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Influence of leaf litter type on the chemical evolution of a soil parent material (sandstone)

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Key words: *Eucalyptus, Quercus suber, Pinus pinaster*, leaf litter, decomposition rate, elemental fluxes, leaching, soil chemistry.

Abstract. The influence of leaves of *Quercus suber* L. and *Eucalyptus globulus* Labill. and needles of *Pinus pinaster* Ait. on a sandstone substrate was assessed through lysimetric studies during a ten-year period at a site in Central Portugal. The decomposition rate of *Q. suber* leaf litter was similar to that of *E. globulus* and higher than that of *P. pinaster* needle litter. The proportion of nitrogen released from the *Q. suber* leaf litter was higher than that lost from the other organic species. Such a release was proportional to the initial nitrogen content in the substrates. The concentrations of both NH_4-N and NO_3-N were much higher in leachates collected under *Q. suber* leaf litter than in those collected under the other organic substrates. A similar trend was found in the leachates collected under the mineral substrate influenced by the studied organic substrates. The leachate concentrations of mineral N (especially NO_3-N) were higher from the mineral substrate under *Q. suber* leaf litter than from this organic substrate itself. The mineral substrate under leaf litter of *E. globulus* or needle litter of *P. pinaster* showed an increase in exchangeable base cations and pH values, and a decrease in extractable Al. Conversely, in the substrate with *Q. suber* leaf litter there was only a slight increase in exchangeable base cations and pH values, and a decrease in extractable Al. These results combined with those obtained in soils under *E. globulus* plantations indicate that changes found in these soils are due to soil and forest management practices rather than to the decomposition process of the respective of leaf litter.

Introduction

Much marginal agricultural land in Portugal has been replaced by *Eucalyptus globulus* Labill. plantations during the last few decades. These plantations have been intensively exploited as coppiced stands and are often blamed for negative effects on soils, e.g. decreasing base cation concentrations and pH values, increasing exchangeable Al (Lozano & Velasco 1981; Florence 1986). Within this context, the soils of such plantations have been compared to those occurring under other major tree species in Portugal, i.e. *Quercus suber* L. and *Pinus pinaster* Ait. (Madeira 1986 and 1989).

Plant cover type influences the properties and evolution of soils (Jenny 1941). Differences in the flux of nutrient elements in the soil-plant system, as well as in the weathering intensity of primary minerals, have been found to be related to the forest cover type (Védy 1973; Robert & Berthelin 1986; Leyval 1988). The effects of tree species on soil characteristics should be related to their biomass characteristics as well as to their leaf litter characteristics and respective decomposition process (Mangenot & Toutain 1980; Alban 1982; Van Miegroet & Cole 1984). However, it is often difficult to separate the specific effects of tree species from the influence of site conditions and management practices, e.g. type and intensity of soil preparation, harvesting techniques and level of biomass removal (Wells & Jorgensen 1979; Florence 1986; Attiwill & Leeper 1987; Madeira 1989). Therefore, the effects of these management practices should be separately studied from the effects related to the plant cover characteristics.

Following the principles mentioned above, experiments isolating the litter effects from overall ecosystem effects were performed to assess the influence of leaf litter of *E. globulus* as compared to that of *Q. suber* and *P. pinaster* on the evolution of a mineral substrate. Two independent lysimetric experiments were carried out to follow the decomposition of leaf litter and its influence on the characteristics of a sandstone, and to follow the characteristics of leachates released from each litter type. Besides the litter decomposition process, special emphasis was given to the evolution of: pH values, concentration of exchangeable Al and base cations, and carbon and nitrogen in the mineral susbtrate. This paper deals with results obtained during a period of ten years. Results related to the first two years of experiment were published elsewhere (Madeira 1986 and 1989).

Materials and methods

The experiments were carried out in central Portugal (39°15′ N, 9°01′ W) in an area located at 85 m elevation and 25 km from the ocean. The mean annual temperature and rainfall, during the experimental period, were 15.5 °C and 789 mm, respectively. The maximum temperature (around 21 °C) occurred in July while January was the coldest month (9.7 °C). The annual rainfall ranged from about 550 to 1250 mm; approximately 75% of rainfall occurred between November and April. The native forest community is dominated by *Q. suber* associated with herbaceous and shrub understorey. The soils are Dystric Cambisols (FAO/UNESCO, 1985) and their parent material is derived from sandstones, occurring in a transition of Cretaceous and Jurassic beds. The soils usually show an Ah horizon above 20-cm depth, a Bw horizon extending to 40–45 cm and a C horizon extending to 70–90 cm. The main characteristics of the soils are shown in the Table 1 (Madeira 1989).

Table 1. Characteristics of soils of the area where the experiments were carried out and of the mineral substrate used in the lysimetric experiments.

Depth (cm)	Particle size distribution sand	silt	clay	Organic C	pH (H_2O)	Extractable Ca	Mg	Al.	ECEC(a)
	g kg^{-1}					cmol (+) kg^{-1}			
Soil									
0–20	672	137	129	17.7	51.	1.15	0.57	0.97	2.82
20–40	698	123	126	5.6	5.2	0.36	0.28	1.02	1.73
40–70	681	118	140	1.9	5.0	0.31	0.38	1.05	1.83
Mineral substrate									
110–120	770	121	99	0.9	5.5	0.27	0.36	0.57	1.38

(a) ECEC: effective cationic exchange capacity.

The experiments were installed in a opening with an area with *Q. suber* and *E. globulus* stands. A first experiment, consisting of a total of 47 PVC cylinders, each 30 cm in diameter and 80 cm height, was performed to evaluate the influence of different leaf litter types on the evolution of sandstone, similar to that occurring in the *E. globulus* and *Q. suber* stands of the neighbourhood. The mineral substrate (sandstone) was collected at a depth 110–120 cm using a digging machine. The layers above that depth were removed to avoid the presence of root fragments and other organic materials. The sandstone was disaggregated, homogeneized, forced to pass through a 5-mm sieve and homogeneized again. The cylinders, exposed to natural weather conditions during the experimental period, were placed over a gravel layer and a sandy layer to avoid rooting ingrowth and to allow drainage. The cylinders were buried down to 60-cm depth to avoid the entering of mineral particles and the removal of litter by the wind.

Fifty five kg of sandstone were introduced in each cylinder, corresponding to a column of 60-cm depth and with bulk density of 1.3 Mg m^{-3}. The characteristics of the mineral substrate, as determined by methods described below, are shown in the Table 1. A set of fourteen cylinders was used for each type of leaf litter: leaves of *E. globulus* and *Q. suber*, and needles of *P. pinaster*. A set of five cylinders without any exogenous organic material was also installed as a control. In October 1982, 328 g (85 °C dry weight) of each litter type were placed on the top of the mineral substrate of each cylinder. The amounts added in October 83, 84, 85, 86 and 87 were, respectively, 308, 200, 180, 180, and 100 g. The main characteristics of the litter substrates, determined by methods described below, are shown in the Table 2.

Table 2. Characteristics of leaf litter of *Q. suber* (Qs) and *E. globulus* (Eg), and needle litter of *P. pinaster* (Pp) used in the lysimetric experiments.

Litter type	C	N	Ca	Mg	K	P	Water soluble	Ethanol soluble	Lignin
	------	------	------	------	mg g^{-1} dry weight	------	------	------	------
Qs	510	21.2	5.6	1.8	2.9	0.47	181	183	317
Eg	537	10.4	20.8	1.8	2.3	0.32	179	306	216
Pp	552	4.1	7.2	2.3	0.9	0.19	130	160	295

A parallel experiment was carried out to study the concentration of carbon, nitrogen (both organic and mineral) and other mineral elements in the effluents (leaching solutions or leachates) from each litter type. For this purpose, the litter substrates were placed in cylinders each 10 cm in diameter and 45 cm in height, with 3.45 kg of commercial washed sand. To each cylinder, 43.62 g of leaf litter (85 °C dry weight) were added in October 83. The amounts added in October 84, 85, 86 and 87 were, respectively, 30.4, 20.1, 20.0, and 20.0 g. Data were obtained from October 83 to May 85 and from October 87 to May 88. The experiment consisted of four cylinders for each litter type, and four cylinders without exogenous organic material (control). Similar sets of cylinders filled with sandstone (particle size<0.5 mm) were used to assess the effect of the sandstone on the characteristics of the leachates released from each litter type, and at the same time to understand the evolution of leachate characteristics under the leaf litter substrates. The cylinders were placed in a opening without any rain protection. They were buried down to 35-cm depth, i.e. 10 cm remaining above ground level. Each cylinder was placed over a plastic funnel filled with commercial washed sand connected, through a plastic tube, to a plastic bottle for collection of natural drainage solutions. The collector bottles were protected (with black plastic) against light, and contained chloroform to stabilize the solutions and to avoid microbial growth.

Decomposition of leaf litter was measured for two years, whereas changes in the mineral substrate were assessed over ten years. From October 82 to November 84 one cylinder with each type of litter was sampled each three months. Additional samples were taken in October 85, November 86, November 87 (three replicates) and November 92. The cylinders without exogenous organic material were only sampled in November 84, 87 and 92. The organic substrates were dried (85 °C) and weighed to assess the respective decay constant, estimated from a single exponential model (Olsen 1963). Subsamples of the substrates of each sampling were ground in a laboratory mill to a particle size < 1 mm for chemical analysis of their concentration of C, N, P, Ca, Mg and K. The determination of hot water and ethanol extractives followed Tappi standard methods. The determination of lignin was made using a standard acid hydrolysis on the extractive free material. The mineral elements in the organic substrates were determined after ashing (6 hr at 450 °C) and taken up in HCl.

The volume of the mineral substrate was divided into the 0–5, 5–15, 15–25, 25–35, 35–45 and 45–55 cm layers. Whole mineral samples were air dried and forced through a 2-mm sieve prior to chemical analysis. The pH was measured in a 1:2.5 soil water suspension using a glass electrode with a calomel reference electrode. Organic carbon content of both mineral and organic substrates was determined by wet oxidation (De Leenher & Van Hove 1958). The content of C in the mineral substrate corresponding to the humified organic matter fraction was obtained according to Bruckert (1979). Kjeldahl N of the substrates was determined using a Digestion System Kjeltec Auto 1030 Analyser. The base cations in the mineral substrate were extracted by 1M ammonium acetate (NH_4OAc) adjusted to pH 7.0, shaken for 1 hr in a 1:10 soil extraction reagent suspension, followed by centrifugation. The extractable Al was determined after a one-hour extraction with 1M KCl (soil solution ratio 1:10).

Leachates from lysimeters were collected according to the occurrence of precipitation. Samples were measured immediately after collection of pH (as indicated above), filtered through a 0.45-μm Nucleopore policarbonate filter and refrigerated at 3–4 °C throughout completion of analysis. Concentration of NH_4^+-N and NO_3^--N was determined by the methods described, respectively, by Dorich & Nelson (1982) and Bremmer (1965).

The Ca, Mg, K and Al of the extracts and solutions were quantified by atomic absorption spectroscopy. The P was quantified by the ascorbic acid method (Watanabe & Olsen 1965).

The amount of N and other elements retained in the mineral substrate influenced by the organic substrates were calculated by difference in respect to the control. The amount of N and cations leached from mineral substrate was obtained by difference between the total amount applied in litter and the amounts retained in the remaining litter and in the mineral substrate. The amount of N input from the atmosphere was certainly less than 2% of the respective amount in the needle litter of *P. pinaster* added during the experimental period to each cylinder (Nuno Cortez, unpublished data).

Data for chemical properties of the mineral substrate under the organic substrates, after five years of experiment, and the concentrations of NH_4^+-N, NO_3^--N and other ions in leachates, collected during 1987/88, were compared

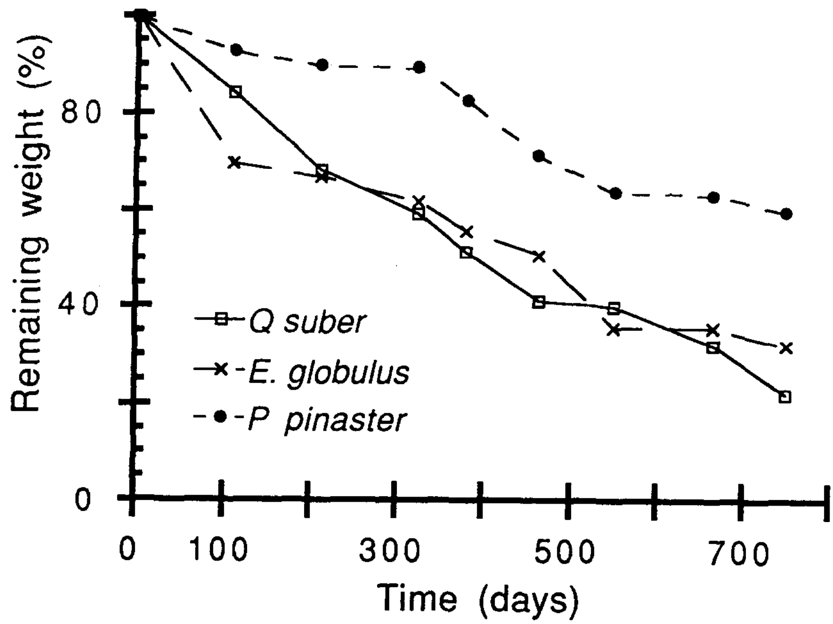

Fig. 1. Remaining weight of litter from *Q. suber, E. globulus* and *P. pinaster* for two year period of experiment.

using analysis of variance and Duncan's new multiple range test for mean separation analysis.

Results

The decomposition of needles from *P. pinaster* (Pp) was slower than that of leaves from *E. globulus* (Eg) and *Q. suber* (Qs) (Fig. 1). Leaves from Qs and from Eg showed similar patterns of decomposition during the two-year experiment period. The annual decay constant, based on data of two years, was 0.27 for needles of Pp and 0.52 and 0.62 for the leaves of Eg and Qs, respectively. Mass remaining at the end of the two years was about 61, 33 and 22% of the original for litter of Pp, Eg and Qs, respectively (Fig. 1). During the first three months of the experiment the leaf litter of Eg decomposed faster than that of Qs (see Fig. 1).

The net release of N, during the first two-year period of the experiment, was higher from the Qs (66%) than from the Eg (45%) leaf litter (Fig. 2a). On the other hand the amount of N in the needle litter (Pp) was slightly higher at the end of the first (102%) and the second (107%) year than at the beginning of the experiment.

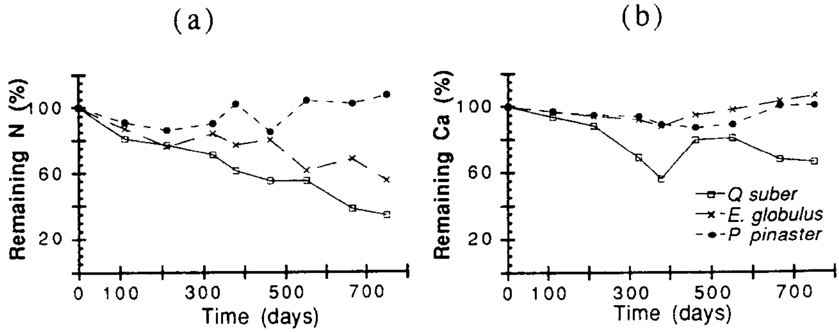

Fig. 2. Proportion of nitrogen (a) and calcium (b) remaining in decomposing litter of *Q. suber, E. globulus* and *P. pinaster.*

A net release of Ca (44%) took place from the Qs leaf litter until the end of the first year of the experiment. This release was much lower from the Eg (15%) and Pp (12%) substrates (Fig. 2b). All of the studied substrates showed an increase in the Ca amount at the end of the second year of experiment due to the new leaf litter added to the lysimeters. However, the amount retained in the Qs substrate was lower than in the others.

The concentration of both NH_4^+-N and NO_3^--N in the leachates from the Qs substrate was significantly higher than in the leachates from the Eg and Pp substrates (Fig. 3). In the leachates from Qs leaf litter, the concentration of NH_4^+-N tended to be higher than that of NO_3^--N. Very low concentration of NH_4^+-N (0.03–0.41 mg l^{-1}) and NO_3^--N (0.10–0.23 mg l^{-1}) were seen in the leachates from the Pp needle litter (Fig. 3).

The concentration of NO_3^--N (6.2–48.3 mg l^{-1}) in leachates collected under the mineral substrate with Qs leaf litter was higher than that determined in the leachates released from the Qs leaf litter itself (2.6–5.5 mg l^{-1}) (Fig. 3). This concentration was higher than that of NH_4^+-N (3.7–5.9 mg l^{-1}). The concentration of NO_3^--N was particularly high in autumn 87 (Fig. 3). Such a pattern was similar to that found during the first two years of the experiment (1983/85) (Madeira 1986). The concentrations of both NH_4^+-N and NO_3^--N in the leachates from lysimeters with Eg and Pp substrates were significantly lower compared to those in the leachates from lysimeters with Qs leaves (Fig. 3).

The pH values of leachates from Qs leaf litter and from sandstone with this letter ranged between 4.3 and 4.8. These values ranged between 6.1 and 7.0 for Pp needle litter and between 7.2 and 7.6 for Eg leaf litter (data not shown).

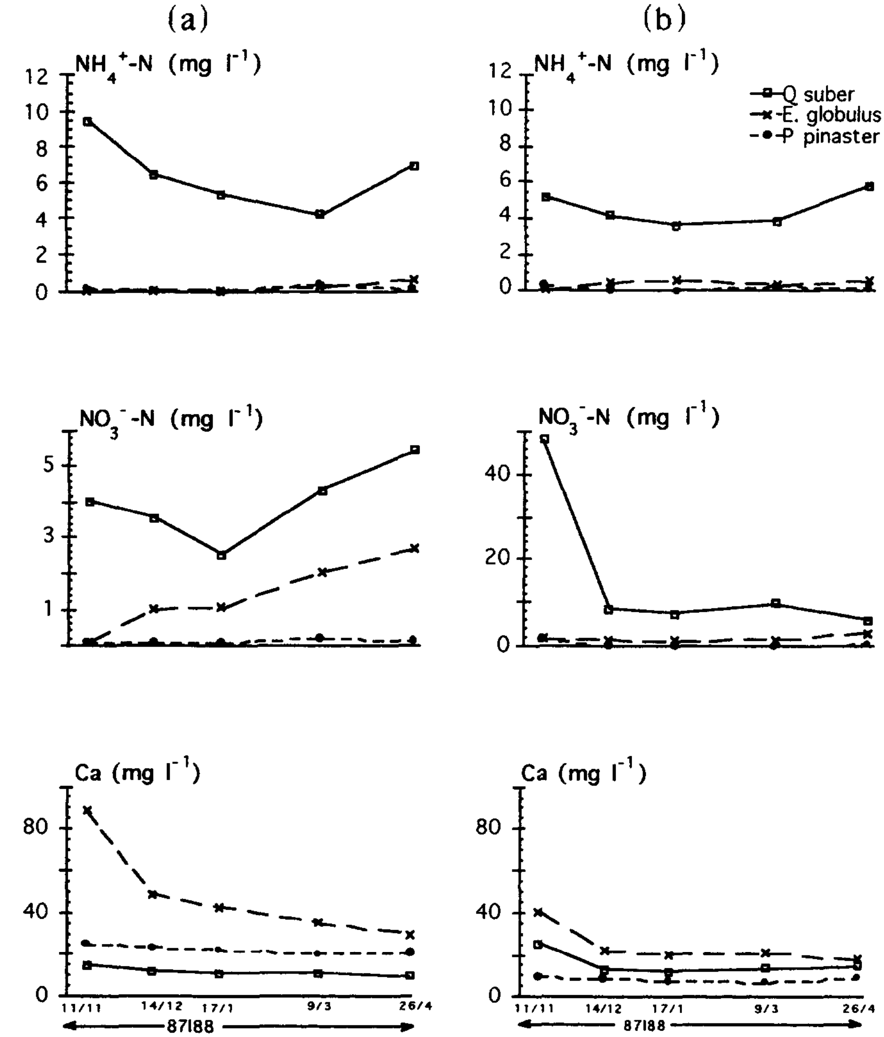

Fig. 3. Concentration of NH_4-N, NO_3-N and Ca in (a) leachates from leaf litter of *Q. suber* and *E. globulus*, and needle litter of *P. pinaster*, and in (b) leachates from the mineral substrate under these organic substrates. The concentration of NH_4-N, NO_3-N in leachates from *Q. suber* differed significantly from the others ($P < 0.05$). Concentrations of Ca always differed significantly ($P < 0.05$) between leachates from the organic substrates themselves, and most of the times between leachates from mineral substrates with litter. Note scale differences on y axes.

The concentration of Ca in the leachates released from the Qs litter itself was significantly lower than that determined in the leachates from the other substrates (Eg and Pp). The concentration in the leachates from Eg substrate

Table 3. Carbon and nitrogen concentrations corresponding to the total and the humified organic matter in the mineral substrate influenced by leaf litter of *Q. suber* (Qs) and *E. globulus* (Eg), and needle litter of *P. pinaster* (Pp) after ten years.

Depth	Qs				Eg				Pp			
cm	Ct	Ch	Nt	Nh	Ct	Ch	Nt	Nh	Ct	Ch	Nt	Nh
	$g\ kg^{-1}$											
0–5	6.0	3.1	0.43	0.27	5.2	2.2	0.34	0.19	7.7	4.1	0.35	0.24
5–15	2.0	1.5	0.20	0.17	1.7	1.2	0.17	0.13	1.7	1.3	0.14	0.12
15–25	1.0	1.0	0.14	0.14	1.2	1.2	0.13	0.13	1.2	1.2	0.12	0.12
25–35	1.0	1.0	0.14	0.14	1.1	1.1	0.12	0.12	0.9	0.9	0.12	0.12

Ct and Ch, and Nt and Nh – carbon and nitrogen corresponding, respectively, to total and humified organic matter.

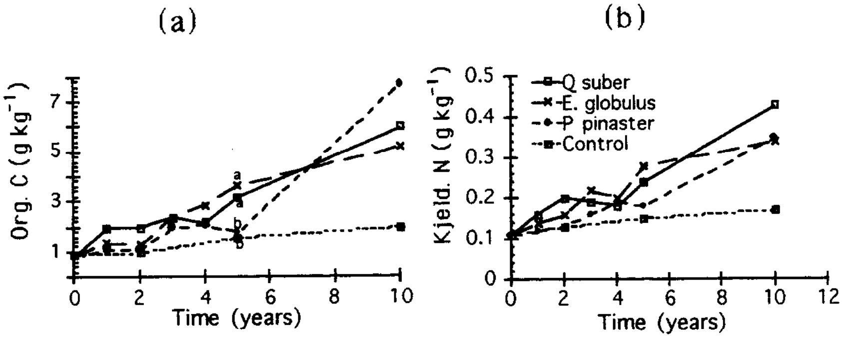

Fig. 4. Content of (a) organic carbon and (b) Kjeldahl N in the 0–5 cm layer of the experimental mineral substrate under leaf litter of *Q. suber* and *E. globulus*, and needle litter of *P. pinaster* along the experiment period. Data with different letters differed significantly ($P < 0.05$) after five years of experiment.

was highest in autumn 87, as was found in 1983/85 (Madeira 1986), and was significantly higher in comparison to that in the leachates from Pp substrate (Fig. 3). The leachates collected in lysimeters with sandstone and Qs leaves showed a higher concentration of Ca than in leachates released from Qs leaves themselves. An opposite trend was found in leachates from lysimeters with sandstone and Eg or Pp substrates (Fig. 3). A similar pattern was found for the magnesium and potassium (data not shown).

The carbon concentration increased similarly in the 0–5 cm layer of the sandstone under the Qs and Eg leaf litter (Fig. 4). After ten years, the highest concentration (7.7 g kg $^{-1}$) was determined in the sandstone under the Pp needle litter. The incorporation of organic carbon was only significant above

Table 4. Amounts of nitrogen and calcium in the litter introduced in the lysimeters, and retained in remaining litter, retained in the mineral substrate and leached after ten years.

Amount	Qs		Eg		Pp	
	N	Ca	N	Ca	N	Ca
	g					
Experiment litter	27.48	7.21	13.48	26.98	5.31	9.36
Remaining litter	2.08	1.04	1.64	4.76	1.92	2.30
Mineral substrate	2.75	0.28	1.60	5.96	1.19	1.85
Leached	22.65	5.89	10.24	16.26	2.20	5.21

Qs and Eg, and Pp – leaf litter of *Q. suber* (Qs) and *E. globulus* (Eg.), and needle litter of *P. pinaster* (Pp), respectively.

15-cm depth (Fig. 4). The incorporation of nitrogen followed a pattern similar to that of carbon and was highest in the sandstone under Qs leaf litter (see Fig. 4 and Table 3). The proportion of carbon as humified organic matter, in respect to the total, was 52–53% in the sandstone with Qs and Pp organic substrates and only 42% in the sandstone with Eg leaf litter (see Table 3). The C/N ratio values of both total and humified organic matter were similar in the sandstone under Qs and Eg leaf litter, and were somewhat higher in that under the Pp needle litter.

Changes in chemical characteristics of the mineral substrate occurred especially in the top layer (0–5 cm) and were mainly noticed after the end of the first year, particularly under Eg leaf litter. Organic substrates of both Eg and Pp induced an increase in exchangeable Ca and pH values, and a decrease in extractable Al, when compared with the control (Fig. 5). However such changes were more pronounced in the mineral substrate under Eg leaf litter. In contrast, Qs leaf litter induced decreased pH values and increased extractable Al. In addition, exchangeable Ca concentration was not significantly different from that found in the control (Fig. 5). Exchangeable Mg showed similar trends to those found for Ca (data not shown).

Relative to the control, exchangeable Ca and pH values increased and extractable Al decreased in the mineral substrate under Eg leaf litter, down to the 55-cm depth (Fig. 5). Such a pattern was only noticed to the 35-cm depth in the substrate under Pp needle litter. On the other hand, Qs leaf litter induced a decrease in pH values and an increase in extractable Al down to a depth of 55 cm. The pattern of the concentration of exchangeable Ca was similar to that found for the control.

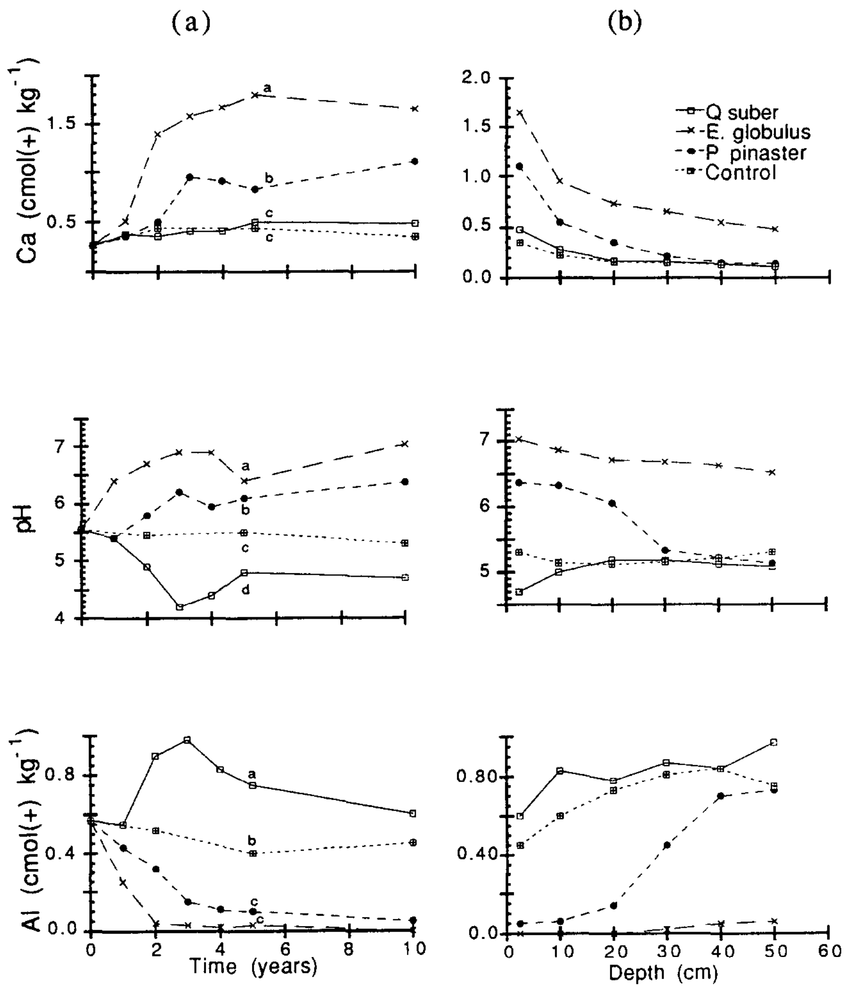

Fig. 5. Exchangeable Ca, pH values and extractable Al in the (a) 0–5 cm layer of the experimental mineral substrate influenced by litter of *Q. suber, E. globulus* and *P. pinaster* along the experiment period, and (b) according to depth after ten years. Data with different letters differed significantly ($P < 0.05$) after five years of experiment.

The highest proportion of nitrogen remaining in litter, after ten years, was found in the Pp needle litter (36%) and the lowest in the Qs leaf litter (8%). A very low amount of calcium (0.28 g) remained in the mineral substrate under Qs leaf litter, constituting a very low proportion (3.9%) of the total added. The highest amount of leached nitrogen was found in lysimeters with Qs leaf litter. This amount was about 2 times higher than that measured from lysimeters with Eg leaf litter and 10 times higher than from those with Pp needle litter (Table 4).

Discussion

The higher resistance of needle litter of *P. pinaster* to decomposition compared to leaf litter of *Q. suber* and *E. globulus* agrees well with other comparisons of coniferous and hardwood litter decomposition trends (Mangenot & Toutain 1980; Edmonds 1980; Harmon et al. 1990). The low decay rate showed by needles of *P. pinaster* may be related to their low content in nitrogen and phosphorous, and the high initial lignin:nitrogen ratio (see Table 2). For a given site and climate, it has been reported that the early stages of litter decomposition are hindered by low concentrations of nitrogen and phosphorous (Berg & Ekbohm 1991; McClaugherty et al. 1987), and by a high initial lignin:nitrogen ratio. However, the leaf litter of *E. globulus*, despite its lower nitrogen and phosphorous contents, decomposed faster than that of *Q. suber* at early litter decay stages (Madeira 1986). Rapid initial loss of weight has been reported for decomposing leaf litter of several *Eucalyptus* species (Birk 1979). The retarded decay *Q. suber* litter may be related to the combination of high lignin and high nitrogen content as referred by Harmon et al. (1990).

The N concentration increased in decomposing leaf litter of *E. globulus* and needle litter of *P pinaster* (see Fig. 1 and Fig. 2), particularly in the latter, as has been documented for needles of several coniferous species (Berg 1986; Berg & Lundmark 1987). Such an increase, which was negligible for the leaf litter of *Q. suber*, was approximately proportional to the initial nitrogen concentration in litter (see Table 2). Other authors have also reported that the mineralization and loss of nitrogen from decomposing organic substrates decreases with a decrease in their nitrogen content or the increase in their C/N ratio (Edmonds, 1980; Mangenot & Toutain 1980). The concentration of mineral nitrogen in the leachates released from the studied organic substrates agrees well with such a trend, i.e. was highest in those from the litter with the lowest C/N ratio (*Q. suber*) and lowest in those from the litter with the highest C/N ratio (*P. pinaster*) (see Table 2 and Fig. 3).

High rates of nitrogen mineralization and nitrification are considered to be a source of acidification (Berthelin et al. 1985; Ulrich 1991). In fact, the low pH values of leachates influenced by leaf litter of *Q. suber*, as compared to those influenced by leaf litter of *E. globulus* and needle litter of *P. pinaster*, may be related to that much higher concentrations of NO_3^--N in leachates from *Q. suber* leaf litter (see Fig. 3). Differences found among substrates compare well with data from other authors who reported much higher concentration of NO_3^--N and more acidity in leachates from soils under tree species or substrates rich in nitrogen (Montagnini et al. 1991; Van Miegroet & Cole 1984; Wedraogo et al. 1993). High concentrations of NO_3^--N in leachates, coinciding with increasing in acidity, should be parallel with a strong leaching of bases (Haynes 1983; Vitousek 1984). Such a tendency was found in the mineral substrate under *Q. suber* leaf litter, where there was a net efflux of base cations (especially Ca), i.e. the concentration of Ca was higher in leachates from mineral substrates with leaf litter of *Q. suber* than in those from the leaf litter itself (see Fig. 3). Thus, the high nitrification rate was followed by nitrate leaching accompanied by base cations leading to the very low amount of Ca retained in the mineral substrate with *Q. suber* leaf litter, after ten years, in comparison with the others (see Table 4). In the mineral substrate with needle litter of *P. pinaster*, the very low N-mineralization rate and the low leaching of nitrate did not prevent a net sorption of base cations, i.e. the increase of the portion of the cation exchange capacity (CEC) occupied by base cations. The highest sorption of base cations in the mineral substrate with *E. globulus* leaf litter may result from the very high amount of Ca released from this litter, in comparison with the others, during the experiment period. Moreover, as CEC also increases with pH values, the high pH values in mineral substrate with *E. globulus* leaf litter may have favoured a higher sorption of base cations.

The increase of organic matter in the mineral substrate, after ten years, was low and mostly localized in the top 0–5 cm layer, in spite of the high amounts of litter added. On the other hand, in experimental *E. globulus* plantations a rapid increase of carbon content in the top soil layer and at depth was found thirty months after planting (Madeira & Pereira 1990/1991). Such an increase, which was mostly due to the amount and distribution of the root mass, suggests that the effect of leaf litter on the soil organic matter formation and incorporation is a slow process in comparison to that of root litter. The similarity in the C/N ratio values of the humified organic matter of the mineral substrate, with leaf litter of *Q. suber* and leaf litter of *E. globulus*, correlates well with the similarity found for the humic acids of soils of the respective plantations (Madeira 1986).

The leaf litter of *Q. suber* induced acidification in the mineral substrate. Such a tendency, however, was not found in the *Q. suber* stands in central Portugal (Madeira 1986 and 1989). The experimental conditions, which included large amounts of added litter and the lack of nutrient and water uptake (because plants were not present in the lysimeters), did not counteract the leaching of NO_3^--N and the associated cation leaching as has been documented in soils after clear cutting (Schlesinger 1991; Bormann & Likens 1979). Such conditions for acidification may be, however, hindered in *Q. suber* stands due to the uptake of nutrients by trees and accompanied understorey vegetation and the low level of biomass removal (Madeira 1986). Data shown here indicate that either leaf litter of *E. globulus* or needle litter of *P. pinaster* promote an increase in sorption of exchangeable base cations in the mineral substrate which was parallel with an increase of pH values and a decrease in exchangeable Al. However, the experimental results obtained are the opposite of those from soils of forest plantations, especially those of *E. globulus* (Florence 1986; Madeira 1986 and 1989). In fact, it has been documented that *E. globulus* plantations can induce a decrease in exchangeable bases (especially Ca) and an increase in extractable Al, thus increasing soil acidity as compared with soils of *Q. suber* stands (Madeira 1986 and 1989). According to our experimental data, such effects cannot be interpreted as due to the characteristic and decomposition process of litter, but to the forest management practices. In fact, shorter forest rotations and intensive biomass utilization, through accelerated nutrient immobilization and removal, may decrease the content of nutrients (especially Ca) in the soil (Wells & Jorgensen 1979; Florence 1986; Attiwill & Leeper 1987; Madeira 1989; Hopmans et al. 1993). As Ca usually occupies a high proportion of the soil exchange sites, a strong decrease in its content can promote accentuated decreases and increases in, respectively, pH values and exchangeable Al (Lozano & Velasco 1981; Madeira 1986 and 1989). The high immobilization of Ca in the biomass of *Eucalyptus* species indicates the importance of forest management practices in such plantations (Madeira 1986 and 1989; Attiwill & Leeper 1987; Hopmans et al. 1993). Additionally, intensive soil preparation, through intensive organic matter mineralization, can significantly contribute to the decrease of the amount of base cations (especially Ca) in soil (Madeira et al. 1989).

The described experiment, isolating litter effects on soil from overall ecosystem effects, made possible to study the influence of the nature of forest litter itself on soil processes and allowed a deeper understanding on the importance of management practices on the soil processes in forest ecosystems.

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