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Soil microbial activity and functional diversity changed by compaction, poultry litter and cropping in a claypan soil

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ABSTRACT

Changes in soil physical characteristics induced by soil compaction may alter soil microhabitats and, therefore, play a significant role in governing soil microorganisms and their activities. Laboratory incubation and field experiments (in 2001 and 2002) were conducted to investigate the effect of soil compaction on soil microbiological properties in a claypan soil amended with poultry litter and cropped to corn (*Zea mays* L.). In both laboratory and field studies, moderate soil compaction increased total soil organic C, β-glucosidase activity, microbial biomass C (MBC), and microbial functional diversity, but decreased soluble organic C (Sol C). However, more severe soil compaction imposed in the laboratory caused an adverse effect on these soil microbiological properties, except for Sol C. Turkey (*Meleagris gallopavo*) litter application and cropping significantly increased soil β-glucosidase activity, MBC, Sol C and microbial functional diversity, partly due to inputs of labile C substrates from both litter and crops. Overall, modification of soil microhabitat by compaction could change soil microbial growth and activity in relation to C and shift soil microbial functional diversity; however, the positive effects of litter addition and cropping could overcome the compaction effect on these soil microbiological properties.

1. Introduction

Public awareness has increased regarding the possible effects of agricultural mechanical operations on human-induced soil degradation (Doran and Safley, 1997). Among the effects of these agricultural operations are both surface and subsoil compaction. The growing size of agricultural machinery and increasing time pressure on farmers to complete mechanical operations, often under wet conditions that are conducive for compaction, has further increased the severity of compaction as a major problem in modern agriculture (Mosaddeghi et al., 2000).

Claypan soils encompass an area of approximately 4 million ha in the midwestern United States (Jamison et al., 1968) and an additional 2.9 million km^2 of land resources globally are restricted by similar subsoil layers (World Soil Resources, 2002). Claypan soils are characterized by a sharp increase in clay content in the subsoil compared to the overlying material (Jamison et al., 1968). Compacting the claypan soil, for example, by field traffic and machinery may be more severe than other soils because the subsoil claypan layer confines applied stresses to the soil surface horizon, causing additional surface soil compaction (Motavalli et al., 2003b). Previous studies reported that the compacted soils with high proportion of silt and clay may have a wide range of soil bulk density of 1.2–1.6 Mg m^{-3} under field conditions (Motavalli et al., 2003b; Chen et al., 2006; Reichert et al., 2009).

Extensive research has examined the effects of soil compaction on soil physical properties and subsequent reductions in crop growth and production (Lindstom and Voorhees, 1994; Lee et al., 1996; Abu-Hamdeh, 2003; Motavalli et al., 2003a). Because soil microorganisms are an important component affecting soil fertility and productivity and the sustainability of agroecosystems, their alteration due to compaction-induced changes in soil physical properties may have a significant impact on agricultural production and environmental resources. However, relatively little information is available that relates modified soil physical properties due to soil compaction with changes in soil microbiological properties (Brussaard and van Faassen, 1994).

Soil compaction increases soil bulk density and decreases porosity and macropore continuity that may create less favorable conditions for soil microorganisms (Jensen et al., 1996). Compacting soil may also alter the spatial distribution and availability of organic substrates and nutrients, and decrease soil water availability and aeration (Breland and Hansen, 1996; Chen et al., 2003). In addition, the shift in soil pore size distribution due to soil com-

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paction may change the microhabitats of soil microorganisms, which subsequently alters microbial distribution and activity, modifies soil microbial community structure, and affects soil functions and processes (Grigal, 2000).

Soil compaction and crop growth may have several complex interactive effects on soil microbiological properties. For example, soil compaction may increase soil strength, decrease drainage and water movement in soils, and limit soil aeration thereby restricting root development (Lipiec and Stepniewski, 1995). These effects may also promote nutrient losses and decrease crop nutrient availability by altering soil microbially mediated processes (Motavalli et al., 2003a). Therefore, soil compaction may decrease crop growth, alter the soil microclimate, reduce subsequent inputs from crop roots, including exudates, and residues which are returned to the soil and possibly affect soil microbiological properties (Mapfumo et al., 1998).

In contrast, crop growth may also minimize the effects of soil compaction in several ways. For example, crop roots can penetrate into soil and, subsequently, decrease soil strength and density by creating biopores and promoting aggregate formation and stability (Brussaard and van Faassen, 1994). Above- and below-ground crop biomass may quantitatively increase soil organic matter and qualitatively provide a variety of carbon (C) substrates which may increase soil microbial growth and activity and alter microbial diversity (Bending et al., 2002; Spedding et al., 2004). Therefore, increased crop growth could create better microhabitats for soil microorganisms and reduce some effects of soil compaction.

Addition of organic materials to soil is one practical method to minimize the effects of soil compaction (Larson et al., 1994; Reicosky, 2002). Among the advantages of incorporating organic amendments, such as animal manure, into soil are reduced compactibility, decreased soil bulk density, increased soil water holding capacity and infiltration, improved soil structure, and maintenance of soil fertility for crop growth (Mosaddeghi et al., 2000; Nyakatawa et al., 2001).

Changes in soil physical and chemical properties resulting from application of organic materials increase growth of soil biota and crops under compacted conditions. Organic amendments, particularly poultry litter, contain diverse soil microbial populations (Acea and Carballas, 1996) and, therefore, their application to soil can enhance soil microbial growth, activity and diversity (Lalande et al., 2000; Parham et al., 2002). For these reasons, applied organic amendments may reduce the deleterious effects of soil compaction on biological properties.

Improved knowledge of the effects of changes in soil physical properties due to soil compaction on soil biological properties may assist in the development of agricultural management practices that may mitigate any undesirable effects of compaction on agricultural production and environmental resources. We hypothesize that one possible mitigation strategy would be to apply organic amendments to the compacted soil. The objectives of this study were: (1) to investigate the effects of surface soil compaction on soil microbial properties, such as soil enzyme activity, microbial biomass C, and microbial functional diversity; and (2) to determine if application of poultry litter and cropping affect any observed changes in soil microbial properties due to soil compaction.

2. Materials and methods

2.1. Laboratory incubation study

The soil used in the incubation study was from the surface horizon of a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) from the Bradford Agronomy Center (38°53′N, 92°12′W) in North Central Missouri. A bulk sample was taken from the 0 to 10 cm depth, air-dried, ground and sieved (2-mm mesh). The particle size distribution of this soil was an average (±standard deviation) of $59 \pm 4\,g\,kg^{-1}$ sand, $711 \pm 7\,g\,kg^{-1}$ silt, and $230 \pm 3\,g\,kg^{-1}$ clay. Selected soil properties were: pH (water) of 6.76 ± 0.02, total organic C (TOC) of $12.7 \pm 0.4\,g\,kg^{-1}$, and total Kjeldahl N (TKN) of $1.19 \pm 0.01\,g\,kg^{-1}$.

The soil was amended with ground (2-mm mesh) poultry litter, which was a mixture of turkey (*Meleagris gallopavo*) excrement plus pine shavings used as bedding material (TOC = $161 \pm 28\,g\,kg^{-1}$; TKN = $17.5 \pm 0.1\,g\,kg^{-1}$) at levels of 0 and $28.3\,g\,kg^{-1}$ soil on a dry weight basis, which resulted in an addition of 0 and 496 mg total N kg^{-1} soil, respectively. The treated soil was moistened to 55% water-filled pore space (WFPS) by assuming a soil particle density of $2.65\,Mg\,m^{-3}$. The treated soil was uniaxially compacted into 76 mm by 76 mm diam. soil cores to four levels of bulk density (1.2, 1.4, 1.6 and $1.8\,Mg\,m^{-3}$) by using a compaction cylinder and hydraulic press. All treatments had three replicates. Each core was placed in a plastic bag containing $20\,cm^3$ of water to maintain humidity. Soil core samples were kept in a dark constant temperature room at 25 °C, and were periodically removed to add water and aerate for 45 min to 1 h. After 28 d of incubation, soil samples were removed from the cores and stored at 4 °C until analysis for soil microbiological properties. Before the analysis, soils were pre-incubated at room temperature overnight.

2.2. Field study and soil sampling

This study was conducted during the 2001 and 2002 growing seasons at the Bradford Agronomy Center in the same field from which the bulk soil was collected for the laboratory incubation study. The soil in this field is part of the Central Claypan Region located in Missouri and Illinois (Soil Conservation Service, 1981). A previous study showed the depth to the claypan at this field site varied between 25 and 30 cm (Motavalli et al., 2003a). Some of the initial characteristics of the surface (0–10 cm) soil were an average (±standard deviation) of $57 \pm 4\,g\,kg^{-1}$ sand, $738 \pm 15\,g\,kg^{-1}$ silt and $206 \pm 21\,g\,kg^{-1}$ clay, pH (water) of 6.04 ± 0.10, TOC of $15.7 \pm 0.8\,g\,kg^{-1}$, and TKN of $1.1 \pm 0.1\,g\,kg^{-1}$ (Motavalli et al., 2003a).

The experimental design used was a split block design arranged in randomized complete blocks with four replications. The experimental plots were broadcast-applied with two levels of poultry litter (0 and 19.0 Mg litter ha^{-1} dry weight basis), containing an average of $316 \pm 46\,g\,kg^{-1}$ TOC and $31 \pm 3\,g\,kg^{-1}$ TKN. After incorporating litter into the soil twice with a disk implement to a depth of 10–15 cm, plots were uniformly surface-compacted 0 and 2 times with a tractor-pulled wagon fixed with a $1.9\,m^3$ water tank filled with water that had an axle load of 2.9 Mg. Tractor-induced soil compaction resulted in an average increase of soil bulk density from 1.26 to $1.40\,Mg\,m^{-3}$ over two growing seasons (Pengthamkeerati et al., 2005). Fallow plots were 3.0 m wide by 6.1 m long, and cropped plots were 3.0 m wide by 9.1 m long. Cropped plots were planted to corn (*Zea mays* L.) variety Pioneer Hybrid 33G26 at a density of 69,000 plants ha^{-1} in 76-cm rows. The fallow plots were maintained free of weeds by periodic applications of glyphosate. For the cropped plots, weed control was through recommended rates of pre-emergence herbicide applications of metolachlor and atrazine and when needed, post-emergence applications of nicosulfuron and mesotrione. Each year, compaction and litter treatments were applied to a previously untreated area of the field.

Periodically, 8–15 subsamples per plot were collected at a depth of 0–10 cm and composited. One half of each soil sample was air dried, ground and passed through a 2-mm mesh sieve for chemical analysis and the other half was kept field moist and stored at 4 °C. Field moist soils were wet sieved (2-mm mesh) and pre-