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Note

Biogeochemical cycles in forests of the "Sierra de Béjar" mountains (province of Salamanca, Spain): decomposition index of the leaf litter

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Summary — Both leaf and total litter decomposition indices were established in 3 forest ecosystems of the "Sierra de Béjar" mountains: a climax *Quercus pyrenaica* Willd oak forest, a paraclimax *Castanea sativa* Miller sweet-chestnut coppice, and a disclimax *Pinus sylvestris* L Scots pine forest. Higher decomposition rates and higher Jenny's decomposition indices were observed in the chesnut leaves than in the oak and pine leaves. Under almost identical climatic conditions, chesnut leaves decomposed faster than those of oak and Scots pine. Thus, litter accumulation was highest in the pine forest, followed by the oak and chestnut forests.

litter decomposition / forest ecosystems / biogeochemical cycles

Résumé — Cycles biogéochimiques dans 3 forêts de la Sierra de Béjar (province de Salamanque, Espagne) : indices de décomposition de la litière. *Les indices de décomposition de la litière et des feuilles ont été déterminés dans 3 forêts de la Sierra de Béjar (province de Salamanque, Espagne) : une chênaie à* Quercus pyrenaica *Willd, une châtaigneraie à* Castanea sativa *Miller et une pineraie à* Pinus sylvestris *L. Les valeurs des indices les plus élevés sont rencontrées dans la châtaigneraie, tandis que la plus grande accumulation de litière se trouve dans la pineraie, bien que les conditions climatiques soient similaires.*

décomposition de la litière / écosystème forestier / cycle biogéochimique

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INTRODUCTION

The mineralization of the humus and the release of nutrients from the leaf litter is a fundamental process in the bioelement dynamics of the forest ecosystems (Vogt *et al,* 1986). This key role of the organic matter decomposition for the mineral nutrition of the plant has been well documented (Swift *et al,* 1979; Berg and Theander, 1984; Santa Regina, 1987).

In a forest ecosystem in equilibrium, a relationship has been suggested between the amount of litter reaching the forest floor annually, and the amount of organic matter decomposed on the soil surface over the same period of time, and the ratio (decomposition index) could be an ecological characteristic (Jenny *et al,* 1949). More recent studies have found a correlation between the apparent litter mass loss with the actual evapotranspiration (AET, Dyer *et al,* 1990), either other related soil-climate parameters (Berg *et al,* 1990) at the northern hemisphere scale.

The aim of this study was to estimate the litter decomposition rates, using the litterbag method (Bocock and Gilbert, 1957), in 3 types of forests and also in a grass meadow, and to compare the results with the amount of quasi-permanent litter on the soils of these 3 types of forests.

Site description

Three permanent plots were chosen in the Sierra de Béjar area (south-east of the province of Salamanca, Spain): i) a climax oak (*Quercus pyrenaica* Willd) forest about 60 years old after clear cutting; ii) a chestnut (*Castanea sativa* Miller) coppice about 15 years old after the last harvest; and iii) a Scots pine (*Pinus sylvestris* L) forest about 30 years old after new planting. The climate of the study area is humid mediterranean, with mean temperature about 11.5°C and mean rainfall about 1 500 mm/yr, ranging from more than 600 mm in winter to less than 100 mm in summer. The calculated potential evapotranspiration is about 700 mm/yr (M° APA, 1984), and the summer water shortage is close to 285 mm in summer; thus, the AET is about 400 mm/yr.

The climax oak forest is widespread in the zone. The oak forest plot is 1 350 m asl, with a density of 1 540 stands/ha, with a mean trunk diameter of 23 cm, and a mean height of 12.5 m. Leguminous shrubs are frequent as understorey.

The chestnut plot is situated at some 1 150 m asl. It is coppice having a density of 9 000 poles/ha, with a mean trunk diameter of 4.5 cm (diameters range from 9 to 1 cm) and a mean of height of 10 m. *Cytisus* genera are frequent as understorey.

The disclimax Scots pine forests are situated about 1 500–1 600 m asl. The pine forest plot is situated at 1 550 m asl and has a density of 1 600 stands/ha, with a trunk diameter of 19 cm and a height of 9 m. Herbaceous species are scarcely found in it.

Finally, the meadow is located in a opening in the oak forest described above. The most common herbaceous species are: *Agrostis castellana*, *Festuca elegans*, *Briza media*, *Holcus mollis*, and *Poa* sp. The meadow and the oak forest are for grazing in spring–summer, with a low density of cattle.

Soil characteristics

The soil of the oak plot is a *humic Cambisol* (FAO, 1987) of varying depth. The parent material is weathered granite and colluvial granitic sands. The A_h horizon has a soil organic content of 4.4%, a C/N ratio of 15.7 and a mean depth of 50 cm.

The soil of the chestnut plot is also a *humic Cambisol* (FAO, 1987) developed on weathered granite. The A_h horizon has a soil organic content of 5.4%, C/N ratio of 15.8 and a mean depth of 40 cm.

The soil of the Scots pine plot is a *Leptosol* and *humic Cambisol* association (FAO, 1987) on weathered granite; appreciable variations in depth and stoniness are observed. The A_h horizon has a soil organic C content of 5.4%, a C/N ratio of 15.6 and a mean depth of 60 cm, when the granite blocks are not near the soil surface.

All the above figures are means of the different A_h subhorizons. These and other soil characteristics have been reported in greater detail in earlier works (Santa Regina and Gallardo, 1985, 1986).

METHODS

Square, 2 mm mesh bags with a surface area of 9 dm^2 were placed in the 4 plots, according to the method proposed by Bocock and Gilbert (1957); 15 g of recently fallen leaves or needles, previously dried (room temperature) to a constant weight, were placed inside of each bag. The leaf humidity at 80°C was also determined (Rapp, 1969). In each plot, 21 litter bags were superficially placed at random, except in the meadow, where both needle and leaf decomposition were tried out. The trials were started on December 1983 and February 1985, and 3 litter bags were taken at random for each species and each time (the 100th, 165th, 200th, 300th, 360th, 425th, and 480th d after starting the experiment). The experiments were completed in December 1984 and May 1986, respectively; nevertheless, in this work only figures obtained at 0 and 360 days have been considered; kinetic aspects of the leaf decomposition have been reported elsewhere (Santa Regina *et al*, 1989).

After the bag collection, the contents were transported to the laboratory and cleaned of mosses and other external deposition. After opening the bags, the residual dry mass of the leaves or needles was cleaned with air and dried to constant weight at 80°C (Rapp, 1969); then the remaining material was weighed.

Litter production was evaluated by placing 10 litter traps (40 x 60 cm) at random in each of the 3 forest ecosystems from November 1983 to February 1986; this method has been explained elsewhere (Santa Regina and Gallardo, 1986). Total and leaf productions were evaluated weighing either the total dried material, or the fallen leaves (after separation of these from the other tree organs in the harvested material), respectively.

The accumulated leaves or the accumulated total litter on the soil were estimated by recovering the organic superficial layers (A_0) from 5 squares (1 x 1 m) at random in both end-September 1984 and 1985; the inorganic A_h horizon was not included in these samples. After this, either the leaves (after separation of these from the other tree organs in the recovered material) or the total litter were dried and weighed, respectively (Santa Regina and Gallardo, 1986).

Different decomposition indices were established considering, under natural conditions, the total litter and only the leaf litter in each forest ecosystem. The indices were determined in the 3 forests during 2 different experimental periods (1984 and 1985), and also in the meadow (oak forest opening).

All the determinations were performed, at minimum, by duplicate (litter-bag experimentation, by triplicate).

RESULTS AND DISCUSSION

Natural decomposition

Assuming that these forest are in steady state condition and the **K** coefficient (Jenny *et al*, 1949) is constant during the 1st year of decompositon, it was calculated according to the formula:

$$\mathbf{K} = \mathbf{P}/(\mathbf{P} + \mathbf{A})$$

where *P* represents the weight of the total litter production returning annually to the soil, and *A* the weight of the total litter accumulated on the floor of the forest before the period of annual litterfall. In this steady state, the annual mass loss of litter is possible to be calculated according to the formula:

$$L = P^*K = P - A^*K$$

where **L** is the annual litter mass loss.

Similarly, it is possible to calculate the *k* constant for the leaves according to:

$$k = p / (p + a)$$

where *k* is the decomposition index for only the leaves, *p* is the annual total leaf production and *a* the weight of the leaves accumulated on the forest floor before litterfall. Identically:

$$l = p * k = a * k$$

where *l* is the annual leaf mass loss.

Those assumptions are, of course, not exact, but could give an approximation of the decomposition processes.

Data from table I show that the total litter production (**P**) in the chestnut coppice is the lowest; oak and pine forests have similar figures (about 870 g/m^2). Nevertheless, there is a great difference between the accumulated litter **(A)** on the forest floor before litterfall in the oak forest, and the Scots pine forest; therefore, the litter decomposition constant of the oak litter is higher than that of the pine litter.

In relation to the leaf decomposition, table II shows that the leaf productions were similar (about 330 g/m^2) in the chestnut and in the oak forest; in contrast, the pine had the highest needle production. The accumulated leaf litter before litterfall was therefore almost twice the amount in the pine forest than in the broadleaf forest. These results point out that the leaf decomposition index is also higher in the oak leaf litter than in the pine needle litter; furthermore, chestnut leaf litter had the highest *k* value.

Comparing tables I and II, it is possible to see that the leaf litter decomposition constants are obviously higher than the total litter decomposition constants, because the total litter includes more wood lignin (twigs, branches) than the leaves or needles alone (Meentemeyer, 1978; Melillo *et al,* 1989). Furthermore, comparing the figures of **L** and *l* of the Scots pine forest, it is observed that the mass loss which occurred in the pine litter is mostly due to the needles (98 g/m^2 from a total of 102 g/m^2). LSD analysis has not showed significative differences among the loss of dry matter weight in the 3 forests.

Table I. Decomposition indices of total litter in the 3 forest ecosystems (**P**, **A** and **K** represent annual total litter production, litter accumulation on the forest floor before fall, and litter decomposition constant, respectively; **L** is the calculated annual litter loss). Mean of 2 years (September 1984 and 1985).

Litter (mean)	C sativa	Q pyrenaica	P sylvestris
P (g/m^2)	590	860	880
A (g/m^2)	2.051	3.779	5.962
A + **P**	2.641	4.634	6.862
K = P/(**A**+**P**)	0.22	0.19	0.13
L (g/m^2)	139	142	102

Table II. Decomposition of leaf litter in the 3 forest ecosystems (*p*, *a* and *k* represent annual total leaf production, leaf accumulation on the forest floor before fall, and leaf decomposition constant, respectively; *l* is the calculated annual litter loss). Mean of 2 years (September 1984 and 1985).

Litter (mean)	C sativa	Q pyrenaica	P sylvestris
p (g/m^2)	342	319	445
a (g/m^2)	779	957	1577
p + *a*	1142	1276	2023
k = p/(a+p)	0.30	0.25	0.22
l (g/m^2)	102	80	98

Experimental decomposition

Table III shows the data of the decomposition rate during the 1st year, for the 2 considered periods (1984 and 1985). The decomposition constant (*ko*) has been calculated according to the formula:

$$ko = (p_0 - r)/p_0$$

where p_0 is the initial quantity of leaves in the litter bag, and *r* the residual quantity of leaves at the end of period (1 year).

Comparing tables II and III, it is observed that these figures are quite close, above all in the 1985 period. Nevertheless, it is necessary to taken into account that the rate inside the litter bags (table III) is lower than the actual rate, because of the difficulty for mesofauna to access into the nylon bags (Bocock, 1964; Joergensen, 1991). On the other hand, the data of the leaf decomposition constant (table II) should be lower than the actual figures, because it is very difficult to separate the small pieces of leaves, and for that, to know exactly *a*. For both reasons, the values of *k* and *ko* are very close.

Decomposition rates of the 3 leaf species placed in the meadow have also been determined (table IV). A slight increase of the decomposition-rate values are observed, but are only significant for the pine needles probably owing to a greater biological activity in the meadow than in the pine forest (Duchaufour, 1984).

Table III. Leaf decomposition indices obtained according to the litter-bag method (leaves or needles placed in their own ecosystem).

ko *(litter bag)*	C sativa	Q pyrenaica	P sylvestris
1984	0.33	0.21	0.24
1985	0.30	0.25	0.22

Table IV. Leaf decomposition indices obtained according to the litter-bag method (leaves or needles placed in the meadow).

ko *(litter bag)*	C sativa	Q pyrenaica	P sylvestris
1984	0.33	0.32	0.28
1985	0.32	0.26	0.26

Assuming that the climate and rock material (granite) is quite similar in the 3 forest ecosystems, the differences between the decomposition indices in the 3 leaf species should mostly be due to the content of bioelements (Berg and Staaf, 1980; Duchaufour, 1984). Table V shows the N and P content of the leaves and needles of the selected forest ecosystems, which confirms that hypothesis. Moreover, the differences of N and P contents are also reflected in the chemical composition of the total litters; so, it is possible to observe that the content of P either in leaves or litter of chestnut is almost double in relation to the other tree species (tables V). This fact could justify the higher decomposition constant found in the chestnut forest with regard to the other forests (table III and IV).

Table V. Nitrogen and phosphorus content (mg/g dry matter) of leaves and litters of the selected forests (mean of 2 years in leaves and mean of 3 years in litters; from Santa Regina, 1987).

ko *(litter bag)*	C sativa	Q pyrenaica	P sylvestris
Leaf N	2.5	8.8	6.4
Leaf P	2.0	1.2	0.8
Litter N	9.2	10.6	7.8
Litter P	2.3	1.0	1.3

However, using the equations proposed by Meentemeyer and Berg (1986), which relate the yearly mass loss (L, in % of initial litter mass) of the litter and the actual evapotranspiration (AET), the results are as follows:

$L = 0.057 * \text{AET} + 3.1$ (all the forests)
$L = 0.129 * \text{AET} - 27.6$ (Scots pine forests)

The results give a litter mass loss of 26% for the broad-leaf forests and 23% for the Scots pine forest, corresponding to litter-decomposition constants of 0.26 for the deciduous forests and 0.23 for the pine forest. These figures are higher than the above exposed constants **K** (table I), although the leaves have similar values (table II). That could mean that the obtained litter decomposition constants **K** are lower than the actual values.

CONCLUSIONS

Results confirm that:

i) The leaf and litter decomposition rates in the 1st year of decomposition follow the order: Scots pine needles<oak leaves< chestnut leaves. The actual leaf and litter decomposition indices are higher than the experimental figures, because of methodological limitations.

ii) Given that the needle production is higher than the oak and chestnut leaf production, the accumulated annual leaf litter increases in the following order: chestnut coppice < oak forest < Scots pine forest.

iii) The higher values of leaf decomposition constant obtained in the meadow for the Scots pine needles point out that the herbaceous plants exert a positive effect on the needle decomposition, probably due to an increase of bioelements and microbial activity.

iv) There is positive relation between the decomposition indices and the major bioelement contents of the leaves.

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