Impact of cropping system on mycorrhiza

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Summary

The impact of cropping system on field communities of mycorrhizal fungi was studied utilising a long-term experiment on a loamy soil. Two contrasting crop rotations each with two fertilisation regimes were compared. The conventional crop rotation (barley-barley-rye-oat-potato-oat) was fertilised at either full or half the normal recommended rate. In the low-input crop rotation, one year with barley was replaced by clover, and oat was cultivated in mixture with pea. For this rotation biotite and raw phosphate was used to compensate for the K and P of the harvested yield; animal manure was used at the beginning only. Clover and straw were returned to the soil either directly or after composting. Mycorrhizal infectivity and effectiveness were studied in bioassays in the growth chamber, and the spore densities of mycorrhizal fungi as well as their species composition in the field were determined. Only the low-input system with application of compost conclusively favoured mycorrhiza, in comparison to some or all of the other systems depending on time and function. The low-input system with no compost was more favourable than the conventional systems in terms of growth effect in 1996, but in 1997, clover incorporation markedly inhibited mycorrhiza in comparison to the other systems. Inhibition of mycorrhizal functions may indicate general mismanagement and imbalance in the soil ecosystem. This stresses the need for further studies on the importance of composting easily decomposable organic matter prior to soil incorporation for management of soil quality.

Introduction

In organic agriculture, one management goal is to increase and maintain soil quality with a high biological activity. Mycorrhizal function is an elementary natural process in soil. Mycorrhiza is a symbiosis between most crops and certain soil fungi. It has a major contribution to soil aggregate formation and stabilisation, phosphorus cycling and crop health. Mycorrhiza cause more efficient phosphorus uptake, decreases risk of soil erosion, and reduces the phosphorus leaching. Mycorrhizal functions are, however, very sensitive to human activities. They can be totally suppressed but also remarkably improved by an appropriate cropping system where crop rotation has a marked impact (Dodd *et al.*, 1990; Johnson *et al.*, 1991).

The possibilities of managing the effectiveness and the diversity of mycorrhizal field communities by cropping systems with varying crop rotations were investigated in a long-term cropping system experiment. The impact of the cropping systems on mycorrhizal infectivity and effectiveness in the original field soil as well as functional potential of fungal populations were determined in bioassays. The influence on fungal community structure was studied through spore morphology in the field.

Materials and methods

Field experiment

A long-term experiment established in 1982 on a loamy soil with two contrasting crop rotations each with two fertilisation regimes, was utilised for soil sampling. There were three complete blocks, each with three different starting points of the rotations. The experiment was located in Ylistaro, Finland (63°N,22°E). The soil properties at the start of the experiment were: pH_{H2O} 5.8, organic C 2.3 % and ammonium acetate-extractable P 5.3 mg l^{-1} (Vuorinen & Mäkitie, 1955). The conventional crop rotation (barley-barley-rye-oat-potato-oat) was either conventionally fertilised (N, P and K 108, 18 and 72 kg ha^{-1} yr^{-1}, respectively) (*system A*) or fertilised with half the conventional amounts of nutrients (*system B*). In the low-input crop rotation, one year with barley was replaced by clover, and oat was cultivated mixed with pea (barley-clover-rye-oat/pea-potato-oat/pea). Animal manure (20 t ha^{-1}) was added once when establishing the experiment. This rotation was fertilised by using biotite and raw phosphate 2-3 t ha^{-1} and 200-300 kg ha^{-1}, respectively, to compensate for the K and P of the harvested yield. Clover and straw were returned to the soil either directly (*system C*) or after composting (*system D*). The average soil P_{H2O} (van der Paauw, 1971) contents in the systems in 1997 were 5.1 (A), 2.9 (B), 1.9 (C) and 2.1 mg l^{-1} (D), respectively.

Bioassay of mycorrhizal infectivity and effectiveness

Soil for the bioassays was collected as composite samples from one stage of the systems, from all the blocks separately. Sampling was performed in the autumns 1996 and 1997, in the growing season with barley and rye, respectively. The preceding crops were oats (A,B) or oats and barley (C,D) for 1996, and barley (A,B) or red clover (C,D) for 1997. *Linum usitatissimum* cv. Linetta (Deutsche Saatveredelung, Lippstadt-Bremen GmbH) was grown as a test plant in the sampled field soil in 1 l PVC pots. The non-mycorrhizal control, with traces of infection in two pots only, was created using benomyl 20 mg (kg soil)$^{-1}$. The pots were organised in three blocks in a growth chamber corresponding to the field blocks. The plants were harvested after four weeks. A representative sample of the root system was cleaned and stained with methyl blue (Grace & Stribley, 1991), and the percentage of colonised root length was determined by the gridline intersect method (Giovannetti & Mosse, 1980). The relative mycorrhizal effectiveness (RME) is presented as the mycorrhizal contribution to the growth of the mycorrhizal plant and defined by the following formula: $RME\ (\%) = [(Y^{myc+}-Y^{myc-})/\ (Y^{myc+})] \times 100$ where Y^{myc+} and Y^{myc-} are the dry weights of the mycorrhizal treatment and the control with inhibited AM functioning, respectively.

Spore extraction

Spores were collected in 1995 from every block of two positions in the rotations, from oats (A,B) or oats and pea (C,D) after potato, and from barley after oats (A,B) or oats and pea (C,D). The spores were extracted from field soil by wet sieving and decanting (Gerdemann & Nicolson, 1963) followed by centrifugation in water and in a 50% sucrose solution (Walker *et al.*, 1982). A 500-µm and a 74-µm sieve were used for wet sieving. After centrifugation the spores were transferred into a dish of water for examination under a dissecting microscope at magnifications up to 50 times with illumination by incident light from a fibre-optic, quartz-halogen light source with a colour temperature of 3200 K (Walker *et al.*, 1993). Spores were characterised and, whenever possible, identified to species using a high-power light microscope.

Results and discussion

Infectivity and effectiveness

Mycorrhizal colonisation was relatively low in the bioassay in 1996. It was clearly highest in the soil from the low-input cropping system with plant residues composted before incorporation into soil (D) (mean 22%; range 11-31%). It was lower in the conventional system with half fertilisation (B) (4%; 1-6%) compared with conventional fertilisation (A) (10%; 2-18%) or the low-input system with no compost (C) (11%; 5-15 %). The lower colonisation with half fertiliser rate in the conventional system may be due to decreased carbon supply to the infecting fungi.

Table 1 Impact of cropping system on mycorrhizal effectiveness. A=Conventional system, B= Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting. RME=mycorrhizal effectiveness or contribution to dry weight. Means of three (1996) or six (1997) replicate pots with ranges in parentheses are presented.

Cropping system	Dry weight $^{myc+}$	Dry weight $^{myc-}$	RME, %
1996, sampling in barley, after oats (A,B) or oats and pea (C,D)			
A	0.171 (0.160-0.176)	0.147 (0.130-0.160)	14
B	0.147 (0.130-0.164)	0.126 (0.115-0.140)	14
C	0.137 (0.110-0.165)	0.094 (0.084-0.108)	31
D	0.156 (0.120-0.205)	0.107 (0.099-0.111)	31
1997, sampling in rye, after barley (A,B) or red clover (C,D)			
A	0.125 (0.115-0.138)	0.094 (0.059-0.119)	25
B	0.119 (0.099-0.130)	0.089 (0.083-0.096)	25
C	0.089 (0.077-0.115)	0.088 (0.078-0.101)	1
D	0.114 (0.101-0.134)	0.078 (0.061-0.087)	32

Like infectivity, the mycorrhizal contribution to dry weight in the bioassay was the highest in the soil from the low-input system with composting (D) both in 1996 and 1997 (Table 1). No difference was observed in either year between the two fertilisation levels of the conventional system. Instead, in soil from the low-input system with plant residues returned uncomposted (C), the effectiveness drastically varied between the two years. In 1996, with a mixture of oat and pea in the field in the preceding growing season, it was as high as with composting, despite of the lower colonisation, while in 1997 it was clearly the lowest. Growth of the mycorrhizal plants, but not of the non-mycorrhizal ones, was also lower than in all the other systems in the latter year, indicating inhibition of mycorrhiza while the plant growth was not directly affected. The uncomposted clover biomass incorporated into the soil the former autumn (1996) had been quickly decomposing in the soil, obviously causing anaerobic conditions and /or toxicity agents unfavourable for mycorrhizal reproduction or functioning. This effect was avoided by composting the biomass before incorporation into the soil.

Mycorrhizal fungal communities

There were no effects of the cropping systems on the functional potential of the mycorrhizal fungal community when inoculated in similar conditions. Differences were, however, observed in spore density. The lowest number of spores was found in the conventional cropping system at both collecting times (Table 2), indicating negative effects on fungal reproduction. In the autumn after the growing season, the highest spore density was in the low-input system with composting (D).

Species richness did not differ between the cropping systems. The most commonly found species were *Glomus claroideum, G. mosseae, Acaulospora scrobiculata* and an unidentified *Glomus*, here called *Glomus "red brown"* (Table 3). These spore types were found in all cropping systems at both collection times. The distribution of spores depended, however, somewhat on the sampling time. For example, *Glomus mosseae* occurred more commonly in soil samples collected in June than in August, while the reverse was true for *G. claroideum*. The lower amounts of *G. mosseae* in August than in June may be due to misidentification. Spores of *G. mosseae* were not mature in August and might therefore have been identified as *Glomus* sp."small white".

Table 2 Impact of cropping system on spore density. A=Conventional system, B=Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting. Means of six replicate pots with standard deviations in parentheses are presented.

Cropping system	Spring, spores per 100 ml soil	Autumn, spores per 100 ml soil
A	26.3 (9.4)	23.8 (14.3)
B	33.8 (17.8)	33.7 (17.0)
C	32.5 (11.7)	32.8 (21.7)
D	32.2 (14.9)	44.2 (21.0)

Table 3 Impact of cropping system on species composition of mycorrhizal fungi. A=Conventional system, B=Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting.

	Number of AMF spores per 100 ml soil									
	Cropping system, Spring 1995					Cropping system, Autumn 1995				
Fungus	A	B	C	D	Mean	A	B	C	D	Mean
Acaulospora scrobiculata	4	4	4	6	4.5	2	2	4	4	3
Glomus caledonium						0.2				0.1
G. claroideum	7	11	11	8	9.5	8	17	10	16	12.8
G. mosseae	6	10	8	9	8.3	1	3	3	4	2.8
G. rubiformis		0.3	0.2		0.1			0.3		0.1
Glomus sp. "small-white"	2	5	2	2	2.5	12	10	8	13	10.8
Glomus sp "red-brown"	7	5	6	7	6.3	2	2	7	7	3
Glomus spp						0.3				0.1
Scutellospora calospora	0.8	0.2	0.5	0.5	0.5			0.5	0.3	0.2

Conclusion

In conclusion, the low-input system with plant residues composted before incorporation was the most favourable of the systems studied for mycorrhiza. It resulted in the highest spore density in soil, the highest root colonisation and the highest mycorrhizal contribution to growth. There was no conclusive difference between the two fertilisation regimes of the conventional system. The low-input system with no composting was more favourable than the conventional systems in terms of growth effect in 1996, but in 1997 after clover incorporation it remarkably inhibited mycorrhiza in comparison to the other systems. Inhibition of mycorrhizal functions may indicate general mismanagement and imbalance in the soil ecosystem. This stresses the need for further studies on the importance of composting easily decomposable organic matter prior to soil incorporation for management of soil quality.

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