Exploring the Role of Arbuscular Mycorrhizal Fungi in Carbon Sequestration in Agricultural Soil [Part III]

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INTRODUCTION

Concern about global warming has created interest in sequestering carbon in the soil to mitigate increases in atmospheric greenhouse gases. Work at 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).

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 portion of soil organic matter (Bedini et al., 2007).

We initiated a 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 through their production of glomalin. Three years of data are presented here.

MATERIALS AND METHODS

I. The study site

A. Farming systems (all with conventional tillage):
- i. Conventional (**CONV**)
- ii. Organic with legume cover crop before corn (**LEGUME**)
- iii. Organic with animal manure (**MANURE**)

B. Crop rotation
Soybean → wheat → corn

C. Soil type
Comly silt loam (fine-loamy, mixed, mesic Typic Fragiudalf)

II. Sampling (Nov 29, 2006; Nov 1, 2007; and Dec 3, 2008)

5 replicate plots per farming system (9.5 X 95 m)
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

III. Data Collection

A. Soils
- i. Water stable aggregates (WSA)
  1-2 mm, 0.25-1.0 mm (and 0.053-0.25 mm in 2007)
- ii. Soil carbon, soil organic matter, bulk density

B. Arbuscular mycorrhizal [AM] fungi
- i. Spore populations (data not presented here)
- ii. Total propagules (MPN bioassay)
- iii. Glomalin

RESULTS

Spores, infective hyphae, and colonized root pieces containing vesicles function as propagules of AM fungi in the soil. Total propagules of AM fungi, as measured by Most Probable Number bioassay, 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. Most propagules were confined to the 20 cm depth mixed by the moldboard plow, but significant quantities of AM fungus inoculum were present to greater depths in the organic compared to the conventionally farmed soils.

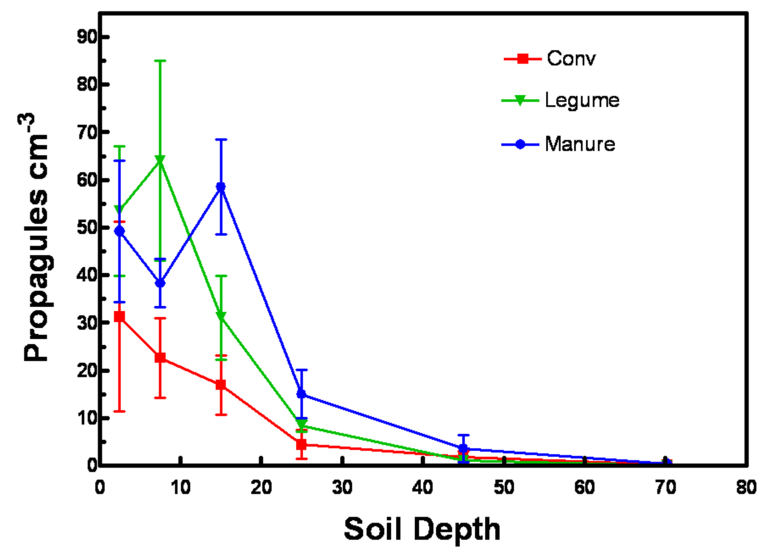

Figure 1. Distribution of propagules of AM fungi with soil depth for three farming systems of The Rodale Institute Farming Systems Trial. Data points are placed at the midpoint of the sample depth. Means of three years ± SEM.

Soil carbon and organic matter also decreased with depth. The organic farming systems had greater soil carbon (**Figure 2**) and organic matter relative to conventionally farmed soil through the 20 cm depth, i.e. throughout the plow layer. In addition, there is an indication that the organic systems stored more carbon in the 20-30 cm layer that did the conventionally farmed soil. 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).

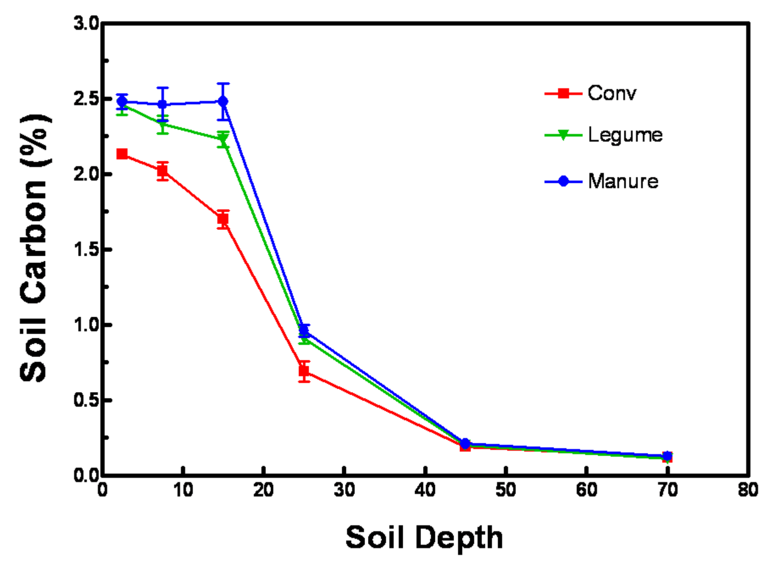

Figure 2. Distribution of soil carbon with depth in the three farming systems of the Farming Systems Trial of The Rodale Institute. Data points are placed at the midpoint of the sample depth. Means of three years ± SEM.

Total carbon storage was greater in the organic vs. conventionally farmed soils (**Figure 3**). Differences between the farming systems tended to be more pronounced either side of the 20 cm transition depth of the influence of the moldboard plow (compare the 10-20 cm and 20-30 cm depths with the other sets). As with other data collected in this experiment, there were no differences among treatments below 30 cm.

Rates of carbon sequestration in soils were greater for the organic *vs.* conventional farming systems (**Table 1**). These values appear to be declining over time, however, as soil carbon levels in the plow layer have not changed appreciably since measured earlier in 2003 (Hepperly et al., 2007).

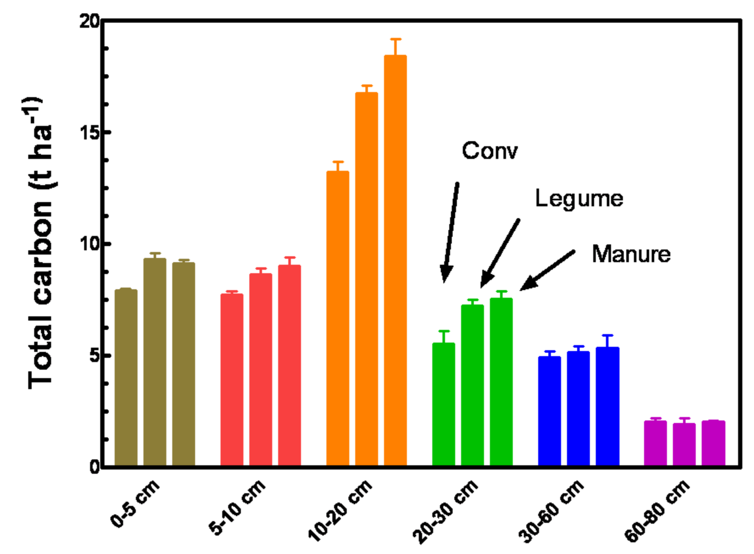

Figure 3. Total amount of carbon in the soil per ha. Data are grouped by farming system (group of three) and depth. Means of three years ± SEM. Values were calculated from bulk density and % carbon measurements, and are corrected for the volume of the soil occupied by stones.

Table 1. Calculated annual enhanced carbon sequestration in the organic relative to the conventional farming systems. Values were calculated: kg C ha^{-1} y^{-1} = (C organic – C conventional)/ years since the start of the experiment.

Year	Farming system	kg C ha^{-1} yr^{-1}	90% Confidence Interval
2006	Legume	476.9 ± 114.6	288 < μ < 665
	Manure	498.5 ± 162.8	231 < μ < 766
2007	Legume	245.4 ± 144.4	8 < μ < 484
	Manure	382.6 ± 102.6	214 < μ < 551
2008	Legume	235.3 ± 109.0	56 < μ < 415
	Manure	266.8 ± 145.8	27 < μ < 508

Means ± SEM, N=5 for 2006, 2007 and 8 for 2008.

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 below 20 cm (**Figures 4, 5,** and **6** for 2006, 2007, and 2008 respectively). Aggregate stability exhibited the same pattern of distribution as soil carbon (**Figure 2**) and AM fungus propagules (**Figure 1**), as expected given the roles of each in stabilizing soil aggregates (Miller and Jastrow, 1990). Glomalin concentrations also declined below 20 cm (**Figures 4, 5,** and **6**), reflecting reduced AM fungus populations below 20 cm. Glomalin concentrations were notably higher in the organic system with manure application *vs.* the conventional. The level of saturation of the soils in 2006 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 and resulted in the differences seen between 2006 and 2007/2008.

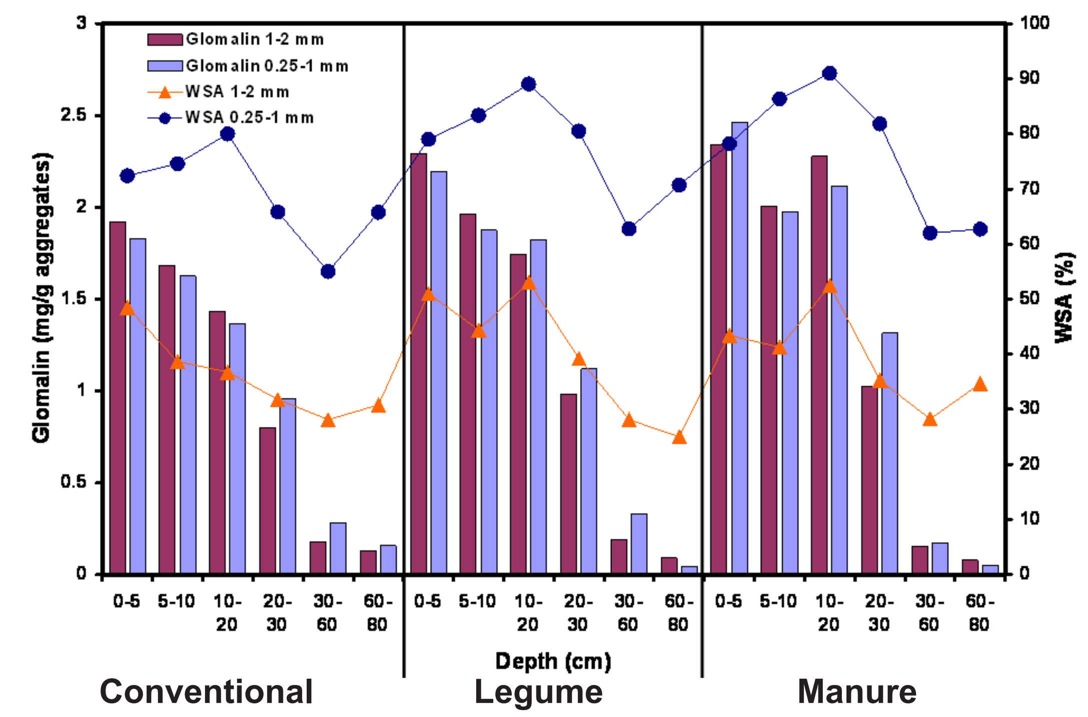

Figure 4. Distribution of water stable aggregates (lines) and glomalin per gram of soil aggregate (bars) for three farming systems and six depths, 2006, n=5.

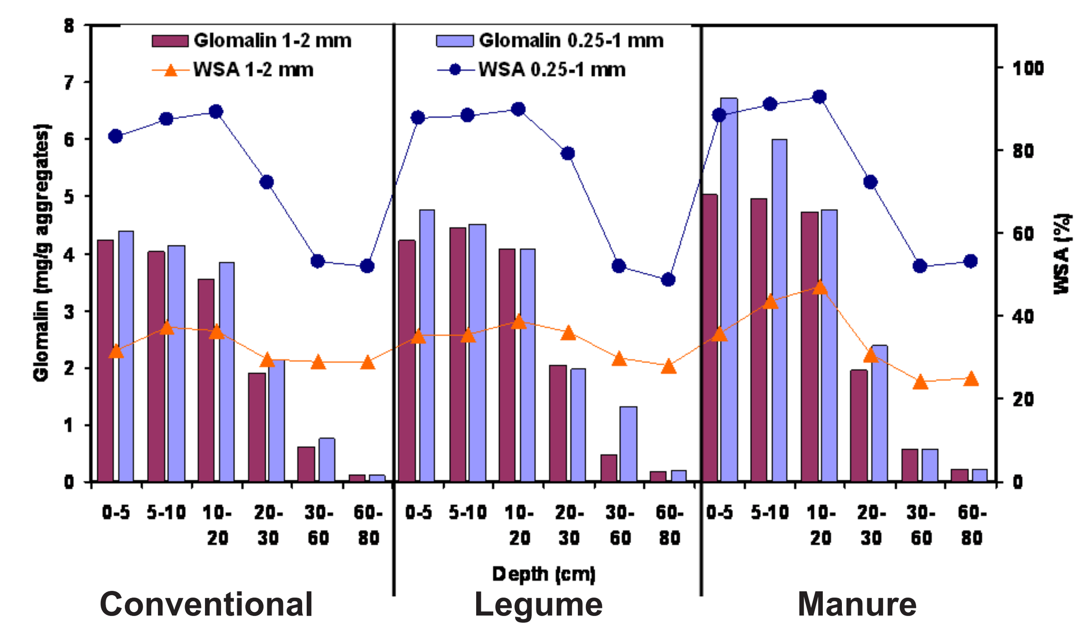

Figure 5. Distribution of water stable aggregates (lines) and glomalin per gram of soil aggregate (bars) for three farming systems and six depths, 2007, n=5.

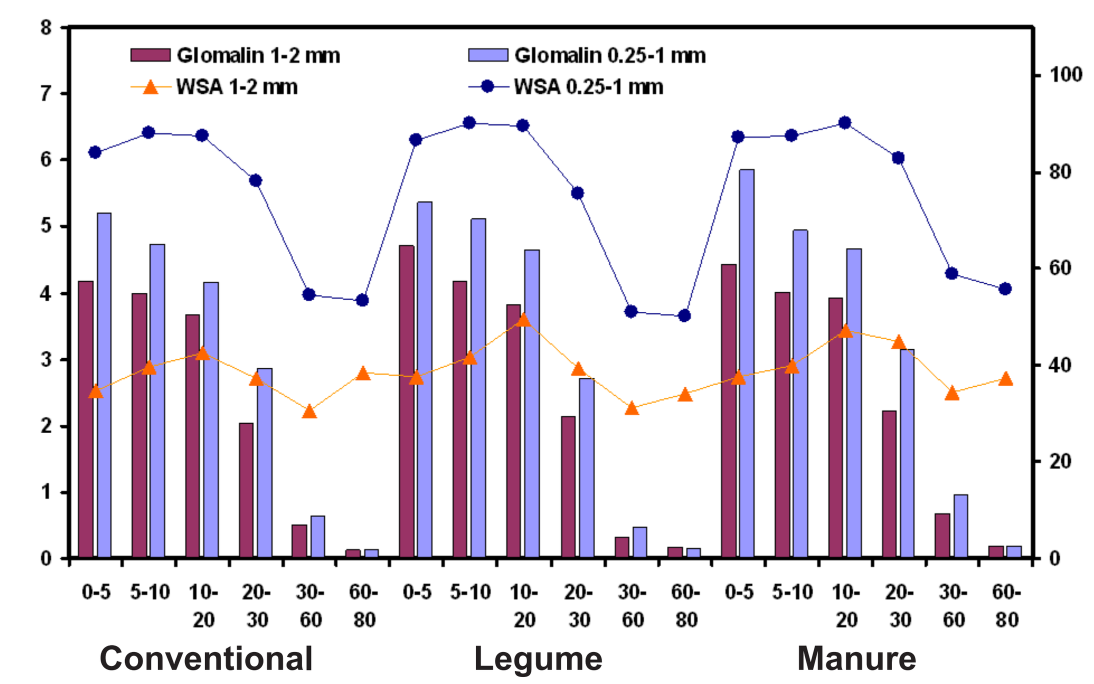

Figure 6. Distribution of water stable aggregates (lines) and glomalin per gram of soil aggregate (bars) for three farming systems and six depths, 2008, n=4.

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, notably within the plow layer, than conventionally farmed soil.
- Rates of carbon sequestration were greater in organic *vs.* conventionally farmed soils.
- Soils of the organic farming systems tended to have 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. Calculating the contribution of AM fungi to the enhanced carbon sequestration observed in the organic farming systems now becomes the focus of the project.

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