2 ± 1.6	8.7 ± 0.8	12.1 ± 0.4	13.2 ± 0.6	11.8 ± 0.8	8.2 ± 3.4

Each value is the mean (± standard error) of two annual-weighted means.

Table V. Annual potential mineral return (kg.ha⁻¹) in the cork-oak plots of Sant Hilari (SH) and Quart (Q).

	N		P		K		Ca		Mg	
$kg.ha^{-1}$	Q	SH	Q	SH	Q	SH	Q	SH	Q	SH
Leaves	27.2 ± 0.7	35.6 ± 3.3	1.33 ± 0.17	3.33 ± 0.14	14.2 ± 2.3	18.4 ± 2.2	29.9 ± 4.4	38.9 ± 0.6	4.05 ± 0.58	3.19 ± 0.12
Twigs	4.7 ± 0.5	5.4 ± 1.4	0.25 ± 0.01	0.77 ± 0.11	2.2 ± 0.7	3.2 ± 0.6	12.5 ± 1.3	10.0 ± 1.6	0.81 ± 0.18	0.62 ± 0.09
Acorns	4.1 ± 0.5	2.8 ± 1.4	0.31 ± 0.08	0.27 ± 0.14	2.6 ± 1.0	1.7 ± 0.9	1.0 ± 0.1	0.8 ± 0.4	0.35 ± 0.06	0.21 ± 0.11
Catkins	0.7 ± 0.4	2.7 ± 1.4	0.10 ± 0.01	0.30 ± 0.18	0.7 ± 0.5	2.4 ± 1.4	0.2 ± 0.1	1.3 ± 0.7	0.13 ± 0.05	0.27 ± 0.15
Miscellaneous	1.5 ± 0.1	6.2 ± 1.3	0.13 ± 0.04	0.56 ± 0.14	0.6 ± 0.1	2.9 ± 0.3	0.8 ± 0.1	2.7 ± 0.4	0.15 ± 0.01	0.72 ± 0.15
Total	38.3 ± 0.7	52.7 ± 8.8	2.10 ± 0.07	5.23 ± 0.43	20.3 ± 1.4	28.6 ± 5.4	44.4 ± 3.0	53.8 ± 2.5	5.43 ± 0.68	5.01 ± 0.32

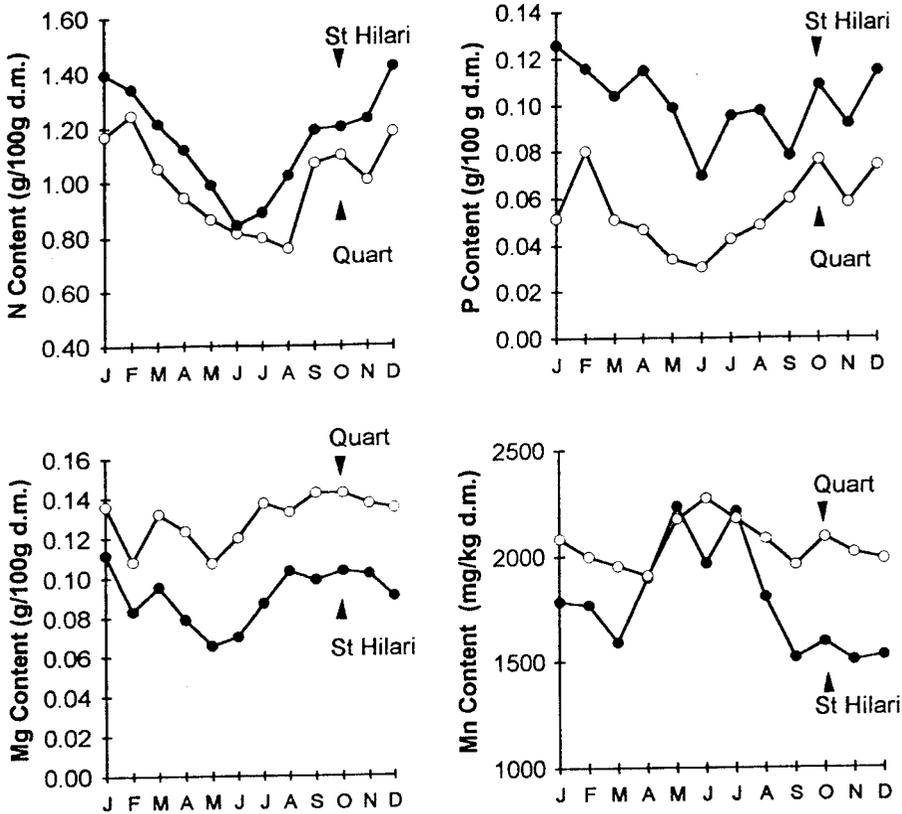Each value is the mean (± standard error) of two annual-weighted returns.

Fig 2. Average monthly mineral concentrations (g.100 g^{-1} dry matter) in the leaf fraction of the litterfall in the two cork-oak forest sites.

and Mn. The N concentration was very similar to that reported by Escudero et al (1985) in *Q rotundifolia* and *Q pyrenaica* and slightly higher than that of *Q ilex* (Rapp, 1971; Ferrés et al, 1984). In addition, the P concentration was comparable with the recorded ranges of P for those earlier mentioned Mediterranean oaks; and the same was true for Ca, except for those oaks grown on a calcareous soil. The K concentration was close to that of *Q ilex* (K 4–4.5 mg.g^{-1}) and higher than that of *Q rotundifolia* (2.9 mg.g^{-1}) and *Q pyrenaica* (2.1 mg.g^{-1}). However, Mg content was similar to that reported in *Q ilex* (Mg

1.2 mg.g-1) and lower than in *Q rotundifolia* (1.8 mg.g^{-1}) and *Q pyrenaica* (2.2 mg.g^{-1}), probably as a consequence of K–Mg antagonism. Differences in climate and interchanging K and Mg content in the soil could explain these observed differences.

With reference to leaf fraction microelements, the Cu and Zn content was in the range of the values previously recorded in other Mediterranean oaks (Escudero et al, 1985; Caritat and Terradas, 1990); however, the Fe and Mn content in the cork-oak leaves was higher than that reported in *Q pyrenaica* (Fe 0.1 mg.g^{-1}, Mn 0.5 mg.g^{-1}), *Q rotundifolia* (Fe 0.1 mg.g^{-1} Mn 0.7 mg.g^{-1})

and *Q ilex* (Fe 0.2 mg.g^{-1}, Mn 1 mg.g^{-1}) by these authors. The high accumulation of Mn found in cork-oak leaves needs further evaluation: it may be a result of the fact that the soil is rich in available Mn or a peculiar feature of *Q suber* species, given a preferential Mn accumulation in the old leaves.

The twig fraction composition was similar to that of leaves, except for their Ca content, which was higher, and Mn, which was lower. The male catkin fraction was rich in N, P, K, Mg and Cu and was poor in Ca. The acorn component, which includes cupules and stalks, often consisted of immature acorns and showed an intermediate composition between male catkins and leaves. The miscellaneous fraction was relatively rich in macronutrients. All these litterfall components were rich in micronutrients.

Seasonal evolution of mineral concentration in leaf litterfall component

The level of N and P in the leaf litterfall component varied seasonally in both plots, but more acutely in Quart (fig 2). As a rule, the concentrations of these two elements were higher in periods of low rate fall (September–April) than in periods of high rate fall (June–August). Mg showed a similar pattern but its concentration was minimal in the period just preceding the greater fall (April–May). Mn variation also appeared to be related to the June–July leaf fall and to the production of new leaves. These variations were less marked in Quart. Seasonal fluctuations of the other elements (Ca, Fe, Cu, Zn) were relatively limited.

The marked seasonal fluctuations of N, P and Mg content in the leaf litterfall fraction could be influenced by the age of the fallen leaves and, eventually, by the occasional winter fall of young leaves. The gradual decrease of the N, P and Mg content during the period preceding the maximum leaf fall suggests that the stock of these elements in old leaves constitutes a reserve which is

mobilized in the period of rapid growth. Besides, P data suggest that this element could be a limiting factor in Quart.

In relation to Ca content, a difference between the two vegetative cycles studied was observed. In Sant Hilari, the average Ca concentration in fallen leaves was about 12 mg.g-1 in the first cycle (June 1989–June 1990), while it decreased to an average value of 8 mg.g-1 in the following period (June 1990–June 1991). In Quart, the difference between the two cycles was less marked.

Annual potential mineral return

Leaves and twigs contribute more than 76% (Sant Hilari) and 81% (Quart) to the potential mineral return of macronutrients (table V). The acorns and miscellaneous contributions were smaller in Quart than in Sant Hilari. The estimated restitution in Sant Hilari, the plot bearing the highest biomass (table I), was N 52, P 5, K 28 and Ca 54, figures that in Quart did not exceed N 38, P 2, K 20, Ca 44 kg.ha^{-1}.year^{-1}. The restitution in Mg was similar in both plots.

In Sant Hilari restitution values were somewhat higher in N and similar as regards the other macroelements when compared with a highland holm-oak wood located at a short distance in the Montseny range which was studied by Ferrés et al (1984) (N 35; K 22; P 4.3; Ca 48; Mg 5.9 kg.ha^{-1}.year^{-1}). *Q suber* restitution values were also comparable with those reported by Rapp (1971) for *Q ilex*, except for Ca which was higher in the holm-oaks growing in calcareous soils studied by this author.

CONCLUSION

We wish to emphasize the markedly Mediterranean character of the cork-oak forest, well-adapted to water-deficit situations and with a high internal control of a large number of nutrients, as belonging to the sclerophyllous Mediterranean systems

(Escarré et al, 1984). This high control capacity is shown by the similar nutrient content of leaves and twigs which indicates readiness in translocation, especially for N and P, and also by the occurrence of seasonal variations in the litterfall mineral content. In *Q suber*, leaves shed at the time of maximum fall have lower N and P content than those shed during the winter rest period. This fact suggests that the stock of elements in old leaves constitutes a reserve which can be mobilized in periods of rapid growth and recovered during rest periods. Micronutrients show a lower retranslocation rate and tend to accumulate over a period of time as has been shown for other species.

We will note that although the plots are small and there are structural differences between sites, the observed mineral contents and returns between them are relatively similar.

Another fact that we wish to emphasize is the similarity of different Mediterranean species of *Quercus* as regards the mineral concentrations in their litter components and total mineral return. Only Mn concentration, reaching nearly 2 000 mg. kg^{-1}, is a distinctive feature of *Q suber* in the Catalonian forests. The site fertility seems to exert a greater influence than the oak species.

In the area under study, characterized by weakly acid soils, it is worth investigating the importance of P as a possible limiting factor in cork-oak production.

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