# Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol

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**Abstract**

Tillage affects the soil physical and chemical environment in which soil microorganisms live, thereby affecting their number, diversity and activity. However, soil disturbance generally has the greatest impact on biological properties, including both free and symbiotic fungal populations. Interest in more ecologically sustainable agricultural systems is rising with increasing recognition that agricultural intensification can adversely affect environmental quality. This paper discusses the effect of tillage system on some soil characteristics, such as pH, C, N and S levels, total and Olsen-P contents including some P forms associated with organic matter, glomalin contents and arbuscular mycorrhizae (AM) parameters, such as root colonization, spore number and total and active hyphal length. Measurements were in the sixth year of an on-going tillage-rotation experiment conducted on an Ultisol under no-till (NT), reduced tillage (RT) and conventional tillage with stubble mixed into the soil (CTS) or stubble burnt (CTB). Soil was sampled at two dates; after wheat (*Triticum aestivum*) harvest (autumn) and 6 months after subsequent grassland seeding (spring). Higher C, N, S, total P and fulvic acid-P concentrations and pH occurred under NT and RT than under CTS and CTB after wheat harvest. However, results at the second sampling were not consistent. AM spore number and active hyphal length were highest under NT having the greatest incidence on AM root colonization and P concentration in shoots of the pasture. Glomalin concentration was higher under NT and RT than under CTS and CTB but no differences in calculated glomalin to total C (ca. 5%) were found. It is concluded that a less disruptive effect of NT influences positively all soil characteristics and also increases P acquisition by the following crop in the rotation system.

*Keywords:* No-tillage; Conventional tillage; Soil characteristics; AM propagules; Ultisol; Glomalin

## 1. Introduction

Alteration of soil conditions by tillage practices has complex effects on soil characteristics thereby affecting environmental conditions, the growth and activity of soil microorganisms and consequently,

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nutrient dynamics. According to the degree of disturbance by tillage systems, changes have been observed in soil water content, aeration and soil temperature, which influence the decomposition rate of residues left in the soil (Ma et al., 1999; Rochette et al., 1999; Espana et al., 2002). Also, such environmental changes can affect microorganisms in different ways; either in number, diversity or activity. Therefore, reduced and particularly no-tillage (NT) practices minimize soil disturbance, increase soil organic matter and improve soil structure compared with conventionally plowed soils (Carter, 1992; Franzluebbers et al., 1995, 1999).

Soil management practices involving the placement or incorporation of residues can change soil environmental conditions for soil organisms responsible in nutrient cycling and organic matter decomposition (Doran, 1980; Clapperton et al., 1997). Accumulation of organic matter and nutrients near the surface under reduced tillage produces beneficial effects on soil physical, chemical and biological properties (Beare et al., 1997; Tebrugge and During, 1999). These improvements are generally associated with enhanced rhizosphere biological activities (Gupta and Germida, 1988; Kladivko, 2001). It has been recently reported that fungal biomass is enhanced in the topsoil under NT (Frey et al., 1999). Although fungi, including those forming mycorrhizal associations with plant roots, may be numerically less abundant than bacteria, they can constitute up to 80% of soil microbial biomass (Lynch, 1990) being the primary decomposers of residues in soil.

Of special relevance in agricultural management systems are the arbuscular mycorrhizal (AM) fungi that are ubiquitous in soil, and play important roles in plant nutrition and soil aggregation (Beare et al., 1997; Jeffries and Barea, 2001; Rillig et al., 2002). To fulfill both functions, extraradical mycelium proliferate in the soil next to the root cortex from which hyphae absorb nutrients, especially those with low mobility such as P, Cu and Zn (Li et al., 1991; Burkert and Robson, 1994; Marschner, 1995). Extraradical hyphae are also very important in soil conservation as they are one of the major factors involved in soil aggregation (Miller and Jastrow, 1992). The improvement in aggregate stability is due to a physical effect of a network around soil particles, together with the hyphal production of significant amounts of an insoluble glycoprotein named glomalin (Wright and Upadhyaya, 1996), which cements soil components (Wright and Upadhyaya, 1998; Wright et al., 1999; Rillig et al., 2002). Glomalin is produced by hyphae of all members of AM fungi but not by other groups of soil fungi (Wright et al., 1996). Well-aggregated soils are more resistant to erosive forces, have better aeration and water infiltration due to heterogeneous protected C microhabitats that enhance microbial diversity (Blevins et al., 1984; Lupwayi et al., 1998) and activity (Palma et al., 2000). Recent reports have highlighted the quantity of C in glomalin relative to total organic C that may be higher than C in microbial biomass (4–5% against 0.08–0.2%, according Rillig et al., 2001). Glomalin may be useful as a sensitive indicator of soil C changes produced by land-use practices (Rillig et al., 2003) and could even be involved in C-sequestration (Rillig et al., 1999).

Mycorrhizal roots, AM spores and fungal mycelia constitute the main propagules left in the soil that colonize plant roots of the succeeding crop in a rotation system. However, hyphae remaining active from the previous crop are thought to be the main source of inoculum in soil (Sylvia, 1992). Living hyphal density can be affected by different agricultural management practices, including soil tillage.

Soil disturbance, both in field and in growth chamber experiments carried out with maize (*Zea mays*), strongly affects root colonization and P absorption during early growth (McGonigle et al., 1990; McGonigle and Miller, 1993). Several studies have supported the hypothesis of a causal relationship between soil disturbance and impaired plant growth due to reduced mycorrhizal effectiveness (Evans and Miller, 1988; Jasper et al., 1989; Fairchild and Miller, 1990). The network of mycorrhizal hyphae extending in the surrounding of root surfaces is an important inoculum source when roots senesce. Disruption of this network is a proposed mechanism by which conventional tillage (CT) reduces root colonization and P absorption. In the same way, hyphae and colonized root fragments are transported to the upper soil layer, decreasing and diluting their activity as viable propagules for the succeeding crop in rotation.

In Chile, volcanic soils cover >5 Mha, on which most cereals in the country are produced. These soils, having high P adsorption capacity need to be fertilized yearly with moderate amounts of phosphate fertilizers, which eventually accumulate in soil as unavailable P

forms (Borie and Zunino, 1983). Also, as these soils are at risk of erosion, local farmers have begun to shift from plowing systems to reduced tillage.

The present study was conducted in a volcanic soil to evaluate, at the beginning of the cycle, the effect of a 5 year crop rotation under four tillage systems on: (a) chemical characteristics especially P forms and (b) glomalin levels and AM propagules left in the soil measured at 3 months from harvesting the preceding crop (wheat) and 6 months after seeding the subsequent crop (grassland) and (c) to correlate the presence of such AM propagules with P concentration in grassland shoots.

## 2. Materials and methods

### 2.1. Description of the experimental field

A nearly level (0.5–2.0% slope) field was located on an Ultisol, at the Carillanca Field Research Station (38°41′S, 72°25′W) located at Temuco, Chile. During the 20 years prior to the setting of the crop rotation, the field of 15 ha was managed with pasture, a mixture of red clover (*Trifolium pratense* L.) and rye grass (*Lolium multiflorum* L.) renewed every 2 years using CT. A typical crop rotation, was initiated in the fall of 1986 to study crop productivity and soil characteristics with time in order to adjust cropping system management. The 5-year rotation comprised 2 years pasture (*Trifolium pratense* L. and *Lolium multiflorum* L.) followed with oat (*Avena sativa* L.), then white lupin (*Lupinus albus* L.) and in the fifth year winter wheat (*Triticum aestivum* L.). Each rotation phase represented a main plot of 3 ha and was managed with CT. Macro and micro nutrients were supplied to each crop according to soil test analysis, taking soil samples every autumn at 0–20 cm depth.

### 2.2. Experimental design and soil sampling

In 1995, after two cycles of the 5-years crop rotation, each main plot was sub-divided into four subplots of 0.75 ha to study crop productivity and soil characteristics under different soil tillage systems. Tillage systems were: (1) no-till, in which crops were directly drilled in the previous year stubble (NT); (2) reduced tillage with only one chisel-plough operation to a depth of 20 cm (RT); (3) conventional tillage consisting of fall moldboard plowing twice to a depth of 20 cm, and stubble mixing into the soil (CTS) and (4) conventional tillage with stubble burnt during fall and moldboard plowing twice to a depth of 20 cm (CTB). All machinery operations were performed along the main length of each subplot.

In 2001, at the beginning of the second cycle of the rotation of each tillage system, soil was sampled in April after wheat and in September during early pasture phase. Wheat cv Renaico-INIA was sown in May 2000, at a seeding rate of 180 kg $ha^{-1}$ with 20 cm row space receiving 150-52-83 kg N-P-K $ha^{-1}$ and 1.5 Mg $ha^{-1}$ $CaCO_3$ in each of the four tillage systems. Pasture consisting of *Trifolium pratense* L. and *Lolium multiflorum* L. was sown in April 2001, in 20 cm row space receiving 40-26-20 kg N-P-K $ha^{-1}$. Mean grain yield for wheat was 7.34 Mg $ha^{-1}$and mean dry matter production for pasture was 5.63 Mg $ha^{-1}$. Three adjacent subplots of 900 $m^2$ were located in a middle transect along the length of each main plot. Soil sampling in April 2001, was 3 months after wheat harvest and 1 week before grass sowing (autumn) and in September 2001 was 6 months after first year grass sowing (spring). Ten soil cores (6.5 cm diameter) to a depth of 10 cm were randomly sampled in each subplot. Each composite soil sample was homogenized in a bucket and kept under refrigeration until analysis.

### 2.3. Mycorrhizal determinations

Root and shoot samples were collected for the determination of root mycorrhizal colonization and P concentration in leaves, when applicable. Roots were thoroughly washed and cut into 1 cm lengths, cleared in 2.5% KOH for 3 days, acidified with 1% HCl and stained with 0.05% trypan Blue for 24 h (Phillips and Hayman, 1970). The percentage of root colonization was measured by the grid-line intersect method (Giovanetti and Mosse, 1990) under a dissecting microscope at 50× magnification.

Total hyphal length was measured by the filtration gridline method (Rubio et al., 2003). Soil subsamples (3 g fresh weight) were thawed and placed into flasks (250 mL) mixed with a glycerol–HCl–water mixture (12:1:7) to give a total volume of 100 mL that was shaken for 30 min at 80 °C. The suspension was

filtered through both 250 and 38 μm mesh sieves. Material retained on the 38 μm mesh sieve was resuspended in 100 mL distilled water, shaken for 1 min and allowed to settle for 30 s. An aliquot of the suspension (3 mL) was transferred to a membrane filter (0.45 μm pore size, 47 mm diameter, grid-line interval 3 mm). The membrane was placed in a filter holder attached to a vacuum system. After filtering, a staining solution (0.05% trypan Blue in a mixture of glycerol–HCl–distilled water) was pipetted onto the membrane and allowed to stand for 10 min. Hyphal length was quantified by using the grid-line method. For the determination of metabolically active hyphae, another aliquot of the suspension from total hyphal length determination was stained by flooding the filters with a solution containing equal parts of iodonitrotetrazolium salt (1 mg $mL^{-1}$), NADH-$Na_2$ (3 mg $mL^{-1}$) and 0.2 M tris buffer at pH 7.4 (Sylvia, 1992). The filter was incubated for 2 h at room temperature and measured as above by the grid-line method. Mycorrhizal hyphae were distinguished from non-mycorrhizal ones according to the criteria reported by Miller et al. (1995).

### 2.4. Soil analysis

Soil pH was determined on a soil/water paste (1/2) and available P as described by Olsen and Sommers (1982) by extraction with a 0.5 M $NaHCO_3$ solution at pH 8.5. Total C, N and S were determined by using a C, H, N, S, O Analyzer (VARIO/EL). Soil total P and P associated with humic and fulvic acids were determined as described by Dick and Tabatabai (1977) and Borie et al. (1989), respectively. Total organic C content in soils (Mg $ha^{-1}$) at 0–10 cm depth was calculated by multiplying organic C (g $kg^{-1}$) by bulk density and depth. Mycorrhizal spores were collected from soil by wet sieving and decanting as described by Sieverding (1991).

Glomalin extraction from whole-soil subsamples (1 g) was conducted as described by Wright and Upadhyaya (1998) with three replicates. Total glomalin (TG) was extracted with 50 mM sodium citrate, pH 8.0 at 121 °C in rounds of 60 min cycles until supernatant showed none of the red-brown color typical of glomalin. Extracts from each replicate were pooled and centrifuged to remove soil particles, and protein in the supernatant was analyzed using a Bradford assay with bovine serum albumin as the standard (Wright and Upadhyaya, 1998). Glomalin-C was estimated by using the upper value of 43.1% suggested by Rillig et al. (2003).

### 2.5. Statistical analysis

Spore data were log transformed to achieve normal distribution and all other data were arcsin transformed prior to variance analysis. For each sampling time, a separate one way analysis of variance with three replicates was performed using the JMP 5.01 (SAS) software. Further comparison of mean values was accomplished using the Duncan's Multiple Range Test ($P \leq 0.05$).

## 3. Results and discussion

Significant differences in total soil organic C were found in the order NT > RT > CTB > CTS (Table 1). Total N and S followed almost the same trend. No differences in C/N and C/S ratios were found, suggesting that these C-bonded nutrients mineralized concurrently with C oxidation. It is important to emphasize here that Chilean volcanic soils are a very unusual soil system developed under a humid but cold climate regime. They have a very high level of organic matter interacting with a clay fraction dominated by

Table 1
Selected chemical properties of an Ultisol 3 months after wheat harvest as a function of four tillage treatments

| Treatment | C (g $kg^{-1}$) | N (g $kg^{-1}$) | S (g $kg^{-1}$) | pH | Olsen-P (mg $kg^{-1}$) | Total P (mg $kg^{-1}$) | Fulvic-P (mg $kg^{-1}$) | Humic-P (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| NT | 67.6 a | 5.8 a | 1.25 a | 5.43 b | 23.8 a | 2281 a | 387 a | 393 b |
| RT | 63.7 b | 5.6 b | 1.16 b | 5.49 a | 19.2 b | 2384 a | 417 a | 610 a |
| CTS | 50.0 d | 4.4 c | 0.9 c | 5.26 d | 21.9 a | 2063 b | 186 c | 329 b |
| CTB | 53.2 c | 4.5 c | 0.9 c | 5.34 c | 17.9 b | 1867 c | 266 b | 413 b |

NT, no-tillage; RT, reduced tillage; CTS, conventional tillage with stubble retained; CTB, conventional tillage with stuble burning. Numbers within a column, followed by the same letter (a–d) are not significantly different ($P \leq 0.05$, Duncan's Multiple Range Test).

allophane or allophane-like secondary minerals with specific surfaces characterized by high physico-chemical sorption capacity (Borie and Zunino, 1983; Galindo and Escudey, 1985). As nutrients like N and S are rapidly integrated into soil organic matter and linked to organic molecules, the transformation of these elements was mostly organic, as has been recently reported by Aguilera et al. (2002) for S, and by Borie et al. (2002) for N. For that reason, C:N:S ratios were almost constant (not shown).

The impact of tillage systems on some soil properties has been routinely studied in long-term experiments (Lal et al., 1994; Salinas-García et al., 1997). Gómez et al. (2001) concluded that 5 years was enough time for detecting changes in soil properties. Results obtained here in the sixth year reinforce such statement. Differences in organic C were $\leq$6% between NT and RT and between CTS and CTB. The largest differences in organic C was between RT and CT. The equivalent of about 13 Mg ha$^{-1}$ of C was retained at 0–0.1 m depth when soil was not ploughed. According to Bell et al. (2003), soil management to increase soil C is due to less mixing and aeration of residues and the promotion and stabilization of aggregates especially in the surface soil layer. These data strengthen the statement that tillage has much more importance in soil organic C preservation than stubble management.

Soil pH was slightly higher under NT and RT than under CT at the first sampling (Table 1). The greater pH observed in CTB compared with CTS may have been due to alkalinity produced by burning. Similar trends occurred at the second sampling, but differences were less significant (Table 2).

Total soil P ranged from 1.867 mg kg$^{-1}$ for CTB to 2.384 mg kg$^{-1}$ for RT (Table 1) being mainly inorganic in nature in comparison with that P bound to humic and fulvic acids which together after wheat harvest, represented 34, 43, 25 and 36% for NT, RT, CTS and CTB, respectively. The higher amounts of total P found in NT and RT compared with CT could be explained by soil mixing with CT that diluted the upper soil layers. On the contrary, due to the scarce mobility of phosphate in these soils, P from fertilizer remained mostly in the upper layer when soil remained undisturbed. It is known that P associated with organic matter has different lability according to the molecular weight of the organic compounds to which P is linked (Borie and Zunino, 1983). Therefore, P associated with fulvic acids (FA-P) would be of higher lability than P associated with humic acids (HA-P) and P associated to humin would represent the most recalcitrant fraction. Averaged across treatments, higher amounts of HA-P were found than FA-P after wheat harvest. However, in the spring, 6 months after grass sowing almost the same amount of HA-P was found, but FA-P levels had decreased nearly 50% suggesting a high hydrolysis rate of this type of P fraction. Such decrease of FA-P together with a concomitant high available Olsen-P could be explained by enhanced organic P mineralization produced in spring when microorganisms were more active. The same trend, but related to a decrease in N associated with fulvic acids when wild forest soil was converted to cropped soil was reported by Borie et al. (2002) in a Chilean Ultisol.

Tillage and crop rotation can influence the number of AM fungus propagules (Johnson and Pfleger, 1992), as well as their community structure (Jansa et al., 2002). Many studies have demonstrated that previous crop and degree of disturbance produced by different tillage systems affect in different ways the effectiveness of the symbiosis due to alteration of mycorrhizal inoculum left in the soil after harvesting. As soil

Table 2
Selected chemical properties of an Ultisol and P concentration in grass shoots

| Treatment | pH | Olsen-P (mg kg$^{-1}$) | Total P (mg kg$^{-1}$) | Fulvic-P (mg kg$^{-1}$) | Humic-P (mg kg$^{-1}$) | Shoot P (mg g$^{-1}$) |
|---|---|---|---|---|---|---|
| NT | 5.85 a | 36.2 a | 2455 a | 188 ab | 418 ab | 2.93 a |
| RT | 5.93 a | 39.6 a | 2379 a | 155 b | 524 a | 2.75 b |
| CTS | 5.57 b | 36.4 a | 2132 a | 217 a | 345 b | 2.76 b |
| CTB | 5.77 b | 37.2 a | 2338 a | 118 c | 394 b | 2.34 c |

Six months after grass sowing as a function of four tillage treatments. NT, no-tillage; RT, reduced tillage; CTS, conventional tillage with stubble retained; CTB, conventional tillage with stuble burning. Numbers within a column, followed by the same letter (a–c) are not significantly different ($P \leq 0.05$, Duncan's Multiple Range Test).

Table 3
Effects of four tillage treatments on mycorrhizal propagules in an Ultisol before (BS) and 6 months after grass sowing (AS)

| Treatment | AM spores (No. 100 gds$^{-1}$) | | Total AM hyphae (m g$^{-1}$) | | Active AM hyphae (m g$^{-1}$) | | Root colonization (%) | |
|---|---|---|---|---|---|---|---|---|
| | BS | AS | BS | AS | BS | AS | BS | AS |
| NT | 755 a | 594 a | 3.5 a | 19.1a | 2.8 a | 7.3 a | – | 53 a |
| RT | 731 a | 550 a | 3.1 a | 10.7 b | 2.3 a | 3.4 b | – | 50 a |
| CTS | 452 b | 199 b | 2.5 a | 10.5 b | 1.4 b | 3.7 b | – | 36 b |
| CTB | 372 c | 311 ab | 2.7 a | 8.7 b | 1.3 b | 3.3 b | – | 42 b |

NT, no-tillage; RT, reduced tillage; CTS, conventional tillage with stubble retained; CTB, conventional tillage with stuble burning. Numbers within a column, followed by the same letter (a–c) are not significantly different ($P \leq 0.05$, Duncan's Multiple Range Test).

inoculum depends on the number of active propagules, such as fungal mycelium, spore number or fragments of colonized roots, the best agricultural management conditions need to be selected for increasing such potential. Therefore, among the main incidental conditions for obtaining high propagule number, previous crop and tillage regime are probably most important. Propagules of AM fungi such as spores and mycorrhizal root extention are intimately associated with a more efficient AM hyphae network (Kabir et al., 1998), which is damaged by the use of a plow.

In this study, AM spore numbers were lower in soils under CT than under RT and NT, both before and after grass sowing (Table 3). The lowest value was obtained when soil was subjected to burning. No significant differences were found in total hyphal length in soil sampled 3 months after wheat harvest which was lower than at 6 months after grass sowing. In spite of higher hyphae levels found after grass sowing, active mycelia represented between 32 and 38% of total hyphae for all treatments, suggesting that soil disturbance mainly affected the viability of hyphae and not their length. The highest length of active mycelia under NT was more than two-fold higher than under CTB. Root colonization was higher in RT and NT than under CT (Table 3). Differences between NT and CTB regimes related to shoot P concentration were associated with similar differences in root colonization and active mycelia.

Lower AM root colonization under CTS and CTB could be explained by a decrease of fungal spores and active fungal mycelia produced by soil disturbance and, as a consequence, soil inoculum decline (Table 3). Tillage and farming systems have been shown to have a negative impact on AM spore numbers (Galvez et al., 2001) and on the density of mycorrhizal hyphae in soil (Kabir et al., 1998). Low shoot P concentration under CT (Table 2) was coincident with low AM fungal propagules (Table 3). These findings are in accordance with those reported for maize growing in growth-chamber by O'Halloran et al. (1986) and Evans and Miller (1988) who suggested that a rapid early season development of AM fungi in maize roots was promoted by NT and ridge-tillage management but was impeded by CT. Such early-season stimulation in plant P acquisition by maize shoots under minimum tillage was associated with higher and faster mycorrhizal development (McGonigle et al., 1990; McGonigle and Miller, 1993). Under field conditions, Galvez et al. (2001) evaluated the effect of tillage and farming systems on indigenous AM fungi and P-uptake in maize, concluding that mycorrhizal colonization of maize roots depended more on tillage regime than on conventional or low-input agricultural management. In our study, spore populations were larger in fall than in spring which is in accordance with the results obtained by Galvez et al. (2001).

Higher concentration of glomalin was found under NT and RT than under CTS and CTB (Table 4). Glomalin represented a significant proportion of total soil C content, ranging from 4.6 to 5.0%. Those proportions were higher than previously reported in an Alfisol from Chile (≈2.5%) when soil was managed under NT for 4–20 years (Borie et al., 2000). In contrast, the amounts of glomalin reported here were much lower than in a forested Chilean Andisol where glomalin exceeded 105 mg g soil$^{-1}$ and represented around 25% of total soil C content (Borie et al. unpublished). Such differences in the contribution of

Table 4
Effects of four tillage treatments on total glomalin concentration and its contribution to soil C content in an Ultisol after wheat harvest

| Treatment | Total glomalin (mg $g^{-1}$) | Glomalin-C[a] (mg $g^{-1}$) | Glomalin-C/SoilC (%) |
|---|---|---|---|
| NT | 7.2 a | 3.1 a | 4.6 |
| RT | 7.4 a | 3.2 a | 5.0 |
| CTS | 5.8 b | 2.5 b | 5.0 |
| CTB | 5.7 b | 2.4 b | 4.7 |

NT, no-tillage; RT, reduced tillage; CTS, conventional tillage with stubble retained; CTB, conventional tillage with stubble burning. Numbers within a column, followed by the same letter (a and b) are not significantly different ($P \leq 0.05$, Duncan's Multiple Range Test).
[a] Calculated based on glomalin having 43.1% C (Rillig et al., 2003).

glomalin-C to soil C could be explained by the different origin of soils having different stabilization according to SOM nature and Fe reactivity (Wright and Upadhyaya, 1998). Glomalin-C contents found in this Ultisol were higher than the 3.4% reported by Rillig et al. (2001) for an Ultisol aged $1400 \times 10^3$ years.

Estimates of AM extraradical hyphal lengths in the field range widely (Rillig et al., 1999) reaching more than 100 m $g^{-1}$ of soil for a pasture community (Miller et al., 1995) in comparison with the highest length in this study of 19 m $g^{-1}$. Families of AM fungi differ in terms of mycelial size (Hart and Reader, 2002) and such differences may contribute to variation in host responsiveness. Using molecular techniques, Jansa et al. (2003) clearly demonstrated that soil tillage altered composition of AM fungal communities colonizing maize roots in field conditions. Jansa et al. (2002) reported a decrease in AM fungal biodiversity produced by soil disturbation from 17 species and 5 genera under NT to 12 species and 2 genera under CT.

To assess AM abundance and activity from soils sampled in field conditions, counting spores and measuring soil hyphae or determining the density of fungal structures in root fragments is time- and effort-consuming. In addition, all these methods are uncertain in precision and are only indirect indicators of AM fungal activity (Wright et al., 1996) which is affected seasonally and by growth stage of host plant. Total glomalin content has exhibited small seasonal changes in a grassland ecosystem from 13 time points in one growing season (Lutgen et al., 2001). Therefore, it appears that quantifying glomalin content or production may be an interesting complementary method for assessing fungal activity in an ecologically meaningful manner (Wright and Upadhyaya, 1998) as a consequence of its low decomposition (Steinberg and Rillig, 2003). In this sense, Lovelock et al. (2004) recently assessed the use of glomalin concentration as an indicator for AM hyphal growth in forest soils.

Finally, local farmers are increasingly interested in managing their soils more ecologically for minor risks of erosion. The area cropped with minimum or NT is increasing yearly. Farmers need the help of soil scientists for obtaining the answers to their doubts, especially in other volcanic soils such as Andisols that contain higher levels or allophane or allophane-like minerals with a higher capacity of stabilizing organic matter in soil in comparison with Ultisols.

## 4. Conclusions

Positive effects of RT and NT on soil chemical and mycorrhizal characteristics was demonstrated. Such effects can be summarized as greater soil C, N, S and P levels and AM fungal propagules left in the soil under NT than under CT; coinciding with enhanced P acquisition by the succeeding crop.

Total glomalin concentration increased when soils were subjected to RT and NT compared with CT and this increase was related to C content. Glomalin-C as a proportion of total soil C remained almost constant among treatments (ca. 5%) and no relationships were found between glomalin levels and AM fungal variables. Such apparent contradiction needs to be more deeply investigated.

## Acknowledgements

Financial support from Fondecyt Grant 1020306 and statistical help from C. Castillo are greatly acknowledged.

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