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# Synergistic influence of an arbuscular mycorrhizal fungus and organic amendment on *Pistacia lentiscus* L. seedlings afforested in a degraded semiarid soil

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**Abstract**

A field experiment was undertaken to evaluate the effect of mycorrhizal inoculation with *Glomus intraradices* and added composted residue on the establishment of *Pistacia lentiscus* L. seedlings in a semiarid area. Composted residue greatly increased macronutrient (NPK) content, soil microbial activity and enzymatic activities, and decreased soil bulk density. There was a significant correlation between soil bulk density and both enzyme activities and labile C fractions (water-soluble C and water-soluble carbohydrates), which are also related to soil microbial activity. The most suitable methodology for revegetating with *P. lentiscus* seedlings was addition of composted residue to soil in conjunction with a mycorrhizal inoculation pretreatment of seedlings in a nursery, to increase available P uptake from composted residue. One year after planting, such a combined treatment had increased the plant height of *P. lentiscus* seedlings by 106% with respect to the control. 

*Keywords*: Enzymatic activities; Soil microbiological biomass; *Glomus intraradices*; Semiarid environment

## 1. Introduction

The semiarid Mediterranean areas of South-Eastern Spain are characterised by long dry periods and scarce, but torrential, rainfall, and very infertile soils. Low organic matter content is a major limitation to the growth of plant species on these soils, especially during the establishment phase (Perry et al., 1987). Likewise, the lack of a natural vegetative cover, which protects the soil surface against rain splash, accelerates the erosion and subsequent desertification of soils. Under such conditions, the rehabilitation of soils degraded by erosion should imply the reestablishment of plant cover, after a previous conditioning of the soil and plants in order to assure the success of soil revegetation.

The use of shrub species such as *Pistacia lentiscus* L. in revegetation programmes for abandoned agricultural lands has recently been encouraged by the agricultural policies of the European Union. *P. lentiscus* is a low-growing shrub, well adapted to water stress conditions, which belongs to the natural succession in certain plant communities of semiarid Mediterranean ecosystems in the South–East of Spain (Barea et al., 1992). However, the knowledge of reafforestation strategies involving *P. lentiscus* is still very scarce.

The ability of plants to establish in semiarid and disturbed soils can be improved by colonisation with arbuscular mycorrhizal fungi (Allen, 1989). Desertification generally reduces the inoculum potential for formation of mycorrhizae, which are key ecological factors governing the cycles of major plant nutrients, particularly in semiarid Mediterranean environments, and hence, revegetation must include the reconstitution of an appropriate mycosymbiont population (Barea et al., 1990).

Land application of organic residues from municipal waste has been increasing because of the need to solve the problem of their disposal, and to counteract the decreasing organic matter content of arid region soils. Beneficial effects of organic amendments are strongly related to improvement of biological fertility, by promoting soil microbial populations (e.g. Roldán and Albaladejo, 1993). However, negative effects have also been reported when such organic residues are used without being composted. Uncomposted organic residues have been shown to depress crop yields (García et al., 1990) and soil mycorrhizal populations

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Table 1
Analytical characteristics of the composted residue used in the experiment

| | |
|---|---|
| Ash (%) | 44.8 |
| pH (1:10) | 6.7 |
| Electrical conductivity EC (1:5, μS $cm^{-1}$) | 4700 |
| Total organic C (g $kg^{-1}$) | 276.0 |
| Water-soluble C (μg $g^{-1}$) | 1950 |
| Water-soluble carbohydrates (μg $g^{-1}$) | 76 |
| Total N (g $kg^{-1}$) | 14.5 |
| N-$NH_4$ (μg $g^{-1}$) | 3350 |
| Total P (g $kg^{-1}$) | 3.8 |
| Total K (g $kg^{-1}$) | 12.0 |
| Cu (μg $g^{-1}$) | 146 |
| Zn (μg $g^{-1}$) | 261 |
| Ni (μg $g^{-1}$) | 25 |
| Cr (μg $g^{-1}$) | 62.9 |
| Cd (μg $g^{-1}$) | 5 |
| Pb (μg $g^{-1}$) | 98 |

(Roldán and Albaladejo, 1993). In this respect, it is advisable that organic residues should be composted before soil amendment in order to eliminate human and plant pathogens.

Biological soil properties largely determine soil quality and fertility, and thus plant establishment and productivity (Pascual et al., 2000). Hence, the study of soil microbial activity is required to assess improvements in soil quality. Soil microbial activity has been frequently assessed through biological and biochemical parameters such as biomass C and enzyme activities. However, the labile C fractions, such as water-soluble C and water-soluble carbohydrates, also can be considered as indicators of soil microbiological activity (De Luca and Keeney, 1993). These C fractions are made up of biodegradable substrates and are used by the soil microorganisms as a carbon and energy source.

The objective of the present work was to determine the effectiveness of a combined treatment, involving mycorrhizal inoculation of seedlings and addition of composted residue to soil, on the reestablishment of *P. lentiscus* L. in a semiarid Mediterranean environment. At the same time, short-term effects of such treatments on soil properties considered to be indicators of soil quality, such as labile C fractions (water-soluble C and water-soluble carbohydrates), biomass C, and enzyme activities (dehydrogenase, urease, protease-BAA, acid phosphatase and β-glucosidase), and soil bulk density, were evaluated.

## 2. Materials and methods

### 2.1. Study sites

The experimental area was located on the El Picarcho range in the Province of Murcia (South–East Spain) (coordinates: 1°10′W and 38°23′N). The climate is semiarid Mediterranean, with an average annual rainfall of 312 mm and a mean annual temperature of 15.3 °C; the potential evapo-transpiration reaches 813 mm $y^{-1}$. The predominant soils are Petrocalcic Xerosol, Petric Calcisol and Haplic Calcisol types (FAO, 1988) developed from limestones, with a silt loam texture.

### 2.2. Materials

One representative shrub species from this area, found generally in semiarid shrublands in South-Eastern Spain, namely *P. lentiscus* L., was used for the reafforestation experiment.

The composted organic residue used was the organic fraction of a municipal solid waste obtained from a municipal waste treatment plant in Murcia. The composted organic residue was mechanically produced by fast fermentation (60 days), mixing the waste heap daily under aerobic conditions. The analytical characteristics of the composted organic residue, determined by standard methods (Page et al., 1982), are shown in Table 1.

### 2.3. Mycorrhizal inoculation of seedlings

The mycorrhizal fungus used in the experiment was *Glomus intraradices*, obtained from the collection of the experimental field station of Zaidín, Granada, Spain (EEZ1).

Arbuscular mycorrhizal inoculum consisted of a mixture of rhizospheric soil from trap cultures, containing spores, hyphae and mycorrhizal root fragments. Once germinated, seedlings were transplanted into the growing substrate, consisting of peat and cocopeat (1:1, v/v) mixed with *G. intraradices* inoculum (5%). Control plants were added with the same amount of the autoclaved mixture of the inoculum, supplemented with a filtrate (<20 μm) of the mixture to provide the microbial populations accompanying the mycorrhizal fungi. Inoculated plants were grown for 8 months under greenhouse conditions, without any fertilisation treatment, at Paisajes del Sur Ltd (Granada).

### 2.4. Experimental design and layout

The experiment was a randomised block design with two factors (compost and arbuscular mycorrhizae) and four replication blocks. In September 1999 an area of 1200 $m^2$ was mechanically prepared with a subsoiler. Eight rows (1 m wide, 25 m long, 3 m apart) were established. In early December 1999 half of the rows were amended, following the randomised design, with compost (0–20 cm depth) at a rate of 6.7 kg $m^{-2}$, which is sufficient to raise the soil total organic carbon (TOC) content by 1%. Three weeks after addition of the compost, *P. lentiscus* seedlings (mycorrhizated and uninoculated) were planted in individual holes, at least 1 m apart in a single row and with 3 m between blocks. At least 32 seedlings per replication block were planted (eight plants × four treatments in each block).

### 2.5. Sampling and laboratory procedures

One year after planting, four soil samples of each treatment were collected (16 samples in total). Each sample consisted of five bulked subsamples (200 $cm^3$ soil cores), randomly collected at 0–20 cm depth in the rhizospheres of five individual plants. The sampling was carried out in early December after the autumn rainy season, when the highest microbial activity could be expected (Lax et al., 1997). Two weeks before soil sampling, four seedlings of each treatment were harvested. Fresh and dry (105 °C, 5 h) weights of shoots, basal stem diameters and heights were measured.

The percentage of root length colonised by *G. intraradices* was calculated by the gridline intersect method (Giovannetti and Mosse, 1980), after staining with trypan blue (Phillips and Hayman, 1970).

Soil pH and electrical conductivity were measured in a 1:5 (w/v) aqueous extract. Total nitrogen was determined by the Kjeldahl method, and the total organic C by Yeomans and Bremner's method (Yeomans and Bremner, 1989). Available P (with sodium bicarbonate) and P in leaves after digestion in nitric-perchloric acid (5:3) were determined by colorimetry, according to Murphy and Riley (1962). Extractable (with ammonium acetate) K was determined by flame photometry.

In soil aqueous extracts, water-soluble carbon (WSC) was determined by wet oxidation with $K_2Cr_2O_7$ and measurement of the absorbance at 590 nm (Sims and Haby, 1971). Water-soluble carbohydrates and total carbohydrates were determined by the method of Brink et al. (1960).

Microbial biomass C was determined using a fumigation-extraction method (Vance et al., 1987).

Dehydrogenase activity was determined following Skujins' (1976) method modified by García et al. (1997). For this, 1 g of soil at 60% of its field capacity was exposed to 0.2 ml of 0.4% INT (2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyltetrazolium chloride) in distilled water for 20 h at 22 °C in darkness. The INTF (iodo-nitrotetrazolium formazan) formed was extracted with 10 ml of methanol by shaking vigorously for 1 min and filtration through a Whatman No. 5 filter paper. INTF was measured spectrophotometrically at 490 nm.

Urease and *N*-benzoyl-L-argininamide (BAA) hydrolysing protease activities were determined in 0.1 M phosphate buffer at pH 7; 1 M urea and 0.03 M BAA were used as substrates, respectively. Two millilitres of buffer and 0.5 ml of substrate were added to 0.5 g of sample, which was incubated at 30 °C (for urease) or 39 °C (for protease) for 90 min. Both activities were determined as the $NH_4^+$ released in the hydrolysis reaction (Nannipieri et al., 1980).

Acid phosphatase activity was determined using *p*-nitrophenyl phosphate disodium (PNPP, 0.115 M) as substrate. Two millilitres of 0.5 M sodium acetate buffer at pH 5.5 using acetic acid (Naseby and Lynch, 1997) and 0.5 ml of substrate were added to 0.5 g of soil and incubated at 37 °C for 90 min. The reaction was stopped by cooling at 2 °C for 15 min. Then, 0.5 ml of 0.5 M $CaCl_2$ and 2 ml of 0.5 M NaOH were added, and the mixture was centrifuged 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, although the substrate was added before the $CaCl_2$ and NaOH.

β-Glucosidase was determined using *p*-nitrophenyl-β-D-glucopyranoside (PNG, 0.05 M; Masciandaro et al., 1994) as substrate. This assay is based on the release and detection of PNP. Two millilitres of 0.1 M maleate buffer (pH 6.5) and 0.5 ml of substrate were added to 0.5 g of sample and incubated at 37 °C for 90 min. The reaction was stopped with tris-hydroxymethyl aminomethane (THAM) according to Tabatabai (1982). The amount of PNP was determined in a spectrophotometer at 398 nm (Tabatabai and Bremner, 1969).

Bulk density was determined by the paraffin method of Barahona and Santos (1981), after maintaining soil moisture at 60% of field capacity for one month.

### 2.6. Statistical analysis

The effects of residue addition and mycorrhizal inoculation, and their interaction, on measured variables were tested by a two-way analysis of variance and comparisons among means were made using the Least significant difference (LSD) multiple range test, calculated at $p < 0.05$. Pearson's correlation coefficients between all the soils parameters measured were assessed. Statistical procedures were carried out with the software package Statgraphics for Windows 7.0.

## 3. Results

### 3.1. Physical–chemical parameters

The addition of composted residue increased soil pH on average 0.36 units with respect to unamended soil (C) (Table 2). The highest increase in soil electrical conductivity was recorded in amended soil without mycorrhizae (CR), although the value reached in this soil (1180 $\mu S\ cm^{-1}$) was not sufficiently high to limit plant growth.

Composted residue significantly increased nutrient content (N, P and K) (Table 2). Mycorrhizae only had a significant effect on soil available P content in amended soil (Table 3).

TOC, total carbohydrates, water-soluble carbon and water-soluble carbohydrates in soil were significantly increased by the addition of composted residue, but mycorrhizae only influenced the labile C fractions, i.e. water-soluble carbon and water-soluble carbohydrates, of amended soil (Tables 2 and 3). In particular, TOC content increased by 100% with respect to unamended soil (C) and by 50% with respect to the dose added with the compost.

Soil bulk density was significantly decreased by the

Table 2
Changes in physical–chemical properties of the soil in response to mycorrhizal inoculation (M) and composted residue (CR) addition ($n = 4$). (C = control soil, without mycorrhizal inoculation and without composted residue addition and CRM = composted residue addition + mycorrhizal inoculation; in parenthesis, standard deviation for each measure. TOC: total organic carbon; Total CH: total carbohydrates; Water-soluble C: water-soluble carbon; Water-soluble CH: water-soluble carbohydrates; Water-soluble PP: water-soluble polyphenols; Total N: total nitrogen)

| | C | CR | M | CRM |
|---|---|---|---|---|
| pH ($H_2O$) | 8.50 (0.03) | 8.09 (0.02) | 8.54 (0.04) | 8.20 (0.07) |
| EC (1:5, μS $cm^{-1}$) | 246 (10) | 1180 (112) | 227 (1) | 668 (211) |
| Total N (g $kg^{-1}$) | 0.8 (0.0) | 1.8 (0.2) | 1.0 (0.1) | 1.5 (0.1) |
| Available $P_2O_5$ (μg $g^{-1}$) | 12 (2) | 126 (17) | 15 (1) | 65 (14) |
| Extractable $K_2O$ (μg $g^{-1}$) | 379 (27) | 1915 (447) | 424 (12) | 1806 (484) |
| TOC (g $kg^{-1}$) | 21.0 (0.6) | 42.0 (1.6) | 21.4 (1.3) | 36.9 (2.6) |
| Total CH (μg $g^{-1}$) | 3060 (192) | 4613 (185) | 2682 (117) | 4260 (336) |
| Water-soluble C (μg $g^{-1}$) | 215 (6) | 935 (55) | 211 (9) | 663 (88) |
| Water-soluble CH (μg $g^{-1}$) | 10 (1) | 37 (1) | 7 (0) | 26 (1) |
| Bulk density (g $cm^{-3}$) | 1.12 (0.03) | 0.90 (0.04) | 1.19 (0.07) | 1.04 (0.03) |

addition of composted residue (Table 2), the greatest decrease being in amended soil without mycorrhizae.

### *3.2. Biochemical parameters, percentage of colonisation and growth parameters of P. lentiscus*

Biomass C and enzyme activities were significantly increased by the application of the composted residue but not by mycorrhizal inoculation (Table 4). In particular, the increase in C-biomass produced by composted organic residue was about 330% with respect to control soil.

The combined treatment of composted residue addition and mycorrhizae significantly increased the growth with seedling height being increased by 106% with respect to the control, and foliar P content of *P. lentiscus* seedlings (Table 4). The percentage of mycorrhizal root length was only significantly increased by mycorrhizae treatment.

## 4. Discussion

The experiment showed that the combination of composted residue and mycorrhizae can considerably improve the growth of *P. lentiscus* in semiarid conditions. This result contrasts with the widely accepted idea that mycorrhizae present little advantage to seedlings grown in fertilised soils (Yanai et al., 1995). The rapid growth of seedlings inoculated with *G. intraradices* as compared with the uninoculated seedlings, in the amended soil might be related to the capacity of the fungus to increase available P uptake from composted residue (Nadian et al., 1996; Roldán et al., 1996). It is worth noting that the increase of extractable P obtained in CR soil was about twice as high as in CRM soil. The fact that the highest contents of P in leaves occurred for seedlings grown in amended soil and inoculated with *G. intraradices* demonstrated a higher accumulation of P as a consequence of mycorrhizal inoculation.

Table 3
Two factors ANOVA (mycorrhizal inoculation and composted residue addition) for all parameters studied. *F* values (significance level)

| | Composted residue (CR) | Mycorrhizae (M) | Interaction (CR × M) |
|---|---|---|---|
| pH ($H_2O$) | 78.362 (0.000) | 3.092 (0.104) | 0.747 (0.413) |
| EC | 33.243 (0.000) | 4.942 (0.046) | 4.276 (0.061) |
| Total N | 53.753 (0.000) | 0.012 (0.918) | 6.692 (0.024) |
| Available P | 57.329 (0.000) | 7.120 (0.021) | 8.761 (0.012) |
| Extractable K | 19.609 (0.001) | 0.009 (0.926) | 0.054 (0.822) |
| TOC | 116.774 (0.000) | 1.981 (0.185) | 2.698 (0.126) |
| Total CH | 49.620 (0.000) | 2.712 (0.126) | 0.003 (0.958) |
| Water-soluble C | 126.150 (0.000) | 7.009 (0.021) | 6.634 (0.024) |
| Water-soluble CH | 580.734 (0.000) | 48.711 (0.000) | 21.243 (0.001) |
| Bulk density | 19.802 (0.001) | 6.067 (0.029) | 0.703 (0.427) |
| C-Biomass | 362.119 (0.000) | 0.002 (0.969) | 3.417 (0.089) |
| Dehydrogenase | 55.080 (0.000) | 2.900 (0.114) | 1.754 (0.210) |
| Urease | 45.371 (0.000) | 2.809 (0.120) | 2.755 (0.123) |
| Protease-BAA | 105.463 (0.000) | 0.895 (0.373) | 1.279 (0.280) |
| Acid phosphatase | 110.410 (0.000) | 0.164 (0.697) | 0.719 (0.422) |
| β-glucosidase | 39.210 (0.000) | 5.064 (0.044) | 0.052 (0.826) |
| Height | 6.769 (0.017) | 8.227 (0.010) | 0.158 (0.699) |
| Basal diameter | 2.310 (0.144) | 1.125 (0.302) | 0.372 (0.555) |
| Mycorrhizal root | 0.501 (0.500) | 16.015 (0.002) | 0.757 (0.411) |

Table 4
Changes in soil biochemical properties, growth, foliar phosphorus and root colonisation in *P. lentiscus* in response to mycorrhizal inoculation (M) and composted residue (CR) addition ($n = 4$). (C = control soil, without mycorrhizal inoculation and without composted residue addition and CRM = composted residue addition + mycorrhizal inoculation; in parenthesis, standard deviation for each measure. TOC: total organic carbon)

| | C | CR | M | CRM |
|---|---|---|---|---|
| C-Biomass ($\mu g\ g^{-1}$) | 176 (30) | 756 (11) | 228 (24) | 706 (38) |
| C-Biomass/TOC (%) | 0.85 (0.12) | 1.80 (0.08) | 1.08 (0.09) | 1.95 (0.13) |
| Dehydrogenase ($\mu g$ INTF $g^{-1}$ soil) | 93 (8) | 197 (21) | 88 (3) | 161 (7) |
| Urease ($\mu mol\ NH_3\ g^{-1}\ h^{-1}$) | 0.29 (0.04) | 6.67 (0.06) | 0.27 (0.02) | 4.13 (1.52) |
| Protease-BAA ($\mu mol\ NH_3\ g^{-1}\ h^{-1}$) | 0.60 (0.06) | 1.22 (0.08) | 0.61 (0.04) | 1.11 (0.02) |
| Acid phosphatase ($\mu mol$ PNP $g^{-1}\ h^{-1}$) | 46.5 (1.3) | 112.1 (10.6) | 37.7 (3.2) | 115.1 (7.8) |
| β-glucosidase ($\mu mol$ PNP $g^{-1}\ h^{-1}$) | 77.6 (3.4) | 127.2 (9.7) | 61.8 (9.0) | 108.4 (7.0) |
| Height (cm) | 23.3 (2.7) | 33.2 (2.3) | 34.4 (0.8) | 48.0 (1.4) |
| Basal diameter (mm) | 4.1 (0.1) | 4.3 (0.2) | 4.4 (0.1) | 5.1 (0.0) |
| Foliar $P_2O_5$ (mg/plant) | 2.0 (0.1) | 3.3 (0.7) | 4.0 (0.8) | 5.7 (0.9) |
| Mycorrhizal root (%) | 8.4 (2.6) | 7.0 (2.1) | 35.4 (10.7) | 49.1 (15.6) |

On the other hand, the decrease of soluble C fractions in amended soil and with inoculated plants can favour root colonisation by *G. intraradices*, which in turn enhances the beneficial effects of arbuscular mycorrhizal fungi such as increased uptake of P by plant roots. Several authors have demonstrated that total percentages of mycorrhizal colonisation and sporulation are negatively correlated with the concentration of soluble C fractions (Pearson et al., 1994; Muthukumar and Udaiyan, 2000), indicating that mycorrhizal fungi act as strong sinks for photosynthates. We also found the highest levels of seedling colonisation in amended soil (CRM), where concentrations of water-soluble carbon and water-soluble carbohydrates were lower than in amended soil and with uninoculated seedlings (CR).

The application of organic materials reduces the soil bulk density and hence increases total porosity, which has a positive effect on plant growth. In a compacted soil, mycorrhizal symbiosis can enhance the uptake of nutrients by plant roots since mycelium of hyphae penetrates small pores more easily than roots (Nadian et al., 1996). Soil bulk density was significantly lower in the amended soils than in the unamended soils. There was a highly significant correlation between soil bulk density and the total carbohydrates and water-soluble carbohydrates contents, with a high level of significance ($p < 0.05$), which indicates the contribution of the polysaccharides to the rhizosphere soil in the improvement of soil structure.

It has been suggested that improvement in the physical properties of a soil, particularly porosity, may affect its biological and biochemical activities, including enzymatic activities (Giusquiani et al., 1995). Thus, the bulk density of soil was negatively correlated with the water-soluble carbon and water-soluble carbohydrates contents, and with all enzyme activities except acid phosphatase activity (Table 5).

Soil microbial activity in semiarid areas is very low due to the low capacity of the soil organic matter to be mineralised (García et al., 1994), which in turn is related to the lack of soil moisture (Rao and Tarafdar, 1992). García et al. (1994) proposed C-biomass and dehydrogenase activity as indices of microbiological activity in arid soils. Stimulation of soil microbial activity, measured as C-biomass and dehydrogenase activity, was only induced by organic amendment.

Several authors (Insam and Merschak, 1997; Beyer et al., 1999) have found that the ratio of microbial biomass C to TOC is a sensitive index of changes in soil organic matter. In our study, the addition of composted residue increased the C-biomass/TOC ratio values, indicating that about 2% of TOC belongs to the microbial carbon of the biomass. This increase in the C-biomass/TOC ratio can be due to both the microbial biomass incorporated in the composted organic residue and the positive effect of the organic amendment on the initial soil microbiota, favouring soil organic matter turnover.

Table 5
Pearson's correlation coefficients between chemical, biochemical and physical parameters of rhizosphere soil ($n = 4$) (TOC: total organic carbon; Total CH: total carbohydrates; Water-soluble C: water-soluble carbon; Water-soluble CH: water-soluble carbohydrates; *,**, *** significant at $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively)

| | TOC | TCH | WSC | WSCH | Bulk density |
|---|---|---|---|---|---|
| Dehydrogenase | 0.995** | 0.984* | 0.999*** | 0.951* | −0.963* |
| Urease | 0.990** | 0.971* | 0.999*** | 0.996** | −0.965* |
| Protease-BAA | 0.998** | 0.984* | 0.984* | 0.978* | −0.941* |
| Acid phosphatase | 0.969* | 0.979* | 0.937 | 0.938 | −0.866 |
| β-glucosidase | 0.970* | 0.993** | 0.976* | 0.989** | −0.979* |
| C-Biomass | 0.990** | 0.968* | 0.966* | 0.955* | −0.874 |
| Bulk density | −0.932 | −0.948* | −0.962* | −0.979* | – |

Measurement of soil hydrolases provides an early indication of changes in soil fertility, since they are related to the mineralisation of such important nutrient elements as N, P and C (Ceccanti and García, 1994). Many researchers have found that soil hydrolase activities are enhanced by the addition of organic materials (Dick, 1992; García et al., 1998). We also found that the hydrolase activities involved in the N (urease and protease-BAA), C (β-glucosidase) and P (acid phosphatase) cycles were higher in amended soils (CR and CRM). The highest increase was observed for the urease activity, due to the organic materials increasing the N substrates in the soil (García et al., 1998).

Mycorrhizae did not significantly increase *P. lentiscus* seedling growth in unamended soil (M), possibly because the soil fertility and quality are so poor that the fungus cannot have beneficial effects on host plant growth and development. Similar results were obtained by France and Cline (1987).

Finally, the addition of compost alone to soil was not sufficient to increase the growth of *P. lentiscus* seedlings in spite of increasing the chemical and biological fertility of amended soil. This result reaffirms the key role of arbuscular mycorrhizae in sustaining the plant cover, as well as, showing the necessity of including mycorrhizal inoculation in revegetation programmes to guarantee plant performance.

One year after planting, we can conclude that the success of revegetation carried out with *P. lentiscus* in a semiarid soil is based on both improvement of soil quality, by means of compost addition, and an increase in seedling resistance to the inhospitable environmental conditions, by use of arbuscular mycorrhizal fungi. Also, the short-term improvements in soil physical, chemical, microbiological and biochemical quality were only due to the addition of composted residue.

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