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Soil microbial biomass under pine forests in the north-western Spain: influence of stand age, site index and parent material

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Abstract

The effects of stand age, site index and parent material on soil biochemical properties related to biomass (extractable C, microbial C and metabolic quotient) were examined in the 0-15 cm mineral soil layers of *Pinus pinaster* and *Pinus sylvestris* stands from NW Spain. Two productivity levels (low and high site index), two ages (young and old) and two parent soil materials (granite and acid schists) were considered. The data indicated that there were differences in microbial parameters in soils under different species. In general in *P. pinaster* forest higher values of biochemical parameters, expressed on organic C basis, were observed in the stands of high site index as compared with the low ones; in contrast, in *P. sylvestris* no differences among stand site index were detected. In both species different results were also observed depending on parent material and a significant effect of stand age was detected for extractable C and microbial C in *P. pinaster* forest developed over granite. The data seem to indicate that measured parameters may have the potential to be used as indicators of the effect of forest management on soil organic matter quality.

Key words: Microbial C, extractable C, metabolic quotient, reforestation, *Pinus pinaster, Pinus sylvestris.*

Resumen

Biomasa microbiana edáfica en pinares del noroeste de España: influencia de la edad de la plantación, índice de sitio y material de partida

Se examina la influencia de la edad de la plantación, índice de sitio y material de partida sobre las propiedades bioquímicas relacionadas con la biomasa microbiana (C extraíble, C microbiano y coeficiente metabólico) del horizonte superficial de suelo (0-15 cm) de plantaciones de *Pinus pinaster* y *Pinus sylvestris* del Noroeste de España. Se consideraron dos índices de sitio (baja y alta calidad), dos edades de plantación (joven y vieja) y dos materiales de partida (granito y esquistos). Los datos indicaban que hubo diferencias entre los parámetros microbianos de suelos bajo diferente vegetación. En general, para *P. pinaster* se observaron valores más altos de los parámetros bioquímicos, expresados en base al contenido de C orgánico, en las plantaciones de alta calidad que en las de baja calidad; por el contrario en las plantaciones de *P. sylvestris* no se detectaron diferencias con respecto al índice de sitio. En las plantaciones de ambas especies se observaron resultados diferentes dependiendo del material de partida y también se observó un efecto significativo de la edad de la plantación sobre el C extraíble y el C microbiano en suelos desarrollados sobre granito bajo *P. Pinaster.* Los resultados parecen indicar que las propiedades bioquímicas medidas pueden ser utilizadas como indicadores del efecto del manejo forestal sobre la calidad de la materia orgánica del suelo.

Palabras clave: C microbiano, C extraíble, coeficiente metabólico, plantación forestal, *Pinus pinaster, Pinus sylvestris.*

Introduction

Forest soils play an important role in sustaining stand productivity and forest values by regulating water uptake, root environment and nutrient cycling; thus a judicious management of soils forms an important component of sustainable forest management (Khanna and Madeira, 2002). Soil microorganisms are the driving force for nutrient supply to plants in both agricultural and forest lands not only because of their ability to carry out biochemical transformations but

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also due to its fast turnover (Smith and Paul, 1990). The physico-chemical soil properties (amount and quality of soil organic matter, mineral nutrients, pH, soil texture, temperature, moisture, etc.) are of particular importance in determining the size and activity of microbial population. Thus, since microorganisms reflect soil environment, the microbial component and, particularly, the ratio of microbial C and N to total organic C and N have been considered to be the most promising early indicators for monitoring changes in soil quality due to land use and management effects before changes in total soil C and N can be easily detected (Sparling, 1998). Studies of diverse authors have showed that the size of soil microbial C and N can be influenced by forest management (Pietikäinen and Fritze, 1995; Bauhus *et al.,* 1998) and that, in general, increased proportionally with forest productivity (Myrold *et al.,* 1989). Therefore, knowledge about soil microorganisms and soil biological processes may improve the scientific basis of forest management decisions, e.g. on the types of species for planting in the area. On this premise, it is surprising to note the scarcity of studies on soil microbial parameters in relation to forest management and productivity.

Forest and abandoned agricultural land being planted with species such as *Eucalyptus sp* and *Pinus sp* has notably increased in Galicia (NW Spain) during the last decades. Since previous studies performed with undisturbed soils under climax vegetation *(Quercus robur)* have shown that microorganisms play an important role in maintaining soil fertility (Díaz-Raviña *et al.,* 1995; Leirós *et al.,* 2000), the monitoring of soil microbial properties in these forest plantations is expected to provide and indication of forest productivity. However, information about this topic is scarce and limited to chemical properties in *Pinus radiata* stands (Sánchez-Rodríguez *et al.,* 2002; González-Prieto and Villar, 2003). The aim of the present study was to assess the effects of parent material and forest plantations characteristics such as tree species, productivity and stand age on the biomass of soil microorganisms in pinewoods of the temperate humid zone.

Material and Methods

A total of forty eight soils under pinewoods located in the temperate humid zone (Galicia, NW Spain) were used for the study. Two stand types *(Pinus pinaster* and *Pinus sylvestris)* of two productivity levels (low site index, 9-14 m of dominant height at 20 years for *P. pinaster* and 5-10 m of dominant height at 30 years for *P. sylvestris;* high site index, 17-23 m for *P. pinaster* and 12-15 m for *P. sylvestris)*, two ages (young, 10-20 yr for *P. pinaster* and 20-35 yr for *P. sylvestris;* old, 25-35 yr for *P. pinaster* and 45-55 yr for *P. sylvestris)* growing on two parent soil material (granite and acid schists) were considered; three soils were sampled for each tree specie, parent material, stand age and site index combination. Values of the site index were obtained using the equation proposed by Alvarez González *et al.* (1999) and Martínez Chamorro *et al.* (1997). The site index is defined as the dominant height of the stand, in meters, at the age of 20 years for *P. pinaster* (Álvarez González *et al.,* 1999) and at the age of 40 years for *P. sylvestris* (Diéguez Aranda, 2004). A detailed description of the plots as well as their exact location throughout Galicia have been given by Fernández *et al.* (2006). The plots were subjectively selected to represent the whole range of stand densities, undergrowth types and growing conditions in Galician pine forests but restricted to two different ranges of age and site index. More often than not, none or scarce (only in some cases low pruning) silvicultural treatments were applied to the forests selected. The litter was discarded and soil samples were taken in spring from the A horizon (0-15 cm depth). From each plot a gross sample, comprising thirty 300 g sub-samples were taken from the whole area of each plot, mixed to constitute a representative soil sample and throughly homogenized after sieved (fraction < 4 mm). Microbial analyses were made on soil fresh stored at 4°C for no longer than 2 weeks. The main soil physico-chemical properties are listed in Table 1.

The microbial biomass C (BC) was determined using the fumigation extraction method described by Vance *et al.* (1987) with modifications indicated by Basanta *et al.* (2002). Briefly, after soil fumigation with $CHCl_3$ for 24 h, the organic C was extracted from unfumigated (extractable C) and fumigated samples with 0.05 M K_2SO_4 using a 1:4 soil-extract ratio. Organic C in the freeze-dried extracts was measured by direct combustion in an elemental analyser (Carlo Erba CHN 1108). Microbial biomass C values were calculated from the equation: biomass C = 2.64 Ec, where Ec is the extractable C flush (difference between extractable organic C from fumigated and unfumigated

Table 1. Main physico-chemical characteristics of the forest soil samples studied (n = 24 soil samples for each tree specie, 12 samples developed over granite and 12 samples developed over schists)

Variable	Parent material	*P. pinaster*		*P. sylvestris*	
		Min	Max	Min	Max
pH(H_2O)	Granite	3.8	4.8	3.7	4.4
	Schist	3.4	4.7	3.8	4.1
Water holding capacity (%)	Granite	41	82	37	109
	Schist	51	85	54	81
Soil moisture (%)	Granite	27	40	16	53
	Schist	22	43	30	39
Organic C (g kg^{-1})	Granite	39	138	43	162
	Schist	61	110	53	131
Total N (g kg^{-1})	Granite	1.74	11.51	2.83	13.01
	Schist	4.35	8.78	3.34	6.96
C/N	Granite	12	22	13	22
	Schist	13	18	12	22
Coarse sand (%)	Granite	25	57	31	73
	Schist	15	40	10	43
Fine sand (%)	Granite	18	51	10	29
	Schist	28	45	11	62
Silt (%)	Granite	7	15	8	21
	Schist	11	25	14	53
Clay (%)	Granite	8	17	8	25
	Schist	11	23	9	36
Non-crystalline Al_2O_3 (g kg^{-1})	Granite	7.8	19.5	8.7	25.4
	Schist	6.5	47.0	10.9	39.0
Non-crystalline Fe_2O_3 (g kg^{-1})	Granite	6.7	23.5	8.3	22.5
	Schist	25.4	49.7	15.4	86.4

samples). Organic C from unfumigated samples was used as index of extractable C. The soil respiration was determined by static incubation of fresh soil samples (75% WHC) in a water bath (28°C) during a 10 day incubation period measuring the CO_2 trap in a NaOH solution, which is then titrated with HCl (Díaz-Raviña *et al.,* 1993). The specific respiration rate or metabolic quotient (qCO_2) was calculated from the soil respiration rate and microbial biomass C (µg CO_2 mg BC h^{-1}) (Anderson and Domsch, 1990).

All results were obtained by triplicate determinations and were expressed on the basis of oven-dry (105°C) weight of soil (absolute values). Since organic matter content is often one of the most influencing factors in microbial biomass and organic matter showed a wide range of variation in soil samples analysed (Table 1), the extractable C (unfumigated samples) and the biomass C values were also expressed as percentage of total C (relative values). The percentages of data variation attributable to parent material, stand age and site index were calculated using a two-way or three-way analysis of variance (ANOVA2 and ANOVA3, respectively). Correlation coefficients between microbial parameters and other edaphic factors were calculated using a matrix of data corresponding to *P. pinaster* soil samples (n = 24), *P. sylvestris* soil samples (n = 24) and *P. pinaster* and *P. sylvestris* soil samples all together (n = 48). Since similar results were obtained independently of the matrix considered, only data of the matrix containing all soil treatments are given in most cases. All statistical analyses were performed using the SPSS program.

Results

The microbial biomass and extractable C values obtained for soil samples studied are shown in Table 2 and Figure 1. In the *P. pinaster* forests the microbial C ranged from 245 to 912 µg C g^{-1} d.w. (overall average

Table 2. Biochemical properties of the forest soil samples studied (n = 24 soil samples for each tree species, 12 samples developed over grante and 12 samples developed over schists)

Variable	Parent material	*Pinus pinaster*			*Pinus sylvestris*		
		Min	**Max**	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**
EC (μg g^{-1})	Granite	88	158	116 ± 24	70	150	118 ± 22
	Schist	112	134	129 ± 12	76	189	134 ± 35
EC/total C (%)	Granite	0.10	0.28	0.17 ± 0.07	0.09	0.25	0,17 ± 0.06
	Schist	0.10	0.19	0.16 ± 0.03	0.10	0.30	0,18 ± 0.06
BC (μg g^{-1})	Granite	305	675	451 ± 121	270	1010	514 ± 267
	Schist	245	912	432 ± 176	291	1604	686 ± 375
BC/total C (%)	Granite	0.39	0.79	0.60 ± 0.15	0.41	0.80	0,62 ± 0.11
	Schist	0.32	0.87	0.51 ± 0.18	0.47	1.22	0,86 ± 0.30
qCO_2 (μg CO_2 mg BC h^{-1})	Granite	1.42	3.96	3.16 ± 0.76	1.95	4.09	2,87 ± 0.65
	Schist	3.26	6.08	4.54 ± 0.77	1.92	4.49	2,77 ± 0.70

EC, extractable C; BC, microbial C; qCO_2, metabolic quotient.

442 ± 148 μg C g^{-1} d.w.) and represented between 0.32-0.87% of total C (mean 0.56 ± 0.16%) and the extractable C varied from 88 to 158 μg g^{-1} d.w. (overall average 123 ± 19 μg g^{-1} d.w.), representing around 0.10-0.29% (average 0.16 ± 0.06%) of total C. In the *P. sylvestris* forests the microbial C oscillated between 270 and 1604 μg C g^{-1} d.w. (0.41-1.22% of total C) and extractable C from 70 to 189 μg C g^{-1} d.w.; the average values for microbial C and extractable C were 601 ± 329 μg C g^{-1} d.w. (0.74 ± 0.25% of total C) and 128 ± 27 μg C g^{-1} d.w. (0.18 ± 0.06% of total C), respectively. A positive and significant ($p < 0.005$) relationship between biomass C and several physico-chemical properties related to organic matter content was observed ($r = 0.62$, $r = 0.42$, $r = 0.56$ and $r = 0.52$ for total C, total N, water holding capacity and moisture content, respectively).

For the matrix of *Pinus pinaster* data, the analysis of variance (ANOVA 3) showed a significant effect of parent material, stand age and site index on extractable C values expressed as absolute values, which explained 12, 7 and 10% of variance, respectively (Table 3); these factors were not independent as indicated by the significant effect of all the possible interactions among them (a total of 47% variance). For the extractable C values expressed as percentage of total C, relative values, the importance of site index increased notably (26% of variation), and the interaction between site index and parent material accounted for a further 33% of variance. For the biomass C absolute values a significant effect of site index (22% of variation) and parent material (13%) was observed, the interaction of these factors being also significant (11%). When biomass values were expressed as percentages of total C the importance of site index as a source of variation decreased and only a significant effect of parent material was observed (21%). In contrast for the matrix of *Pinus sylvestris* data only a significant effect of site index on extractable C absolute values (21% of variance) and of parent material on biomass C relative values (23% of variance) was detected.

When the parent material factor was excluded and the data were analysed independently for each parent material and tree species by ANOVA 2 (Table 4), for *Pinus pinaster* matrix data a significant influence of the factors analysed was detected on soils developed on granite. For the extractable C absolute values the site index explained 26% of variation and the interaction between this factor and stand age a further 50%. The extractable C relative values were mainly determined by site index, which accounted for most of the variance (73%). Site index also showed a significant influence on biomass C estimates expressed as absolute values (44% of variance) or as relative values (site index and stand age interaction explained 44% of variance). In contrast, for *Pinus sylvestris* data, analysis of variance only showed a significant effect of site index on biomass C absolute values (28% of variance) in soils developed over schist.

Specific respiration values in the soil samples from *P. pinaster* and *P. sylvestris* forest ranged from 1.42 to 6.08 μ g CO_2 mg BC h^{-1} (average 3.85 ± 1.02 g CO_2 mg

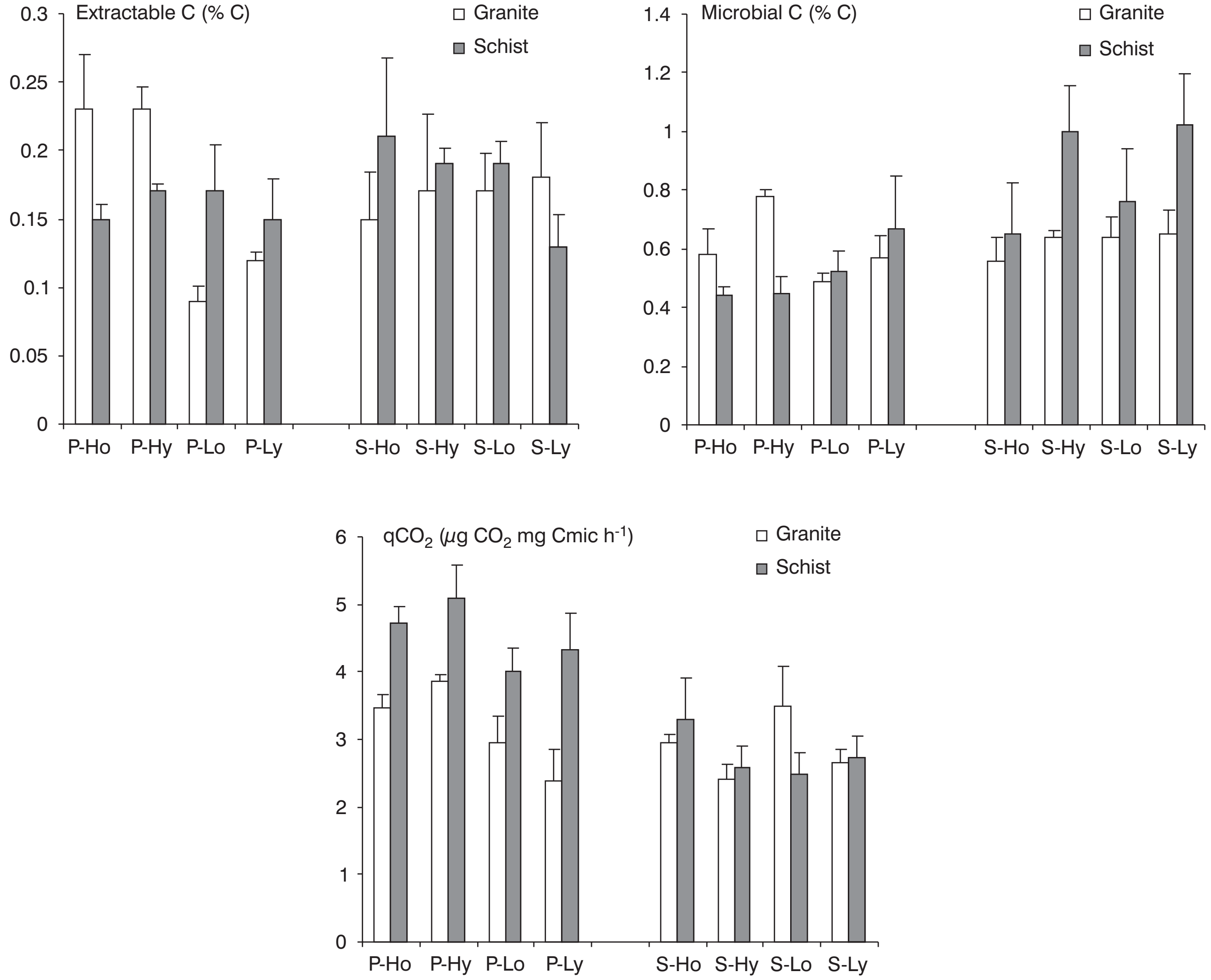

Figure 1. Biochemical properties values (mean of the three field replicates ± SE) in the soil samples from *Pinus pinaster* (P) and *Pinus sylvestris* (S) forest growing on two parent material (granite, schist) and showing two different productivity levels (H, high site index; L, low site index) and stand age (o, old; y, young).

BC h^{-1}) and from 1.92 to 4.49 µg CO_2 mg BC h^{-1} (average 2.82 ± 0.67 g CO_2 mg BC h^{-1}), respectively (Table 2, Fig. 1). A negative relationship between qCO_2 and microbial C was found ($r = -0.595$, $p < 0.001$). In *P. pinaster* forests, the metabolic quotient values were mainly determined by the parent material and the site index which explained 47% and 19% of the variation, respectively while in *P. sylvestris* forests no significant influence of the factors considered was detected (Table 3). When data were analysed independently for each parent material, only a significant influence of site index (48% of variation) was detected in soil developed over granite under *P. pinaster* forests (Table 4).

Discussion

The effect of the experimental factors, site index, stand age and parent material on biochemical properties was tested by means of ANOVA 2 and ANOVA 3. Different results were observed depending on tree species considered. Thus, while for *Pinus pinaster* a significant influence of site index and parent material, particularly the former, was detected on most analysed variables, for *Pinus sylvestris* the influence of these factors decreased considerably, being not significant in most cases. Different results were also observed for each parent material analysed. For soils

Table 3. Three-way analysis of variance of the effect of parent material (PM), stand age and site index (SI) on extractable C (EC), microbial biomass C (BC) and metabolic quotient (qCO_2) (n = 24 soil samples for each tree specie, 12 samples developed over granite and 12 samples developed over schists)

Tree specie	Variable	Source	Percentage of explained variance	F ratio
P. pinaster	EC (μg g^{-1})	Parent material (PM)	12	8.67^{b}
		Age	7	5.36^{a}
		Site index (SI)	10	7.61^{b}
		PM x SI	8	5.71^{a}
		Age x SI	7	5.36^{a}
		PM x Age x SI	32	23.37^{c}
	EC/total C (%)	Site index (SI)	26	11.58^{b}
		PM x SI	33	14.58^{b}
	Biomass C (μg g^{-1})	Parent material (PM)	13	4.81^{a}
		Site index (SI)	22	8.02^{b}
		PM x SI	11	4.20^{a}
	BC/total C (%)	Parent material (PM)	21	6.26^{a}
	qCO_2 (μg CO_2 mg BC h^{-1})	Parent material (PM)	47	25.62^{c}
		Site index (SI)	19	10.34^{b}
P. sylvestris	EC (μg g^{-1})	Site index (SI)	21	5.89^{a}
	BC/total C (%)	Parent material (PM)	23	6.64^{a}

[a], $p < 0.05$; [b], $p < 0.01$; [c], $p < 0.001$. Only significant factors are included.

Table 4. Two-way analysis of variance of the effect of stand age and site index (SI) on extractable C (EC), microbial biomass C (BC) and metabolic quotient (qCO_2) (n = 24 soil samples for each tree specie, 12 samples developed over granite and 12 samples developed over schists)

Tree specie	Parent material	Variable	Source	Percentage of explained variance	F ratio
P. pinaster	Granite	EC (μg g^{-1})	Site index (SI)	26	13.65^{b}
			Age x SI	50	26.32^{c}
		EC/total C(%)	Site index (SI)	73	24.76^{c}
		BC (μg g^{-1})	Site index (SI)	47	9.52^{b}
		BC/total C (%)	Age x SI	44	6.74^{a}
		qCO_2 (μg CO_2 mg BC h^{-1})	Site index (SI)	48	9.36^{b}
P. sylvestris	Schist	BC (μg g^{-1})	Site index (SI)	28	4.93^{a}

[a], $p < 0.05$; [b], $p < 0.01$; [c], $p < 0.001$. Only significant factors are included.

developed on granite, the soil biochemical properties of *Pinus pinaster* forests were mainly determined by the site index (26-73% of variation) or by the interaction between this factor and the stand age (44-50% of variation). In general, as expected, the biochemical properties values were greater in stands with higher site index (Figure 1). In contrast, for soils developed over schist the influence of the mentioned factors decreased notably and only a significant effect of site index on biomass C was detected in *P. sylvestris* forests.

The concentrations of microbial C and extractable C, which were similar to those found in previous studies in similar soils (Díaz-Raviña *et al.,* 1988; 1993; 1995; Prieto *et al.,* 1998; Leirós *et al.,* 2000; Basanta *et al.,* 2002), lied in the reported range given for forest soils (Wardle, 1992). As previously observed, among the soil characteristics analysed total C ($r = 0.62$, $p < 0.001$), total N ($r = 0.42$, $p < 0.01$), water holding capacity ($r = 0.56$, $p < 0.001$) and moisture content ($r = 0.52$, $p < 0.001$) were significantly and positively related to biomass C (Díaz-Raviña *et al.,* 1988; 1995). The data showed that these soils had a relatively high microbial biomass but this represent a low percentage of total C (less than 1%). This is consistent with the observation of diverse authors showing that in organic soils the biomass constituted a lower proportion of total C than in the soils that were poor in C (Cerri and Jenkinson, 1981; Wardle, 1992). It maybe pointed out that the microbial biomass of forest soils from temperate humid zone, despite the fact that only amount to a smaller percentage of organic soil C, contributes substantially to plant available nutrient content (Díaz-Raviña *et al.,* 1993, 1995). According to diverse authors the ratio of microbial C and extractable C to total organic C are related to substrate quality. If this is true, these parameters would be expected to increase with site index (productivity) and they should also decrease with stand age in aggrading forest, assuming that substrate quality was higher in young stands than in old stands. Our results showed that in the *P. pinaster* forest developed on granite, microbial biomass and extractable C values were significantly higher in soils from stands with high site index than those with low site index. A influence of stand age, which was significant in a few cases (extractable C and microbial C in *P. pinaster* forest developed over granite), was detected; in general the biochemical properties values were on average higher in young stands than in old stands, indicating a decline in substrate quality, although the opposite trend could also be observed.

Likewise, the metabolic quotient values are similar to those reported in the literature for woodland soils (Wardle, 1993; Leirós *et al.,* 2000; Merino *et al.,* 2004). The negative relationship between qCO_2 and biomass C is consistent with studies of other authors indicating that microorganisms were more C efficient on substrate supporting high concentrations of microflora (Wardle and Gahni, 1995; Bauhus *et al.,* 1998). In principle, the qCO_2 values were expected to decrease with increasing substrate quality being higher under unfavourable than under favourable conditions. The qCO_2 undoubtedly indicates microbial efficiency for substrate utilization, but this quotient may not reflect disturbance and ecosystem development (Wardle and Ghani, 1995). Our data clearly support this hypothesis since stands with low site index and old age did not exhibited higher qCO_2 values than those stands with high site index and young age. The composition of the microbial population could partly explain this behaviour since zymogenous/autochthonous and bacteria/fungi ratios can drastically affect the qCO_2 values (Dilly and Munch, 1998). However, it should be noted that in *P. pinaster* forest soils developed on schist showed higher qCO_2 values than those developed over granite; in contrast, in *P. sylvestris* no differences between parent material or even higher values were exhibited in soils developed over granite. In addition, for *P. pinaster* the higher microbial C and extractable values were exhibited by soils developed over granite and the opposite was true for *P. sylvestris* forest, particularly for biomass values. Thus, the combination of information derived from several indices used (microbial C, extractable C and qCO_2) seems to indicate that soils developed over granite were more favourable for *P. pinaster* plantations.

Conclusion

The results showed that field data interpretation of biochemical properties of forest soils is difficult, particularly when several factors exerting an influence on microbial communities are involved. However, in general in *P. pinaster* forest higher values of soil biochemical parameters, expressed on an organic C basis, were observed in the stands of high site index as compared with the low ones; in contrast in *P. sylvestris* no differences among stand site index were detected. In both species different results were also observed depending on parent material and a significant effect of stand age were noted for extractable C and microbial C in *P. pinaster* forest developed over granite. Since microbial parameters measured were sensitive to the factors stand age, site index and parent material, they may have the potential to be used as indicators of the forest management on soil organic matter quality. Further studies are necessary in order to confirm these preliminary field data.

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