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Effects on rainfall gradient on tree water consumption and soil fertility on *Quercus pyrenaica* forests in the Sierra de Gata (Spain)

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ABSTRACT

Calculation of water consumption and nutrient fluxes were made for four Quercus pyrenaica forests along a rainfall gradient, located in the "Sierra de Gata" mountains (CW Spain), to obtain information about the evolution of fertility in long terms.

It is concluded that the water content at the beginning of the active growth period of the vegetation depends mainly of the soil characteristics; for that, there was a positive correlation between the annual evapotranspiration and the precipitation in the May-August period, but not with annual precipitation. So, the greater abundance of rainfall in the wet season did not tend substantially to increase water consumption by the vegetation. On the other hand, there was a high correlation between the volume of annual rainwater and that of drained water; the excess of water in the soil produced on winter gives as result a nutrient leaching of the soil and a consequent loss of fertility. This was confirmed by the net balance of several bioelements, the Ca/Al ratio and pH of the soil solution, and canopy leaching values.

Key words: water balance, nutrient balance, soil fertility, rainfall gradient, forest , ecosystem.

1. INTRODUCTION

Evapotranspiration is a relevant parameter in the understanding of terrestrial ecosystems, especially in Mediterranean areas, where water availability is scarce during dry periods (Piñol *et al.* 1991). The soil behaves as a buffered system which receives water intermittently and releases it continually by evapotranspiration (Garnier *et al.* 1986). Thus, in climates with a Mediterranean influence, a greater winter rainfall may positively affect soil moisture during the active period. Piñol *et al.* (1991) point out that annual evapotranspiration is positively correlated to annual rainfall in the Mediterranean area. This possible variation in water availability may cause differences in both photosynthetic efficiency and light interception (Jarvis & Leverenz 1983, quoted in Tenhunen *et al.* 1990), as a consequence of a lesser limitation in transpiration.

However, the differences in the volume of rainfall affect the evolution and properties of the soil profile (Birkeland 1984). Low saturation of bases and greater weathering of the original material is usually associated with humid regions (Quilchano 1993); this is due to the differences in the excess of water in the soil produced by the different pluviometry, giving rise to leaching processes of nutrients in the soil, with the resulting loss of fertility.

This double influence of rainfall on hydric and nutritional availabilities appears to have positive and negative effects, respectively, on forest productivity. The first results found in four *Quercus pyrenaica* forests, situated along a pluviometric gradient, indicate that neither productivity (Martín *et al.* 1993) nor the leaf area index (Gallego *et al.* 1994) respond to that gradient.

This study is part of a research project on the ecology of *Quercus pyrenaica* forests. Water fluxes have been con-

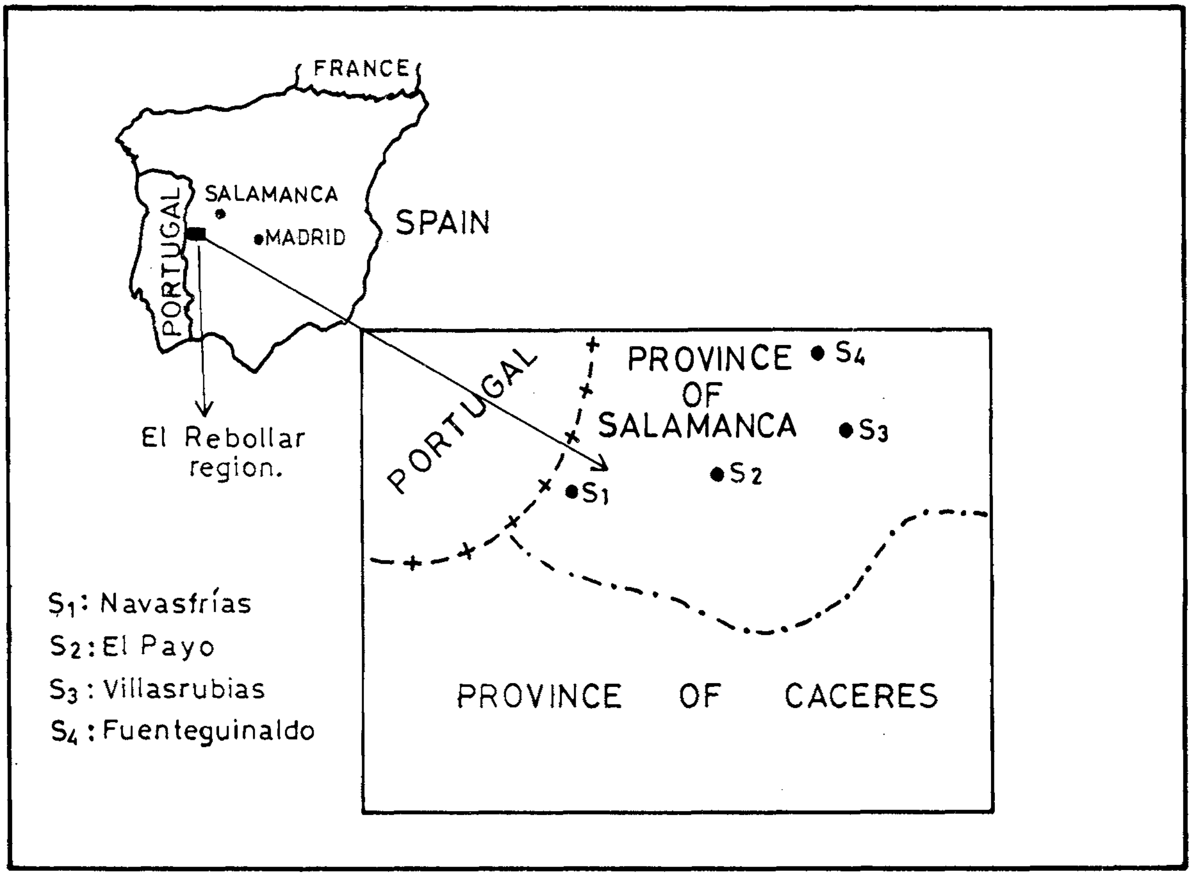

Figure 1. Localization map of the studied area.

sidered as a major determinant of vegetation growth as well as a vector for nutrient transport to and across the ecosystem. In this study we have tried to establish water and several bioelements balances in four *Quercus pyrenaica* forests along a marked pluviometric gradient, in order to obtain information on the effect of rainfall amounts on annual and summer evapotranspiration, and on nutrient leaching from the soils, and their fertility. Results are also related to productivity of these forests.

2. METHODS

2.1. The study area

This study was carried out in *Quercus pyrenaica* natural forests, classified as *Quercus robori-pyrenaicae* communities, located on the Northern face of the Sierra de Gata (40_ 2’ 40” N; 3_ 0’ 50” W, Salamanca Province, CW Spain; Figure 1). *Quercus pyrenaica* is a deciduous Mediterranean species, whose chorology corresponds to the southwestern region of Europe. The climate is humid Mediterranean, according to Emberger’s climogram, most of the rainfall being concentrated in the cold part of the year, and dryness coinciding with the warmer season and the growing period. The soils are generally humic Cambisols (Gallardo *et al.* 1980), over Paleozoic granites and slates.

Four experimental plots, situated close to one another (maximum 15 km), were selected along a pluviometric gradient. The major characteristics of the plots are summarized in Table 1.

2.2 Field sampling procedure

The devices used in each plot for collecting water to chemical analysis are:

a) Above the canopy or in a large forest gap close to the plot:

- Three aerodynamically shielded rain gauges (“open gauge”) for collecting bulk precipitation (**Bp**);
- Three funnels surmounted by an inert wind filtering

Table 1. Specific characteristics of the plots.

Experimental plot	Navasfrías (S1)	El Payo (S2)	Villasrubias (S3)	Fuenteguinaldo (S4)
Altitude (m.a.s.l.)	1000	940	900	870
P, mm	1,580	1,245	872	720
tm _C	11.4	N.d.	N.d.	13.3
Substrate	Slates and grauwackes	Calc-alkaline granite	Slates and grauwackes	Calc-alkaline granite
Dominant vegetation	Q. pyrenaica+ Pteridium+ grasses.	Q. pyrenaica+ grasses.	Q. pyrenaica+ scrubs+ grasses.	Q. pyrenaica+ abundant scrubs.
T.d. (N_/Ha)	820	406	1043	738
M.t.h., m	13	17	8.5	12
D.B.H., cm	15.2	25.4	11.0	16.5
L.A.I.	1.8	1.9	2.0	2.6

P, mm: Mean annual precipitation;
tm, _C: Mean annual temperature.
T.d.: Tree density.

M.t.h.: Mean tree height
D.B.H: Mean tree diameter at a height of 1.3 m.
L.A.I.: Leaf area index.

The S1, S2, S3, and S4 notation in Table 1 follows the decreasing order of precipitation and will be used hereafter in the text.

of polyethylene coated wire mesh ("filter gauges"), collecting bulk precipitation plus certain amount of dry deposition (**Fg**).

The 'filter gauge' enhaces the aerosol impaction, and the 'open gauge' minimizes this component in bulk precipitation (Miller & Miller 1980).

b) Beneath the trees:

- 12 standard rain gauges, randomly located, for collecting throughfall (**Tf**);
- 12 helicoidal gutters, around trunks, covering the basal area size ranges, for collecting stemflow (**Sf**).

c) On and in the soil:

- Six non-bounded gerlach type collector troughs in each plot (Sala, 1988) for measuring surface runoff (**Sr**).
- Soil solutions were collected using zero-tension lysimeters; six installed 20 cm below the soil surface, to collect water draining from the humic horizon (**SSr**), and other six installed at 60-100 cm of depth, to collect water of deep drainage (**D**)

The lysimeters were made from PVC, and the different type of rain gauges consisted of a polyethylene funnel. All devices were connected to a 5 l collecting bottle. Different filters were used to prevent contamination of water.

Water precipitation was recorded hourly with two tipping-bucket rain-gauges located above the crown in S1 and S4. Global shortwave radiation, air temperature, relative humidity and wind velocity were recorded as hourly means, using a data logger (Starlog 7000B Unidata) also only in S1 and S4.

Soil water content was measured with a neutron moisture gauge (Troxler 3321 A 110 mC of Americium/Berilium) at 12 access tubes in each stand. Soil moisture was measured every 20 cm from 20 to 100 cm depth, as a maximum, according to the depth of the soil. On the surface, soil moisture was measured by gravimetric method. Measurements were taken approximately once a month (occasionally every two weeks) over forty months: from March 1990 until September 1993. The calibration curves were determined from gravimetric samples and dry bulk densities, according to Vachaud *et al.* (1977).

The physical and chemical soil characteristics were studied in three selected profiles of each plot. The results have been discussed in previous papers (e.g. Moreno *et al.* 1993 and Quilchano 1993).

3.3. Calculation of water balance

Taking as a basis the hourly record in S1 and S4, the daily distribution of rainfall on S2 and S3 was estimated, once the high correlation existing between the distribution of rainfall on the four sites was verified. The records were also used to estimate the daily distribution of throughfall, taking into account the crown capacity for water retention (Zinke 1967). The Penman potential evapotranspiration was estimated following the recommendations of the FAO (Smith 1991).

The water balance equation was used as a basis: $dS/dt = Bp - EA - Sr - D$; (1)

where S is the soil water storage, Bp the precipitation, EA the actual evapotranspiration, Sr the surface runoff, and D the deep drainage, i.e. the flow of water below the root zone (including almost all the roots). This notation will be used hereafter. The precipitation, runoff and changes in soil water storage are readily measurable, but both EA and D are difficult to measure or to calculate.

Hence a water balance model was used which employed a simplified relationship between the drainage component and soil water content, characterizing the downflow of water across a certain level according to the water content existing above that level (this function is called the drainage characteristic; more detailed information in Rambal 1984 and Joffre & Rambal 1993).

The equation (1) is solved iteratively, for each period comprised between two readings of soil moisture, with a time step of one day (during periods of heavy precipitation, time step of one hour), i.e., starting at Sn and ending at Sn+1, fitting the term EA, the only unknown. The iterations continue until the measured and calculated value of Sn+1 coincide. It is always considered that $EA \leq EP$ (potential evapotranspiration).

When it is not possible to obtain this equality (1), a term known as "others" is introduced. It is probably a combination of EA, Sr and D. This is because in a rainy period EA can be greater than EP (Rutter 1975); moreover, even when the soil is not humid enough, deep drainage can exist, flowing through paths of rapid circulation, i. e. macropores (Beven & German 1981), which is not included in the calculation model used.

3.4.Calculation of nutrient fluxes

Above ground, water fluxes were measured, on an event basis (64 cases), immediately after each rainfall event, over the period 21 September 1990 - 20 September 1993. In 23 events, water was collected for chemical analysis.

The fluxes on a mass basis (kg ha^{-1}), for each parameter, were calculated multiplying the average weighted concentration (mg l^{-1}) by amount of water (mm), either measured (aboveground parameters and surface runoff) or calculated (deep drainage).

The net forest water (i.e., deposition in throughfall + stemflow, minus bulk deposition) is regressed against the gain in the deposition resulting from the aerosol deposition on the "filter gauge" (Bp - Pf). This regression results in an intercept term representing the mean value of canopy exchange (CE) for equal time periods (Lakhani & Miller 1980). Dry deposition (Dd) is calculated thus: $Dd = Tf + Sf - Bp - CE$, where Tf, Ef, Bp and CE are known. Total deposition (Tdep) from atmosphere is Bp + Dd. More detailed information can be found in Lakhani & Miller (1980) and Bellot (1988).

3.5. Laboratory analytical procedure

pH was measured with a pHmeter Beckman 3500, and dissolved organic carbon (D.O.C.) was measured on a T.O.C.A. (315A Beckman). These analyses were performed as soon as possible after collection (within first day). Na and K were analyzed by flame emission; Ca and Mg by atomic absorption spectrometry; Fe, Mn and Al, by ICP; P were determined spectroscopically by molybdenum-blue method; Cl^-, $NO3^-$, $SO4^{2-}$ and $NH4^+$, were analyzed by ion-chromatography. Complete analysis were generally done within about one week.

3.6. Statistical Analyses

Statistical analyses were performed by one-way analysis of variance with repeated measures, followed by a posteriori contrasts (Tukey-test) for multiple comparison of means, in order to detect variations between sites and between years. The results were expressed as equality probabilities (p). Simple regresion models were used to assess relationships between P and EA or D. The results were expressed as regression coefficients (r^2) and level of significance (p).

Table 2. Annual water balance of the four plots, in mm / year. % in relation to precipitation. The years refer to the period between 21/IX to 20/IX.

Year	Flows	S1 mm	S1 %	S2 mm	S2 %	S3 mm	S3 %	S4 mm	S4 %
1990 -91	Precipitation	1306		1188		1045		782	
	Interception	144	11	95	8	112	11	76	10
	Surface Runoff	2.1	0.2	1	0.1	3	0.3	0	0.0
	Deep Drainage	868	66	791	67	626	60	443	57
	Others	16	1.2	0	0.0	20	1.9	0	0.0
	Actual Evapotr.	408	31	382	32	385	37	325	42
	Potential Evapotr.	817		820		822		825	
1991 -92	Precipitation	777		658		610		442	
	Interception	147	19	160	24	112	18	96	22
	Surface Runoff	4	0.5	2	0.3	1	0.2	0	0.0
	Deep Drainage	212	27	170	26	111	18	19	4
	Others	49	6.3	15	2.3	25	4.1	13	2.9
	Actual Evapotr.	506	65	475	72	475	78	421	95
	Potential Evapotr.	806		819		832		845	
1992 -93	Precipitation	1086		953		820		650	
	Interception	163	15	131	14	127	15	125	19
	Surface Runoff	6	0.6	1	0.1	1	0.1	0	0.0
	Deep Drainage	404	37	373	39	239	29	106	16
	Others	54	5.0	18	1.9	20	2.4	8	1.2
	Actual Evapotr.	525	48	506	53	536	65	509	78
	Potential Evapotr.	753		763		773		783	

4 RESULTS AND DISCUSSION

4.1. Water balance

Precipitation

Table 2 shows the annual rainfall values for the three years, which, from the point of view of pluviometry and comparing them with the mean annual values (see Table 1) can be defined as normal (1990-91), very dry (1991-92) and moderately dry (1992-93). During the three studied years, the pluviometric gradient from which we started *a priori* was maintained; the differences between plots remained fairly constant during the three years, in relative terms (88, 78 and 59% of the rainfall in S1, for S2, S3 and S4, respectively). Annual precipitation differed significantly, among all plots and among all years (ANOVA, $p < 0.001$ in both cases). Nevertheless, daily rainfall distribution is similar in all the plots, with correlation coefficients around 90%. The seasonality of the rainfall and its acute irregularity are outstanding features; in this sense, in the 1990-91 period, rainfall was very abundant during autumn-winter but no important precipitations were recorded after mid-March. On the other hand, over the following two years the rainfall, although less abundant, was distributed more regularly with important precipitation recorded until the beginning of June. Averaged across all plots and years, the intensity of the precipitation was generally moderate and it was never above 14 mm h^{-1}. The intercepted water was 16% of the annual rainfall, and 14% during leafless period.

Evapotranspiration

EA only differs significantly among S4 - S1 plots (ANOVA, $p < 0.05$); S4 generally gives lower values, due to less precipitation and its smaller soil water storage (Table 2). These differences are mitigated even more if we subtract from EA the intercepted water, of little value for the vegetation (Rutter 1975). Between years significant differences are, in fact, found (ANOVA, $p = 0.001$), but with the lowest during the year of highest precipitation. Pooling together all plots, anual Bp and EA are uncorrelated ($r^2 = 0.17$, $p < 0.05$). The annual values of EA in relation to EP average 46% (range 39-50%), 55% (range 50-61%) and 72% (range 70-74%), in the years 1990-91, 1991-92 and 1992-93, successively. The moderate amount of water stored in the soil (Moreno *et al.* 1993) does not prevent there being a large water deficit during the active period. The maximum values of actual evapotranspiration in absolute terms were generally reached in June (sometimes May or July). Consumption begins to decrease generally in July, reaching very low values as early as August, when available soil water is practically depleted, remaining almost constant for approximately one month, depending on when the first autumn rains occur. Paz & Díaz-Fierros (1985) found in *Quercus robur* that the soil remained dry for two months in a year with 1368 mm of rainfall in the northwest of Spain; Joffre & Rambal (1988, 1993) obtained similar results in southern Spain. The daily mean values of EA, for the May-July period and for August, are shown in Table 3. Polling all plots, a positive relationship ($r^2 = 0.72$, $p < 0.001$) between total precipitation in the May-August period and the EA during this same period was found.

Comparing the monthly EA values of the four plots, significant differences were obtained between S4 and the other three plots, which showed slightly higher values; however, if the water intercepted is subtracted, these differences become considerably reduced. Daily EA distribution in the four plots is very similar, with correlation coeficients above 0.85.

Drainage

Drainage (D) increased with rainfall (Table 2), and significant differences were established both on the level of years and of plots (ANOVA, $p < 0.001$ and $p = 0.05$, respectively). Thus, pooling all plots, the existing relationship is: $D = 0.997*Bp - 494$ ($r^2 = 0.85$; $p < 0.001$), expressing D and Bp as mm year^{-1}. This relationships did not be set up for each plot indvidually due to a insufficient number of data (only 3 years).

These results indicate how easily an excess of water, and therefore deep drainage, can occur in these soils; a precipitation above 490 mm year^{-1} causes an excess of water in the soil, and practically all the rainwater over that figure will be drained. In other papers consulted, this limit was (mm·year^{-1}) 360 (Avila 1988), 400 (Piñol *et al.* 1991), 578 (Rambal 1984), 450 (Likens *et al.* 1977), 420 (Hudson 1988), 470-500 (Lewis 1968). Additionally, the rapid moistening of the deep horizons could imply the existence of water loss by drainage, due to rapid circulation in macropores (Beven & German 1981), although the soil is still far from reaching field capacity, a fact that is not included in the model used.

Surface runoff

The results indicate that the runoff decreases according to the following order: S1>S3>S2>S4 (table 2), and is well correlated with the slope of the plots (Table 1); the latter plot, with almost no slope, has null runoff. The greatest amounts were obtained for the year with the least precipitation. It occurs mainly in autumn (when rain intesity is greater); at no time the runoff was due to saturation of water in the soil. In these plots, according to our observations, this water did not transport appreciable amounts of sediment. The volume of water lost through surface runoff can also be said to be very low, as is frequently true in forest ecosystems (Rambal 1984; Francis & Thornes 1990; Soler & Sala 1992).

4.2. Nutrient balances

Atmospheric deposition

Amounts of atmospheric deposition can be described as moderate to scarce, in almost all the elements (Figure 2), when compared with those obtained in the northeastern Spain (e.g., Avila 1988; Bellot 1988; Belillas & Rodá 1991), Europe (e.g., Miller *et al.* 1987; van Breemen *et al.* 1988; Tietema & Verstraten 1991), U.S.A. (e.g., Likens *et al.* 1977; Lindberg & Owens 1993), and with mean values obtained by Parker (1983). They are especially low for ions such as $SO4^{2-}$, $NH4^{+}$ and $NO3^{-}$, which are mainly anthropogenic (Belillas & Rodá 1991), which in more industrialized regions show clearly higher values. There is no evidence of acid or polluted depositions of anthropogenic origin in this region. Regarding the differences along the pluviometric gradient, when the total deposition is considered (bulk and dry) the amounts were similar among plots.

Losses from the soil

The leaching of elements, nutritive or otherwise, from the soil, is a process controlled mainly by the content in anions and hydrogen ions, as the electrochemical equilibrium in the solution draining from the soil is maintained (Johnson *et al.* 1986).

The results obtained are shown in Table 4 and Figure 2.

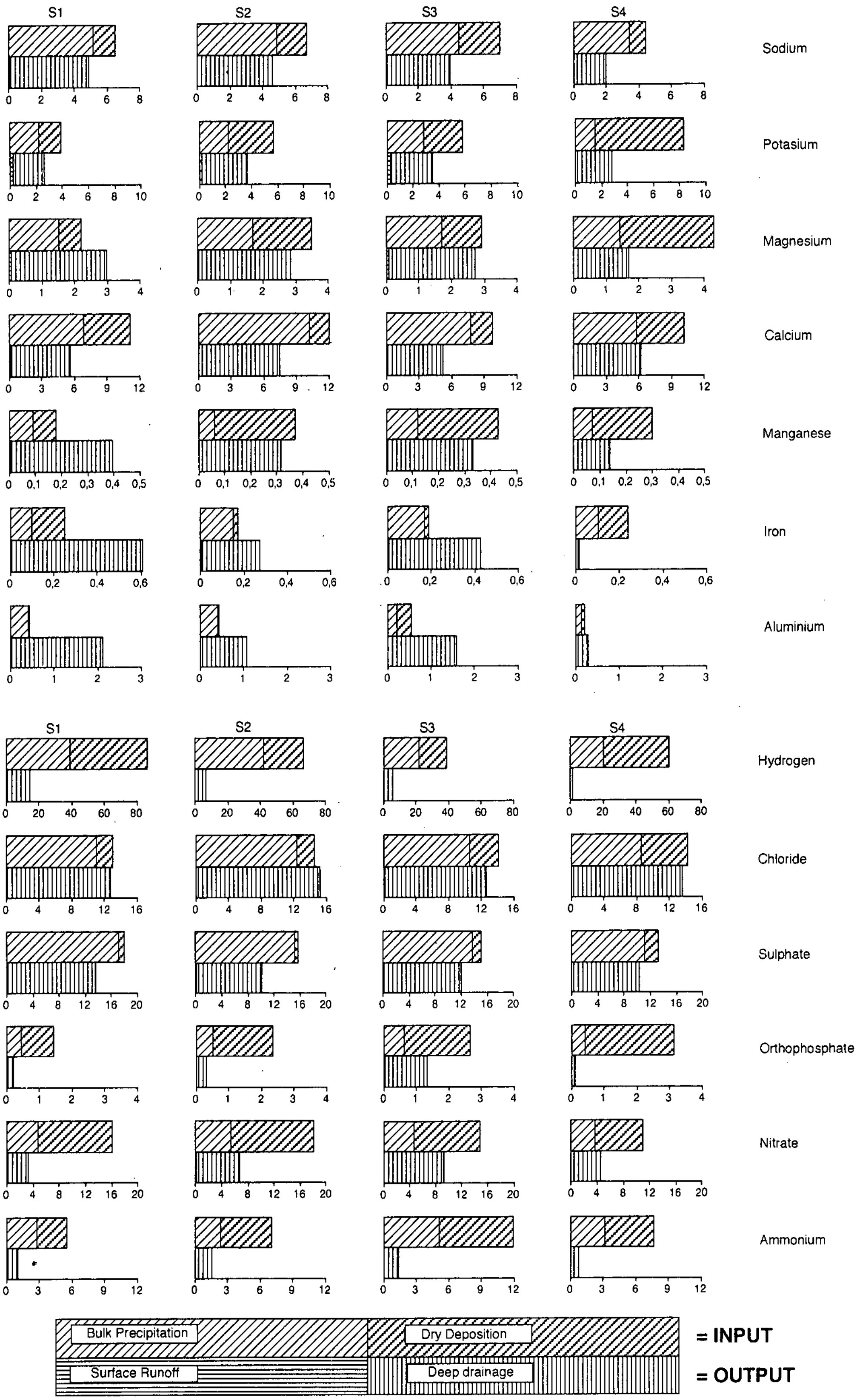

Figure 2. Annual balance of dissolved elements in four different plots (S1 to S4), calculated as the difference between input (bulk and dry deposition, upper bars) minus output (surface runoff and deep drainage, lower bars).
Values expressed as kg ha-1 year-1, except H+ (g ha-1 year-1).

Table 3. Mean daily values of actual evapotranspiration in two different periods, May-June-July (M-J-J) and August (A). Values expressed in mm day-1.

EA	S1 M-J-J	S1 A	S2 M-J-J	S2 A	S3 M-J-J	S3 A	S4 M-J-J	S4 A
1990	1.85	0.90	1.84	0.76	1.83	0.86	1.42	0.62
1991	1.83	0.43	1.49	0.74	1.76	0.94	1.33	0.45
1992	2.28	1.05	2.09	0.80	2.06	0.81	1.67	0.43
1993	2.59	1.14	2.59	0.99	2.73	0.90	2.65	0.80
Means	2.14	0.88	2.00	0.82	2.10	0.88	1.77	0.57

The scanty change produced in the pH of the water when passing through the soil is indicative of the reduced effect of the hydrogen ions on the leaching process of bases in the soils studied, except on the surface, where there is an important increase in the nutritive cations in the solution. In the rest of the soil the process is inverted, with a retention of bases and a leaching of hydrogen ions (Table 4). The increase in pH is higher in S2 and S4 (granite) than in S1 and S3 (grauwackes); also the increase is lower in the more rainy plots. These differences coincide with the content in base-cation and thus the buffering capacity of the soils (Quilchano 1993).

As for the anions, their behaviour is highly irregular, although all of them experiment a considerable increase on passing through the forest floor (Table 4). Almost all the phosphate is subsequently retained as a consequence of the high adsorption capacity of P that the soil minerals have (Yanai 1991). $NO3^-$, together with the cation $NH4^+$, show more complex behaviour, which will not be discussed in this paper. Cl^- and $SO4^{2-}$ pass through the soil with hardly any significant gains or losses; as a whole they may represent an important flow as regards the washing of cations; this is, however, not so much due to the fact that they represent fairly low atmospheric deposition rates, especially in $SO4^{2-}$, considered to be largely responsible for the leaching of bases (David *et al.* 1991).

Therefore, neither the hydrogen ions nor the anions seem to be an important source for causing the leaching of bases in the studied soils. Thus, although Na, K, Mg and Ca undergo a considerable increase on passing through the forest floor (especially K), together with an increase in pH, the concentration of all of them decreases again in both the humic and the exchange horizons (together with a decrease in pH) (Table 4). That is, the cations are retained in the soil (either by root absorption or by entry into the exchange sites), so that the losses from the soil are lower than the atmospheric inflow, there being thus a net gain (Figure 2). The order of these gains (% with respect to the Tdep) is: K > Ca = Na > Mg > Mn > Fe > Al.

The sum of the net losses (outputs - inputs) of the four major cations is known as the Cationic Denudation Rate (CDR, Avila 1988), expressed in keq ha^{-1} $year^{-1}$. In our case the results are: -0.24 (S1), -0.35 (S2), -0.24 (S3) y -0.57, i.e., the CDR is negative due to the existence of net gains. If we consider Bp instead of Tdep, in order to contrast it with the results in the literature, the results are: 0.14 (S1), 0.06 (S2), 0.07 (S3) y 0.10 (S4). In any case these values are well below the mean of 1.03 keq ha^{-1} $year^{-1}$, described by Avila (1988); of the 22 cases given by this author, 19 show net loss values higher than those obtained in our plots, two of them show similar values, and only one shows net losses lower than our case. The values in the 22 cases vary from -0.12 to 4.4. In the Mediterranean region, the values obtained are 1.3 in Montseny (Avila 1988) and 1.8 in Prades (Escarré *et al.* 1984).

The soils show a greatly decreased base saturation level, lower in the plots with higher rainfall (Quilchano 1993), hence the availability of bases, to be exchanged for H^+ or to accompany an anion, is scarce. This fact, together with the scant acidity of the precipitation and the anion content of the atmospheric inflow, contributes to the scant leaching of the bases of these soils.Another aspect of interest in obtaining a knowledge of the fertility conditions of the soil is the Ca/Al ratio (molar quotient) in the soil solution as Abrahamsen (1983) pointed out; this author, quoting Ulrich (1981), points out that a value of 1 or less indicates a degraded state of the forest soils, even phytotoxicity by Al. In our case the values obtained were:

	S1	S2	S3	S4
Ess	0.95	1.52	2.07	4.04
D	1.79	4.73	2.23	14.73

Table 4. Volume weigted mean annual chemical concentratios in four different flows (S1 to S4).

mg/l	pH	DOC	Cl	SO4	PO4	NO3	NH4	Na	K	Mg	Ca	Mn	Fe	Al
Tf-S1 (23)	5.45	9.9	1.9	1.61	0.15	0.53	0.26	0.53	0.85	0.50	1.36	0.050	0.030	0.05
Tf-S2 (23)	5.53	13.9	2.3	1.89	0.46	0.83	0.31	0.67	1.84	0.72	1.48	0.090	0.030	0.06
Tf-S3 (23)	5.64	15.7	2.5	1.92	0.43	0.83	0.32	0.70	1.85	0.85	1.62	0.130	0.040	0.10
Tf-S4 (23)	5.59	23.5	3.5	2.30	1.16	0.73	0.60	0.65	3.19	1.14	2.00	0.100	0.050	0.10
Sr-S1 (17)	5.73	48.8	3.07	2.73	0.40	1.56	0.78	0.73	5.87	1.59	2.58	0.176	0.120	0.34
Sr-S2 (16)	5.81	115.9	5.66	3.54	1.62	6.29	3.11	0.921	7.54	2.18	3.19	0.312	0.172	0.78
Sr-S3 (14)	6.22	81.0	6.75	6.92	2.50	4.12	2.53	1.131	6.35	3.55	4.06	0.348	0.154	0.60
Sr-S4 (7)	6.62	147.2	7.34	11.67	8.71	16.00	9.52	1.83	45.06	4.84	9.97	0.487	0.175	0.26
SSr-S1 (9)	5.74	21.0	3.09	3.81	0.03	0.49	0.60	1.02	1.72	1.08	1.08	0.034	0.038	0.77
SSr-S2 (10)	5.53	28.9	2.84	3.14	0.09	4.43	1.29	0.87	3.38	1.04	1.21	0.054	0.054	0.54
SSr-S3 (8)	5.89	57.2	3.29	2.93	0.25	6.67	1.22	1.00	2.88	1.89	2.74	0.060	0.080	0.90
SSr-S4 (5)	6.01	47.8	5.17	6.15	0.21	16.29	1.38	0.761	0.14	2.70	6.51	0.093	0.081	1.09
D-S1 (9)	5.49	8.4	2.81	2.96	0.04	0.67	0.23	1.06	0.54	0.63	1.22	0.085	0.079	0.46
D-S2 (5)	5.79	4.8	3.97	2.46	0.07	1.64	0.39	1.13	0.84	0.69	1.79	0.074	0.069	0.26
D-S3 (5)	5.72	17.2	4.46	4.22	0.45	3.28	0.49	1.41	1.14	0.94	1.85	0.116	0.152	0.56
D-S4 (3)	6.12	12.3	8.01	6.11	0.07	2.74	0.45	1.20	1.68	1.04	3.70	0.083	0.011	0.17

Tf= Througfall; Sr=Surface runoff; SSr= Subsurface runoff; D=Deep drainage.
The numbers of analysed events, for each flow and plot, are shown in n parentheses.

Ess is water draining from the humic horizons and D is water of deep drainage.

Although the Ca/Al values do not indicate a very unfavourable situation, common in areas with much more acid precipitation than that obtained in this study (Abrahamsen 1983), they do show the effect of the abundant precipitation on the soil fertility in this area, with S1 values which indicate a very low level of fertility, and with high levels of Al in the soil water. The situation improves (lower relative importance of Al) as the pluviometric gradient decreases.

In addition to the Ca/Al quotient, the net gains for K, Mg, Na, $NH4^+$, $H4PO4^-$, Fe, Mn, among others, increase when precipitation decreases (Figure 2).

5 CONCLUSION

Although the study dealt with situations where the precipitation was markedly different, both on the level of years and of plots (range from 442-1306 mm year^{-1}.), the soils had a similar water content in the different years at the beginning of the active growth period of the vegetation; the water content depends mainly on the soil characteristics and not so much on the precipitation received during the wet season (Moreno *et al.*, 1993).

Taking as a basis the soil water balance, we obtained decreasing transpiration rates over the active period, reaching acutely low levels. Unless the oaks have an efficient deep radicular system for extracting water from the weathered bedrock, they could be subjected to an important restriction of water during part of the summer season. Moreover, the vegetation shows great dependence on the rains of the dry season. The water gradient does not seem to define outstanding differences in the water consumption patterns for the vegetation in this area.

The relative facility with which an excess of water in the soil is produced in winter, together with the high correlation existing between the volume of rainwater and that of drained water, cause an important leaching of the soil and a consequent loss of fertility, which becomes greater as the pluviometry gradient increases. This fact is evident in the figures of the CDR and the Ca/Al ratio. In fact, both on the level of dry matter production and leaf area index, the higher values are obtained in the plots with less precipitation (Martín *et al.* 1993; Gallego *et al.* 1994).

It can be concluded that the greater abundance of rain in the wet season did not tend to increase water consumption by the vegetation, at least not substantially; on the other hand, it did entail a greater leaching of the soil and the consequent loss of fertility, which is especially manifested in a decrease of bases, degree of saturation and pH, as demonstrated by Quilchano (1993) in these same forests.

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REFERENCES

ABRAHAMSEN, G. (1983). Sulphur pollution: Ca, Mg and Al in soil and in soil water and possible effects on forest trees. En: B. Ulrich & J. Pankrath (eds.), Effects of accumulation of air pollutants in forest ecosystems. D. Reidel Publishing, 207-218.

AVILA, A. (1988). Balanç d'aigua i nutrients en una conca d'alzinar del Montseny. Estudis i monografies 13. Diputació de Barcelona, 219 pp.

BELILLAS, M. C. & RODA, F. (1991) Nutrient budgets in a dry heatland watershed in northeastern Spain. Biogeochemistry 13, 137-157.

BELLOT, J. (1988) Análisis de los flujos de deposición global, transcolación, escorrentía cortical y deposición seca en el encinar mediterráneo de L'Avic (Sierra de Prades, Tarragona). Tesis Doctoral, Univ. Alicante.

BEVEN, K. & GERMANN, P. (1981). Water flow in soil macropores, II A combined flow model. J. Soil Sci. 32, 15-29.

BIRKELAND, P.W. (1984). Soil and geomorphology. Oxford University Press. New York.

DAVID, M.B., VANCE, G.F., FASTH, W.J. (1991). Forest soil response to acid and salt additions of sulphate: Aluminium and base cations. Soil Science 151, 208-219.

ESCARRE, A., GRACIA, C.A., RODA, F. & TERRADAS, J. (1984). Ecología del bosque esclerófilo mediterraneo. Investigación y Ciencia 95,68-78.

FRANCIS, C.F. & THORNES, J.B. (1990). Matorral erosion and reclamation. En: J. Albadalejo, M.A. Stocking y E. Díez (Eds.), Degradación y regeneración del suelo en condiciones ambientales mediterraneas. C.S.I.C., 87-116.

GALLARDO, J.F., CUADRADO, S.& PRAT, L. (1980). Características de los suelos forestales de la sierra de Gata. Stvdia Oecologica I, 241-264.

GALLEGO, H.A., RICO, M., MORENO, G. & SANTA-REGINA, I. (1994). Leaf water potentials and stomatal conductances in Quercus pyrenaica willd. forest: Vertical gradients and response to environmental factors. Tree physiology 14, 1039-1047.

GARNIER, E., BERGER, A. & RAMBAL, S. (1986). Water balance and pattern of soil water uptake in a peach orchard. Agriculture Water Management 11, 145-158.

HUDSON, J. (1988). The contribution of soil moisture storage to the water balances of upland forested and grassland catchments. Hydrol. Sci. J. 33, 289-309.

JOFFRE, R.; RAMBAL, S. (1988). Soil water improvement by trees in the rangelands or southern Spain. Acta OEcologica, OEcol. Plant. 9, 405-422.

JOFFRE, R. & RAMBAL, S. (1993). How tree cover influences the water balance of mediterranean rangelands. Ecology 74, 570-582.

JOHSON, D.W., COLE, D.W., VAN MIEGROT, H. & HORNG, F.W. (1986). Factors affecting anion movement and retention in four forest soils. Soil Sci. Soc. Am. J. 50, 776-783.

LAKHANI, K.H. & MILLER, H.G. (1980) Assessing the contribution of crown leaching to the element content of rainwater beneath trees. In: Hutchinson T.C. & Havas, M. (Eds) Effects of Acid Precipitation on Terrestrial Ecosystems (pp 161-171). Plenum Press.

LEWIS, D.C. (1968). Annual hydrologic response to watershed conversion from oak woodland to annual grassland. Wat. Resour. Res. 4, 59-72.

LIKENS, G.E., BORMANN, F.H., PIERCE, R.S., EATON, J.S. & JOHNSON, N.M. (1977). Biochemistry of a forested ecosystem. Springer-Verlag, New York, 148 pp.

LINDBERG, S.E. & OWENS, J.G. (1993) Throughfall studies of deposition to forest edges and gaps in montane ecosystems. Biogeochemistry 19, 173-194.

MARTIN, A.; GALLARDO, J.F. & SANTA REGINA, I.(1993). Interacción entre la hojarasca y el suelo en ecosistemas forestales de la Sierra de Gata (Provincia de Salamanca, España). En: J.F. Gallardo (Ed.), El estudio del suelo y de su degradación en relación con la desertificación. MAPA, Madrid. I, 1689-1695.

MILLER, H.G. & MILLER, J.D. (1980) Collection and retention of atmospheric pollutants by vegetation. In: Drabløs, S. & Tollan, A. (Eds) Ecological impact of acid precipitation. Proc. conf. ecol. impact acid precip. Norway, 1980, SNSF project. pp 33-40

MILLER, H.G., MILLER, J.D. & COOPER, J.M. (1987) Transformations in rainwater chemistry on passing through forested ecosystems. In: Coughtrey, P., Martin, M., & Unsworth, M. (Eds) Pollutant transport and fate in Ecosystems (pp 171-180). Blackwell Scientific.

MORENO, G, CUADRADO, S, GALLARDO, J.F. & HERNANDEZ, J. (1993). Dinámica estacional de la humedad edáfica en bosques de Quercus pyrenaica considerando un gradiente pluviométrico. Procc. Congreso Forestal Español. Lourizán, España, 1, 163-169.

PAZ, A. Y DIAZ-FIERROS, F. (1985). Contribución al conocimiento de la utilización del agua del suelo por las especies forestales (Quercus robur y Pinus pinaster) bajo clima templado húmedo. An. Edaf. y Agrobiol. 64, 1081-1100.

PARKER, G.G. (1983) Throughfall and stemflow in the forest nutrient cycling. Adv. Ecol. Res. 13, 58-121.

PIÑOL, J., LLEDO, M.J. & ESCARRE, A. (1991). Hydrological balance of two Mediterranean forested catchments (Prades, northeast Spain). Hydrologycal Sciences - Journal des Sciences Hydrologiques 36, 95-107.

QUILCHANO, C. (1993). Contribución al estudio de algunos parámetros edáficos relacionados con los ciclos biogeoquímicos en ecosistemas forestales. Tesis Doctoral. Universidad de Salamanca

RAMBAL, S. (1984). Water balance and pattern of root water uptake by a Quercus coccifera L. evergreen scrub. Oecologia 62, 18-25.

RUTTERS, A.J. (1975). The hidrological cycle in vegetation. In: J.L. Monteith (Ed.), Vegetation and atmosphere. Academic Press, 111-152.

SALA, M. (1988). Lavado superficial de las vertientes. In: S.E.G. (ed.), Metodos y técnicas para la medición en el campo de procesos geomorfológicos. Monografia 1, 25-30.

SMITH, M. (1991). Report on the expert consultation on procedures for revision of FAO Guidelines for prediction of crop water requirements. Land and Water Development Division. F.A.O., 45 pp.

SOLER, M. & SALA, M. (1992). Effects of fire of clearing in a Mediterranean Quercus ilex woodland: an experimental approach. Catena 19, 321-332.

TENHUNEN, J.D., SALA, A., HARLEY, P.C., DOUGHERTY, R.L. & REYNOLDS, J.F. (1990). Factors influencing carbon fixation and water use by mediterranean sclerophyll shrubs during summer drougth. Oecologia 82, 381-393.

TIETEMA, A. & VERSTRATEN, J.M. (1991) Nitrogen cycling in an acid forest ecosystems in the Netherlands under increased atmospheric nitrogen input. The nitrogen budget and the effect of nitrogen transformations on the proton budget. Biogeochemistry 15, 21-46.

VACHAUD, G., ROYER, J.M. & COOPER, J.D. (1977). Comparison of methods of calibration of a neutron probe by gravimetric or neutron-capture model. Journal of Hidrology 34, 343-355.

VAN BREEMEN, N., VISSER, W.F.J., & PAPE, TH. (1989) Biogeochemistry of an oak-woodland ecosystem in the Netherlands affected by acid atmospheric deposition. Agric. Res. Rep. PUDOC, Wageningen. 197 pp.

YANAI R.D.(1991). Soil solution phosphorous dynamics in a whole-tree harvested northern hardwood forest. Soil Sci. Soc. Am. J. 55, 1746-1752.

ZINKE, P.J. (1967). Forest and water in the light of scientific investigation. U.S. Senate Doc. 469, 62d Congr. 2nd Sess. 106 pp.