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SHORT NOTE

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Vertical distribution of arbuscular mycorrhizal fungi under corn (*Zea mays* L.) in no-till and conventional tillage systems

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Abstract We compared the vertical distribution (0–25 cm) of arbuscular mycorrhizae, extraradical hyphae, and glomalean spores at grain-filling of corn under conventional tillage versus no tillage. Root colonization, total hyphae density, and spore density were correlated, and were highest at a depth of 0–15 cm in soil. Tillage significantly reduced total hypha density and spore density at 0–5 cm depth, but did not affect root colonization. Plowing below 15 cm is likely to diminish AM fungus inocula in the rooting zone of establishing seedlings.

Key words Extraradical hyphae · Metabolically active hyphae · Spore density · Root colonization · Soil depth

Introduction

Although AM fungi exist as colonized roots, spores, and extraradical hyphae, quantitative studies typically focus on root colonization and spore number (Vilariño et al. 1993). Extraradical hyphae, however, may influence the efficiency of mycorrhizae more strongly than root colonization (McGonigle et al. 1990). Besides supplying soil nutrients to plants, extraradical hyphae may improve soil aggregate stability (Miller and Jastrow 1992). Notwithstanding their fundamental roles in bridging from plant to soil (O'Neil et al. 1991) and as inocula (Sylvia 1992), the distribution of extraradical hyphae in the soil profile has rarely been measured.

Both pot studies (Jasper et al. 1989) and a field study (Douds et al. 1993) have shown that soil disturbance reduces AM fungus populations. Tillage often reduces mycorrhizal colonization of *Zea mays* L. (corn) (McGonigle et al. 1990). Although in general spore number diminishes with depth in soil (Smith 1978; An et al. 1990) and spores are not usually found below plant rooting zones (Mosse et al. 1981), tillage can alter the vertical distribution as well as the size of AM fungus spores (Douds et al. 1993). We investigated the influence of tillage on the vertical distribution of AM root colonization, spores, and extraradical mycelium within the top 25 cm of soil planted to corn.

Materials and methods

At the McGill University research field station (45°25′N and 73°56′W) in Quebec, Canada, we imposed two treatments at random on twelve 6×10 m plots on a sandy loam soil. Conventional tillage (CT) consisted of fall moldboard plowing followed by spring disking, and no-till (NT) involved no tillage other than a planter directly seeding into the prior year's stubble. We planted corn at a density of 80 000 plants per ha in early May 1993.

At the grain-filling stage, we sampled soil at random locations along rows with a 3.25-cm diameter soil corer to a depth of 25 cm to extract mycorrhizal roots, spores, and extraradical hyphae. We collected five cores from each plot, and divided each core into sections corresponding to 0–5, 5–10, 10–15, 15–20 and 20–25 cm depths. We thoroughly mixed all sections from the same depth within a plot to form composite samples to represent each depth in each plot.

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We separated roots from each composite sample, stained (Phillips and Hayman, 1970) and quantified AM colonization by the grid-line intersect method (Giovannetti and Mosse 1980). We removed glomalean spores by wet sieving and decanting (Pacioni 1992), and counted them under a stereoscopic microscope at ×200 magnification. We extracted hyphae and assessed their metabolic activity by using a modification of the technique of Abbott et al. (1984) as described in Kabir et al. (1996).

We used repeated measures (in space) analysis of variance to detect treatment differences across depth in soil. When treatment effects were significant ($P<0.05$), we compared means with a protected Least Significant Difference test. We also examined Pearson product-moment correlations among response variables with Bonferroni-corrected probabilities.

Results

In both CT and NT treatments, we recovered most AM fungus hyphae and spores from the top 0–15 cm of the soil, where mycorrhizal colonization of roots was most extensive (Table 1). The lengths of total and metabolically active hyphae in the top 15 cm represented 84% and 87%, respectively, of those in the entire CT profile, and 87% and 90% of those in the NT profile. Seventy-four percent and 76% of spores in CT and NT soils, respectively, were in the top 15 cm. Total hypha density, active hypha density, and spore density differed significantly between CT and NT soils only in the top 5 cm. At this depth, CT soil hypha and spore density were 40% and 50% lower, respectively, than those of NT soil. There was no effect of tillage on root colonization. Total hypha density was significantly correlated with spore density ($n=60$, $r=0.80$, $P\leq0.001$) across all depths and treatments, and both were significantly correlated with root colonization ($n=60$, $r=0.74$, $P\leq0.001$, and $n=60$, $r=0.65$, $P\leq0.001$, respectively).

Discussion

Densities of total and metabolically active AM fungus hyphae and spores differed with tillage only in the top 5 cm of soil. The direct effect of tillage on the integrity of the AM fungus mycelium, or indirect effects of tillage on the soil environment, which are especially high at the surface, may have caused these differences. The 0–5 cm depth of CT soil was more intensively disturbed than greater depths by spring disking. In a greenhouse experiment, McGonigle and Miller (1996) observed similar negative effects of soil disturbance on hypha density. Douds et al. (1993) also found negative effects of tillage on AM fungus sporulation. The top 5 cm of NT soil contained 48% more organic matter than that of CT soil (unpublished data), and consequently may have been favorable to AM fungus proliferation. Although we did not measure residue cover, the effect of tillage in reducing residue in corn fields is well documented (Shelton et al. 1995), and may have contributed also to our results.

In both tillage systems, AM fungus populations diminished markedly below 15 cm. Similar results were obtained for AM fungus spores by An et al. (1990) under soybeans on a silty loam, and by Smith (1978) in an Australian wheat field under NT and CT. Physical, chemical, and gas properties of soil change with depth and influence the distribution of soil organisms. Fungi are especially sensitive to low partial pressures of oxygen which prevail at depth (Brady and Weil 1996). AM fungi are also likely to be scarce where roots are sparse (Anderson et al. 1987), and although not measured by

Table 1 Vertical distribution of mycorrhizal hyphae, spores and root colonization (mean values with ±se) in soil. Different letters indicate a significant ($P\leq0.05$) difference between treatment means at a given depth (*NT* no-till, *CT* conventional tillage)

Depth	Tillage	Total hypha density (cm ml^{-1})	Active hypha density (cm ml^{-1})	Spore density (ml^{-1})	Root colonization (%)
0–5 cm					
	NT	178.6±21.0a	102.3±10.2a	12.9±1.1a	56.8±4.1a
	CT	99.1±12.3b	63.8± 6.5b	6.5±0.6b	57.5±6.1a
5–10 cm					
	NT	242.1±15.3a	137.3±10.6a	21.4±1.2a	74.7±2.8a
	CT	232.4±13.5a	130.1±12.6a	18.2±2.3a	67.2±6.6a
10–25 cm					
	NT	228.1± 7.3a	120.8± 9.3a	21.2±1.8a	62.2±6.2a
	CT	237.5±14.8a	113.5±14.8a	17.8±1.2a	71.8±2.8a
15–20 cm					
	NT	57.3± 7.6a	23.3± 3.9a	10.7±2.8a	36.0±4.1a
	CT	65.0± 7.7a	30.7± 5.9a	9.8±1.5a	47.2±8.2a
20–25 cm					
	NT	24.7± 4.7a	10.7± 2.6a	5.1±0.9a	19.8±3.5a
	CT	31.1± 5.6a	14.5± 3.2a	3.8±0.8a	20.7±5.2a

us, corn root density is known to decrease below 15 cm (Mengel and Barber 1974). Because we found AM fungus populations to be greatest above 15 cm depth, our results suggest that deep plowing (to more than 15 cm) hinders subsequent mycorrhiza formation by reducing propagule density in the rooting zone.

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