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Original article

Biomass, litterfall and nutrient content in *Castanea sativa* coppice stands of southern Europe

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Summary – Aboveground biomass and nutrient content, litterfall and nutrient return to the soil were studied in *Castanea sativa* Mill forests near Salamanca (Spain), Montpellier (France) and Catania (Italy). Best regression equations for the aboveground biomass were obtained by applying the allometric Y (biomass) = aX $(DBH)^b$ method. The three different regression equations were very similar, especially when comparing the Italian and French sites. The main source of difference concerned the different DBH repartition for trees at the six sites. Litter production was higher in the Spanish stand than in the Italian stands. N, Ca and Mg recycled in the same proportion in all stands. In contrast, twice as much P and K was recycled in the Italian stands than in the Spanish stand.

biomass / litterfall / *Castanea sativa* / nutrient content

Résumé – Biomasse, retombée de litière et teneur en nutriments dans des taillis de *Castanea sativa* Mill du sud de l'Europe. *Les biomases et les minéralomasses, les retombées de litière et la restitution au sol de bioéléments par leur intermédiaire ont été étudiées dans des peuplements de* Castanea sativa *Mill en Espagne (province de Salamanque), en Italie (massif de l'Etna) et en France (Cévennes). Les meilleurs corrélations et résultats ont été trouvés avec des régressions allométriques de type : Y (biomasse) = aX (diamètre tronc à 1,30 m)^b. Les paramètres des différentes équations de régression sont semblables et très proches pour les châtaigniers de France et d'Italie. La principale source de différences, au niveau stationnel, résulte de la répartition différente des arbres en fonction des classes de diamètre du tronc à 1,30 m dans les six stations étudiées. Les retombées de litière sont plus importantes dans la station espagnole que pour les peuplements de Sicile. La restitution au sol de N, Ca et Mg se fait dans les mêmes proportions dans toutes les placettes étudiées, alors que le recyclage vers le sol de P et de K est le double dans les stations italiennes par rapport au site espagnol.*

biomasse / minéralomasse / litière /* Castanea sativa *Mill

INTRODUCTION

Forest biomass, forest productivity and the attendant uptake and nutrient management have been widely studied over the last few decades (Bray and Gorham, 1964; Kira and Shidei, 1967; Wittaker and Niering, 1975; Cabanettes and Rapp, 1978; Cole and Rapp, 1980; Grier et al, 1981, 1992; Satoo and Madgwick, 1982; Ohmann and Grigal, 1985; Freedman et al, 1986; Brown et al, 1989; Douglas and McNaughton, 1990).

The role of nutrients in forest ecology and productivity has recently received more attention (Ranger and Bonneau, 1984, 1986), especially in relation to: i) agricultural abandonment, which allows reforestation on much better soils than in the past, involving larger amounts of nutrients in the biogeochemical cycle of forests; ii) the increased nutrient input from dry atmospheric deposition and by rain, and their recycling within the biogeochemical cycle.

There is now much available data on biomass and nutrient contents in various forest stands; however, they mainly focus on highly productive or widely representative species, or are related to specific site conditions. Comparisons and extrapolations are also often limited by marked methodological differences.

Sweet chestnut (*Castanea sativa* Mill) stands are very common all around the western Mediterranean Basin. Formerly managed as coppices, these stands were regularly clear-cut every 15 to 25 years, according to their local productivity under various local conditions.

In the past, sweet chestnut stands served two purposes: their fruits were consumed as a staple food for local people, while the wood was used for local purposes such as wine barrels, vineyard pegs, tool handles and carpentry.

Castanea sativa coppice management is now more or less abandoned. Fruit production occurs mostly in orchards and the wood is only used for barrels or fuel. Nevertheless, chestnut coppices cover large areas in the Mediterranean mountains of France, Italy and Spain. In these countries, and in Portugal, several sites were investigated simultaneously.

Although these sites have various types of soil, the climates are similar. Differences in latitude are minimized by the corresponding stand elevations above sea level. Since most of the sites were studied by the same methodology, it was possible to compare biomass, nutrient content and productivity of some in order to establish a general model for nutrient management processes occurring in *Castanea sativa* Mill stands of the western Mediterranean.

Biomass of individual trees, aboveground stand biomass, their yearly increments and nutrient contents were studied in coppices of Spain, Italy and France. Litterfall and nutrient removal from trees to the soil were also assessed and allowed us to estimate aboveground primary production, as well as nutrient uptake from the soil, by the same aboveground part of the forest ecosystem.

MATERIAL

Study sites

In Italy, four *Castanea sativa* stands were selected around the Etna volcano along an elevational gradient. Two stands were situated between 1 400 and 1 600 m above sea level (Balilla and Fossa la Nave) on the southern side of the volcano, while two others (Monte Crisimo and Piano Porcheria) were on the eastern slope between 1 000 and 1 200 m above sea level. Balilla and Monte Crisimo were mature stands, whereas Fossa la Nave and Piano Porcheria were even-aged young coppices. The two stands of Balilla and Fossa la Nave had a mean density of 250 stems ha^{-1} and a mean shoot density of 1 700 stems ha^{-1}. The two stands at elevations were more dense, with, respectively, 290 and 440 stems ha^{-1} and 5 500, 5 700 shoots ha^{-1} (Leonardi et al, 1995a).

Table I. Site and forest characteristics for the experimental plots.

Site	*Altitude (m)*	*Mean temp (°C)*	*Pluviometry (mm year^{-1})*	*Parent material*	*Soil*	*Tress /ha*	*Age (years)*	*STm^2*
Fossa la Nave	1 600	7.5	1 110			1 895	8	26.0
Balilla	1 400	8.4	1 110	Volcanic ash and lava	Regosol volcanic	1 529	22	112.9
Monte Crisimo	1 200	13.3				5 529	12	94.1
Piano Porcheria	1 000	13.3	1 180			5 668	7	28.1
San Martín	960	14.2	1 180	Granite	Cambisol	3 970	25	
Le Vernet	800	12.7	690	Schist	Cambisol	2 706	>30	33.0

The San Martín stand (Spain) was located in the Sierra de Gata (Caceres Province), west of Salamanca, at 940 m elevation. The French stand of Le Vernet was located at 800 m elevation, on the southern part of the Massif Central in the Cevennes mountains, about 100 km north of Montpellier.

Although there were few climatic differences and the elevations of the different stands compensated for the latitude differences, soils at the study sites were very different: humic leached brown soils in Spain, acid brown soils in France and volcanic regosoils at Etna volcano. The general climate, soil and forest data (stand density, tree age) are indicated in table I.

METHODS

Biomass determination

The diameter at breast height (DBH) of all trees at each experimental plot were measured and their distributions in diameter classes were calculated for the Italian, French and Spanish sites (fig 1). Forty-two representative trees of the different diameter classes were felled to establish their aboveground biomass: 31 in Italy, eight in Spain and ten in France.

Each harvested tree was divided into trunk, branches and leaves, according to their height (0–1.3, 1.3–3, 3–5 and 5–7 m). Total branch mass and individual branches were weighed in the field. Subsamples were brought to the laboratory for further analysis: moisture content, after drying to constant weight at 80 °C, for trunk, branch and leaf samples. The proportion of leaves per branch, and the ratios of branch and leaf weight to the branch diameter, were also determined. For each tree, the trunk, branch and leaf weights and total biomass were correlated with DBH using regression analysis. Various regression equations, calculated for the 49 studied trees, indicated the following determination coefficient values:

- logarithmic expression $r \leq = 0.4500$
- exponential regression $r \leq = 0.7695$
- linear regression $r \leq = 0.4500$
- power regression $r \leq = 0.4500$

for the same correlation coefficient $r = 0.914$.

Consequently, the power regression equations: Biomass = a $(DBH)^b$ were selected.

Litterfall

Thirty litter traps, with a 0.25 m^2 collection area, were distributed randomly at the Spanish site and 40 at the Italian sites. The litter traps were removed monthly and the collected material subdivided into leaves, reproductive material, wood and undetermined products, oven-dried at 80 °C, weighed and expressed on a surface area basis (ha).

Chemical analysis and nutrient determination

Representative biomass and litter samples were ground, then used for chemical analysis. After mineralization of the plant material, Ca, Mg and K were determined using atomic absorption spectrophotometry or flame photometry. Phosphorus was determined colorimetrically using

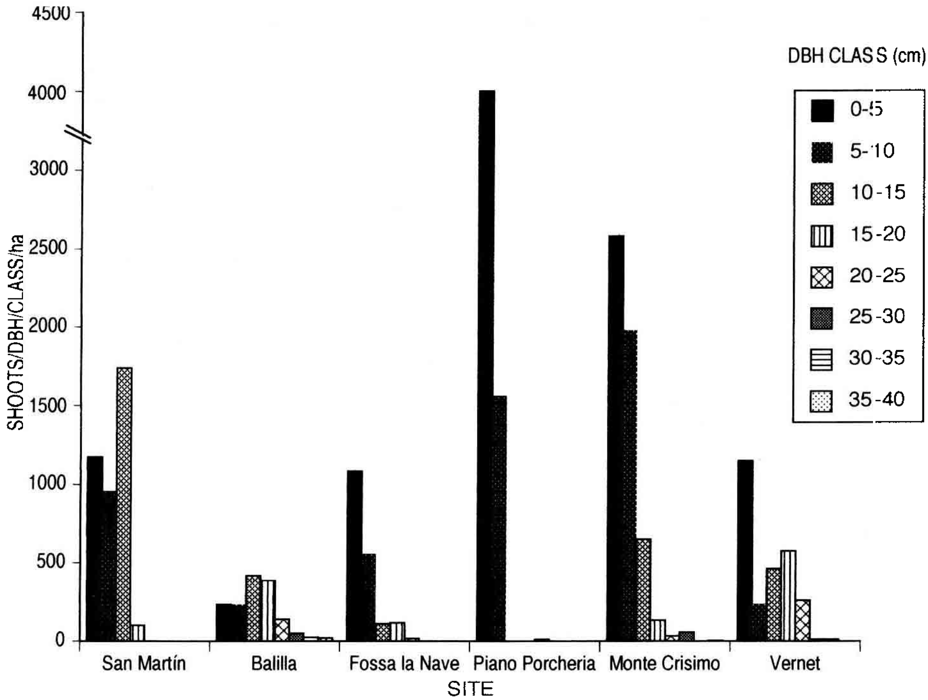

Fig 1. DBH class distributions.

metavanadate (Chapman and Pratt, 1979) and nitrogen by the Kjeldahl method or directly with a macro-N Heraeus device. The chemical results, expressed as percentage of the plant tissue, were correlated with the biomass or litterfall values to determine the amount of nutrients in the biomass or litter on a surface area basis.

RESULTS AND DISCUSSION

Aboveground tree biomass

From all the 49 felled, measured and weighed trees, wood and leaf biomass

Table II. Aboveground biomass for the three sites (kg ha^{-1}).

Site	*Stand age (years)*	*Biomass (kg ha^{-1})*				
		Trunk	*Branches*	*Wood*	*Leaves*	*Total*
San Martín	25	104 702	11 807	116 509	3 910	120 419
Balilla	22	78 642	17 249	95 891	3 659	99 550
Monte Crisimo	12	65 465	14 503	79 968	3 289	83 257
Le Vernet	>30	118 233	31 533	149 766	3 606	153 372

were determined relative to DBH of the trunk for each tree.

The following regression equations for total aboveground biomass (kg), expressed in terms of DBH (cm), were calculated for each country:

$$\text{Italy biomass} = 0.137\ (\text{DBH})^{2.247}$$
$$n = 28\ r = 0.970$$
$$\text{Spain biomass} = 0.066\ (\text{DBH})^{2.628}$$
$$n = 8\ r = 0.996$$
$$\text{France biomass} = 0.118\ (\text{DBH})^{2.336}$$
$$n = 10\ r = 0.936$$

Figure 2 represents the individual regression curves for DBH of *Castanea sativa* trees and aboveground biomass in he three countries. Similar equations were given by Canadell et al (1988), Ferres et al (1980), Rapp et al (1992) and Gallego et al (1995), for various *Quercus* species. However, extrapolation to other areas leads to a loss of precision in the estimates (Satoo and Madgwick, 1982; Harding and Grigal, 1986; Pearson et al, 1987).

Figure 2 also shows the close similarity between these different regression equations, especially between the Italian and French sites. The only major source of difference seems to be between the DBH repartition of all trees of each of the six sites, which induced us to consider different

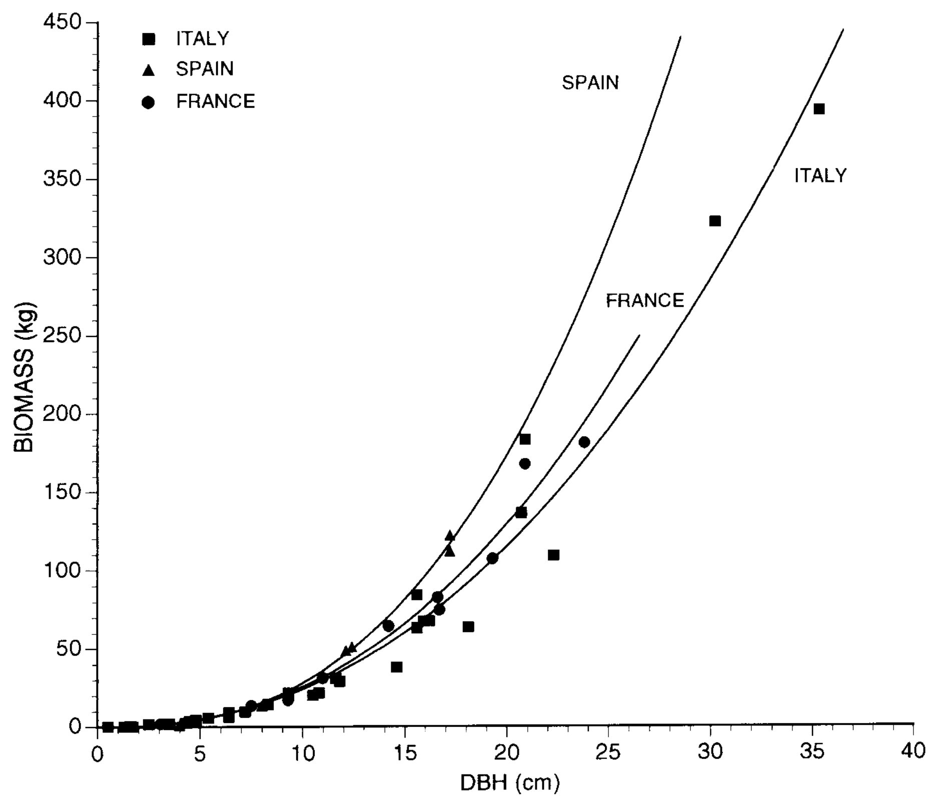

Fig 2. Individual regression curves between DBH and aboveground biomass in the three countries.

sample trees for each site. It was thus possible to establish single regression equations between DBH and aboveground trunk, branch and leaf biomass, integrating all trees from the six study sites in the three countries.

These global regression equations are as follows:

$$\text{Trunk biomass} = 0.064\,(\text{DBH})^{2.401} \quad n = 42\ r = 0.919$$

$$\text{Branch biomass} = 0.023\,(\text{DBH})^{2.307} \quad n = 42\ r = 0.879$$

$$\text{Leaf biomass} = 0.004\,(\text{DBH})^{2.296} \quad n = 22\ r = 0.856$$

$$\text{Total wood biomass} = 0.080\,(\text{DBH})^{2.421} \quad n = 49\ r = 0.916$$

The graphical expressions of these last four equations are given in figure 3 and confirm the accuracy of the approach adopted, even though the samples studied in Spain, and some of those of France, had smaller DBH in comparison to some trees felled in Italy.

Stand biomass estimates

As two of the Etna stands were young coppices clear-cut 7 years ago, only the three relatively even-aged stands of Monte Crisimo, Balilla, San Martín and Vernet were used for comparison. The available data had been determined previously (Gallego et al, 1994; Leonardi et al, 1995b) using specific regressions for each country. Table II summarizes the aboveground stand biomass for trunk, branches and leaves from the three sites.

The total biomass was: Monte Crisimo: 83.2 Mg ha^{-1}; Balila: 99.6 Mg ha^{-1}; San

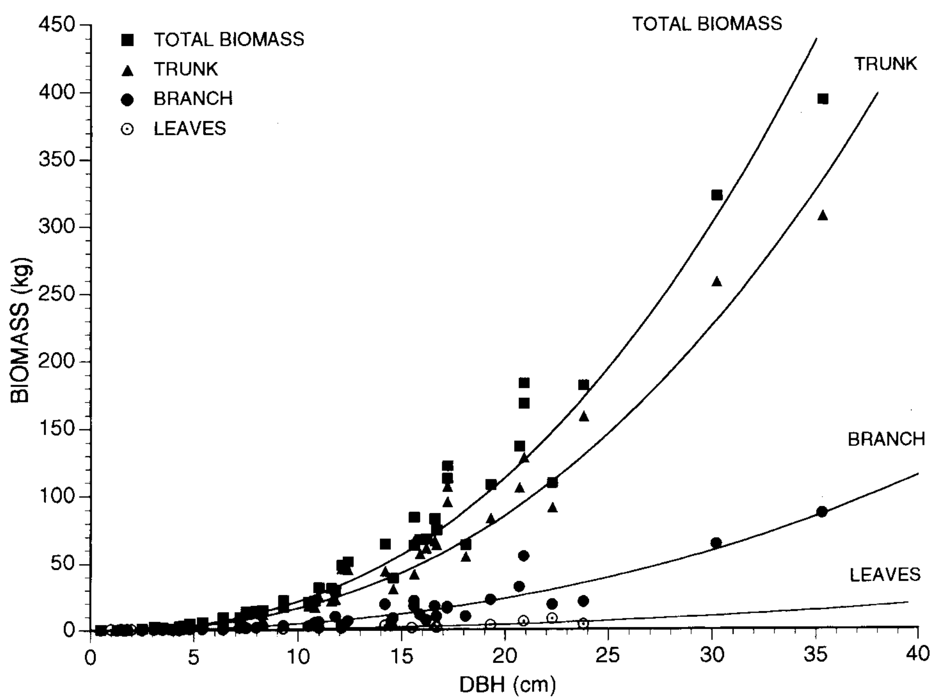

Fig 3. Relationships between biomass and DBH for different organs.

Table III. Chemical composition (%) of the different components for the three *Castanea sativa* stands.

Components	*N*	*P*	*K*	*Ca*	*Mg*
Trunk					
San Martín	0.06	0.028	0.04	0.11	0.02
Balilla	0.08	0.009	0.03	0.23	0.04
Monte Crisimo	0.04	0.009	0.01	0.17	0.06
Branches					
San Martín	0.60	0.078	0.33	0.35	0.14
Balilla	0.51	0.031	0.25	0.57	0.10
Monte Crisimo	0.35	0.074	0.18	1.02	0.21
Leaves					
San Martin	1.53	0.250	0.92	0.33	0.25
Balilla	1.80	0.270	0.92	0.78	0.37
Monte Crisimo	1.70	0.280	0.72	1.16	0.59

Martín: 120.4 Mg ha^{-1}; Vernet: 153.4 Mg ha^{-1}.

The young stands had much lower biomass values: Fossa la Nave: 22.0 Mg ha^{-1}; Piano Porcheria: 24.1 Mg ha^{-1}

In the old stands, with trees aged from 12 to more than 25 years, the biomass values were directly related to the stand age, indicating a mean yearly increment of the aboveground perennial part of 4.7 mg ha^{-1} at San Martín, 4.5 at Balilla, 6.9 at Monte Crisimo and 5.0 at Vernet. Similarly, the proportion of leaves to perennial biomass was 2.4% at Vernet, 3.4% at San Martín, 3.8% at Balilla and 4.1% at Monte Crisimo (table II). The latter value was closely correlated with the high productivity of that stand. For Vernet, mean productivity was probably underestimated because high mortality was indicated by remaining standing dead trunks. This was confirmed by the low percentage of leaves compared to the perennial aboveground material.

The aboveground biomass values for the six studied stands in the western Mediterranean area were in agreement with data reported for other *Castanea sativa* stands. Ranger et al (1990a, b) indicated aboveground biomass values of 9.7, 39.7, 60.5, 107.2 and 119.9 Mg ha^{-1} for *Castanea sativa* coppices aged, respectively, 2, 5, 9, 15 and 19 years. Berthier (1984) found that aerial biomass amounted, respectively, to 25.2, 37.8 and 67.8 Mg ha^{-1}, 5, 8 and 11 years after clear-cut.

In contrast, La Marca (1984) determined much higher biomass values, ie, 107 Mg ha^{-1} for a 13-year-old *Castanea sativa* stand.

Nutrient accumulation in biomass

Table III indicates the chemical composition (N, P, K, Ca and Mg) of the aboveground perennial material of the three

Table IV. K and P concentration in biomass of Piano Porcheria and Fossa la Nave coppices

	Potassium (%)	*Phosphorus (%)*
Trunk		
Old stand	0.02	0.009
Young stand	0.10	0.022
Branch		
Old stand	0.22	0.052
Young stand	0.40	0.069

Table V. Nutrient immobilization in aboveground biomass (kg ha^{-1}).

Components	*N*	*P*	*K*	*Ca*	*Mg*
Leaves					
San Martín	59.8	9.8	36.0	12.9	10.9
Balilla	65.8	9.7	33.7	28.5	13.5
Monte Crisimo	55.9	9.1	23.7	38.1	19.4
Wood					
San Martín	133.6	38.5	80.9	156.5	37.4
Balilla	150.9	12.4	66.7	279.2	48.6
Monte Crisimo	77.2	16.7	32.7	259.2	69.9
Leaves					
San Martín	193.4	48.3	116.9	169.4	48.3
Balilla	216.7	22.1	100.4	307.7	64.1
Monte Crisimo	133.10	25.8	56.4	297.3	89.3

even-aged sites studied. The main differences between the Spanish and Italian sites concerned calcium and phosphorus. The calcium contents of the Sicilian *Castanea sativa* trees were twice those of the San Martín trees. In contrast, the phosphorus content seemed higher in trunks of the Spanish stand than in the two Italian stands. For the branches, generally having younger tissues than the stems, the phosphorus content was similar for all stands. The differences were minimal for the other three nutrients analyzed.

Differences in relation to tree age were also noted, especially in the four coppices around the Etna volcano. They mainly concerned phosphorus and potassium. These two nutrients occurred at higher concentrations in coppices of Piano Porcheria and Fossa la Nave, clear-cut 7 years ago (Leonardi et al, 1995a). The concentrations are given in table IV.

The total nutrient accumulation in biomass is given in table V. For the five nutrients analyzed, the total aboveground biomasses were 576.3 kg ha^{-1} in San Martín and 711.0 and 601.9 kg ha^{-1} in the two Sicilian stands. The perennial part amounted to 446.9, 557.8 and 455.7 kg ha^{-1} for the same five nutrients. For all sites, the

Table VI. Litterfall (leaves and total litter) and amounts of nutrients returning yearly to the soil.

Litter fraction	*Organic matter*	*N*	*P*	*K*	*Ca*	*Mg*
Leaves						
San Martín	3 429	41.5	6.8	15.4	18.5	11.0
Balilla	2 984	28.0	4.9	15.3	29.2	14.0
Monte Crisimo	2 664	29.0	4.5	17.8	23.7	12.2
Total litter						
San Martín	5 245	57.9	8.0	21.7	26.4	13.4
Balilla	5 822	53.3	7.7	30.2	57.6	18.6
Monte Crisimo	5 093	47.8	6.2	22.9	43.3	15.8

relationship between nutrients was as follows: Ca > N > K > Mg > P.

The increased calcium levels resulted from the high calcium content in woody tissues, especially with the development of cell walls during lignification. The high nitrogen levels could be explained by the fact that there were more branches in the older and higher trees, with a more developed canopy.

Castanea sativa exhibits different features concerning storage and concentration of nutrients in the different parts of the tree as compared to other hardwood species (Jokela et al, 1981; Lemoine et al, 1988; Albert and Prescoller-Tiefenthaler, 1992; Helmisaari, 1992; Saur et al, 1992).

Litterfall and return of nutrients to the soil

The amounts of yearly litterfall for leaf litter and total litter (leaves + wood + reproductive organs + undetermined organs) are indicated in table VI.

Leaf litter production was very similar at Balilla and Monte Crisimo. Litter production seemed higher at San Martín. The three stands had similar total litter values, the Italian stands produced more nonleaf litter than the Spanish stand. Comparison of leaf litterfall between the Etna sites also showed that the leaves lost 18.5% of their weight before litterfall (leaf biomass-leaf litter mass).

Tableau VII. Leaf and total litterfall in the three studied sites.

	Leaf litter (kg ha^{-1} year^{-1})	*Total litter (kg ha^{-1} year^{-1})*
San Martín	93.2	127.4
Balilla	91.4	167.4
Monte Crisimo	87.2	136.0

The relation between leaf litterfall and stand age was also very significant: in the two younger coppices of Fossa la Nave and Piano Porcheria: leaf litter amounted to only 1 230 and 1 350 kg ha^{-1} year^{-1}, respectively (Leonardi et al, 1995b).

Concerning nutrients, the results for leaf litter and total litter were similar to those of nutrient accumulation in the biomass. At the same age, *Castanea sativa* litter from the Etna stands contained more calcium than those from the San Martín site, and it was always the contrary for phosphorus. The total levels for the five analyzed nutrients (Leonardi et al, 1995a; Martin, 1995) are given in table VII.

This indicates again that there was much higher calcium content in the litterfall in the Etna *Castanea sativa* stands as compared to the San Martín stand in Spain. For the other four nutrients, the quantities were very similar, with a slight increase in magnesium in *Castanea sativa* tissues at the Etna volcano, probably related to the volcanic soils that are rich in this element.

The rotation coefficient: nutrients in litterfall x 100/nutrients in biomass gave the values for sites in the two countries (table VIII).

Nitrogen, calcium and magnesium were recycled in the same proportion in all stands, although the total amounts were

Table VIII. Rotation coefficients between the Spain and Italy stands.

	N (%)	*P (%)*	*K (%)*	*Ca (%)*	*Mg (%)*
Spain	29.9	16.6	18.6	15.6	27.7
Italy	28.9	29.0	33.9	16.7	23.4

very different. In contrast, phosphorus and potassium were recycled two-fold faster in the Etna stands than in those of the San Martín stand.

It appears that nutrient management is related to the availability of nutrients such as phosphorus and potassium for the trees. Nutrients which are in lower amounts in volcanic soils are recycled through the plant soil system in much higher proportions than other nutrients available in higher quantities in the soil.

CONCLUSION

The present study of *Castanea sativa* Mill trees in France, Italy and Spain indicated that it is possible to establish a single allometric biomass regression for all chestnut trees of the Mediterranean area. Differences in aboveground stand biomass resulted mainly from variations in stand density of individual trees and their repartition between DBH classes. The results were similar for litterfall especially in evenaged stands, with variations being closely related to the age of the coppices.

Aboveground nutrient concentrations in tree organs, as well as the biomass and litterfall quantities, varied between the Spanish and Italian stands, especially for calcium and phosphorus. This indicates a correlation between nutrient uptake and availability in the soil. The Spanish site is located on cambisols, and the Italian ones on volcanic substrata of the Etna volcano.

The rotation coefficients (nutrients in litterfall x 100/nutrients in biomass) were high for phosphorus and potassium in the Etna volcano stands. It seems that nutrient mangement is also closely related to nutrient availability in the soil.

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