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Ability of different plant species to promote microbiological processes in semiarid soil

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Abstract

In semiarid climate soils, the establishment of a plant cover is fundamental to avoid degradation and desertification processes. A better understanding of the ability of plants to promote soil microbial processes in these conditions is necessary for successful soil reclamation. Six different plant species were planted in a semiarid soil, in order to know which species are the most effective for the reclamation of semiarid areas. Six years after planting, the rhizosphere soils were studied by measuring chemical (pH, electrical conductivity, total organic carbon and other carbon fractions), physical (% of saggregates), microbiological (microbial biomass carbon and soil respiration), and biochemical (dehydrogenase, phosphatase, β-glucosidase and urease activities) parameters. In general, in all the soil–plant systems plant nutrients, organic matter and microbial activity increased compared to the control soil. For some species, such as *Rhamnus lycioides*, the increase in the total organic carbon content (TOC) in the rhizosphere zone was almost 200%. A positive correlation was found between TOC and water-soluble carbon ($p<0.001$); both parameters were negatively correlated with electrical conductivity. Microbial biomass carbon and soil respiration were highest in the rhizosphere of *Stipa tenacissima* (98% and 60%, respectively, of increase on soil control values) and *Rosmarinus officinalis* (94% and 51%, respectively, of increase on soil control values). These microbiological parameters were correlated with the percentage of stable aggregates ($p<0.01$). Enzyme activities were affected by the rhizosphere, their values depending on the shrub species.

Keywords: Semiarid plant species; Microbial processes; Rhizosphere; Enzyme activities; Soil reclamation

1. Introduction

In arid and semiarid ecosystems, where variation in the spatial and temporal availability of water and nutrients is extreme, dominant plants cause changes in soil properties that lead to complex local interactions between vegetation and soil (Wilson and Agnew, 1992). The floristic composition and productivity of annual plants in these regions are strongly affected by small-scale variations in resources (Haase et al., 1996), particularly in the understorey of shrubs and trees. In the Mediterranean region of southeastern

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Spain, inappropriate agricultural practices are compounded by local vegetation, soils and climatic variables (Lopez-Bermudez and Albaladejo, 1990). A key factor in degradation of these soils is the loss of plant cover, allowing increased erosion and salinization processes to occur (Albaladejo et al., 1994). The presence of vegetation in this area is important since it provides physical protection and contributes organic matter that enhances soil water holding capacity (WHC) and soil fertility characteristics (Garcia et al., 1994). These plants also affect the composition of the soil microbial community (Roldan et al., 1994), which can influence soil aggregate stability (Lynch, 1981; Caravaca et al., 2002a).

The rhizosphere is a zone of enhanced microbial activity because plants excrete 10–20% of their photosynthates as root exudates (Lambers and Poorter, 1992), which can serve as substrates for the microbial community, thus increasing the number of microorganisms in this zone (Salt et al., 1998). The high microbial biomass and microbial diversity in plant rhizospheres increase the potential for xenobiotic degradation (Lappin et al., 1985).

The microorganism species that populate the rhizosphere depend on the species and age of plant, and on the type of soil. Microbiological and biochemical parameters (soil microbial biomass, soil respiration, and enzyme activities) can be considered good biomarkers of the metabolic status and quality of soil (Nannipieri et al., 1990; Garcia et al., 2000); this is important when deciding the type of plants most suited for reclamation of semiarid disturbed soils, where recycling of nutrients by microbial activity is essential if plants are to survive.

In this paper, the ability of six different semiarid plant species to regenerate the microbiological processes of the soil was investigated. Our objective was to know which plant species are the most effective for reclamation of semiarid lands, and which parameters can be useful to assess the recovery of the soil microbial community. For this purpose, chemical (pH, electrical conductivity, total organic carbon and carbon fractions), physical (aggregate stability), microbiological (microbial biomass carbon and basal respiration) and biochemical (enzyme activities) parameters were measured in the rhizosphere soil of several plant species and in a control soil.

2. Material and methods

2.1. Study sites

The study was conducted in the province of Murcia (Southeast Spain) (co-ordinates: 1°10′ W and 38°23′ N). The climate in this area is semiarid Mediterranean, with an annual mean temperature of 16 °C and total annual rainfall of about 300 mm, mostly concentrated in autumn and spring. The potential evapotranspiration reaches 900 mm year^{-1}. The predominant soils are Petrocalcic Xerosol (FAO et al., 1998), developed from limestone with a silt loam texture.

2.2. Materials

The plants used for the planting experiment were *Olea europaea* sbsp. *sylvestris* L., *Pistacia lentiscus* L. (common name, Lentisk), *Retama sphaerocarpa* L. (common name, Retama), *Rhamnus lycioides* L., *Rosmarinus officinalis* L. (common name, Rosemary) and *Stipa tenacissima* L. (common name, Esparto grass). Most of these species are native to the area only *S. tenacissima* L. may be considered as invader; *R. sphaerocarpa* L. is able to fix N. All are low-growing shrubs which reach heights of 1–2 m, and are widely distributed in the Mediterranean region. They are well adapted to water stress conditions and, therefore, could potentially be used in replanting of semiarid disturbed land.

2.3. Experimental design

The plantation was established in 1995 and covered a total area of 10 000 m^2, which was mechanically prepared with a subsoiler. Following a randomised design with six replicate blocks, 120 seedlings were planted in individual holes, at least 3 m apart. The experiment was conducted under semiarid conditions, without irrigation and fertilization. An area without vegetation (density of plant cover in this area was <5%) was considered as "control soil".

2.4. Sampling and laboratory procedures

In spring 2001, 6 years after planting, six randomly selected plants of each species in each block, were

carefully dug from the field. The soil strongly adhering to roots and collected within the space explored by roots was considered as rhizosphere soil (six samples for each species). Six soil samples were also collected from areas without vegetation (control soil). Sampling was carried out in spring because soil microbial activity in the Mediterranean climate is highly in this season (Garcia et al., 1997a). The samples were brought to the laboratory on the same day and kept in the refrigerator at 4 °C for a maximum of 1 month until analysis.

2.5. Chemical analysis

Electrical conductivity was measured in a 1:5 (w/v) aqueous solution. Total N and total organic carbon (TOC) were determined after pre-treatment with HCl to eliminate carbonates with an Elemental Analyzer. Total P and K were determined in the nitric-perchloric digestion extract, P by the method of Murphy and Riley (1962) and K by flame photometry.

The following parameters were determined in the (1:5) aqueous extract of soils, obtained after 2 h of mechanical shaking, centrifugation at 5000×*g* and filtration through a 100-μm membrane: water-soluble carbon (WSC) by oxidation with $K_2Cr_2O_7$ and measurement of absorbance at 590 nm (Sims and Haby, 1971); soluble carbohydrates by the method of Brink et al. (1960) and soluble polyphenolic compounds by the method of Kuwatsuka and Shindo (1973).

2.6. Physical analysis (aggregate stability)

The percentage of stable aggregates was determined by the method described by Lax et al. (1994). An aliquot (4 g) of sieved (0.2–4 mm) soil was placed on a 0.250-mm sieve and wetted by spray. After 15 min, the soil was subjected to an artificial rainfall of 150 ml with an energy of 270 J m^{-2}. The soil remaining on the sieve was put in a previously weighed capsule (T), dried at 105 °C and weighed (P1). The soil was then soaked in distilled water and, after 2 h, passed through the same sieve with the aid of a small stick to break the remaining aggregates. The residue remaining on the sieve, which was made up of plant debris and sand particles, was dried at 105 °C and weighed (P2). The percentage of stable aggregates with regard to the total aggregates was calculated by (P1−P2)×100/(4−P2+T).

2.7. Soil microbial biomass and related parameters

Microbial biomass carbon (MBC) was determined using the fumigation–extraction procedure (Vance et al., 1987), and the 0.5 M K_2SO_4 extracted C was measured in the same way indicated for water-soluble carbon. Basal respiration was determined on 50 g dry soil, moistened to 50% of its WHC and incubated in hermetically sealed flasks in the dark at 28 °C. The CO_2 released was measured in an IR CO_2 detector for 1 h after 10 h of continuous flushing. The metabolic quotient (qCO_2) was calculated dividing the C-CO_2 released from the sample in 1 h by the microbial biomass carbon content.

2.8. Enzymatic assays

2.8.1. Dehydrogenase activity

Dehydrogenase activity (DHA) was determined by Skujins' method (1976) modified by Garcia et al. (1997b). Soil (1 g) at 60% of its WHC was treated with 0.2 ml of 0.4% INT (2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyltetrazolium chloride) for 20 h at 22 °C in the darkness. The iodo-nitrotetrazolium formazan (INTF) formed was extracted with 10 ml of a mixture of 1:1.5 ethylene/chloride acetone by shaking vigorously for 1 min and filtering through Whatman No. 5 filter paper. INTF was measured spectrophotometrically at 490 nm.

2.8.2. Urease activity

Two milliliters of phosphate buffer (0.1M) pH 7 and 0.5 ml of 6.4% urea were added to 0.5 g of soil

Table 1
pH values, electrical conductivity, and nutrient contents of the different rhizosphere soils

Plant species	pH	Electrical conductivity (μS cm^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})
S. tenacissima	8.0a	270cd	4.0a	7.2b	1.12a
R. officinalis	7.9a	190d	2.9b	6.1bc	0.51c
O. europaea	8.0a	315cd	2.9b	7.5b	0.88ab
R. sphaerocarpa	7.7b	450a	3.9a	10.2a	0.77b
P. lentiscus	8.0a	330bc	1.8c	5.4c	0.92ab
R. lycioides	7.5b	380b	1.8c	10.5a	0.82ab
Control	8.3a	270cd	2.9b	5.5c	0.41c

Values followed by the same letter are not significantly different at the $p<0.05$ probability level.

Table 2
Organic carbon fractions in the different rhizosphere soils

Plant species	Total organic carbon (g kg^{-1})	Water-soluble carbon (mg kg^{-1})	Water-soluble carbohydrates (mg kg^{-1})	Water-soluble polyphenols (mg kg^{-1})
S. tenacissima	31.6ab	95b	23.1b	13.1a
R. officinalis	21.3cd	79bc	18.3c	14.1a
O. europaea	30.3ab	80bc	8.7d	7.5b
R. sphaerocarpa	29.5b	150a	20.3bc	9.5ab
P. lentiscus	21.4c	86b	11.0d	10.8ab
R. lycioides	33.6a	170a	29.0a	14.5a
Control	16.7d	59c	16.6c	8.2b

Values followed by the same letter are not significantly different at the $p<0.05$ probability level.

incubated at 30 °C for 90 min and the volume made up to 10 ml with distilled water. The ammonium released after addition of 0.1 ml 10 M NaOH was measured using an ammonium selective electrode (CRISON micro pH 2002). A control without urea was used for each sample (Nannipieri et al., 1980).

2.8.3. Phosphatase activity

Two milliliters of 0.1 M maleate buffer (pH 6.5) and 0.5 ml of 0.115 M *p*-nitrophenyl phosphate (PNPP) were added to 0.5 g of soil and incubated at 37 °C for 90 min. The reaction was stopped by cooling to 2 °C for 15 min and then 0.5 ml of 0.5 M $CaCl_2$ and 2 ml of 0.5 M NaOH were added to the soil mixture before centrifugation at 4000 rpm for 5 min. The *p*-nitrophenol (PNP) formed was determined in a spectrophotometer at 398 nm (Tabatabai and Bremner, 1969). Controls were made in the same way, but without incubation and cooling.

2.8.4. β-glucosidase activity

Two milliliters of 0.1 M maleate buffer (pH 6.5) and 0.5 ml of 50M *p*-nitrophenyl-β-D-glucopyranoside (PNG) were added to 0.5 g of soil. Then the same procedure reported for the phosphatase assay was followed, except that the NaOH was substituted by Tris buffer.

2.9. Statistical analysis

Differences between soil samples were tested by analysis of variance, and comparison among means were made using the Least Significant Difference (LSD) multiple range test, calculated at $p<0.05$.

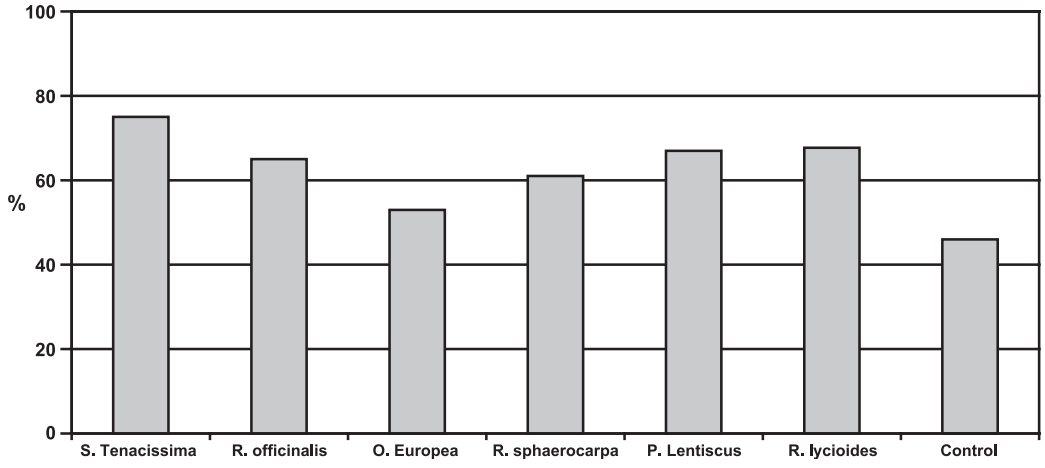

Fig. 1. Percentage of stable aggregates in the rhizosphere of shrubs growing in semiarid soils (LSD: ±10.15).

Table 3
Microbial biomass carbon and ratios between microbiological parameters

Plant species	MBC	qCO_2	MBC× 100/TOC
S. tenacissima	625a	43.0×10^{-3}a	2.08bc
R. officinalis	630a	40.8×10^{-3}a	3.65a
O. europaea	383c	51.7×10^{-3}a	1.26e
R. sphaerocarpa	580a	44.6×10^{-3}a	1.98c
P. lentiscus	475b	49.2×10^{-3}a	2.32b
R. lycioides	585a	41.7×10^{-3}a	1.74d
Control	341c	52.9×10^{-3}a	1.99c

MBC: microbial biomass carbon expressed as μg C g^{-1} soil; TOC: total organic carbon; qCO_2: metabolic quotient, expressed as (mg CO_2-C g^{-1} MBC h^{-1}).
Values followed by the same letter are not significantly different at the $p<0.05$ probability level.

Statistical procedures were carried out with the software package Statgraphics for Window 7.0.

3. Results

The pH of all the soils sampled under the different plant species (Table 1) was in the neutral–basic range (7.5–8.3). Soils under *R. sphaerocarpa* and *R. lycoides* had significantly lower values that the other plant species; control soils without vegetation always showed higher pH values. The EC was highest in the rhizosphere of *R. sphaerocarpa* and *R. lycioides* and lowest in *R. officinalis* and *S. tenacissima* and the control soil.

The nutritional elements (N, P and K) are also shown in Table 1. The higher N values corresponded to the rhizosphere of *S. tenacissima* and *R. sphaerocarpa*, the other species presenting values close to those of the control. *P. lentiscus* and *R. lycioides* showed the lowest values. Phosphorus behaved differently since the highest values were found in the rhizosphere of *R. sphaerocarpa* and *R. lycioides*. K showed similar values in all the rhizospheres and always higher than in the corresponding controls.

It can be seen in Table 2 that the rhizosphere of all plants examined showed higher TOC values than the control soil, reaching 200% in *R. lycioides*, *S. tenacissima*, *O. europaea* sbsp. *sylvestris* and *R. sphaerocarpa*. The lowest TOC values were found for *R. officinalis* and *P. lentiscus*, although in both cases they were still higher than in the control soil. All rhizospheres showed values of water-soluble carbon higher than the control soil. These values were particularly high in the rhizospheres of *R. sphaerocarpa* and *R. lycioides*, where they were three times larger than of the control soil. The differences were less pronounced for the content of water-soluble carbohydrates, which showed the highest value in the rhizosphere created by *R. lycioides*. Polyphenolic compounds were also higher under this plant species, alongside *R. officinalis* and *S. tenacissima*.

Fig. 1 shows the percentages of stable aggregates in the rhizosphere soil of each species. The maximum value corresponds to the rhizosphere of *S. tenacissima* (163% higher than that of the control), and all

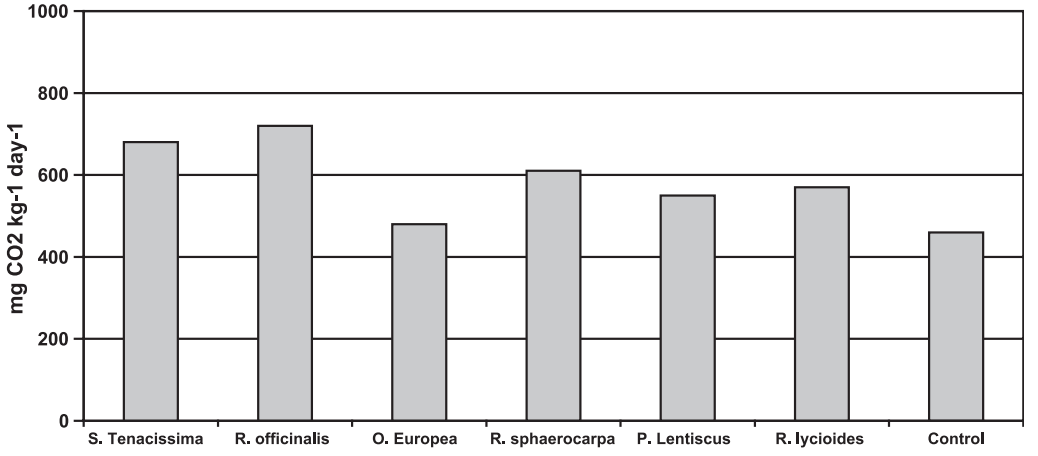

Fig. 2. Basal respiration in the rhizosphere of shrubs growing in semiarid soils (LSD: ±6.69).

Table 4
Enzyme activities determined in the different rhizospheres

Plant species	Dehydrogenase (μg INTF g^{-1} h^{-1})	β-glucosidase (μmol PNP g^{-1} h^{-1})	Urease (μmol NH_3 g^{-1} h^{-1})	Phosphatase (μmol PNP g^{-1} h^{-1})
S. tenacissima	162ab	89.3b	0.72abc	115.7b
R. officinalis	171a	98.8b	0.95a	111.4b
O. europaea	136b	82.9bc	0.64bcd	108.3b
R. sphaerocarpa	136b	168.2a	0.61cd	115.6b
P. lentiscus	114c	54.7d	0.71abc	105.9b
R. lycioides	152b	87.3b	0.87ab	154.7a
Control	130b	66.3cd	0.42d	82.0c

Values followed by the same letter are not significantly different at the $p<0.05$ probability level.
INTF: iodo-nitrotetrazolium formazane; PNP: *p*-nitrophenol.

rhizosphere soils presented higher values than the control.

The MBC was highest for *R. officinalis* and lowest for *O. europea* sbsp. *sylvestris*, where it was equal to that of the control soil (Table 3). Basal respiration behaved similar to MBC (Fig. 2). The ratios between MBC and TOC, and between basal respiration and MBC (qCO_2) are also shown in Table 3.

Table 4 shows several enzymatic activities. The overall metabolic activity indicated by dehydrogenase (oxydoreductase enzyme) activity points to two groups of plants: a group producing large values: *S. tenacissima*, *R. officinalis* and *R. lycioides* and the rest, which hardly differed from the control values. The rhizosphere zones clearly affect the hydrolases studied since in all cases these activities were higher than in the control soil (Table 4). Not all the plant species affected enzyme activities in the same way. For example, the rhizosphere of *R. sphaerocarpa* showed the highest β-glucosidase activity, while the highest phosphatase activity was found in the rhizosphere created by *R. lycioides*.

4. Discussion and conclusion

The tendency for the pH to decrease slightly (not always significantly) in the rhizosphere is presumably due to the release of acidic exudates (Shen et al., 2001). Such exudates also increase salinity since there is a negative correlation between pH and EC (Table 5). Garcia and Hernandez (1996) found that salinity has a strong negative effect on the microbial activity of these soils, particularly when the salinity is due to chlorides as opposed to sulphates, and with values of EC>390 dS m^{-1}. In our case, EC should not affect microbial activity because sulphates are more abundant than chlorides in this soil (Lax et al., 1994), and EC values, except for *R. sphaerocarpa*, are lower than 390 dS m^{-1}.

4.1. TOC and labile fractions

All plant species increased the organic matter content in the rhizosphere, which is of a great importance in semiarid regions, where the content of

Table 5
Correlation matrix between several parameters determined in the different rhizospheres

Parameter	r^2 (p) (n=21)	Parameter	r^2 (p) (n=21)
PH-Elect. Conductiv.	−0.516 (0.016)	Dehydrogenase-Basal respiration	0.675 (0.0008)
TOC-WSC	0.684 (0.0006)	Dehydrogenase-WS carbohydrates	0.538 (0.0119)
Aggregates-WS Carbohydrates	0.537 (0.0142)	Dehydrogenase-Polyphenol	0.555 (0.0091)
Aggregates-Polyphenols	0.634 (0.0021)	Dehydrogenase-Urease	0.506 (0.0191)
Aggregates-MBC	0.654 (0.0013)	Phosphatase-TOC	0.707 (0.0003)
Aggregates-Basal respiration	0.608 (0.0035)	Phosphatase-WSC	0.764 (0.0001)
MBC-Basal respiration	0.899 (0.0000)	β-glucosidase-WSC	0.528 (0.0138)
Aggregates-MBC	0.654 (0.0013)	Urease-MBC	0.621 (0.0027)
Dehydrogenase-MBC	0.724 (0.0002)	Urease-Basal respiration	0.603 (0.0039)

organic matter is very low (Garcia et al., 2000), and a diminution in soil organic matter could be accompanied by a deterioration in soil structure, an increase in bulk density and a decrease of hydraulic conductivity (Albaladejo et al., 1994). Plant cover has a considerable influence on the quantity of exudates and plant debris the soil receives (Caravaca et al., 2002b), e.g., the rhizosphere of *R. officinalis* and *P. lentiscus* L. which were the slowest growing plants of those studied and exuded the least C, showed the lowest values of TOC. Rhizospheres with higher TOC values, namely these of *S. tenacissima*, *R. sphaerocarpa*, *R. licioides* showed an increased biomass and root elongation (Haase et al., 1996; Caravaca et al., 2003). Thus, these species may be suggested to be used for soil restoration under semiarid climate conditions.

Water-soluble carbon (WSC) can be used as indicator of early changes in soil organic matter (Bolinder et al., 1999). WSC is a labile part of the organic matter together with the light fraction of the organic matter and microbial biomass C. The rhizospheres can be considered an important source of energy and nutrients for the microorganisms. Root exudates and the amount of below-ground plant mass contribute to the increase in this parameter (Campbell and Zentner, 1993) and a clear correlation between TOC and WSC was found here (Table 5). Species with an extensive root system, such as *R. lycioides* and *R. sphaerocarpa*, showed the highest values of WSC.

Significant differences in the content of water-soluble carbohydrates and polyphenols were observed between the rhizosphere and control soil, as well as among different rhizospheres. According to Van Veen et al. (1985), soils with a lower input of labile organic matter from the plant cover do not show a high potential microbial activity because there is insufficient available energy. In our study, planting with species such as *R. lycioides*, *S. tenacissima* and *R. sphaerocarpa*, contributed to potential microbial activity because of the increased concentration of water-soluble carbohydrates and phenolic compounds. The high concentration of carbohydrates and polyphenols in the rhizosphere was probably not only due to the mineralization of soil organic matter because no correlation between TOC and these carbon fractions was observed. The different composition of the exudates might be responsible for the differences observed in these parameters.

4.2. Stable aggregates

In agreement with Haines and Francis (1993), the different rhizospheres studied showed a higher percentage of stable aggregates than the control soil. In semiarid conditions, an increase in the aggregate stability will improve the soil structure and also, increase resistance to erosive processes (Roldan et al., 1994; Anderson, 1991). A positive correlation was found between the percentage of stable aggregates and the content of water-soluble carbohydrates, indicating their action as cementing elements (Elliott and Lynch, 1984). Invading species, such as *S. tenacissima*, contribute most to aggregate stability.

4.3. Microbial biomass and respiration

Differences in MBC in the soils studied are higher than the differences in TOC in the same samples, confirming that MBC is a sensitive index of changes in the organic C content of soils (Powlson et al., 1987). A positive correlation between TOC and MBC usually holds, but only at equilibrium and in soils where C is a limiting factor (which is usually the case in agricultural soils) (Anderson and Domsch, 1993; Insam and Parkinson, 1989). In our study, this correlation was not found; however, in the rhizosphere, C availability is probably not a limiting factor. It is also possible that the soils examined had not yet reached equilibrium. These could be the reasons for the lack of a relationship between TOC and MBC.

It is known that the MBC/TOC ratio is very dependent on the climatic conditions (Insam and Parkinson, 1989; Insam, 1990), particularly on the precipitation/evapotranspiration ratio. According to these authors, when this climatic ratio is >1 (as in arid zones), the values of MBC/TOC ratio should be higher than those obtained. However, our study was carried on rhizosphere soil, and in this zone the behaviour of this ratio seems to be different. MBC usually constitutes 1–5% of total organic carbon and MBC/TOC ratio differs markedly between soils. The highest value of this ratio was found in *R. officinalis* and *P. lentiscus*. Again it can be caused by the fact

that these soils might have not reached equilibrium yet.

Soil microbial respiration is a useful index for measuring soil microbial activity (Nannipieri et al., 1990). When MBC was low, basal respiration (BR) was also low; a positive correlation between microbial quantity (MBC) and activity (BR) is established. In disagreement with Powlson et al. (1987) and Saviozzi et al. (2001), we found no significant correlation between TOC and BR in our soils. This suggests that in semiarid climates part of the organic C probably has no direct relation with microbial activity (perhaps the non-easily decomposable organic matter). In contrast, a positive correlation was found between labile carbon fractions (water-soluble carbohydrates and polyphenols) and the percentage of stable aggregates. The root exudates of *R. officinalis* and *S. tenacissima* stimulated soil microbial activity, both furnishing organic substrate for microbial activity and creating a more favourable microhabitat.

The specific respiration rate of the soil microbial biomass (qCO_2) (Anderson and Domsch, 1993) has been used by Insam and Domsch (1988) to evaluate the status of soil microbial communities in reclamation studies. Garcia and Hernandez (1996) found that qCO_2 (CO_2/MBC) increased when a semiarid soil was subjected to stress; in our case, revegetation with these plant species does not imply a stress for the soil. In general, qCO_2 showed a similar value in all cases, perhaps again attributable to the fact that only the rhizosphere was studied. The values of qCO_2 were higher than those found by Insam (1990) in soils from several regions in North America, and by Insam and Haaelwandter (1989) in the Rotmoos Ferner (Austria) and Athabasca Glacier (Canada). This can be due to the arid-climatic conditions existing in the area, since the metabolic quotient (qCO_2) values are influenced by climate, increasing with temperature (Insam, 1990).

4.4. Enzyme activities

Enzymes may be considered early indicators of biological changes (Bandick and Dick, 1999; Wick et al., 2001). The enzymes involved in the dehydrogenase assay are mainly intracellular and related to oxidative phosphorylation processes (Trevors, 1986). A correlation between DHA and CO_2 evolution or MBC was confirmed in our study. Although the use of enzymes has been criticised by several authors (Benefield et al., 1977), Garcia et al. (1997b) found that DHA is a good index of the status of soil microbial activity in semiarid Mediterranean areas.

In general, hydrolases involved in the N (urease), P (phosphatase) and C (β-glucosidase) cycles showed higher values in the rhizosphere soils than in the control. It seems clear that the rhizosphere induces the synthesis of such enzymes. Nitrogen containing substrates may be produced, for instance, in greater quantity when the plant cover is *R. officinalis* and *R. lycioides*. Speir et al. (1980) also found that urease and protease activities of unplanted soils gradually decreased over 5 months of fallow, whereas increases were observed in planted soils. The higher phosphatase activity may be attributable to the depletion of available P by roots on soil microorganisms and/or the adsorption of inorganic P.

Phosphatase and β-glucosidase activities were correlated with WSC, which suggests that this fraction could contain substrates which stimulate the synthesis of these enzymes. The maximum value of β-glucosidase activity was found in *R. sphaerocarpa* (a leguminous plant), probably due to the exudates of this species which may increase the available substrates for β-glucosidase. This suggests that there may be qualities unique to each plant species that increase the activity of specific enzymes. The scarcity of C inputs from *P. lentiscus* (a species with low TOC in the rhizosphere, probably due to its slow growth) may be responsible for the low value of β-glucosidase activity, which was similar to that measured in the control soil. This is in agreement with Hayano and Tubaki (1985), who indicated that lower C inputs decrease enzyme synthesis. No correlation was found between phosphatase and β-glucosidase activity and parameters such as MBC or basal respiration. Soil enzymes that have significant abiotic activity may confound attempts to correlate enzyme activities with microbial biomass (Burns, 1978; Nannipieri et al., 1990).

It can be concluded that autochthonous plant species used to establish a plant cover in soils under semiarid climatic conditions influence a soil's chemical, physical, and biological properties, and therefore its quality. Microbial growth in the rhizosphere, as well as its activity, is closely related to root exudates and plant debris which differ from one plant species

to another. This has a great ecological significance due to the role played by microorganisms in the nutrient cycle and a great importance in choosing suitable plant species for reclamation of disturbed semiarid land.

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