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Leaf litter decomposition and nutrient release in a maquis (evergreen sclerophyllous) ecosystem of North-Eastern Greece

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Summary. Litterbags were used to study the decomposition of leaves from two evergreen sclerophyll shrubs *Arbutus unedo* L. and *Quercus coccifera* L. in a maquis ecosystem of North-Eastern Greece. Over a 1-yr period leaf litter of *A. unedo* and *Q. coccifera* lost 37 and 33%, respectively, of initial ash-free dry weight. Among the leaf litter constituents studied, relatively high loss of potassium, moderate loss of calcium and magnesium and accumulation of nitrogen and phosphorus over the 1-yr period of study was observed.

Key words: Litter, decomposition, nutrient release, evergreen sclerophyllous ecosystem

Introduction

The rates of accession and decomposition of litter are key processes in any ecosystem because of the role they play in the accumulation of "dead" material and recycling of organically-bound plant nutrients. In the Mediterranean type ecosystems, which are found in fire-prone environments with nutrient-poor soils, the dynamics of litter and the nutrient fluxes under normal conditions or after fire are very important. Periodic fires are a major process of nutrient mineralization but decomposition is critical for nutrient recycling during inter-fire periods in these semi-arid ecosystems (Yielding, 1977; Schlesinger & Hasey, 1981; Fousseki & Margaris, 1981; Arianoutsou & Margaris, 1982; Woods & Raison, 1983).

In the Mediterranean climate of Greece, maquis ecosystems are predominant within a precipitation regime of 600–900 mm. At the lower rainfall limit mixed communities of seasonal dimorphic and drought-deciduous shrubs occur. Until recently, it was generally accepted that these distributions were mainly due to differences in water use efficiency and carbon balance (Margaris, 1981). It appears, however, that the evergreen leaf type associated with nutrient-poor soils (Beadle, 1966; Mooney & Rundel, 1979) may also result in the conservation of nutrients through relatively slow rates of decomposition (Monk, 1966).

In this paper the rates of decomposition and nutrient release of leaves from *Arbutus unedo* L. and *Quercus coccifera* L. both evergreen species and the most representative tall shrubs of Greek maquis ecosystems, are considered as a basis for a better understanding of nutrient cycling in these systems.

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Material and methods

Study area

The study was conducted in a stand of sclerophyllous evergreen shrubs, near the village of Stavros in Northern Greece. The experimental plot is at an elevation of 20 m on metamorphic rocks of biotitic gneiss and amphibolites. It has a north-east exposure and the slope is less than 5°. The climate is Mediterranean with mild and wet winters and hot dry summers (fig. 1). The dominant plant species, in terms of biomass, are *Quercus coccifera* L. (32%) and *Arbutus unedo* L. (15%) (Arianoutsou & Mardiris, 1987). Other woody species occurring in the area are *Phillyrea media* L., *Erica arborea* L., *Quercus ilex* L., and *Cistus sp.* The litter phytomass is mainly comprised of *Arbutus unedo* and *Quercus coccifera* leaves (46.02% and 47.15% dry mass respectively) (Arianoutsou, 1989a). The site has not been burned for at least 20–25 years.

Field Methods

Freshly abscissed leaves of *Arbutus unedo* and *Quercus coccifera* were collected early in June, when most of litterfall occurs, by shaking shrubs over traps of nylon netting. For each species approximately 1–2 g of air-dried leaf material were weighed and placed into bags of nylon netting ([illegible]) with 1 mm mesh. Each bag had a code number and was tightly sealed with plastic tape. Sixty bags were prepared for each species.
The litterbags were transferred to the field shortly after their preparation at the end of June and placed on top of the litter layer. The bags were secured with a tether to prevent movement. Sampling was carried out at intervals of 2–6 weeks. On each occasion 5 bags were selected on a random basis and placed in a paper bag to minimize losses of the experimental litter. In the laboratory the bags were dried at 80 °C in an oven for 48 hours and then the litter was removed from the bags and weighed.
Sampling of leaves was carried out in May at the end of the plant growing season (Arianoutsou & Mardiris, 1987). Samples were transported to the laboratory, ovendried (80 °C for 48 hours), weighed and ground in an analytical mill to pass through a 40 mesh screen.

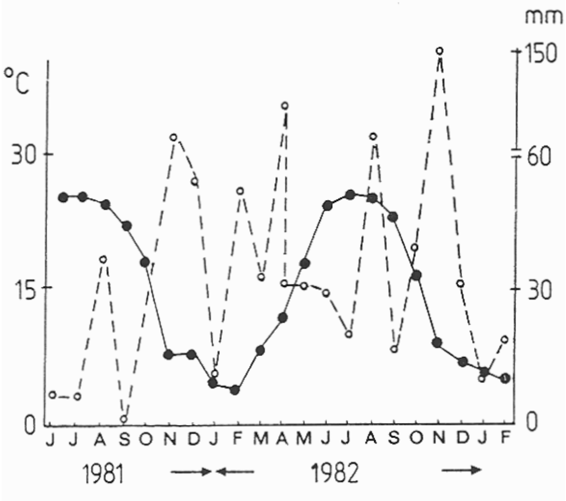

Fig. 1. Meteorological data for the study area where the study is conducted. Air temperature (°C) (●–●–●). Rainfall (–○–○–).

Sub-samples from the bulked collections of mature and abscissed leaves were used for the element analysis. For the analysis of Ca, Mg and K aproximately 1 g of ovendried ground plant material was weighed and ashed in a muffle furnace at 500 °C for 3 hrs. The ashed material was heated with a 3–4 ml of 1 : 1 water : conc HCl in a water bath of 80 °C for 30 min. The solutions were then filtered through a Whatman #41 filter paper and brought to a final volume of 50 ml with distilled water. The element concentrations were determined in a Varian AA 775 atomic absorption spectrophotometer (Allen *et al.*, 1974).

Nitrogen was determined after Kjeldahl digestion in a Technicon auto-analyser (Varley, 1966).

For the determination of phosphorus the samples were heated in a muffle furnace for about 1 h at 250 °C until smoke production stopped and then ashed to 500 °C for 4 additional hours. The ash was then digested with 20% HNO_3 for 30 min, filtered through Whatman #41 filter paper and brought to 100 ml volume. Phosphorus concentration was then determined in a Technicon auto-analyser (Varley, 1966).

Subsamples of litterbag residue were ashed in a muffle furnace at 500 °C for 3 hrs to determine ash content.

Data are expressed in ash-free dry mass remaining in the litterbags.

Results

Mass loss was rapid during the initial period of decomposition (fig. 2). Thirty per cent (30%) of the abscised *A. unedo* leaf mass and 12.5% of the *Q. coccifera* leaf mass was lost in a period of less than a month. Thereafter, mass loss was approximately linearly related to period of exposure and only 7% of the *A. unedo* but 20.5% of the *Q. coccifera* leaf mass was lost. At the end of the 1 year period 37% and 33% of the initial mass of the leaves of *A. unedo* and *Q. coccifera*, respectively, was lost.

Regarding the nutrient constituents, reabsorption of nitrogen, phosphorus and potassium occurs in both species before the abscission of leaves. Concentration of nitrogen, phosphorus and potassium in abscissed leaves was lower by a factor of 23%, 16% and 49% respectively (table 1). An increase in the concentration of nitrogen in the litter bags material was observed at the end of the 1-yr study period (table 1). More specifically, while the abscissed leaves of *A. unedo* and *Q. coccifera* contained 7.20 and 7.30 mg · g^{-1} dw of

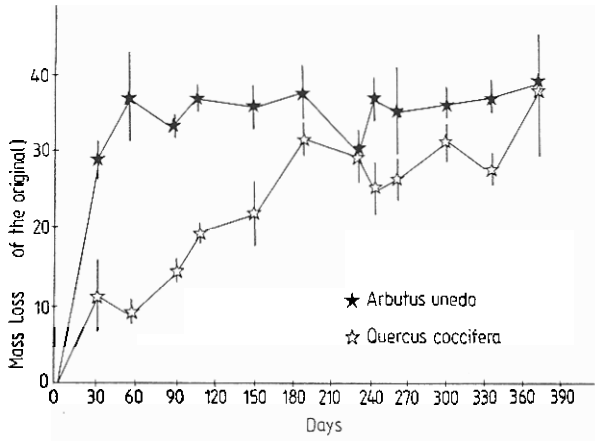

Fig. 2. Mass loss of *Arbutus unedo* and *Quercus coccifera* leaves which were abscissed during summer. Error bars represent ±SE.

Table I. Concentration (mg · g^{-1} d.w.) of some inorganic constituents in mature, abscissed and decomposing foliage of *Arbutus unedo* and *Quercus coccifera* after 1 year in the field

	Element in leaves				
	N	P	K	Ca	Mg
Mature leaves (May)					
Arbutus unedo	9.30	0.16	7.85	10.40	1.50
Quercus coccifera	9.70	0.25	5.15	8.15	1.17
Abscised leaves					
Arbutus unedo	7.20	0.13	4.04	16.74	2.46
Quercus coccifera	7.30	0.20	3.42	12.82	1.51
Decomposed leaves					
Arbutus unedo	9.72	0.17	0.93	8.80	1.30
Quercus coccifera	9.49	0.26	0.67	7.66	0.94
Percent change before abscission					
Arbutus unedo	−23	−16	−49	+61	+64
Quercus coccifera	−25	−19	−33	+57	+29
Percent of the initial content*					
Arbutus unedo	85	82	15	33	33
Quercus coccifera	82	82	12	38	39

* % Remaining: $100 \times \left(\frac{\text{Final weight} \times \text{Final concentration}}{\text{Initial weight} \times \text{Initial concentration}}\right)$

nitrogen respectively, the decomposing material contained 9.72 and 9.49 mg · g^{-1} dw. A slight increase in phosphorus concentration was also encountered. Abscissed leaves of *A. unedo* and *Q. coccifera* contained 0.13 and 0.20 mg · g^{-1} dw of phosphorus respectively, while the decomposed leaves had a concentration rising up to 0.17 and 0.26 mg · g^{-1} dw (table 1). Over the 1-yr period of study high loss of potassium (15%), moderate loss of calcium (33%) and magnesium (33%) and accumulation of nitrogen (85%) and phosphorus (82%) occurred in the decomposing foliage of both species (table 1) as compared to the original content of mature leaves.

Discussion

During the 1-yr study period 37% and 33% of the *A. unedo* and *Q. coccifera* leaf litter has been decomposed. Yielding (1977) found that evergreen chaparral foliage decomposed at the rate of 11–24% per year. The more detailed study of Schlesinger & Hasev (1981) revealed that the loss rates over a 1-yr period in chaparral were 15 to 19% for the evergreen *Ceanothus megacarpus* and 20–24% for the drought-deciduous *Salvia mellifera*. In a more recent study Schlesinger (1985) reports that *Ceanothus* litter lost 3[illegible]–32% of the ash-free dry mass during the 1st year of decomposition, which losses for *Salvia* were ranging from 35–40%. He attributed the difference observed in this previous report (Schlesinger, 1985) to the greater rainfall of that year. Woods & Raison (1983) reported that weight losses of abscissed leaves in one year ranged from 25% for *Eucalyptus pauciflora* to 39% for *E. delegatensis*.

At a given site and climate, one may expect rates of mass-loss from litter to be related to its chemical properties. Many studies have demonstrated such relationships (e.g. Aber & Melillo, 1982; McClaugherty & Berg, 1987). Berg & Staaf (1980) have proposed a schematic model of forest litter decay which is suggesting that early decay stages are regulated primarily by nitrogen and phosphorus concentrations, whereas lignin concentration exerts the dominant control in the latter stages. For the evergreen sclerophyllous leaves a significant positive linear relationship between the initial concentration of N or P in leaves and their loss in weight has been reported (Woods & Raison, 1983). The initial concentration of nitrogen or phosphorus in leaves provides an indication of the decomposability of the substrate. Leaves with a high concentration of nitrogen are likely to be less lignified than abscissed leaves. The degree of leaf sclerophylly increases with decreasing content of protein and phosphorus in the leaves (Loveless, 1962) and the decomposability of leaves decreases as their index of slcerophylly increases (Chromack & Monk, 1975). In this study, rates of mass-loss in the initial phase of decomposition (c. 30 days) appeared to be related to the initial nitrogen and phosphorus concentrations in the litter.

Before the abscission of leaves, reabsorption of nitrogen, phosphorus and potassium occurs in both species, while the amount of calcium and magnesium seems to increase before this event. Gray (1983) also reported large quantities of N and P reabsorbed from chaparral shrub foliage before abscission. This process is an important determinant of litter quality. From the relatively moderate nitrogen concentration, 0.93% and 0.97% of the live foliage of *A. unedo* and *Q. coccifera* respectively, leaf litter of both species had even less quantity. Schlesinger (1985) reports similar results for *Ceanothus* evergreen shrub live foliage and litter, with the very interesting notice that despite the relatively high nitrogen concentrations (1.60% of dry mass) in the live foliage of *Ceanothus*, its leaf litter had nearly identical concentration of N with those of the drought-deciduous plant *Salvia mellifera*.

The relatively slight increases in the concentration of nitrogen and phosphorus in the aged litter-bag material (as compared to freshly abscissed leaves) may indicate either an enrichment from the environment or nitrogen conservation relative to carbon loss. Accumulation of nitrogen have been reported for various periods after the initiation of decomposition (Bocock, 1963; Gosz *et al.*, 1973; Odum *et al.*, 1979; Aber & Melillo, 1980; Schlesinger & Hasey, 1981; Fousseki & Margaris, 1981; Melillo *et al.*, 1982; Schlesinger, 1985). Many studies report that nitrogen release starts only after 12 months- or even more of decomposition (chlesinger, 1985, among others). Besides that, during litter decay N and P are often retained in microbial biomass as organic fractions are respired.

Similar results have been reported by other workers. For example, Gosz *et al.* (1973) working on the decomposition and nutrient release on several plant species (yellow birch, sugar maple and beech) found that the concentration and absolute weight of N, S and P in the decomposing leaf litter was increasing with time. Potassium and magnesium were rapidly released from the litter by leaching. Ca release was similar to weight loss indicating that it is a structural component primarily released by decomposition. Lousier & Parkinson (1978) in a comprehensive review of decomposition and nutrient losses from litter, concluded that the mobility series for these nutrients is rather K > Mg > Ca > N, a finding which agrees with the studies of Schlesinger and Hasey (1981). Lossaint (1973) found that the nutrient losses in a *Quercus ilex* maquis litter of Southern France followed the mobility series K > P > Mg > N > Ca. Specht (1981) working on the decomposition of *Banksia ornata* heath in Southern Australia found that both total phosphorus and total nitrogen content remained essentially constant for almost 2 years from the initial leaf fall. Schlesinger (1985) classified loss of constituents into three categories, according to whether changes were dominant by leaching, cellular decay, or immobilization. For the soluble component, losses began with the onset of autumn rains of the 1st yr of decomposition, presumably due to leaching, e.g. losses of potassium were 70–80%. These values are in accordance with our data showing rapid initial potassium losses of 85–88% (table 1) assosiated with the rapid mass loss which occurred at the onset of the summer storm and autumn rains (fig. 1). Structural components like Ca shared a similar pattern of loss, following that of mass loss. Nitrogen, phosphorus and lignin generally showed little or no loss and had periods of net accumulation during the 3-yr period of their study.

Our data suggest a mobility series of K > Ca = Mg > P = N for the 1-yr study period. Since leaves comprise 70% of the total litter-fall in the maquis ecosystems of Greece (Arianoutsou, 1989a), these inputs may be key-factors in the nutrient cycling processes near to the soil surface. In the experimental site, an annual leaf litterfall of 158 $g \cdot m^{-2}$ of

A. unedo and 131 g · m^{-2} of *Q. coccifera* [Arianoutsou, 1989a] would "immobilize" N at a rate of 1536 mg · m^{-2} and 1480 mg · m^{-2} respectively for the two species (using data of table 1), greatly exceeding the inputs of this nutrient in the precipitation (572 mg · m^{-2}) entering the litter layer over the same area (Arianoutsou, 1989b). For phosphorus the figures give an amount of 27 mg · m^{-2} · a^{-1} and 34 mg · m^{-2} · a^{-1} bound in *A. unedo* and *Q. coccifera* decomposed leaf litter. These amounts equal that entering the system through annual atmospheric deposition (24 mg · m^{-2}, Arianoutsou, 1989b). The importance of nitrogen and phosphorus mineralization rates in the Mediterranean ecosystems of Greece are critical in two respects: i) evidence suggest a limited availability of nitrogen and phosphorus in evergreen sclerophyllous ecosystems (Margaris *et al.*, 1984), ii) the current fire-cycle interval seems to be longer that the residence time for the leaf litter studied (unpublished data), suggesting that decomposition plays an important role to the nutrients, supply in the mature evergreen sclerophyllous ecosystems of Greece. The contributions of roots and below-ground processes are, however, unknown but are likely to be important in semi-arid systems.

In conclusion, decomposition and nutrient mobilization are complex phenomena, involving the structure of soil fauna and microflora communities, their nutritional demands and seasonal activity, and the chemistry of plant tissues operating within the constraints of climatic factors (Daubenmire & Prusso, 1963; Gosz *et al.*, 1973; Anderson, 1986 among others). As yet few studies have been made on the interactions of these factors under the Mediterranean climate conditions, and hence future research may reveal new synergetic or antagonistic effects on decomposition and nutrient cycling.

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The work reported here is part of a larger study on patterns of growth and aspects of nutrient cycling in evergreen sclerophyllous ecosystems of Northern Greece.

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