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Original article

Litter fall and nutrient turnover in Kermes oak (*Quercus coccifera* L.) shrublands in Valencia (eastern Spain)

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Abstract – Litter fall has been measured in three Kermes oak (*Quercus coccifera*) shrublands, 10, 40 and 70 years after fire in the province of Valencia (eastern Spain). Annual inputs varied between 3.2 and 5.2 t ha^{-1} $year^{-1}$ (D.M.), with more than 90 % of them coming from Kermes oak. In spite of the perennial character of this species, under our experimental conditions it behaved as a deciduous one, and showed litter fall peaks in May. Leaf litter was the most important source of nutrient return to the soil (60–70 %) followed by twig (6.8–14.5 %) and flower and fruit (4.4–17.3 %) litter. The total nutrient input (macro- and oligo-elements) due to litter fall was 85.3–167.8 kg ha^{-1} $year^{-1}$. Ca is the most important element followed by N, K, Mg and Na. The input of Fe, Mn, Zn and Cu due to litter fall was 0.55–2.31 kg ha^{-1} $year^{-1}$. (© Inra/Elsevier, Paris)

Kermes oak / litter fall / nutrient turnover / retranslocation / *Quercus coccifera*

Résumé – Production de litière et apport au sol d'éléments minéraux dans des garrigues de chêne Kermès (*Quercus coccifera* L.) dans la région de Valence (Espagne). La production de litière du chêne Kermès (*Quercus coccifera*) a été déterminée à Valencia (Espagne) dans des garrigues âgées de 10, 40 et 70 ans après incendie. La production varie de 3.2 à 5.2 t ha^{-1} an^{-1} dont plus du 90 % correspond au chêne Kermès. Bien que le chêne Kermès soit une espèce à feuilles persistantes, dans les conditions de notre expérience, le rythme de retombée de litière est de type annuel et le chêne Kermès se comporte comme une espèce décidue facultative, avec une chute des feuilles pendant le mois de mai. Les feuilles constituent la source principale de restitution des éléments minéraux au sol (60–70 %). Elles sont suivies des rameaux (6.8–14.5 %) et des inflorescences et des fruits (4.4–17,3 %). La minéralomasse totale de la litière (macro- et oligo-éléments) se situe entre 85,3 à 167,8 kg ha^{-1} an^{-1} selon la parcelle. Le calcium est l'élément le plus

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important (50 %) suivi de N, K, Mg et Na. Les quatre oligo-éléments analysés (Fe, Mn, Zn et Cu) représentent de 0,55 à 2,31 kg ha^{-1} an^{-1}. (© Inra/Elsevier, Paris)

chêne Kermès / chute litière / restitution des nutriments au sol / *Quercus coccifera*

1. INTRODUCTION

Kermes oak (*Quercus coccifera* L.) is one of the most important shrub species in the Mediterranean Basin, where it covers more than 2 million hectares [8]. It grows under a typical Mediterranean climate and on a great variety of soil types, either on acidic or basic parent materials [3]. In Spain, it is widely distributed along the Mediterranean coastal provinces, where it sometimes constitutes the potential vegetation, either as climax or as paraclimax (disclimax) communities [19]. It is also present in the interior, where it is associated with degraded stands of sclerophyllous perennial forests, such as those dominated by holly oak (*Quercus rotundifolia* Lamk.) and cork oak (*Quercus suber* L.). Due to its ability to regenerate vigorously from stumps and roots and to resist browsing, it plays a fundamental role in erosion control (especially after fire) and as a major fodder source for wildlife and livestock (mostly goats and sheep). It is also a refuge for small game animals, such as rabbit (*Oryctolagus cunniculus*) and red legged partidge (*Alectoris rufa*), which are often the most interesting natural resources of these plant communities from an economic point of view [3, 4]. Finally, it contributes to soil formation and increases soil fertility through the dynamics of its large root system [3] and also through litter fall. This is especially important on nutrient-poor soils, where plant communities rely to a great extent upon the recycling of litter nutrients.

Structure, function and potential usage of Kermes oak shrublands have been discussed by several authors in France [11, 16, 25], Greece [7, 9, 10, 15, 26], Spain [3, 4] and other Mediterranean countries [8, 24]. However, the litter fall and nutrient cycles of those ecosystems have seldom been studied [14, 17, 18, 23]. Therefore, the objectives of our study were 1) to contribute to the knowledge of litter fall and nutrient cycles in Kermes oak shrublands in Spain and 2) to provide new data from stands with different ecological conditions and fire histories.

2. MATERIALS AND METHODS

2.1. Study area and sampling methods

Our experiments were conducted in Valencia (eastern Spain), where Kermes oak shrublands constitute the major vegetation type. There were three experimental sites: 1) Chera, old growth Kermes oak shrubland more than 70 years old; 2) Buñol, mature Kermes oak shrubland 40 years old; and 3) Venta Moro, young Kermes oak 10 years old. Cover was always almost 100 %. The age of the aerial part of the stand was estimated using the date of the last fire (*table I*).

The climate could be included in the lower meso-Mediterranean belt of Rivas Martínez [19] with a dry ombrotype. The mean annual rainfall is 515 mm, and the average temperature is 13.5 °C. There is a possible frost period from late autumn (November) to early spring (March), with an absolute minimum temperature of –12 °C. The soil belongs to the Calcic Cambisol–Calcaric Regosol association [5]. The potential vegetation is an evergreen sclerophyllous forest: *Bupleuro rigidi–Quercetum rotundifoliae* with *Pistacia lentiscus* [19]. However, due to fire, browsing and other human influences, the current vegetation type is a continuous Kermes oak garrigue (*Rhamno lycioidis–Quercetum cocciferae*).

Our sampling methods were similar to those used by Rapp and Lossaint [18] and Merino

Table I. Site and soil characteristics of the study sites in Valencia (eastern Spain).

	Venta Moro	Buñol	Chera
Site characteristics			
Age (year)	10	40	>70
UTM	XJ4270	XJ9365	XJ7585
Longitude	1°20'10"	0°40'30"	0°50'50"
Latitude	39°20'50"	39°20'30"	39°30'40"
Elevation (m)	950	725	750
Annual precipitation (mm)	515	505	525
Annual temperature (°C)	12.0	14.0	14.4
Slope (%)	10	5	15
Height (m)	0.60	1.55	2.00
Soil characteristics			
Texture	clayey/sand	clayey/silt	clay
pH-H_2O	8.00	7.65	8.02
Organic matter (%)	5.65	2.26	5.34
Ca (ppm)	3150	3800	3350
Mg (ppm)	1650	1050	1200
P (ppm)	6.5	6.6	7.3
K (ppm)	105	252	475
C/N	8.83	8.12	9.45
N (%)	0.35	0.15	0.33

and Martín [14]. Fifteen 0.25-m^2 collecting baskets in each plot were randomly positioned 25 cm above the soil in the Kermes oak shrublands. They had a 2-mm nylon mesh screen bottom, and were identified by a number. Freshly fallen litter was collected every month for 2 years. Then, it was divided into two subsamples: one for Kermes oak and another for other species. The first was subdivided again into three fractions including leaves, woody materials, flowers and fruits. All samples were oven-dried at 75 °C, and then weighed to the nearest milligram. The different fractions of litter samples were bulked on a monthly basis for each plot and then ground for chemical analyses.

2.2. Chemical analyses

Each litter fraction was analysed monthly for the main major-elements (N, P, K, Ca, Mg and Na) and also for those trace-elements involved in oxidation–reduction processes (Fe and Cu) and in catalytic reactions (Zn and Mn). The ground samples were analysed for total N by semimicro distillation following a Kjeldahl digestion. The amount of the other mineral elements present in each fraction was determined by ignition of the plant material (1–2 g/sample) for 24 h at 490 °C. Fe, Cu, Mn, Zn, Ca and Mg were determined by atomic absorption (lanthanum chloride was used to control interference of other elements in the Ca and Mg analyses). Na and K were determined by emission spectrophotometry. Finally, P was determined colorimetrically, after reduction of phospho-molybdate by stannous chloride to molybdenum blue.

3. RESULTS AND DISCUSSION

3.1. Litter fall

In terms of quantity (*table II*), the average annual litter production was 5 229 ± 538 kg ha^{-1} $year^{-1}$ (D.M.) in the oldest stand (Chera), 3 733 ± 284 in the mature one (Buñol) and 3 242 ± 302 in the youngest one (Venta Moro). These figures are higher than those found in the French literature [17, 18] in *Q. coccifera*

Table II. Litter fall (kg ha^{-1} $year^{-1}$ D.M. and percentages) of three experimental Kermes oak shrublands in eastern Spain.

Sites	Chera (70 years)			Buñol (40 years)			Venta Moro (10 years)		
Fractions	Mean	S. E.	%	Mean	S.E.	%	Mean	S.E.	%
Total	5 229	10.29	100.00	3 733	7.62	100.00	3,242	9.32	100.00
Kermes oak	4 718	10.01	90.23	3 649	7.53	97.76	3 010	9.03	92.84
Leaves	3 183	8.16	60.87	2 945	7.14	78.90	2 377	8.82	73.32
Woody	629	11.20	12.04	540	8.20	14.46	200	9.50	6.67
Fruits	635	10.02	12.14	13	7.90	0.36	334	8.91	10.30
Flowers	271	7.25	5.18	151	6.72	4.04	99	7.95	3.00
Other	511	9.32	9.77	84	6.25	2.24	232	7.32	7.16

S.E.: Standard error (%).

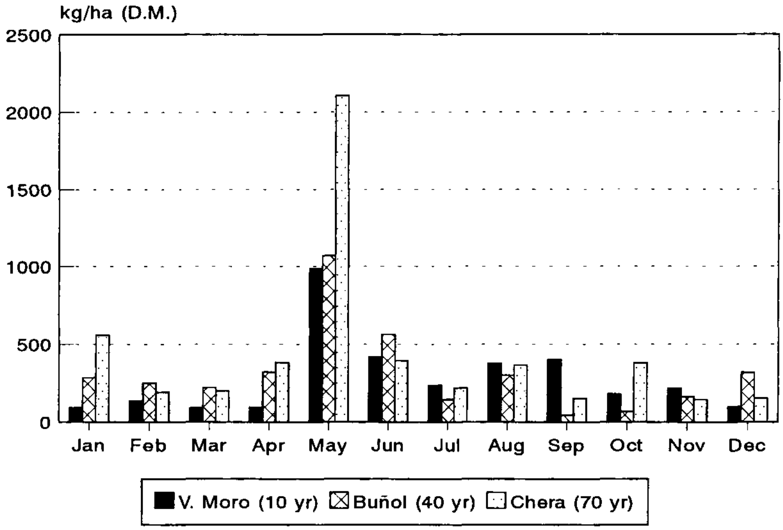

Figure 1. Mean monthly litter fall of Kermes oak shrublands in Valencia (eastern Spain).

shrublands but similar to or only slightly higher than those offered by Merino and Martín [14] for low shrublands of SW Spain.

Peaks of litter fall occurred in May at all sites (*figure 1*). During that month, the leaf fraction was the most important one, amounting to more than 80 % of the total litter production (*figure 2*). The April litter fall was low in our experimental plots in contrast to French garrigues, where litter fall peaks occur in April [18]. Shoot growth occurred from late May to early June. On shallow and nutrient-poor soils (e.g. Buñol, Venta Moro), Kermes oak shoots lost almost all their old leaves during a short period of time immediately before shoot growth occurred. However, deciduous behaviour was not observed in Chera, though the litter fall peak also occurred in May. This behaviour, which agrees with that described by Addicot and Lyon [1] and Specht [23] for other Mediterranean evergreen species, could be regarded as a strategy to reduce evapotranspiration in that critical period. Vernal abscission seems to be related to intense movements of nutrients to the growing points of plants. Therefore, in our case it could also be considered as a strategy to favour the replacement of old leaves by new ones with a greater photosynthetic efficiency. In consequence, on shallow soils and under long drought periods, Kermes oak could behave as a facultative deciduous species. This situation could be related to the ability of the species to sustain summer drought. When leaf abscission occurs before the summer drought period, the litter decomposition process does not begin until the first autumn rains. Thus, litter may reduce herb growth more than in plant communities with other abscission cycles. In addition, we must not forget the role of litter fall in summer in reducing soil evapotranspiration.

In our case, leaf litter is the most important litter fall fraction, amounting to more than 60 % of the total litter fall (*table II*). This figure, and those of the other litter fall fractions agree with the general situation described by Bray and Gorham [2] and Rodin and Bazilevich [21] for forests of the world. However, Kermes oak does not show cladoptosis, an active process of branch abscission that makes them fall simultaneously with leaves (*figure 2*). This process has been observed by Escudero and Arco [6] and Martín et al. [13] in other Mediterranean and sub-Mediterranean *Quercus* species.

The litter fall cycle is clearly annual in our three experimental sites, just as other scientists [17, 18] have described for the French garrigue. This contrasts with the litter fall cycle of other Mediterranean tree species such as holly oak and cork oak [6, 20] and *Quercus faginea* [22].

3.2. Nutrient concentration

The mineral composition of the leaf and woody fractions of litter fall is shown for each experimental site in *table III*. All these values are the weighted averages of the composition of materials shed throughout the year.

Venta del Moro sites contained the lowest mineral concentration, except for Mg, for every month which was related to the soil analyses (high Mg and low levels of N, Ca, P and K).

We observed monthly variations in the elements of different fractions; for example, the concentration of N and P in leaf fractions seemed to decrease when litter fall was higher. After June we observed an increase in these mineral concentrations. The reason could be that the plant needs these elements, which are very scarce in forests soils, and seems to retain them through leaves before autumn. On the other hand, this process had not been observed for the other elements (for example K was at maximum from August to December, and Zn was highest from September to October).

3.3. Nutrient inputs

The nutrient input due to litter fall (*table IV*) increases with the age of the stand and obviously with the amount of litter fall. The total annual input for the nutrients analysed in our experiments was 85.3 kg ha^{-1} $year^{-1}$ at Venta Moro (the youngest stand), 130.9 at Buñol (the mature one) and 167.8 at Chera (the oldest stand). Leaf and woody litter are especially important both because of their major contribution to total litter fall (*table*

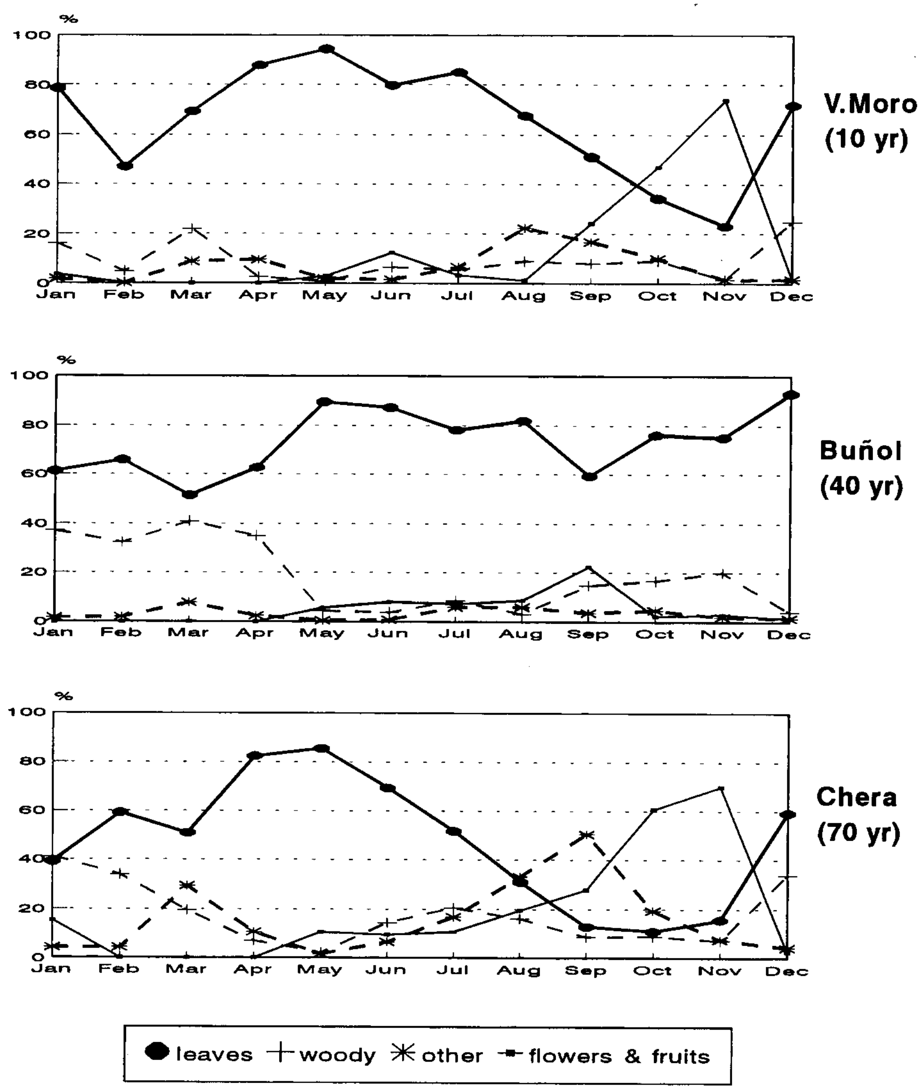

Figure 2. Monthly litter fall fractions of leaves, woody materials, flowers and fruits and other as a percentage of total litter fall in Kermes oak shrublands in Valencia (eastern Spain).

II) and their high nutrient content (*table III*).

Ca input through litterfall was the largest among those of the nutrients analysed. With amounts of 78.6 kg ha^{-1} $year^{-1}$ at Chera, 57.6 at Buñol and 34.4 at Venta Moro, it alone represents 50 % of the major-elements recycled through litterfall. N is next, with amounts of 45.5, 36.7 and 24.4 kg ha^{-1} $year^{-1}$ (30 % of the elements analysed), respectively, at those experimental areas. The other elements,

Table III. Mineral composition of the leaf and woody fractions of litter fall in three experimental Kermes oak shrublands in eastern Spain.

		mg/g (D.M.)						µg/g (D.M.)			
		N	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn
Leaf	V. Moro	8.61	0.35	2.84	12.02	2.65	1.39	111.47	32.33	7.00	35.44
	Buñol	9.94	0.48	3.71	13.71	1.57	2.74	170.96	238.36	7.80	56.77
	Chera	10.1	0.59	4.16	13.62	1.40	1.76	124.60	110.00	7.05	54.00
Woody	V. Moro	6.76	0.51	2.92	16.17	1.55	0.53	243.90	26.46	9.28	23.90
	Buñol	9.12	0.53	1.60	20.54	0.89	4.19	339.00	77.74	11.43	44.20
	Chera	8.10	0.62	3.46	20.52	1.18	3.96	220.50	40.12	9.35	35.00

Table IV. Annual return of nutrients through litter fall (kg ha^{-1} $year^{-1}$ D.M.) in three Kermes oak shrublands of eastern Spain: Venta Moro (10 years), Buñol (40 years) and Chera (70 years).

Sites	N	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn
V. Moro	24.43	1.22	9.16	34.37	8.60	3.99	0.44	0.04	0.03	0.04
Buñol	36.73	1.81	12.75	57.55	5.48	14.28	0.75	0.86	0.12	0.58
Chera	45.47	2.93	24.67	78.57	6.98	7.84	0.71	0.41	0.10	0.09

in descending order of importance (by weight), are K, Mn, Na and P. The four trace-elements analysed return to the soil through litter fall in total quantities of 1.3 kg ha^{-1} $year^{-1}$ at Chera, 2.3 at Buñol and 0.6 at Venta Moro. This means 0.7–1.7 % of the total amount of the elements analysed.

Comparison of our data with those of the French garrigues presented by Rapp [17] and Rapp and Lossaint [18] is not easy owing to differences in sampling and laboratory techniques. However, though the nutrient (major- and trace-elements) content of the French garrigue litter fall was higher than that of ours (maybe owing to higher nutrient concentrations in the soil), the total amount of nutrients returned to the soil is slightly higher in the Spanish Kermes oak shrublands owing to higher figures of litter biomass.

A final aspect that should be discussed is that related to retranslocation of nutrients. In the present case, the process of vernal abscission and subsequent resprouting seems to be related to intense movements of nutrients to the growing points of the plant. The major nutrient content of leaves, wood and bark of live Kermes oak shoots (*table V*) is slightly higher than that of leaf and woody litter fall. It seems, therefore, that retranslocation of nutrients occurs before leaves and shoots are shed. This behaviour could be regarded as a strategy to increase efficiency in the utilization of nutrients. It might constitute a valuable process for plants growing on nutrient-poor soils (such as those of our experimental sites) and under adverse climates (such as the semiarid Mediterranean one). However, it usually gives an inaccurate estimate of resorption because it does not include correction for weight loss of leaves. For instance, nutrients that are not resorbed at all will increase their concentration (and hence give negative resorption values) owing to the weight loss of

Table V. Mineral composition of leaf and woody litter fall and live leaves, wood and bark of Kermes oak in Valencia (eastern Spain).

	mg/g (D.M.)						µg/g (D.M.)			
	N	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn
Leaf litter fall	9.5	0.5	3.4	13.2	1.9	2.0	138	126	7	47
Woody litter fall	8.0	0.5	2.7	19.2	1.2	1.3	292	48	10	34
Live leaves	11.8	0.7	5.3	11.3	1.7	0.3	140	190	8	27
Live wood	4.8	0.3	3.3	13.6	1.7	0.1	90	30	7	22
Live bark	6.1	0.4	1.9	27.6	1.0	2.4	239	179	9	22

leaves during senescence as a consequence of reduction of other mobile nutrients and compounds such as carbohydrates. This is probably the main reason for the increase in Mg and Ca and the rather low of resorption for most mobile elements, for example N and P.

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