Exploring the Role of Arbuscular Mycorrhizal Fungi in Carbon Sequestration in Agricultural Soil

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INTRODUCTION

Concern about global warming has created interest in sequestering carbon in the soil as a possible mechanism of mitigating increases in atmospheric greenhouse gases. Work at The Rodale Institute's Farming Systems Trial®, indicates significant potential for carbon sequestration in organically farmed soils. The Farming Systems Trial was initiated in 1981 to develop organic farming systems that were economically competitive with conventional, chemically based agriculture. Prior to 1981, the 5.6 ha site was utilized to produce corn and wheat via conventional practices. Initial soil carbon levels were approximately 2.0%. Over the first 22 years of the experiment, carbon levels in the organically farmed soils rose to 2.5% while those of the conventionally farmed soil remained at 2.0% (Hepperly et al., 2007). These values translated into rates of carbon sequestration for the three farming systems of 981, 574, and 293 kg ha^{-1} yr^{-1} for the organic manure-based, organic legume-based and conventional systems, respectively (Hepperly et al., 2007).

Sampling at this site in the 1990's showed significantly higher populations of arbuscular mycorrhizal [AM] fungi in organic vs. conventionally farmed soil (Douds et al., 1993). AM fungi are symbiotic soil fungi that can enhance their host plant's ability to take up mineral nutrients, grow at low soil moisture levels, and resist pathogens. In addition, they produce glomalin; a glycoprotein that i) plays a role in stabilizing soil aggregates, ii) is resistant to degradation, and iii) can be a significant proportion of soil organic matter (Bedini et al., 2007).

We initiated a two year study in 2006 to test the hypothesis that AM fungi play a significant role in the enhanced carbon sequestration observed in organically vs. conventionally farmed soils. The first year of data is presented here.

MATERIALS AND METHODS

I. The study site

- A. Farming systems (all with conventional tillage):
  - i. Conventional
  - ii. Organic with legume cover crop
  - iii. Organic with animal manure
- B. Crop rotation
  - Soybean → wheat → corn
- C. Soil type
  - Comly silt loam (fine-loamy, mixed, mesic Typic Fragiudalf)

II. Sampling (November 29, 2006) and data collection

5 replicate plots per farming system
Deep soil cores (3.2 cm diameter) collected following corn
0-5 cm
5-10 cm
10-20 cm
20-30 cm
30-60 cm
60-80 cm

- A. Soils
  - i. Water stable aggregates (WSA)
    - 0.25-1.0 mm, 1-2 mm
  - ii. Soil carbon, soil organic matter
- B. Arbuscular mycorrhizal fungi
  - i. Spore populations
  - ii. Total propagules (MPN bioassay)
  - iii. Glomalin

RESULTS

Populations of spores of AM fungi declined with depth, but the effect of farming system upon populations did not agree with our earlier published results collected over three years, 1989-1991 (Table 1 A,B,C) (Douds et al., 1993). Earlier work showed larger populations of AM fungus spores in the two organic farming systems than in the conventionally farmed soils. The current sampling indicated that AM fungus spore populations in the conventional were equivalent to those of the organic farming system with manure. Populations were lowest in the organic system with legume cover crops. Verification of this awaits results of the autumn 2007 sampling.

Table 1. Spore populations of three AM fungus species groups in soils of The Farming Systems Trial. Means of 5 observations ± SEM. Spores 50 cm^{-3}.

Depth (cm)	Farming System Conventional	Legume	Manure
A. Glomus claroideum / Glomus etunicatum			
0-5	21.6 ± 3.9	2.6 ± 1.4	20.4 ± 6.7
5-10	8.0 ± 1.5	1.4 ± 0.4	6.4 ± 2.2
10-20	3.0 ± 0.7	2.4 ± 1.1	11.2 ± 4.9
20-30	3.4 ± 0.9	0.6 ± 0.4	1.6 ± 0.4
30-60	3.8 ± 2.9	0.8 ± 0.2	3.6 ± 1.0
60-80	3.2 ± 3.2	0.2 ± 0.2	1.2 ± 0.2
B. Glomus geosporum			
0-5	5.6 ± 4.1	0.6 ± 0.4	5.6 ± 1.5
5-10	1.0 ± 0.3	0.8 ± 0.4	5.6 ± 1.1
10-20	1.0 ± 0.3	2.0 ± 0.8	5.2 ± 1.3
20-30	0.4± 0.4	3.6 ± 2.4	5.6 ± 1.3
30-60	0.6 ± 0.6	0.6 ± 0.4	0.8 ± 0.5
60-80	0 ± 0	0.2 ± 0.2	0 ± 0
C. Glomus mosseae			
0-5	144.6 ± 25.5	60.0 ± 7.6	131.8 ± 25.6
5-10	30.0 ± 2.9	47.6 ± 4.0	80.6 ± 25.5
10-20	15.2 ± 2.4	53.6 ±17.3	55.6 ± 13.0
20-30	3.0 ± 1.6	3.2 ± 2.2	7.0 ± 1.9
30-60	1.2 ± 1.0	0.8 ± 0.8	0.2 ± 0.2
60-80	0 ± 0	0.6 ± 0.6	0 ± 0

Spores are not the only infective units of AM fungi. Infective hyphae and colonized root pieces containing vesicles also function as propagules. Total propagules of AM fungi predictably decreased with soil depth and were nearly nonexistent below 30 cm (Figure 1). The organically farmed soils tended to have greater numbers of propagules than found in the conventionally farmed soil (60% and 24% more in the manure and legume based systems, respectively). Most propagules were confined to the 20 cm depth mixed by the moldboard plow, e.g. 88% for the organic with legume system.

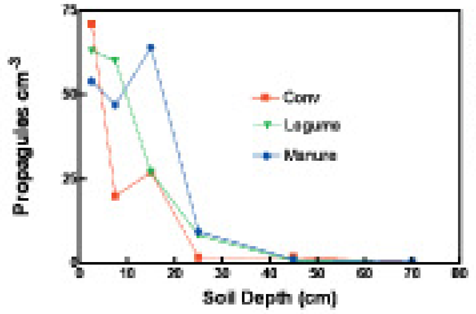

Figure 1. Distribution of propagules of AM fungi with soil depth for three farming systems of the Rodale Institute Farming Systems Trial. Means of three replicates.

Soil carbon and organic matter also decreased with depth (Figure 2 A, B). The organic farming systems had greater soil carbon and organic matter relative to conventionally farmed soil through the 10-20 cm depth, i.e. throughout the plow layer. Values for the farming systems were indistinguishable in the 30-60 cm depth and below. These data confirm earlier published results from the Farming Systems Trial (Hepperly et al., 2007).

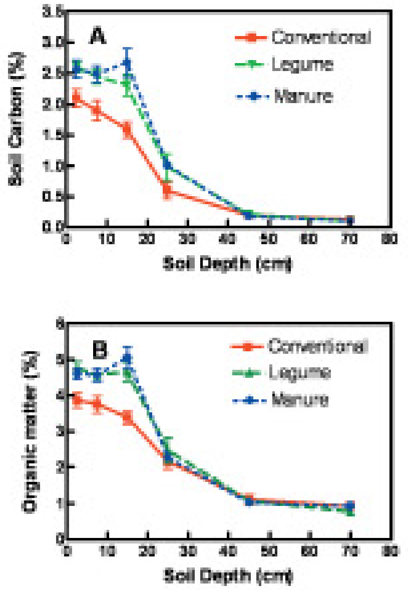

Figure 2. Distribution of soil carbon (A) and soil organic matter (B) with depth in the three farming systems of the Farming Systems Trial of The Rodale Institute. Means of 5 observations ± SEM.

Stability of soil aggregates in the 0.25-1.0 mm and 1-2 mm size categories was significantly affected by depth (Pr > F <0.0001), with declining stability and glomalin concentrations below 20 cm (Figures 3 and 4), reflecting the declining AM fungus populations below 20 cm. The organic treatments had significantly higher overall WSA and glomalin concentrations relative to soils of the conventional farming system. There were linear relationships between WSA and glomalin in both the 1-2 (R^2 = 0.7855) and 0.25-1 (R^2 = 0.6393) mm aggregates (Figure 5 A,B). There was no significant difference between treatments in the 1-2 mm aggregates (Pr > F = 0.1456), but there was a difference in the 0.25-1 mm aggregates (Pr > F = 0.0066). The level of saturation of the soils at the time of sampling and during storage prior to drying may have impacted the distribution of aggregates among size classes and also their stability in water.

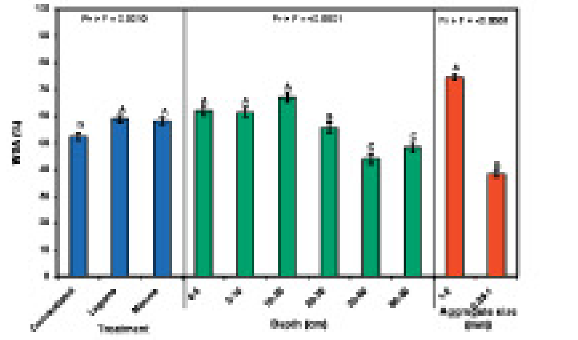

Figure 3. Percentage of water stable soil aggregates (WSA) as determined by farming system, depth, and aggregate size category.

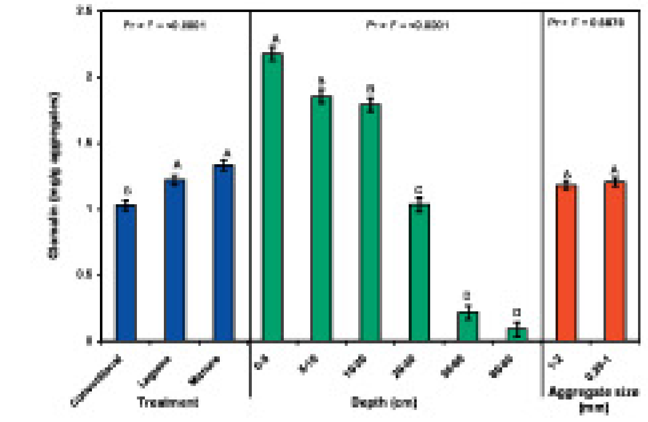

Figure 4. Glomalin concentration in soil aggregates as determined by farming system, soil depth, and soil aggregate size category.

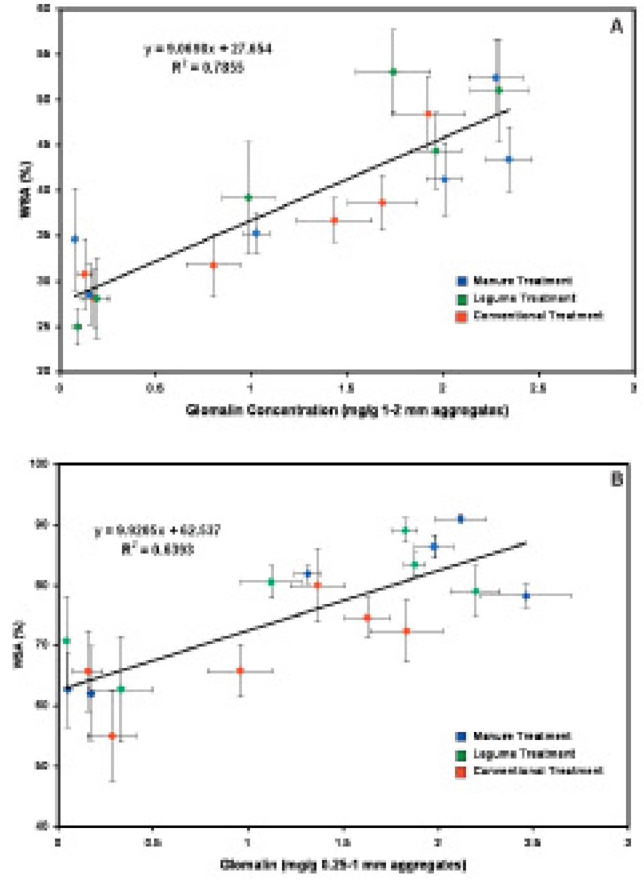

Figure 5. Relationship between glomalin concentration of 0.25-1.0 mm (A) and 1.0-2.0 mm (B) soil aggregates and percentage of those aggregates that is stable in water (WSA).

There was a strong linear relationship between glomalin concentration of soil aggregates and the value of percentage soil carbon for the associated farming system X depth combination, r^2 = 0.9523 and 0.9817 for 0.25-1.0 and 1-2 mm aggregates, respectively (Figure 6).

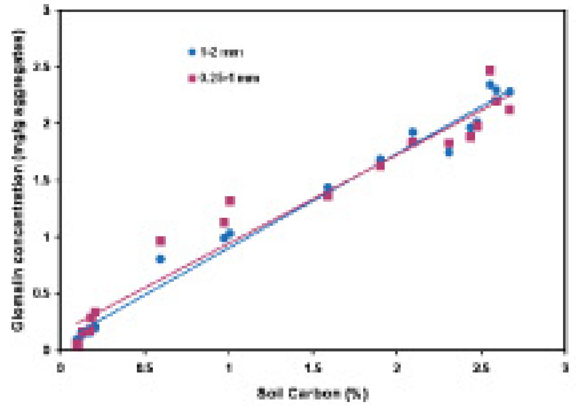

Figure 6. Relationship between soil carbon (%) and glomalin concentrations (mg g^{-1} of aggregates) from the 1-2 mm and the 0.25-1 mm aggregate size categories. Each point is the mean of 5 observations of a farming system X depth combination.

SUMMARY

- AM fungus populations declined with depth, becoming nearly extinct below 30 cm. Approximately 90% of the propagules of AM fungi were confined to the plow layer.
- Soils farmed via organic farming systems had higher levels of soil C and organic matter, notably within the plow layer, than conventionally farmed soil.
- Soils of the organic farming systems had larger percentages of water stable aggregates, and higher levels of glomalin within those aggregates, than soils from the conventional farming system. This reflects the greater population of AM fungi in the organic and the role they are believed to have in soil aggregation. Glomalin levels were highly correlated to soil C.
- Distribution of soil C, through the soil profile and across farming systems, mirrors that of AM fungi and glomalin. Attributing the enhanced carbon sequestration observed in the organic farming systems to AM fungi, i.e. moving beyond correlation to cause and effect, is not possible at this time.

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ACKNOWLEDGEMENTS

We would like to thank S. Campbell and J. Lee for technical assistance. This work is supported by the Agricultural Research Service under the GRACEnet project.