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ORIGINAL PAPER

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Interactions between crop residues application and mycorrhizal developments and some soil-root interface properties and mineral acquisition by plants in an acidic soil

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Abstract The addition of plant residues and the appropriate management of arbuscular mycorrhizal (AM) symbioses have been tested in an acidic soil, an Andisol from Southern Chile, to ascertain whether these agro-technologies help plants to withstand potential mineral deficiency and the toxicities inherent to the low pH conditions. Firstly, the effects of legume (lupine) and non-legume (wheat) crop residues on some key root-soil interface activities (including AM development), on mineral acquisition by the plants, and on the yield of wheat growing in the test Andisol were investigated in a pot experiment under greenhouse conditions. Both lupine and wheat residues were added at a rate equivalent to 300 g m^{-2} to the natural soil. These organic amendments increased soil pH (wheat more than lupine), P availability and AM development (lupine more than wheat), plant performance and mineral acquisition (wheat more than lupine). Because of an increase in mycorrhizal activity, which appeared to be involved in the effect of the added crop (particularly lupine) residues, the role of the AM symbiosis was further investigated in a tailored inoculation assay, using a selected AM fungus (*Glomus etunicatum*), in interaction with lupine and wheat residues. A significant effect of AM inoculation on the reduction of Zn and Cu, and Mn and Al acquisition was demonstrated, which could be of interest in acid soils with regard to potential toxicity problems.

Keywords Low soil pH · AM fungi · Crop residues · Nutrient availability · Alleviation of toxic minerals

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Introduction

The application of crop residues, particularly those from legumes (Paré et al. 2000), and the appropriate management of mycorrhizal symbioses (Liu et al. 2000) are being considered among the diverse technological practices applicable to low-input agricultural systems to benefit their sustainability, an agro-ecological issue that must be based on the optimization of the rate of turnover and recycling of organic matter and nutrients (Altieri 1994; Jeffries and Barea 2001). Crop residues are applied to the soil as a source of nutrients for the plant, a practice that fits in well with the current world-wide trends towards resource conservation in agriculture, and, particularly, with the growing interest of local farmers in alternative agricultural practices, such as organic farming and zero- or reduced-tillage. Mycorrhizal symbioses are known to play a critical role in plant nutrition, based on the ability of the external mycorrhizal mycelium developing around the host plant roots to efficiently explore a larger volume of soil, thereby enhancing mineral acquisition by the plant (Smith and Read 1997). In particular, the commonest mycorrhizal type developing in agricultural systems, the arbuscular mycorrhizal (AM), is considered a key component in low-input-based agro-technologies (Jeffries and Barea 2001).

Both the use of crop residues (Tang and Yu 1999; Paré et al. 2000; Paul et al. 2001) and the improvement of AM developments and functionality (Clark 1997; Borie and Rubio 1999) can have a special significance in acid soils due to the particular problem of acidification itself (Bolan et al. 1991) and to the commonly associated toxicity of Al and Mn and the deficiency of P, Ca, Mg, K and Zn (Marschner and Dell 1994; Clark et al. 1999) in these low pH soils.

Soil acidification and aluminium toxicity are probably the major limiting factors to plant growth and crop production in many agricultural areas of the world (Kamprath 1984; Baligar and Fageria 1997). Much research has been directed towards correcting the problem, including the application of mineral lime or other pH-

raising materials to replenish plant nutrients and reduce the toxicity of Al and Mn. Because of excessive costs, especially in developing countries, a proposed alternative has been to apply organic residues to the soil (Sanchez and Salinas 1981). Most of the beneficial effects of the application of organic residues, including crop residues, to acid soils have been attributed to a decrease in aluminium phyto-toxicity as a consequence of increasing pH (Kretzschmar et al. 1991), to an increase in N and exchangeable cations such as Ca, Mg, and K (Tang and Yu 1999; Mitchell et al. 2000) or to an enhancement of available P (Hue and Amien 1989; Hafner et al. 1993). Both an increase in OH ions and the phosphate concentration result in the formation of Al-OH (Wagatzuma and Ezoe 1985) or Al-P species able to reduce the activity of Al^{3+} (Alva et al. 1986). It is well known that changes in soil pH and/or the added organic matter itself can affect the activity of soil microorganisms, either free-living (Robson and Abbott 1989) or forming mycorrhizal associations (Clark and Zeto 1996, 2000; Clark 1997; Siqueira and Moreira 1997; Paré et al. 2000). On the other hand, given the variable composition of different types of organic materials added to soil, it is reasonable to assume that organic residues, including crop residues, will not produce a similar effect on soil chemical or biological soil components. The chemical composition of plant material can in fact differ greatly among species, among plants of different ages and among plant parts (Tang et al. 1997), and, consequently, be decomposed at different rates.

Acidic soils, mainly Ultisols and Andisols, are very common and abundant in Southern Chile where they cover more than 5×10^{10} m^2 with cereals as the main crop. These soils, having high P-fixing capacity, need intensive P fertilisation rates for obtaining economic yields and have more than half of their total P as organic P (Borie and Zunino 1983). The low P availability together with the high Al activity of these soils was investigated in some studies, which demonstrated that the AM symbiosis plays a crucial role in P cycling (Borie and Barea 1983; Rubio et al. 1989; Mendoza and Borie 1998; Borie and Rubio 1999).

Although previous studies have found increased levels of AM fungal inoculum and root colonization rates in low-input as compared with intensive farming systems, in the field (Sattelmacher et al. 1991; Kurle and Pfleger 1994; Douds et al. 1995) information is scarce in relation to the effects of added crop residues on mycorrhizal developments in acidic soils. Therefore a research programme was undertaken, the general objective of which was to evaluate the effects of crop residues on root-soil interface activities, including AM development, on mineral acquisition by the plants, and on the yield of wheat growing in an Andisol from Southern Chile.

As a part of such a programme the present study aimed: (1) to determine whether the application of residues from either a legume or a non-legume crop affects soil pH, acid phosphatase activity, P availability, AM development and mineral acquisition by the plants; (2) to assess whether any change in some of these plant-soil activities/responses is due to the effect of the residues on the natural mycorrhizal potential of the soil; and (3) to study the effect of the interaction between residue application and a tailored mycorrhizal inoculation on the target root-soil interface activities, and on mineral acquisition by wheat plants.

Materials and methods

Two sequential experiments were carried out. The first one aimed to assess the effect of residue application on the natural soil, having its own mycorrhizal potential, and the second, aimed to ascertain the effect of AM inoculation in interaction with residue amendments.

Experimental conditions

Some properties of the Andisol (Typic Distrandepts) soil of low P status are presented in Table 1. The soil was collected from a 5- to 25-cm depth, crushed and sieved through a 2-mm sieve. Lupine and wheat residues were obtained from field-grown plants collected at maturity. Shoots and leaves of white lupine and wheat straw were dried at 70°C, and finely ground. The characteristics of the tested residues are also reported in Table 1. Certain chemical soil properties were determined according to Olsen and Sommers (1982), for available-P; Dick and Tabatabai (1977), for total-P; Walkey and Black (1934), for organic matter (SOM); and calcium, magnesium, potassium, aluminium, copper, zinc and manganese were determined by atomic absorption spectroscopy. Carbon and N in the organic residues were determined by using a Leco CHN Analyzer; the mineral contents were determined as before.

Wheat cultivar "Otto" was used as the test plant. This species and variety is currently cropped in the region under study. Seeds were surface sterilised with 70 mM NaOCl for 5 min and rinsed thoroughly before being planted into 1-l pots containing 800 g soil amended or not with the residues. Both crop residues were previously and thoroughly mixed with soil and put as an upper layer of 5 cm in the pots at a rate equivalent to 300 g m^{-2}. Basic fertilisation was done at a rate equivalent to 200 kg N ha^{-1} as KNO_3 and 100 kg P ha^{-1} as Ca $(H_2\ P0_4\ )_2$. Pots were incubated at 25±3°C in the greenhouse at approximately 60% of water holding capacity for 6 days before planting. Plants were thinned to two per pot 10 days after sowing and irrigated manually with distilled water as needed (judged by weighing pots) during the experiment. A photosynthetic photon flux density of 400–500 µmol m^{-2} s^{-1} was applied as supplementary light. Every 2 weeks 10 ml nutrient solution (Johnson et al. 1996) without P were added to each pot. Wheat plants were grown in a greenhouse with 16-h light periods. Throughout the experiment, the temperature was kept at 25±3°C by using a standard thermostatic device.

Harvest and analyses

At maturity (about 90 days of cultivation), the wheat plants were harvested and the shoots and roots were dried (at 70°C) and weighed. Shoots were crushed, ground and converted into ash in a furnace at 550°C. Ashes were further acid digested, P content was quantified by spectrophotometry (Murphy and Riley 1962), and calcium, magnesium, potassium, aluminium, copper, zinc and manganese determined by atomic absorption spectroscopy. Before drying, a portion of roots was separated and AM colonization was estimated by the method described by Giovanetti and Mosse (1980) after clearing and staining (Phillips and Hayman 1970). Root length was determined by the method of Tennant (1975). Soil pH was measured in a soil/water paste (1/2) and available P by the method described by Olsen and Sommers (1982). Acid phosphatase activity in the root-associated soil was estimated, as described by Tabatabai and Bremner (1969).

Table 1 Selected chemical properties of the soil and plant residues

	pH (H_2O)	Total C g kg^{-1}	Total N g kg^{-1}	C/N	Total P mg kg^{-1}	Org-P mg kg^{-1}	Avail-able-P mg kg^{-1}	SOM mg kg^{-1}	Mineral concentration[a]										Al sat g kg^{-1}
									K	Ca	Mg	Al	Na	Cu	Mn	Zn	CEC		
Soil	5.48	–	–	–	2,540	1,480	4	180	0.7	9.33	1.23	0.07	0.07	–	–	–	11.33	6.1	
Lupine straw	–	410	17.2	24	594	–	–	–	5,860	6,588	2,010	565	–	20.6	3,423	144	–	–	
Wheat straw	–	420	9.4	44	1,527	–	–	–	5,880	1,108	972	235	–	16.2	31.5	138	–	–	

[a] In cmol (+) kg^{-1} (soil); and in mg kg^{-1} (residues)

Experiment 1

Wheat seeds were sown in the pots containing the natural soil having, therefore, its natural mycorrhizal (AM) potential. The experimental design consisted of a factorial combination of two crop residues (lupine and wheat) added at two rates equivalent to 0 and 300 g m^{-2}. Treatments were arranged on greenhouse benches in a randomised complete block design with four replicates per treatment. In addition to all the general determinations described, in this particular experiment, the effect of the crop residues on the availability of soil P, both organic and inorganic, was measured (Dick and Tabatabai 1977). Soil amended with the lower level of organic residues was characterised by its organic and inorganic P contents according to the procedure of Hedley et al. (1982). Briefly, 0.5 g soil was shaken for 16 h with 30 ml 0.5 M $NaHCO_3$ pH 8.5, and centrifuged at 3,000 *g*; P was analysed in the supernatant as available-Pi and available-Po. The remaining soil was further extracted by shaking for 16 h in 0.5 M NaOH, and centrifugation at 3,000 *g*; in the supernatant P was analysed as labile-Pi and -Po.

Experiment 2

The objective of this experiment was to assess the effect of AM inoculation, as suggested by results from experiment 1. Soil was treated in a microwave oven as previously described (Borie and Rubio 1999) for two consecutive days. To reintroduce the normal microbiota (except for AM propagules), the sterilized soil was inoculated with a filtrate of the AM inoculum [10 ml pot^{-1} of a soil/water mixture (1/1, v/v)] which had been filtered through Whatman no. 1 filter paper which retains AM propagules but not other natural components of the soil microbiota, and was allowed to stand for 10 days before use. Once distributed into pots, the soil in half of these pots was mixed thoroughly with *Glomus etunicatum* CH 110 inoculum (Morton and Bentivenga, INVAM culture collection). The inoculum had been multiplied in our laboratory using sudangrass (*Sorghum bicolor* L) as a host plant grown in the tested Andisol and consisted of a mixture containing root fragments + hyphae + spores. The experimental design was a factorial combination of two mycorrhizal treatments, two crop residues at two rates and eight replicates.

Statistical analyses

The data were subjected to analysis of variance using the ANOVA procedures of the SAS Institute, SAS/STAT, version 6 (1990). Statistical significance was determined at $P < 0.05$. Means were compared by the Duncan's multiple range test. The overall means and the *t*-test for paired samples were calculated by the Statistics Made Visual Software of the SAS Institute (1990).

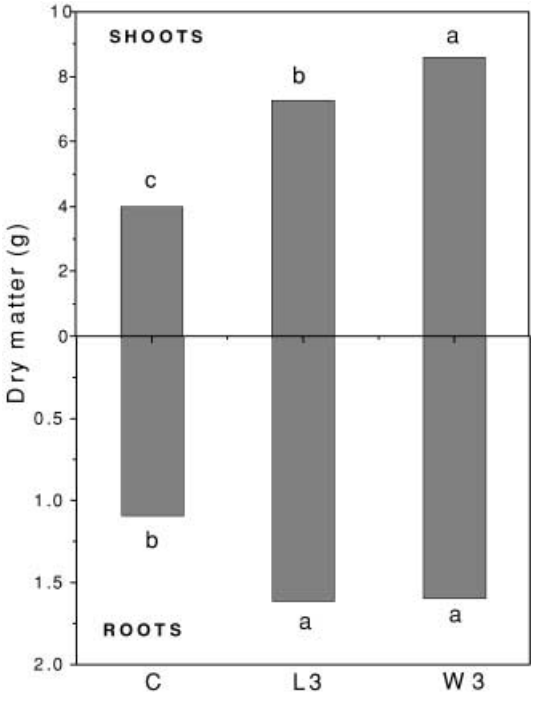


Fig. 1 Shoot and root dry weight of wheat plants as influenced by crop residue application to the soil. Means followed by the same letter within the same parameter are not significantly different at $P < 0.05$ by Duncan's multiple-range test (*C* un-amended control, *L* lupine residues, *W* wheat residues, *3* amount of residue added at a rate equivalent to 300 g m^{-2})

Results

Experiment 1

The application of lupine (L) or wheat (W) crop residues at a rate equivalent to 300 g m^{-2} (L3 and W3), increased both shoot and root biomass accumulation by the wheat plants growing in the acidic soil, which maintained its own mycorrhizal potential without any mycorrhizal inoculation management (Fig. 1).

Results summarised in Fig. 2 indicate that both crop residues increased the root length, and L3 improved AM development since it increased the "total mycorrhizal root length". Figure 2 also shows that wheat residue additions (W3) induced a significant increase in soil pH

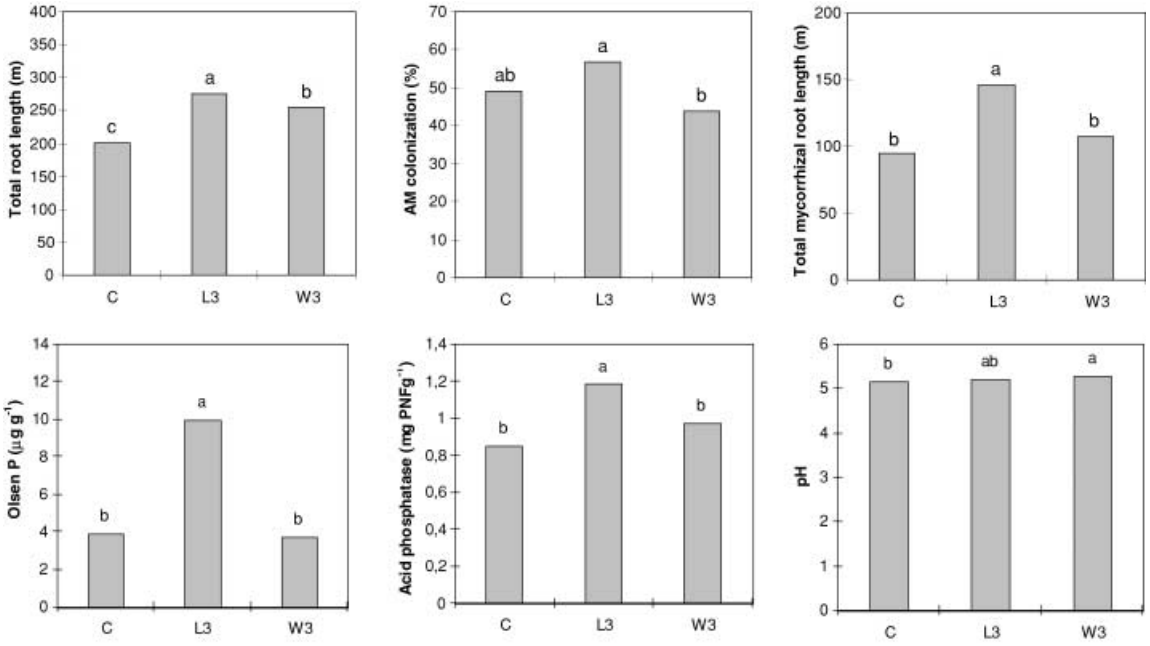


Fig. 2 Root-soil interface traits as influenced by crop residue application to the soil. Means followed by the same letter within the same parameter are not significantly different at $P < 0.05$ by Duncan's multiple-range test (*C* un-amended control, *L* lupine residues, *W* wheat residues, *3* amount of residue added at a rate equivalent to 300 g m^{-2})

Table 2 Overall effect of mycorrhizal inoculation (*Glomus etunicatum* CH 110) on several experimental variables, irrespective of the type (lupine or wheat) and/or amount of crop residue applied to the soil (*NS* not significant)

Experimental variable	Status of the soil-plant system		Significance degree
	Non-mycorrhizal	Mycorrhizal	
Shoot dry weight (g)	7.6±0.4	8.2±0.2	NS
Root dry weight (g)	1.9±0.2	2.0±1.1	NS
Available soil P (µg g^{-1})	4.4±0.5	9.8±0.2	***
Soil pH (water)	5.4±0.1	5.6±0.1	NS
Acid P-asa (mg PNF g^{-1})	0.9±0.1	0.6±0.1	**
Shoot P conc. (µg g^{-1})	455.0±15.0	450.0±18.0	NS
Shoot K conc. (mg g^{-1})	11.2±0.3	12.1±0.2	*
Shoot Ca conc. (µg g^{-1})	844.0±36.0	783.0±23.0	NS
Shoot Mg conc. (µg g^{-1})	747.0±55.0	664.0±27.0	NS
Shoot Zn conc. (µg g^{-1})	89.1±4.6	65.2±3.7	**
Shoot Cu conc. (µg g^{-1})	24.6±1.4	15.9±0.7	***
Shoot Al conc. (µg g^{-1})	459.0±53.0	261.0±22.0	**
Shoot Mn conc. (µg g^{-1})	24.6±1.4	15.9±0.7	***
Shoot P content (mg)[a]	3.6±2.0	3.6±0.8	NS
Shoot K content (mg)	81.9±4.7	99.8±3.8	**
Shoot Ca content (mg)	6.1±0.3	6.4±0.2	NS
Shoot Mg content (mg)	5.5±0.3	5.5±0.2	NS
Shoot Zn content (µg)	667.0±41.0	541.0±36.0	*
Shoot Cu content (µg)	192.0±17.0	136.0±7.0	**
Shoot Al content (mg)	4.7±0.5	2.1±0.1	***
Shoot Mn content (µg)	514.0±31.0	378.0±7.0	***

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

[a] Mineral content = amount in plant shoots (two plants per pot)

with respect to that produced by the plant itself, while L3 increased both the available P concentration and the acid phosphatase activity in the rhizosphere soil.

L3 residue application increased the concentration of P, Mg, K, Ca, Zn, and Cu in wheat shoots, while W3 increased only that of K, Zn and Cu. Both residues, but wheat more than lupine, increased shoot content of P, Mg, K, Ca, Zn, Cu, Mn and Al (Fig. 3). Except for Mg and Ca, wheat residues were more effective than those from lupine in benefiting mineral accumulation in shoot biomass.

Fractionation of P in soil after harvest indicated that the available Pi fraction was significantly increased by both lupine (more effective) and wheat residue amendments, with L3 also increasing the labile (Po) fraction (Fig. 4).

Experiment 2

The overall effects of a tailored AM inoculation (*G. etunicatum*), independent of whether or not the soil

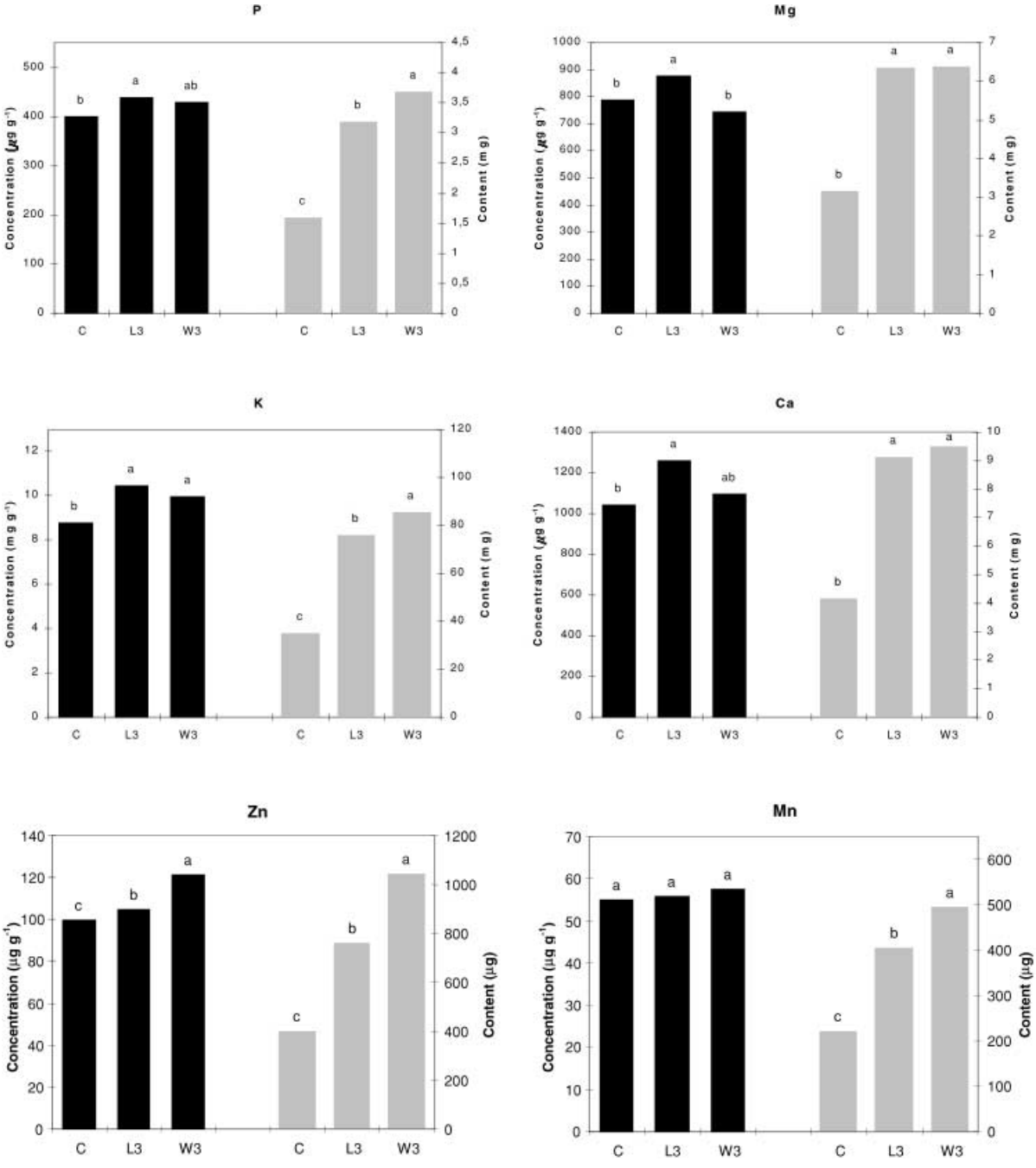


Fig. 3 Mineral concentration and content [total amount in plant shoots (two plants per pot) as influenced by crop residue application to the soil]. Means followed by the same letter within the same parameter are not significantly different at P <0.05 by Duncan's multiple-range test (*C* un-amended control, *L* lupine residues, *W* wheat residues, *3* amount of residue added at a rate equivalent to 300 g m^{-2})

was amended, and the type (L or W) of residue applied, are recorded in Table 2. It is clear that AM inoculation: (1) lowered significantly both the concentration and content (total amount in plant shoots) of Zn, Cu, Mn, and Al in plant shoots, (2) increased the amount of available P in the rhizospheric soil, and (3) lowered the phosphatase activity in plant rhizosphere.

To assess whether AM inoculation interacts with each of the tested residues, data from key parameters were analysed separately and recorded in Figs. 5 and 6. Figure 5 illustrates key root-soil interface traits, showing that: (1) L3 application improved AM development; (2) soil pH was increased in the rhizosphere of mycorrhizal, non-amended, control plants, but this AM effect was not shown in residue-amended soil; (3) the available P concentration in soil after harvest was higher when mycorrhizal plants rather than non-mycorrhizal plants were grown; (4) the phosphatase activity in the rhizosphere of mycorrhizal, non-amended plants was lower than that associated with non-mycorrhizal controls, but this AM effect was not shown in residue-

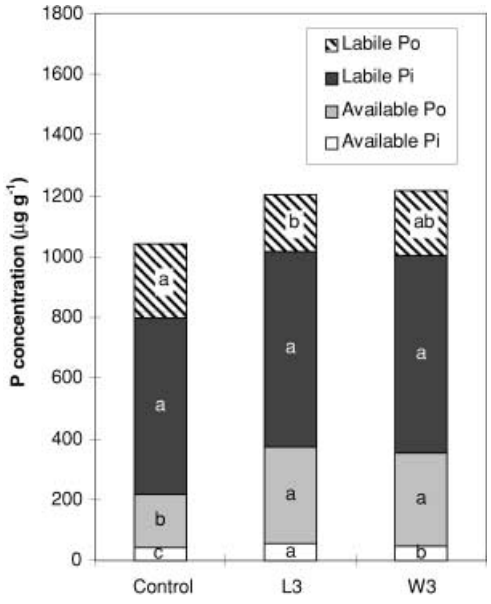


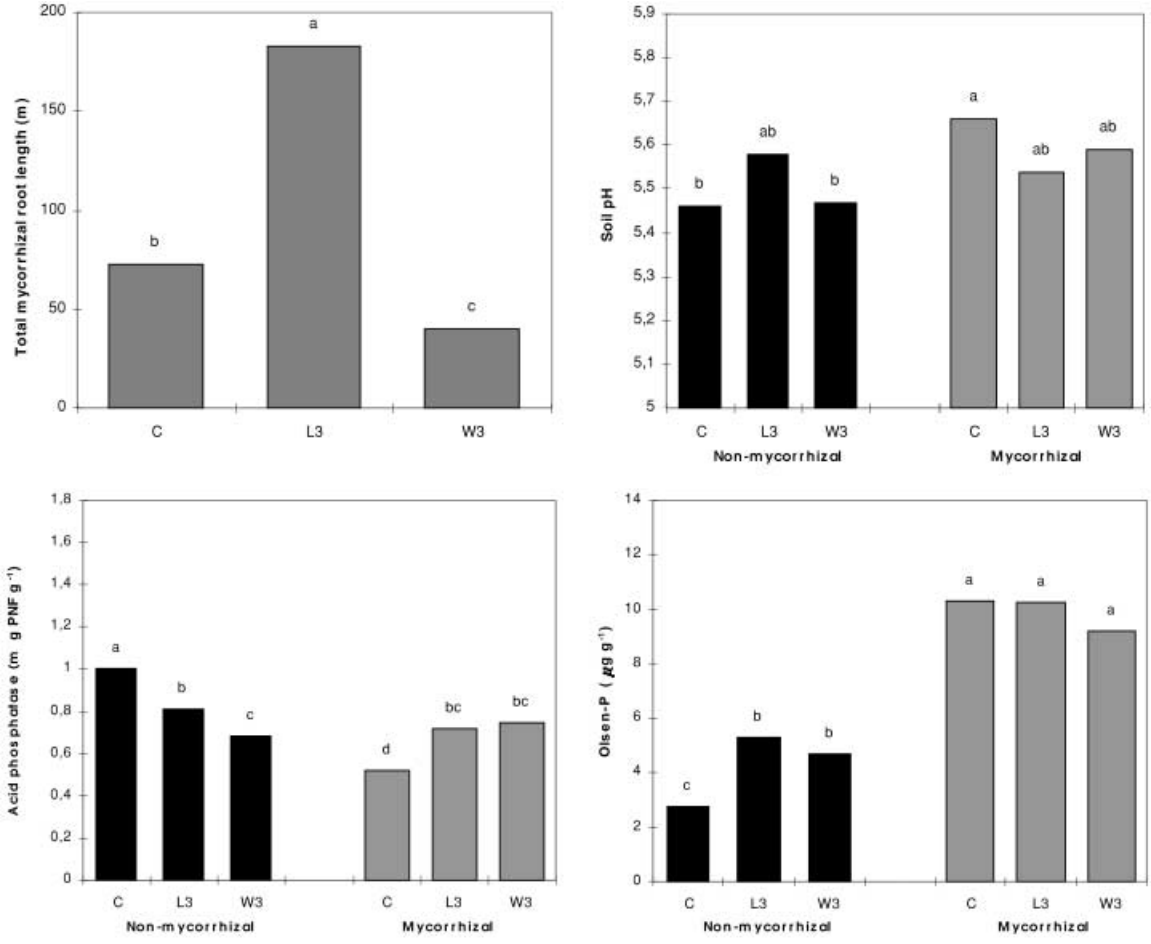
Fig. 4 Labile and available P fractions in soil amended with crop residues after plant harvest. Means followed by the same letter within the same parameter are not significantly different at P <0.05 by Duncan's multiple-range test (*C* un-amended control, *L* lupine residues, *W* wheat residues, *3* amount of residue added at a rate equivalent to 300 g m^{-2})

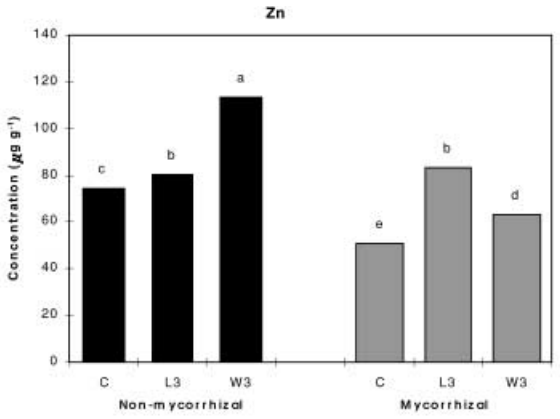
Fig. 6 Effect of mycorrhizal inoculation and crop residue application to the soil on mineral concentration and content [total amount in wheat plant shoots (two plants per pot)]. Means followed by the same letter within the same parameter are not significantly different at P <0.05 by Duncan's multiple-range test (*C* un-amended control, *L3* lupine residues and, *W3* wheat residues added at a rate equivalent to 300 g m^{-2}) ▶

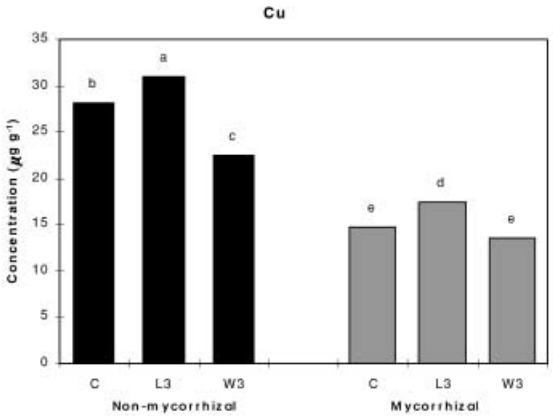
amended rhizospheres; and (5) in general, there was an inverse relationship between P availability and phosphatase activity in the soil, whether the plant growth was mycorrhizal or non-mycorrhizal.

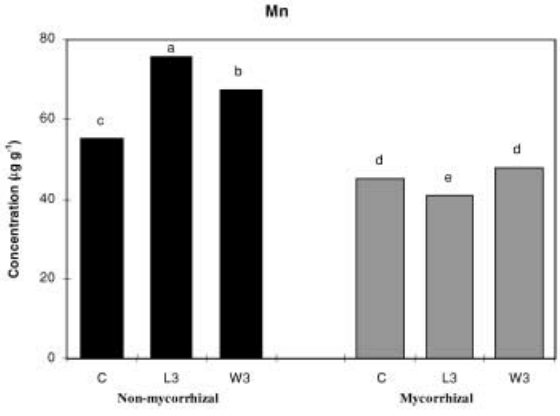
For each type of residue treatment, plant acquisition of Zn, Cu, Mn and Al was, in general, depressed by mycorrhizal inoculation (Fig. 6).

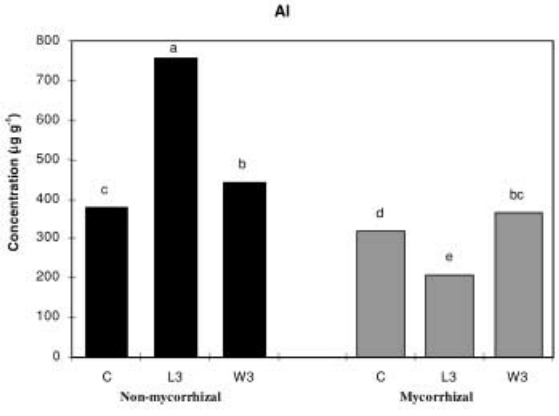
Fig. 5 Effect of mycorrhizal inoculation and crop residue application on root-soil interface traits. Means followed by the same letter within the same parameter are not significantly different at P <0.05 by Duncan's multiple-range test (*C* un-amended control, *L* lupine residues, *W* wheat residues, *3* amount of residue added at a rate equivalent to 300 g m^{-2})

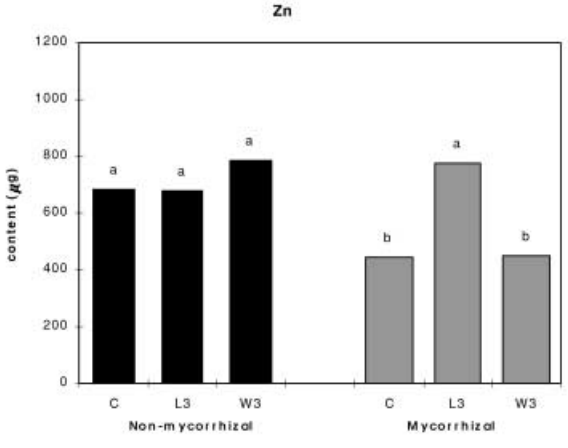


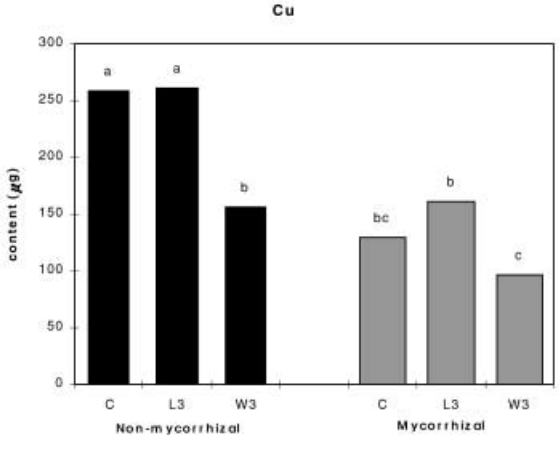

Zn
Concentration (μg g-1)
C
L3
W3
Non-mycorrhizal
Mycorrhizal

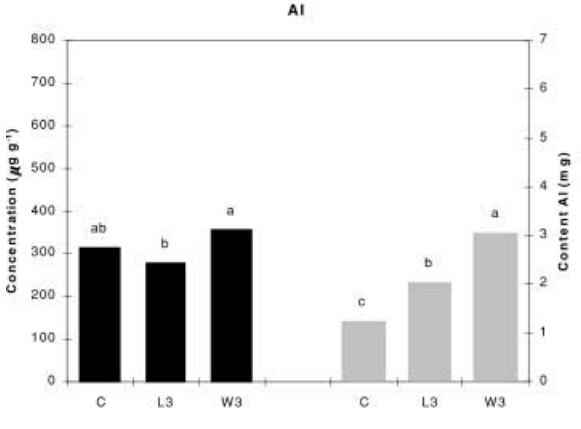

Cu
Concentration (μg g-1)
C
L3
W3
Non-mycorrhizal
Mycorrhizal

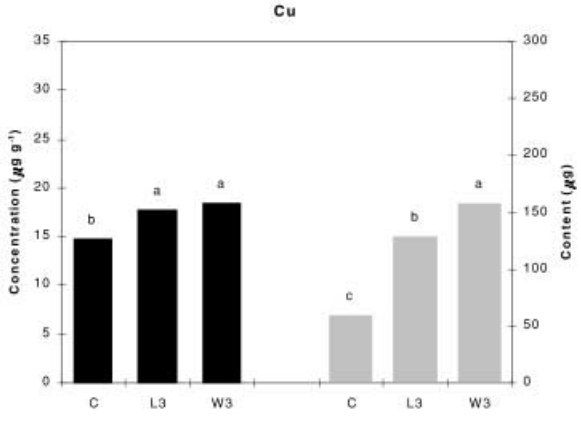

Mn
Concentration (μg g-1)
C
L3
W3
Non-mycorrhizal
Mycorrhizal


Al
Concentration (μg g-1)
C
L3
W3
Non-mycorrhizal
Mycorrhizal


Zn
content (μg)
C
L3
W3
Non-mycorrhizal
Mycorrhizal


Cu
content (μg)
C
L3
W3
Non-mycorrhizal
Mycorrhizal


Al
Concentration (μg g-1)
Content Al (mg)
C
L3
W3


Cu
Concentration (μg g-1)
Content (μg)
C
L3
W3

Discussion

The impact of a low-input technology (crop residue application) combined with a biotechnological practice (mycorrhiza management) has been studied with regard to investigating how these agro-technological applications affect plant performance in an acidic soil.

According to the aims of this study, the following three main points deserve further discussion: (1) how the addition of plant residues improves the growth of and mineral acquisition by the plant, (2) the influence of residue origin on soil-root activities, particularly the pH, P availability and the natural mycorrhizal activity of the soil, and on plant mineral acquisition, and (3) the effect of a tailored mycorrhizal inoculation and its interaction with residue application on the experimental variables described under (1) and (2).

The pot bioassay designed ad hoc to mimic interactions which occur in living soil-plant situations (experiment 1) demonstrated some clear effects of added plant material on mineral acquisition. To evaluate the effect of any particular treatment on mineral acquisition by plants it has been accepted that the total mineral content is a useful parameter, since it takes into account well-balanced effects on mineral concentration in plant tissues and biomass production (Jarrel and Beverley 1981). In fact it was the data on shoot mineral content which allowed us to identify beneficial effects of residue application in enhancing plant acquisition of P, K, Ca and Mg. This effect agrees with previous reports supporting the idea that most of the beneficial effects of the application of organic residues, including crop residues, to acid soils have been attributed to an increase in exchangeable cations such as Ca, Mg, and K (Tang and Yu 1999) or to an increase of available P (Hue and Amien 1989; Hafner et al. 1993). The increase in either the available P (Olsen and Sommer 1982) or in the fraction of available Pi in the soil can account for the beneficial effect of added residues on P nutrition. In addition to changes in the pools of available P, the other two interacting soil-root interface activities studied, i.e. soil pH and mycorrhizal developments, also contribute to the effect on mineral acquisition by the plant.

The concentration (in some cases) and the content of Zn, Cu, Mn and Al in the plant are increased by the addition of crop residues, with those from wheat being the more effective. However, similar to the results described by Kabata-Pendias and Pendias (1984), the concentration of these metals in the plant did not reach toxic levels.

In spite of the information being sometimes contradictory (Tang and Yu 1999), the effect of plant residues on plant performance in acid soils, as based on the enhancement of mineral availability, has been related to their effectiveness in increasing soil pH (Noble et al. 1996; Tang et al. 1997, 1999; Tang and Yu 1999). Furthermore, it has been suggested that such an effect is positively correlated with the concentration of excess cations in the plant material (Tang and Yu 1999). This was evident when the effect of lupine residues, with more cations, was compared with that of wheat straw, with lupine inducing a higher increase in soil pH (Tang and Yu 1999). However, this was contrary to what was found in the present study. The reasons to account for a lower activity of lupine residues in increase soil pH, in comparison with wheat straw, cannot be envisaged with the available data from this experiment. The only consistent observation was that plants that grew in soil amended with lupine residues had a significantly higher level of mycorrhizal colonisation than those growing in un-amended or wheat-straw amended soil. It could be assumed that, in addition to the nutritional effects of the residues, the increased pH in soil amended with wheat straw contributes to the increased mineral content of the plants growing on this substrate, while the effect of lupine material application is more likely to be based on the level of mycorrhizal activities. In fact, the enhancement of mycorrhizal colonisation by lupine residues is involved in the effect of this material on mineral acquisition patterns, a typical AM effect in acid soils (Arines et al. 1989; Clark and Zeto 1996, 2000; Clark 1997).

To go deeper into assessing the effect of mycorrhizal activities, experiment 2 further investigated the role of a tailored inoculation with a selected AM fungus in interaction with lupine and wheat residues application. The interaction between AM inoculation and certain residue treatments resulted in beneficial effects on key root-soil interface properties affecting mineral availability, such as the size of some available P pools in soil and mycorrhizal developments. Mycorrhizal inoculation lowered the acid phosphatase activity in the plant rhizosphere, thus confirming previous reports (Azcón and Barea 1997). In spite of the fact that AM inoculation did not enhance the effect of residue application on plant growth and macronutrient accumulation, it was demonstrated that AM symbiosis reduced Zn, Cu, Mn and Al acquisition with respect to non-mycorrhizal controls. It is noteworthy that the concentration and content of these elements in plant shoots were similar for mycorrhizal plants from experiment 2 (Table 2) and experiment 1 (Fig. 3), while values for these parameters were higher (closer to toxicity levels) in non-mycorrhizal plants in experiment 2 (Table 2). This supports the role of AM fungi in regulating the acquisition of potentially toxic metals. Such a mycorrhizal activity was shown both in the non-amended test acidic soil, similar to other situations described previously (Arines at al. 1989), and in the soil treated with the crop residues as assayed here. This corroborates the proposed role of AM systems as a “biological buffer” acting at enhancing/reducing the acquisition of minerals from the soil in accordance with the plant’s demands and with toxicity risks (Barea 1991). It has been speculated that the mechanism to account for such an effect relies on the retention of metals in the fungal exostructures.

The overview analysis of the effects of AM inoculation in interaction with plant residues, irrespective of their origin (Table 2), clearly supports the view that AM inoculation significantly lowers both the concentration and content of Zn, Cu, Mn, and Al in plant shoots and increases the amount of available P in the rhizospheric soil.

In conclusion, this study corroborated the view that the incorporation of plant residues can be recommended as a low-input agro-technological practice in minimising acidification constraints. This study presents new data which shows, at least in part, that an enhancement of mycorrhizal activities, in interaction with plant residue amendments, appears to benefit plant performance and nutrient acquisition. This could be accounted for by the uptake of nutrients by the mycorrhizal mycelium once released (solubilised) from the organic amendments.

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