

Micronutrients in biomass fractions of holm oak, beech and fir forests of the Montseny massif (Catalonia, NE Spain)

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Summary – This study is part of a larger research programme on different forest ecosystems in the Montseny massif (Barcelona, NE Spain). The contents of 4 micronutrients (Mn, Fe, Zn and Cu) are given for some biomass fractions in individual monospecific stands of holm oak (*Quercus ilex* L), beech (*Fagus sylvatica* L) and fir (*Abies alba*). The behaviour of different micronutrients is related to relative mobility. Mn, Fe and Zn concentrations increase with leaf age. Nutrient levels of the Montseny stands are compared with those found in other forests of the same species. We have observed relatively high Mn concentrations in different biomass fractions of the holm oak forest studied. This can be related to the low soil pH values. Our 3 forests show different micronutrient allocational patterns. Total quantities of the micronutrients in the biomass are only calculated for *Q. ilex* forest. Values found are 33.6 kg Mn/ha, 15.0 kg Fe/ha, 2.8 kg Zn/ha and 0.17 kg Cu/ha.

biomass fraction / micronutrient / *Quercus ilex* / *Fagus sylvatica* / *Abies alba*

Résumé – **Éléments traces dans la biomasse de la chênaie, de la hêtraie et de la sapinière du massif de Montseny.** Ce travail fait partie d'une étude sur les différents écosystèmes forestiers du massif de Montseny (Barcelone, NE, Espagne). La composition en Mn, Fe, Zn et Cu de différents compartiments de la biomasse est analysée pour des parcelles monospécifiques de chêne vert (*Quercus ilex*), de hêtre (*Fagus sylvatica*) et de sapin (*Abies alba*). Les concentrations en Mn, Fe et Zn augmentent au cours du vieillissement de la feuille. Les niveaux de ces concentrations ont été comparés pour les espèces correspondant à celles d'autres forêts. Le niveau du Mn est relativement élevé dans les différents compartiments des arbres de l'espèce chêne vert. Cette différence est à mettre en relation avec la basse valeur du pH du sol. A chacune des 3 forêts étudiées correspond un type différent de répartition de ces éléments traces.

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L'immobilisation totale dans la biomasse de ces éléments traces n'a été calculée que pour le peuplement de chêne vert. Elle est évaluée pour le Mn, le Fe, le Zn et le Cu respectivement à 33,6, 15,0, 2,8 et 0,17 kg/ha.

compartiment de la biomasse / élément trace / *Quercus ilex* / *Fagus sylvatica* / *Abies alba*

INTRODUCTION

Studies on mineral element cycling in forest ecosystems have focused mainly on the major nutrients. Data on micronutrients are relatively scarce, and most aspects of the role of micronutrients in ecosystems' components are poorly understood. We know that micronutrients accumulate in highly metabolically active parts of the plant, like leaves and twigs, because of their involvement in enzymatic reactions within coenzyme molecules (Kramer and Kozlowski, 1979). Concentrations of the relatively immobile elements increase with the age of leaves, probably due to a passive accumulation in the transpiration flow and to relatively low absorption rates (Larcher, 1977). The lowest concentrations are found in wood; nevertheless, wood is the biomass fraction containing the greatest quantity of micronutrients, simply because it is the largest one. Concentrations usually decrease as the stem diameter increases. Bark is an area of accumulation and usually has high micronutrient concentrations (Denaeyer De Smet, 1971).

As occurs frequently with major nutrients, rates of change and total content of oligoelements vary greatly among species. The aim of this study was to determine the levels of 4 micronutrients (Mn, Fe, Zn and Cu) in the different biomass fractions of holm oak (*Quercus ilex*), beech (*Fagus sylvatica*) and silver fir (*Abies alba*), growing in

monospecific forest canopies, in 3 different stands of the Montseny range in northern Spain, and also to look for differences related to the life cycles and leaf morphology in these 3 species by comparing the micronutrient contents of the various biomass fractions.

THE STUDY AREA

The experimental plots are located in the Montseny massif, about 40 km NNE of Barcelona.

The evergreen oak plot (41° 16' N, 2° 21' E, 665 m asl) measures 0.23 ha and lies within La Castanya Biological Experimental Station, at the foot of a rough mountain slope (30°). The slope in the plot is slight, varying from 7 to 23°, and the orientation is W and NW. The bedrock consists of a metamorphic schist, and the soil is a ranker (U 2 b/c, gravelly phase) associated with a dystic cambisol (Bd). Mean annual precipitation is around 900 mm and mean annual air temperature is 9 – 10 °C. The tree layer is dense and formed exclusively of *Quercus ilex*. The basal area was 26.6 m²/ha in 1979. There were 2 100 stems/ha with a DBH > 5 cm and 536 stems with DBH > 15 cm. The dominant trees were 9–12 m in height and had an estimated age of 60 – 90 years.

The beech plot (41° 46' N, 2° 28' E, 1 165 m asl) measures 0.12 ha and is located in the Santa Fe Valley. The slope is gentle (5°). The bedrock is a

deep altered granodiorite, and the soil is a dystric-humic cambisol (Bd - Bh, 1 a). Mean annual precipitation is about 1 200 mm (Rod, 1983) and average air temperature is 8 - 9 °C. The canopy is dense and consists of *Fagus sylvatica* with some isolated individuals of *Ilex aquifolium* as subdominants. The basal area was 26.7 m²/ha in 1980. There are 1 460 stems/ha with a DBH > 5 cm and 625 stems/ha with DBH > 15 cm. The dominant trees are 16 -20 m in height and 50-60 years old. The last tree thinning was carried out between 15 to 30 years ago.

The fir plot (41° 47' N, 2° 27' E, 1 355 m asl) is in the Passavets fir forest. It measures 0.12 ha and is situated on a NNW slope. The bedrock is a hornfels and the soil is a ranker (U 2 d, stony phase) associated with dystric lithosols. The mean annual precipitation is 1200 mm and the mean temperature is 7-8 °C. The tree layer is dense and is composed entirely of *Abies alba* Mill. The basal area was 42.4 m²/ha in 1980. There were 567 stems/ha with a DBH > 5 cm and 467 stems/ha with DBH > 15 cm. The dominant trees were 21-25 m in height and from 120-160 years old.

METHODS

For the holm oak forest (La Castanya stand) we used the field samples of the biomass fractions collected previously by Ferres (1984). These samples, obtained from 15 trees from even stem diameter class, were divided into: leaves (separated into age classes); 1 or 2 year-old twigs of 0-1 cm diameter (bark included); wood from the branches (divided into 1 cm diameter classes); wood from the boles, and bark from the branches and boles. We took additional bole wood samples from 10 trees with a Pressler borer.

In the beech stand (Santa Fe) we collected samples of leaves, twigs and thin

wood from 10 trees (September 1983). In the fir forest (Passavets) we collected samples of leaves, 1-5 yr-old branches and wood boles belonging to 3 fir trees.

Bulked samples of each biomass fraction from the different trees in each plot were analysed. They were dried to constant weight at 80 °C. Mn, Fe, Zn and Cu were analysed by atomic absorption with a PYE UNICAM Sp-1900 (Spectroscopy Service, Barcelona University) after acid digestion, following the methods described by Allen *et al* (1974) for Mn, Fe and Zn. For Cu, due to the low concentrations, it was necessary to adopt a different procedure: the samples were digested with HNO₃ and HClO₄ on a hot plate, gradually increasing the temperature to 210 °C and maintaining it at this level to the end of the digestion. These Cu analyses were carried out in the Department of Soil Science of the University of Aberdeen.

The micronutrient concentrations were analysed in order to determine individual tree variability in the different biomass fractions of 11 holm oaks. The variability of the different elements is less than 12% in all the biomass fractions except in the stem wood where it is between 12 and 22%. Total micronutrient quantities have been calculated from the biomass values obtained by dimensional analysis (Ferres, 1984) and micronutrient concentrations.

RESULTS AND DISCUSSION

Micronutrient concentrations

The concentrations in the different fractions agree with the general trends discussed in the introduction, as can be seen in table 1.

In the holm oak, we can combine our data with those of Ferres (1984) for major nutrients to obtain the following nutrient ranking: Ca > N > K > Mg - P > Mn > Fe > Na > Zn > Cu. In the cases of the beech and fir stands, we lack similar data on the major nutrients, but the micronutrient ranking is identi-

Table I. Average concentrations (ppm) of Mn, Fe and Zn in the different biomass fractions of the evergreen oak, fir and beech forests of Montseny.

	Mn	Fe	Zn	Cu
	ppm			
Holm oak				
New leaves	667	120	29	8.4
Leaves 1-year-old	1137	183	34	-
Leaves 2-years-old	1498	203	42	3.9
Leaves total	977	159	32	
Twigs of the same year				
Twigs 1-year-old	489	281	34	8.4
Twigs 2-years-old	445	226	29	8.4
Twigs total	475	229	29	
Wood				
Wood 0-1 cm	281	131	22	5.4
Wood 1-5 cm	85	42	12	-
Wood 0 > = 5 cm	57	106	7	0.8
Wood total	97	99	10	
Bark	447	186	33	5.4
Inflorescences	614	144	42	
Acorns	551	42	14	
Fir				
Branches 1-year-old	312	257	50	-
Branches 5-years-old	295	463	48	6.9
Leaves 1-year-old	202	113	31	2.3
Leaves 5-years-old	421	198	46	2.3
Stem wood	21	15	10	0.8
Beech				
Leaves	618	212	36	5.4
Stem wood	139	48	28	6.9
Twigs	196	124	43	3.9

cal. Concentrations in the individual biomass components are as follows.

Leaves

In the holm oak, Fe concentrations in the leaves are similar to these found in the Rouquet (Rapp, 1971) and Zn concentrations are close to those found in Prades (Escarre *et al*, 1983). Mn levels are higher than those at either Rouquet or Prades

(table II). Montseny beech leaves show Fe levels similar to other beech forests (Guha and Mitchell, 1966; Heinrichs and Mayer, 1980), but for Mn we observed relatively low values. Fir has low Mn concentrations. As expected, at Montseny the beech leaves are richer in Fe than the leaves of the holm oak or the fir.

The Mn requires further comment. We know that micronutrients are, in general, more available in areas with a slightly acid

Table II. Mn, Fe and Zn concentrations in the different biomass fractions reported from other studies at 3 different locations.

<i>Species</i>	<i>Fraction</i>	<i>Mn</i>	<i>Fe</i>	<i>Zn</i>	<i>Location</i>
		<i>ppm</i>			
<i>Quercus ilex</i>	leaves 1 year	290	150	50	Le Rouquet (Rapp, 1971)
	leaves 2 years	440	210	70	
	twigs	160	200	60	
	branches	80	90	50	
	stem wood	60	60	20	
<i>Quercus ilex</i>	leaves 1 year	891	107	38	Prades (Escarré <i>et al</i> 1983)
	leaves 2 years	900	130	47	
	twigs 1 year	472	101	34	
	twigs 2 years	365	93	24	
<i>Fagus sylvatica</i>	leaves	1800	300	46	Solling (Heinrichs and Mayer, 1980)
	branches wood	420	120	10	
	stem wood	260	270	11	
<i>Picea abies</i>	leaves 1 year	560	150	34	Solling (Heinrichs and Mayer, 1980)
	leaves 2 years	980	220	33	
	twigs 1 year	440	220	59	
	twigs 2 years	510	340	83	
	stem wood	160	180	21	

pH (Sutcliffe and Baker, 1979). This is reflected in the biomass content of these nutrients. Nihlgård and Lindgren (1977) studied 3 beech forests growing on different soil types and found that Mn oxidizes and precipitates, becoming unavailable to plants at a pH higher than 6. As a result, the concentrations and contents of this element in plant tissues are higher in beech forests growing on acid soils where production is also low. Olsen (1948) observed that, on calcareous soils, beech leaves show concentrations of Fe higher than those of Mn, while on acid soils, the reverse is true. Passama (1970) analysed Mn, Fe and Zn in the leaves of holm oaks growing on acid and calcareous soils and found that there was a general tendency for the levels to increase with acidity, especially for Mn.

Thus, the Mn concentrations in the Montseny holm oak could be a consequence of the relatively high amounts of Mn in the soil and the low pH values when compared with the other sites with holm oak forests studied by Lossaint and Rapp (1971) and Escarré *et al* (1983). Incidentally, the beech and fir stands studied here have relatively less acidic soils than at the other European sites where the same species have been studied, and this may explain why Mn levels are lower in Montseny.

Twigs, branches and stems

The twigs in the holm oak stands have Mn and Zn concentrations similar to those found in Prades (Escarre *et al*, 1983) and higher concentrations of Fe.

The concentration of Cu in the twigs is higher than that of the leaves for holm oak and fir, but for beech the reverse is true. In general, fir branches are relatively rich in micronutrients. The observations of micronutrient accumulation, and especially of Fe, in relation to the age of the twigs, made by Heinrichs and Mayer (1980) for *Picea abies* forests, suggest a storage function. Our results for fir could also be the result of the storage of the less mobile elements in that biomass fraction.

The stem wood is poor in micronutrients in the 3 species, except for Cu in the beech (table I).

Using the data collected by Rodin and Bazilevich (1967) on temperate forests, holm oak leaves contain, in general, lower concentrations than are found in the leaves of deciduous trees and are closer to the concentrations found in conifers; however, the holm oak wood is richer than that of deciduous trees. This pattern is not observed clearly in our Montseny data.

Other fractions

We have considered the bark, inflorescences and fruits for the holm oak alone (table I). Our results do not require much comment. It is worth noting, however, that Fe and Zn are present in relatively low concentrations in acorns, showing a pattern similar to that observed for Na (Ferres, 1984) in the same stand. Mn and, especially, Zn have quite high values in the inflorescences.

Micronutrient levels in the biomass

The micronutrient levels in the biomass obviously depend on the quantity of the biomass. In figure 1 we show the distribution of Mn, Fe and Zn in the holm oak. Table III shows data from the different types of forests. Note that the 3 holm oak forests are rather poor in Mn and Fe when compared with the *F sylvatica* and *P abies* stands. However, they are relatively rich in Mn when compared with stands of Mediterranean pines.

Table III. Above ground contents of Mn, Fe and Zn recorded in a range of studies.

Species	Mn	Fe	Zn	Location
	Kg.ha ⁻¹			
<i>Quercus ilex</i>	19	18	6	Le Rouquet (1)
<i>Quercus ilex</i>	15	8	2	Prades (2)
<i>Quercus ilex</i>	33	15	3	La Castanya (3)
<i>Fagus sylvatica</i>	29	5	–	Öved (4)
<i>Fagus sylvatica</i>	123	81	4.6	Solling (5)
<i>mixed forest</i>	41	3.4	5	Hubbard Brook (6)
<i>Pinus pinea</i>	2.6	24.5	4.2	Montpellier (7)
<i>Pinus halepensis</i>	1.8	34	–	Grabells (8)
<i>Picea abies</i>	85	65	12	Solling (5)
<i>Picea mariana</i>	12	11	3	Schefferville (9)
<i>Quercus stellata</i>	89	–	–	Oklahoma (10)

(1) Rapp (1971); (2) Escarré *et al* (1983); (3) present study; (4) Nihlgård and Lindgren (1977); (5) Heinrichs and Mayer (1980); (6) Whittaker *et al* (1979); (7) Rapp and Cabanettes (1980); (8) Rapp (1978); (9) Allan and Rencz (1982); (10) Johnson and Risser (1974).

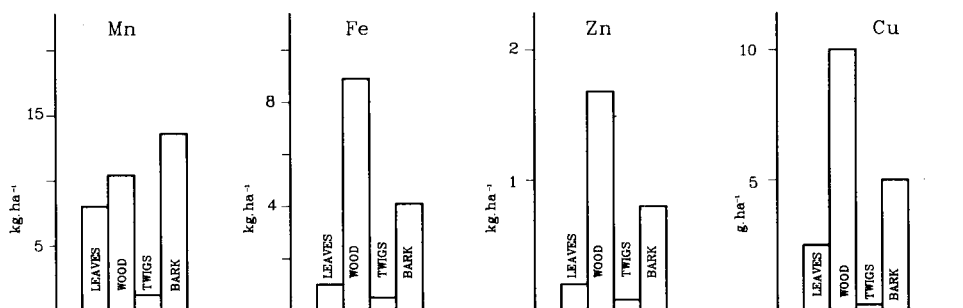


Fig 1. Amount (kg. ha^{-1}) of Mn, Fe and Zn measured in the different fractions of the evergreen oak forest of La Castanya.

CONCLUSION

The concentration ranking of the micronutrients studied in the Montseny stands is the same for all 3 types of forest: $\text{Mn} > \text{Fe} > \text{Zn} > \text{Cu}$. The holm oak shows values similar to those found at other sites with the same species, except for Mn. The high levels of Mn in Montseny are probably due to low soil pH and the resulting high concentrations of soluble Mn in the soils.

Usually, high micronutrient concentrations are found in the most metabolically active tissues: the leaves and twigs. The levels in fir branches are the exception. Mn, Fe and Zn levels increase with leaf age as do the other accumulating elements such as Ca and Na (Ferres, 1984). On the other hand, N and P are translocated more easily. Concentrations of these metals in the wood decrease as the diameter increases, as do the macronutrients, because of a dilution phenomenon.

The wood and bark of the holm oak forest contain a large proportion of the nutrient content, as is usual in forest ecosystems, because of their great quantity. The main part of the Fe, Zn and Cu is found in the wood, bark, leaves and twigs. Mg, Na, N and K show the same pattern. The highest

quantities of Mn and Ca are found in the bark.

As for the macronutrients, the foliar micronutrient levels represent an important percentage of the total amount of these elements if we bear in mind that the leaf biomass is only 3.8% of the total biomass of this forest. The percentage of Mn located in leaves is especially high and is greater than the percentage of N. Leaf nutrients have a higher turnover rate than the nutrients stored in other biomass fractions.

Our 3 forests show different micronutrient allocational patterns, and this is probably related to their different modes of life (deciduous, evergreen conifers, broad-leaved evergreens). Beech tends to have higher concentrations of Mn and Fe in the leaves. Holm oak has a relatively even distribution (except for the high levels of Mn in leaves). Fir, as other conifers, shows high micronutrient levels in the branches.

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