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Improving soil structure by promoting fungal abundance with organic soil amendments

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ABSTRACT

Building soil structure in agroecosystems is important because it governs soil functions such as air and water movement, soil C stabilization, nutrient availability, and root system development. This study examined, under laboratory conditions, effects of organic amendments comprised of differing proportions of labile and semi-labile C on microbial community structure and macroaggregate formation in three variously textured soils where native structure was destroyed. Three amendment treatments were imposed (in order of increasing C lability): vegetable compost, dairy manure, hairy vetch (*Vicia villosa* Roth). Formation of water stable macroaggregates and changes in microbial community structure were evaluated over 82 days. Regardless of soil type, formation of large macroaggregates (LMA, >2000 μm diameter) was highest in soils amended with vetch, followed by manure, non-amended control, and compost. Vetch and manure had greater microbially available C and caused an increase in fungal biomarkers in all soils. Regression analysis indicated that LMA formation was most strongly related to the relative abundance of the fungal fatty acid methyl ester (FAME) 18:2ω6c ($r = 0.55$, $p < 0.001$), fungal ergosterol ($r = 0.58$, $p < 0.001$), and microbial biomass ($r = 0.57$, $p < 0.001$). Non-metric multidimensional scaling (NMS) ordination of FAME profiles revealed that vetch and manure drove shifts toward fungal-dominated soil microbial communities and greater LMA formation in these soils. This study demonstrated that, due to their greater amounts of microbially available C, vetch or manure inputs can be used to promote fungal proliferation in order to maintain or improve soil structure.

1. Introduction

Soil aggregates are the foundation for A horizon soil structure, and aggregate dynamics influence how well a soil functions for crop production. In well-aggregated soils, water availability, movement, and infiltration are enhanced while surface crusting, run-off, and erosion are reduced (Bronick and Lal, 2005). Soil aggregation also affects oxygen diffusion, plant nutrient availability, development of plant root systems, and soil organic matter (SOM) dynamics (Lal, 1991; Bronick and Lal, 2005). The intensive tillage and monoculture cropping often used in modern agriculture has led to degraded structure in many soils, leading to deterioration of soil quality through erosion and losses of SOM, thus managing soil structure has become important to those interested in sustainable agroecosystem management (Lal, 1991).

Aggregation is the reorganization of primary soil particles into clusters where, according to Martin et al. (1955), "the forces holding the particles together are much stronger than forces between adjacent aggregates". Kay (1998) and Bronick and Lal (2005) discuss extensively the environmental, biological, and chemical factors that mediate soil aggregation, which include available water, texture, parent material, exchangeable ions and nutrients, SOM content, and the microbial community. The importance of SOM and soil biological factors in aggregate dynamics is highlighted in the widely accepted hierarchical aggregation model of Tisdall and Oades (1982).

Of the factors involved in aggregation SOM and the microbial community are the most readily manipulated through soil management to produce lasting improvements in soil structure (Bronick and Lal, 2005). Soil and crop management practices that reduce SOM, such as tillage and monocropping, tend to degrade soil structure; while practices such as amending with manure, compost, or cover crop inputs build SOM and have positive effects on aggregation (Bronick and Lal, 2005). Microbes are intertwined with SOM because as decomposers they mediate aggregation when organic residues in soil act as a focal point for microbial activity (Jastrow, 1996). In several studies, addition of labile carbon substrates to

Abbreviations: FAME, fatty acid methyl ester; LMA, large macroaggregates; MRPP, multi-response permutation procedure; NMS, non-metric multidimensional scaling; SOM, soil organic matter; TOC, total organic carbon.

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soil induced rapid increases in microbial activity and concurrent increases in aggregate stability (Martens, 2000; Abiven et al., 2007). Lynch and Bragg (1985) observed that organic matter additions to soils did not stimulate aggregation when microbes were inhibited.

Within the soil microbial community fungi play a key role in aggregation because their hyphal networks and polysaccharide exudates stabilize macroaggregates (Gupta and Germida, 1988; Tisdall, 1991). Chantigny et al. (1997) observed that increases in glucosamine (a fungal biomarker) coincided with improved aggregate stability and concluded that fungi are probably the most important soil microbes involved in aggregation. Beare et al. (1997) and Simpson et al. (2004) concluded that improvement of structural stability and C sequestration in no-till soils was likely due to fungal activity. Others have observed reduced macroaggregate stability when fungicides were added to soil (Beare et al., 1997; Bossuyt et al., 2001). Given the importance of fungi to soil structure, information on agricultural management practices that increase fungal presence in a soil agroecosystem may be useful to producers who need to build soil structure.

Jastrow et al. (2007) suggested that soil management practices could be used to improve soil structure and sequestration of soil C by altering the soil physicochemical environment such that fungal growth is promoted. This might be accomplished by using various amendments which can affect the soil microbial community in different ways depending on amendment C:N ratio, biochemical composition, and complexity of available carbon substrates. Larkin et al. (2006) found that manure inputs caused increased bacterial populations, while Carrera et al. (2007) found vetch cover crops to increase fungal phospholipid fatty acid biomarkers. Schutter et al. (2001) also saw increased fungal biomarkers in soils following cover crops. Wander et al. (1995) found cover crops to foster the greatest microbial diversity while manure amended soils were less diverse but more metabolically active. Larkin et al. (2011) and Saison et al. (2006) observed that compost additions increased fungal biomass.

Some researchers have concurrently examined the effects of plant residues on fungi and aggregate formation in soils where native structure has been destroyed. De Gryze et al. (2005) observed that aggregate formation increased with increasing amounts of wheat residue (*Triticum aestivum* L.) and was generally correlated with fungal hyphae production. Helfrich et al. (2008) observed maize residues (*Zea mays* L.) to rapidly stimulate macroaggregate formation; however, macroaggregate formation was delayed when a fungicide was also applied to the soil. While these studies build on the concept that management practices might be used to drive fungal mediated aggregate formation, to our knowledge there is a lack of studies that simultaneously compare multiple, commonly used amendments, such as vetch, manure, and compost, across different soils, for effects on the microbial community and corresponding changes in soil aggregation. The purpose of this research was to begin to fill this information gap.

The objective of this study was to provide information on which amendments may be best suited to building soil structure via promotion of fungal growth. To achieve this objective amendments with different organic C bioavailabilities (from most to least available: hairy vetch, dairy manure, and compost) were systematically compared for effects on fungal biomass and macroaggeagate formation in soils with different physical and chemical properties. The formation of large macroaggregates was the primary focus because they are critical in protecting soil organic matter from biodegradation, reducing soil erosion, improving water movement through the soil profile (Six et al., 2000; Franzluebbers, 2002) and have been shown to be sensitive to soil management (Haynes et al., 1991; Chan et al., 2002). It is expected that results from this study could be helpful to producers and researchers interested in building soil structure by using organic amendments to drive shifts in the microbial community that in turn promote aggregate stabilization.

2. Materials and methods

2.1. Organic amendments

Three amendments were evaluated, including hairy vetch (*Vicia villosa* Roth), dairy manure, and vegetable compost. The vetch was a winter cover crop planted in fall 2008 at The University of Kentucky Horticulture Research Farm in Lexington, KY and harvested in spring 2009. Fresh dairy manure was obtained from the University of Kentucky Dairy Research Facility, Lexington, KY. The green-waste based compost was purchased from Peaceful Valley Organic Supplies (Grass Valley, CA).

Compost was air-dried for 48 h, and the vetch and manure were dried at 65 °C and subsequently allowed to equilibrate to air-dry moisture content and forced through a 2 mm sieve before being used in soil incubation experiments. Total organic C (TOC) and total N (TN) of the amendments were determined via LECO dry combustion. A proximate organic C distribution of amendments was determined using a fractionation procedure that segregates total organic carbon into four pools with decreasing bioavailability including (from highest to lowest): water soluble C, acid soluble C, lipid C, and lignin–humic C pools (Ryan et al., 1990; D'Angelo et al., 2005). Elemental analysis (Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, P, Ni, and Zn) of organic amendments was determined using the nitric acid digestion procedure described in D'Angelo et al. (2012). Digests were analyzed for metals and metalloids using a Varian Vista-PRO Inductively Coupled Argon Plasma (ICP) (Palo Alto, CA) by the University of Kentucky, Division of Regulatory Services. Carbon:N ratios and other amendment characteristics are presented in Table 1.

2.2. Soil collection and processing

In autumn of 2009, three agricultural soils with different textures and chemical properties were collected to a depth of 15 cm, passed through a 4 mm sieve, and air dried at 4 °C. The soils included Maury silt loam (Fine, mixed, active, mesic Typic Paleudalfs); Salvisa silty clay loam (Fine, mixed, active, mesic Mollic Hapludalfs); and Yeager sandy loam (Sandy, mixed, mesic Typic Udifluvents). Basic properties of these soils are given in Table 2.

Table 1
Total organic C (TOC), C fractionation, and elemental content of organic amendment materials used in the study.

Amendment characteristic	Units	Amendment		
		Compost	Manure	Vetch
TOC	(%)	17.4	43.9	40.9
Nonpolar C	(% of TOC)	2.2	3.9	3.2
Water soluble C	(% of TOC)	7.1	11.4	24.9
Acid soluble C	(% of TOC)	17.1	21.3	29
Lignin and humic C	(% of TOC)	73.6	63.4	42.9
Total N	(%)	1.4	2.6	4.0
C:N		12.4	16.9	10.2
Ca	($g\,kg^{-1}$)	20.0	30.3	9.9
K	($g\,kg^{-1}$)	6.7	11.7	28. 9
Mg	($g\,kg^{-1}$)	5.2	10.4	2.4
P	($g\,kg^{-1}$)	3.1	9.5	4.2
Co	($mg\,kg^{-1}$)	10.0	2.5	0.4
Cr	($mg\,kg^{-1}$)	27.0	2.9	0.7
Cu	($mg\,kg^{-1}$)	62.2	136.4	13.9
Fe	($mg\,kg^{-1}$)	11800	1240	303.5
Mn	($mg\,kg^{-1}$)	363.1	248.3	90.8
Mo	($mg\,kg^{-1}$)	1.0	3.9	0.4
Ni	($mg\,kg^{-1}$)	26.4	7.9	1.5
Zn	($mg\,kg^{-1}$)	176.6	1010	71.2