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LEAF DECOMPOSITION AND NUTRIENT RELEASE IN MONTANE FORESTS OF NORTHWESTERN ARGENTINA

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ACEÑOLAZA, P. G. & GALLARDO LANCHO, J. F. 1999. **Leaf decomposition and nutrient release in montane forests of northwestern Argentina.** This study aimed to gain further insight into the leaf decomposition dynamics in *Alnus acuminata* forests through their nutrient release patterns. Three forests of different ages in San Javier mountains (Tucumán, NW Argentine) were selected in order to know the evolution of the nutrient release process using the litterbag method in a forest chronosequence. Decomposing leaf P and K contents decreased rapidly, whereas Cu, Fe and Zn tended to increase over time. The sequence of element loss during decomposition was in the following order: K > P > Na > N > Ca > Mg. Only Ca, Cu, Fe and Mn showed statistical differences according to stand ages.

Key words: Forest ecosystems - leaf decomposition - *Alnus acuminata* - subtropical forest - bioelement cycles

ACEÑOLAZA, P. G. & GALLARDO LANCHO, J. F. 1999. **Penguraian daun dan pembebasan nutrien di hutan gunung di barat laut Argentina.** Kajian ini bertujuan untuk memahami dengan lebih mendalam mengenai dinamik penguraian daun di hutan *Alnus acuminata* melalui pola pembebasan nutrien. Tiga hutan yang berbeza umurnya di pergunungan San Javier (Tucuman, Argentina BL) dipilih untuk mengetahui evolusi pembebasan nutrien menggunakan kaedah beg sarap dalam kronourutan hutan. Kandungan P dan K daun yang diuraikan hilang dengan cepat sekali, manakala Cu, Fe dan Zn pula semakin bertambah. Turutan unsur kehilangan semasa penguraian ialah mengikut susunan berikut: K>P>Na>N>Ca>Mg. Hanya Ca, Cu, Fe, dan Mn menunjukkan perbezaan statistik mengikut umur dirian.

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Introduction

The decomposition process of organic matter is important because it affects structural and functional aspects of terrestrial ecosystems (Gallardo & Merino 1993). The supply and distribution of organic matter, and the consequent litter nutrient content return are important aspects of the dynamics of ecosystems, the rate of nutrient release being fundamental to the way in which this occurs (Blair 1988). Following plant death, retained elements return to the soil through mineralisation, and then (unless they disappear due to leaching and/or volatilisation) become available again for use in the system (Martín *et al.* 1997). The pattern of decomposition and the ensuing nutrient release are therefore an important determinant for the overall functioning of the ecosystem.

Many factors affect the mineralisation of organic matter such as the nature of the organic matter, the initial mineral composition, the lignin content (Berg & Staaf 1980, Melillo *et al.* 1982, Granhall & Slapokas 1984, Dyer *et al.* 1990), macro- and micro-climatic variables (Swift *et al.* 1979), forest age (Edmonds 1979, Berg & Staaf 1980, Sharma & Ambasht 1987), and soil biotic activity (Swift *et al.* 1979), which is in turn a result of the other factors.

Alnus acuminata ssp. *acuminata* (Andean alder) is a species native to South America. It is very common on the humid eastern side of the Andean Cordillera, from Venezuela to northwestern Argentina (Furlow 1979). In the Province of Tucumán there are alder forests on the humid hillsides between 1400 and 2700 m above sea-level (Aceñolaza 1995). The species is a fast-growing, nitrogen fixer (Rodríguez Barrueco 1966) that often colonises bare soils.

Many comparative studies about litter decomposition have been conducted throughout the world with either a single species in multiple location or among different species in a single location (Martín *et al.* 1994). However, the relationship between decomposition rate and nutrient release in forest sites with different ages has received comparatively little attention (Edmonds 1979, Berg & Staaf 1980, Sharma & Ambasht 1987). Crews *et al.* (1995) stated (in a chronosequence of rain forest in Hawaii) that the factors which regulate N availability to biota control the productivity in early soil development, whereas late in soil development the factors which regulated P availability are what control that same productivity.

In the present study our aim was to gain insight into nutrient release patterns in a sequence of *A. acuminata* forests of different ages representing three sere stages. The purpose of this selection was to learn the evolution of the nutrient release process during the leaf decomposition in a forest chronosequence. The initial hypothesis is that forest age would influence nutrient release rates. In this sense, Aceñolaza *et al.* (1995) observed in an old alder forest that the soil acidification produced by the oxidation of ammonia caused a decrease in the decomposition rate of the litter in these forests.

Materials and methods

Study site

This research was carried out in alder forests of different ages at the *Parque Biológico Sierra de San Javier*, which is a protected area and belongs to Tucumán National University in northwestern Argentina. Climate is temperate and humid (mesothermic humid), average annual rainfall is 1552 litre $m^{-2} y^{-1}$ and is monsoon-like (concentrated mostly during the summer). Mean annual temperature is 14.2 °C (Aceñolaza 1995).

Most soils at this reserve are poorly developed due to the steepness of the slope (ranging from 20 to 25 %), and are classified as Entisols (Soil Survey Staff 1990) on Tertiary and Quaternary sediments overlying a metamorphic basement. The mean altitude of the forests studied is 1600 m a.s.l., and they generally face eastward.

Three neighbouring forests with similar geographical conditions were selected: a) 'young', 5–10 y old; b) 'mature', 25–25 y old; and c) 'old', 40–45 y old. The soils present at this site are more developed than those on hillsides because they are at the top of the mountain; they have an argilic (illuvial) horizon; thus, the soils are classified as Udalfs (Soil Survey Staff 1990). They are acidic soils, unsaturated in bases, with a texture ranging from loam to clay (Aceñolaza 1995).

Analytical methodology

To follow leaf decomposition, litter bags were filled with 10 g of falling alder mature leaves (fresh weight, known moisture content). This method has been successfully used by other researchers (Bocock *et al.* 1960, Edmonds 1979, Wieder & Lang 1982, Sharma & Ambasht 1987, Martín *et al.* 1997). The 18 × 15 cm^2 bags were made out of 1-mm-mesh nylon netting. Fifty bags were placed under trees in each of the forests and an effort was made to ensure that they would all be under similar ecological conditions. Over a two-year period five randomly-chosen bags per time period were removed (from April 1991 until April 1993) at 0, 2, 6, 14, 30, 62, 254, and 715 days from the beginning of experiments.

At the laboratory, residual material was dried at 70 °C for 48 h and weighed. Ashing was made by calcination up to 500 °C in three steps: first 0–120 °C, second 120–250 °C, and third 250–500 °C.

Two samples, from each time period, were chemically analysed. Laboratory analyses were done (in duplicate) according to Martín *et al.* (1995) for the quantitative determination of ten elements: total C, N, P, Ca, Mg, Na, K, Fe, Cu, and Zn. C was determined on a Carmhograph Wösthoff; N with the Kjedahl's method using a Bouat-Afora device; P was determined by colorimetry, using the vanadate-molybdate method; Ca, Mg, Fe, Cu and Zn were determined with a Varian AA1475 atomic absorption spectrophotometer (Martín *et al.* 1994); Na and K were determined by flame photometry (Martin *et al.* 1995).

The presented values correspond to the mean of two determinations.

Results

Since the dynamics of dry weight loss has been discussed elsewhere (Aceñolaza & Gallardo Lancho 1995), in the present work this aspect was not further addressed.

Table 1 and Figures 1 to 3 show the data on the release of leaf-retained elements. The initial chemical composition of the leaves was similar for all three age groups with regards to macronutrients (Table 1). However, important differences were found for micronutrients; the young forest had the highest concentrations of Fe, Cu, and Zn, probably owing to the higher extraction capacity of the younger alders (Aceñolaza & Gallardo Lancho 1995).

Initial C, N, and Mg contents and C/N ratio (Table I) remained almost invariable for different aged forests. A reduction was observed in K, Fe, Cu, and Zn initial concentration values for the forest temporal sequence.

Alnus acuminata is a N-fixing species, which explains the high initial N and low C/N values (Duchaufour 1984). N concentrations remained constant or increased slightly during decomposition.

Over two years of decomposition, concentrations in C and N remained more or less constant, but with an increase of C in the mature forest (22%). Absolute N content decreased in all the forests studied (Figure 1b) with highly significant statistical difference ($p < 0.001$). No significant differences were found between forest ages. No differences were found for C/N ratios related to time or to stand age (Table I).

Both the concentration (Table 1) and content (Figure 1c) of P decreased significantly during the first two of months ($p < 0.001$), but there were no significant differences according to forest age.

Ca contents tended to remain constant or to increase slightly during decomposition (Table I and Figure 2a). The concentration of Mg remained fairly constant, whereas the content of this element decreased ($p < 0.005$) slightly (Figure 2b). Concentrations and contents (Table 1 and Figure 2c) of K decreased significantly ($p<0.001$) during the first two months (similar to P); no differences were found according to forest ages.

Absolute Na contents remained fairly constant (Figure 3a) but followed an irregular behaviour pattern. No differences were found for time or according to forest ages.

The concentrations of Fe, Zn, and Cu tended to increase during decomposition (Table 1). Fe showed the greatest percentages of increase (Figure 3b) in all three forests at the end of the first year ($p < 0.001$), and also showed significant differences according to forest ages ($p < 0.005$). The concentrations of Zn underwent variable increases, reaching 500% for the old forest, but no statistical differences were found, not even for forest age. Cu increased by 15% in the old forest after the first two months, but this did not represent statistical differences; in the young forest, the levels of this element tended to remain constant, so differences between forest ages were found ($p < 0.001$).

Table 1. Dry weight (g; s.d. standard deviation; n = 5), leaf chemical composition (concentration, mean of 2 determinations) and time (days) at different studied forests

Time (days)	Age (y)	Dry weight g (± s.d.)	C ($g\ g^{1}$)	N ($mg\ g^{1}$)	C/N	P ($mg\ g^{1}$)	Ca ($mg\ g^{1}$)	Mg ($mg\ g^{1}$)	K ($mg\ g^{1}$)	Na ($mg\ kg^{1}$)	Fe ($mg\ kg^{1}$)	Cu ($mg\ kg^{1}$)	Zn ($mg\ kg^{1}$)
	5–10	1.00 (0.29)	0.44	28.4	15.4	1.44	5.52	1.53	4.45	198	84	24	54
0	20–25	1.00 (0.12)	0.44	27.2	16.0	1.18	5.85	1.60	3.56	175	51	15	27
	40–50	1.00 (0.04)	0.43	27.6	15.8	1.64	5.45	1.44	3.05	337	54	15	27
	5–10	0.96 (0.27)	0.43	27.6	15.6	1.26	7.80	2.43	2.58	422	83	15	30
2	20–25	0.96 (0.17)	0.43	25.8	16.5	1.38	6.00	1.64	4.37	149	77	16	30
	40–50	0.94 (0.22)	0.47	32.9	14.4	1.48	7.99	1.74	2.38	253	75	15	20
	5–10	0.94 (0.32)	0.45	29.6	15.3	1.32	8.40	2.19	2.46	234	80	21	38
6	20–25	0.84 (0.17)	0.48	26.5	18.1	1.07	7.87	1.83	2.36	267	93	18	59
	40–50	0.90 (0.30)	0.45	28.4	15.9	1.61	8.50	2.19	1.56	423	77	16	36
	5–10	0.83 (0.29)	0.48	29.4	16.3	1.28	6.13	1.91	2.12	477	74	16	38
14	20–25	0.82 (0.14)	0.44	26.7	16.4	1.51	8.21	2.00	2.00	310	96	22	41
	40–50	0.77 (0.21)	0.44	29.0	15.1	1.33	9.38	2.11	2.05	221	74	22	51
	5–10	0.75 (0.13)	0.48	28.4	16.8	1.11	8.19	2.08	1.93	269	104	20	49
30	20–25	0.80 (0.13)	0.49	31.3	15.7	1.61	7.97	1.64	1.67	414	137	23	60
	40–50	0.79 (0.19)	0.50	30.2	16.4	1.57	9.58	1.20	2.39	411	104	22	63
	5–10	0.75 (0.14)	0.47	29.5	16.0	1.13	7.47	1.83	2.36	406	80	20	59
62	20–25	0.81 (0.16)	0.47	35.8	13.1	0.93	8.05	2.11	1.35	463	200	22	56
	40–50	0.84 (0.17)	0.49	29.2	16.7	1.24	9.41	2.18	1.56	364	113	22	55
	5–10	0.72 (0.31)	0.47	28.0	16.6	0.97	8.48	1.96	1.42	370	419	23	70
254	20–25	0.52 (0.32)	0.45	33.0	13.6	0.70	7.93	1.68	0.77	361	583	33	64
	40–50	0.70 (0.26)	0.48	25.9	18.6	0.98	9.12	1.89	1.08	337	402	30	105
	5–10	0.57 (0.09)	0.46	27.7	16.6	1.01	12.5	2.10	0.48	334	758	27	80
715	20–25	0.56 (0.54)	0.43	33.1	12.9	0.68	7.82	1.25	0.20	259	966	40	72
	40–50	0.67 (0.44)	0.49	23.7	20.6	0.67	8.83	1.60	0.61	309	693	38	156

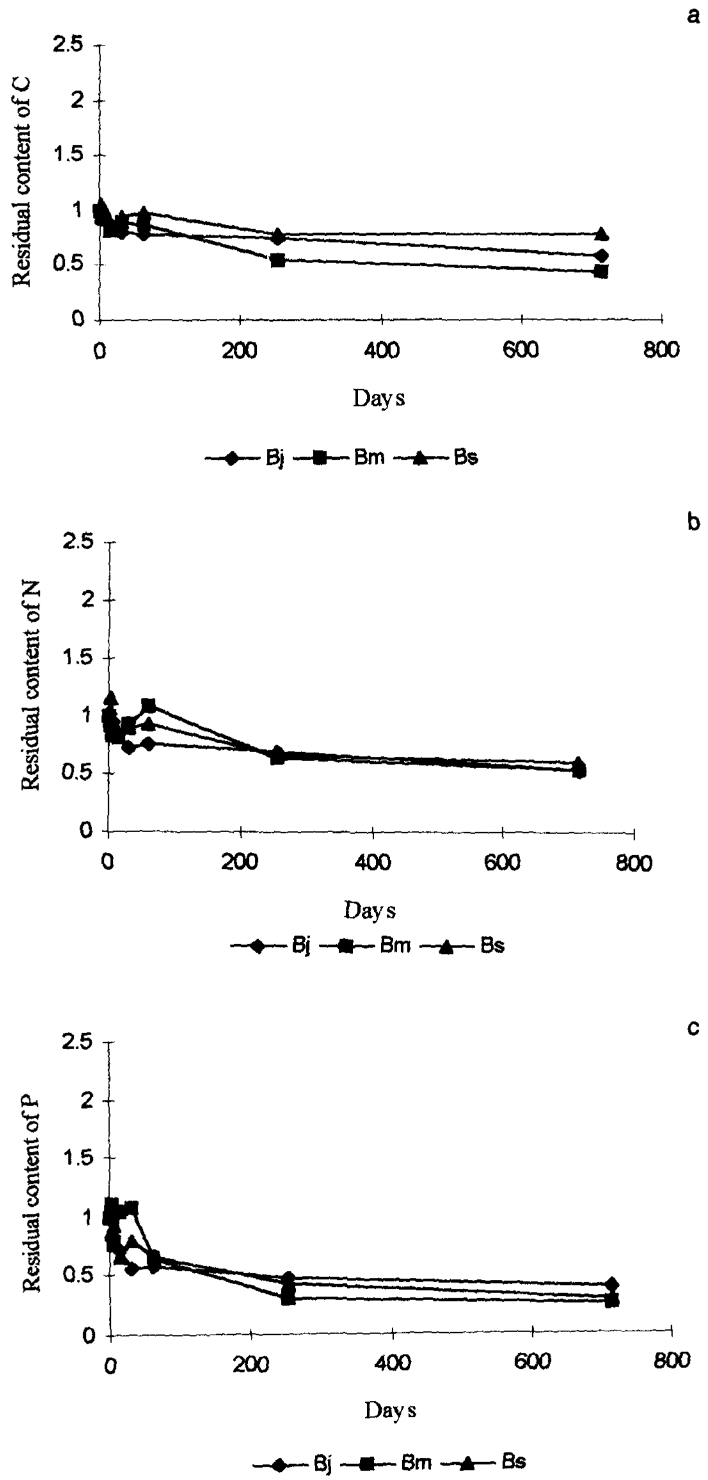

Figure 1. Evolution of nutrient release; content values referred to one initial gram of the elements. Mean of two determinations (Bj: young forest; Bm: mature forest: Bs: old forest). a: carbon, b: nitrogen, c: phosphorus.

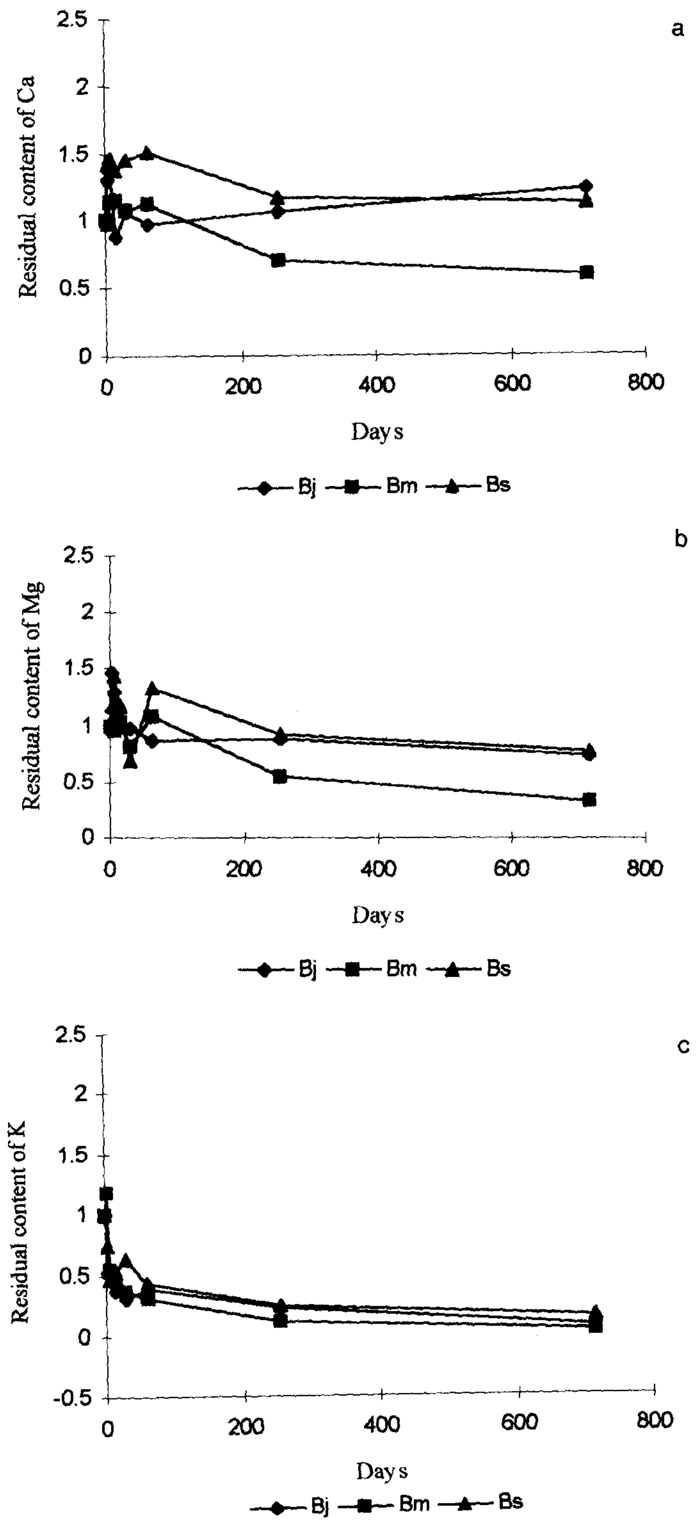

Figure 2. Evolution of nutrient release; content values referred to one initial gram of the elements. Mean of two determinations (Bj: young forest; Bm: mature forest: Bs: old forest). a: calcium, b: magnesium,

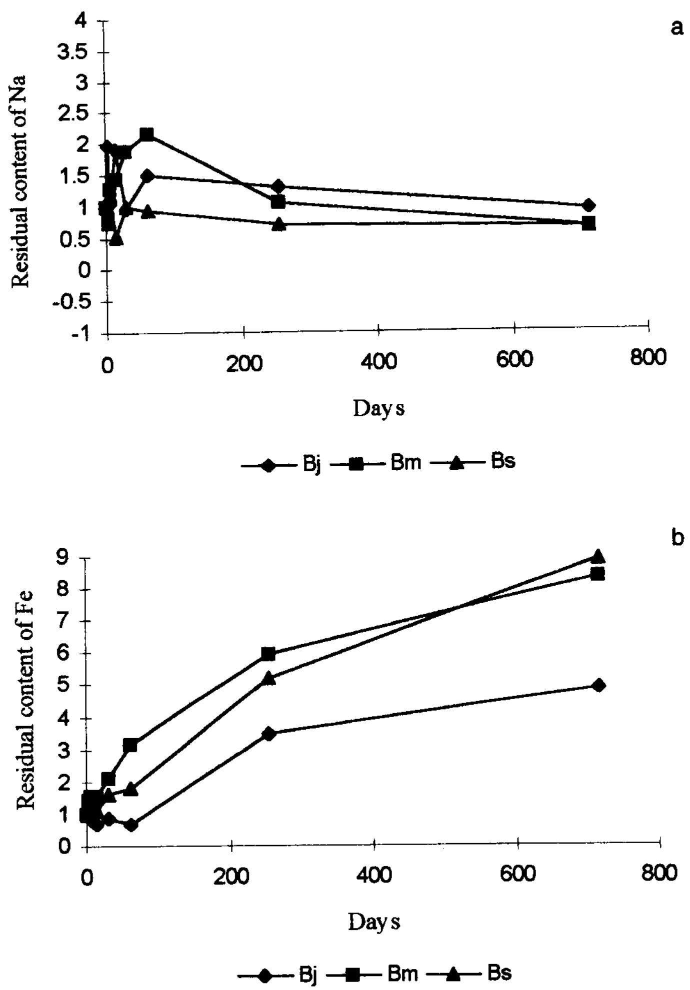

Figure 3. Evolution of nutrient release; content values referred to one initial gram of the elements. Mean of two determinations (Bj: young forest; Bm: mature forest: Bs: old forest). a: sodium, b: iron.

Discussion

The initial contents of the elements (Table I) are similar to the values obtained by Edmonds (1980) and Sharma and Ambasht (1987) for *Alnus rubra* and *A. nepalensis* respectively.

In general, the study shows that nutrient release from alder leaves during the entire period occurred acording to the following sequence:

K > P > Na > N > Ca > Mg

The lowest initial concentrations of some of the bioelements observed in the older alder forest with respect to the younger one could be due to a 'dilution effect' (an increase in biomass occurs for the same amount of bioelements; Martín *et al.* 1995).

Nitrogen contents (Table 1) were similar for all three forests and high in comparison with other species.The same N release pattern has been reported by other authors (Bocock 1964, Santa Regina *et al.* 1989) but contrasts with that by Edmonds (1980), who, for *A. rubra,* detected a release of N equivalent to 33% after 2 y of decomposition. Santa Regina *et al.* (1989) suggested that an increasing trend for N content could be due to microbial fixation (since carbon-energy resources are abundant and seasonal moisture is adequate). This increase in N contents may also be due to leaching of tree leaves, insect excretions and transport through fungi micelle (Gosz *et al.* 1973). However, in this study (Figure 1b) no absolute increase in N contents was observed, possibly because of the low C/N ratio in residual leaves (Table 1).

C/N ratio observed here was low compared to that for *A. rubra* (31.5; Edmonds 1980). Sharma and Ambasht (1987) reported a C/N ratio of 17.5 for *A. nepalensis.* Lutz and Chandler (1946) indicated that 'critical' C/N ratio varies for N mineralisation on forest soils, ranging between 20 and 30; above these values microbial immobilisation occurs. Because in our study the C/N ratio was initially close to 15–16, according to the suggestions of Lutz and Chandler (1946), a net release of N was observed. It should be noted that C/N ratio was frequently used to characterise the degree of decomposition of soil organic matter (Duchaufour 1984). An increase in the values of this ratio at more advanced stages of succession of the old forest would indicate a lower decomposition rate of plant remains; this was observed (Aceñolaza & Gallardo Lancho 1995) in these forests and attributed to acidification of the soil epipedon (as a consequence of nitrification) during advanced seral stages (this increase is only observed after 250 days).

A rapid loss of P was observed during the first 2–3 months (Figure 1c); this coincides with the loss reported by Edmonds (1980) and Sharma and Ambasht (1987), and is consistent with the mobility of this nutrient (a constituent of phosphated sugars, phospholipids, and nucleic acids; Barceló Coll *et al.* 1990). Gosz *et al.* (1973) reported an increase in absolute P contents during the first year of decomposition in deciduous forests, probably due to external causes (canopy leaching).

Absolute Ca content remained approximately constant (Figure 2a). The loss of this element was therefore apparently constant. However, some variations are seen, in this case attributed to other source contributions, mainly the deposition of atmospheric particles (Moreno *et al.* 1996), throughfall, animals, contribution from the soil, and others. Notwithstanding, the changes observed in this element cannot be fully explained because of the methodology used.

The pattern followed by Mg was irregular (Figure 2b). This element underwent an increase during the first days of decomposition: thereafter its levels began to decrease and, finally, the lowest absolute concentration was attained at the end of the second year. This effect has also been observed by Rapp (1971), who suggests that Mg is a leachable element, and its presence can therefore be explained in terms of a balance between loss from organic remains and gains through canopy leaching.

K followed a similar pattern to that of P (Figure 2c). The first two months of decomposition coincided with the end of the rainfall season, with the subsequent release of P and K (easiest washable elements). K is abundant in plant cells but does not form stable structures, and this is why it is easily washed off (Barceló Coll *et al.* 1990).

Na followed an irregular pattern (Fig. 3a), which might have been caused by difficulties in analytical accuracy owing to its low concentrations; nevertheless, Moreno *et al.* (1996) found an important annual input of Na in western Spanish coppices with a high annual rainfall; then Na concentration depends strongly on rainfall.

An inverted pattern for Cu, Fe and Zn was found; all these elements increased after the first rainy season. This might have been caused by biological immobilisation (Duchaufour 1984) as a result of the accumulation of atmospheric dust, throughfall, new green material (Lousier & Parkinson 1978), or imported from the soil (Santa Regina *et al.* 1989, Turrión *et al.* 1997), where these oligoelements are found as 'free' forms in relatively high concentrations.

Only Ca (basic cation), Cu, Fe, and Mn (acidic cations) presented statistical differences between stand ages. Lower values of Ca and higher values of Cu and Zn in the decomposing litter of the 'mature' forest as opposed to those in the 'young' forest could be a result of the soil acidification referred to above (Aceñolaza *et al.* 1995).

Conclusion

Losses of P and K can be explained by the fact that these elements are readily washed off by the rain; increases in Zn, Fe, and Cu in the decomposing litter were found due mostly to external contribution. N and C remained constant.

Element release rates and patterns were very similar in all three forests; only Ca, Cu, Fe, and Mn showed statistical differences between stand ages. Soil acidification of the mature alder forest has an effect on the release of these bioelements.

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[C.S.I.C. = Consejo Superior de Investigaciones Cientifícas;
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