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Long-term impact of farming practices on soil organic carbon and nitrogen pools and microbial biomass and activity

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ABSTRACT

Conventional agriculture with intensive tillage and high inputs of synthetic chemicals has critically depleted the soil C pools. Alternative practices such as no-tillage and organic inputs have been shown to increase soil C content. However, the long-term impact of these practices on soil C pools was not fully understood under humid and warm climate conditions such as the southeast USA. We hypothesized that a combination of sustainable production practices will result in greater microbial biomass and activity and soil organic C than any individual practice. To test this hypothesis, we conducted a long-term experiment examining how different farming practices affect soil C and N pools and microbial biomass and activities in a fine-sandy loam (FAO: Acrisol) in the southern Appalachian mountains of North Carolina, USA. The experiment was a randomized complete design with four replications. Six management treatments, i.e., tillage with no chemical or organic inputs (Control, TN), tillage with chemical inputs (TC), tillage with organic inputs (TO), no-tillage with chemical inputs (NC), no-tillage with organic inputs (NO), and fescue grasses (FG), were designed. Organic C and N pools and microbial properties in 0–15 cm soils were markedly different after 15 years of continuous treatments. Both no tillage and organic inputs significantly promoted soil microbial biomass by 63–139% and 54–126%; also microbial activity increased by 88–158% and 52–117%, respectively. Corresponding increases of soil organic C by 83–104% and 19–32%, and soil organic N by 77–94% and 20–32% were measured. The combination of no tillage and organic management increased soil organic C by 140% over the conventional tillage control, leading to a soil C content comparable to an un-disturbed grassland control. No tillage reduced the proportion of organic C in the light fraction with $d < 1.0$ g cm^{-3} (from 1.53–3.39% to 0.80–1.09%), and increased the very heavy fraction with $d > 1.6$ g cm^{-3} (from 95% to 98%). Organic inputs, however, had little impact on C distribution among different density fractions of the soil except light fraction in tillage treatment. Over all, no-tillage practices exerted greater influence on microbial biomass levels and activity and soil organic C levels and fractionations than organic inputs. Our results support the hypothesis and indicate that management decisions including reducing tillage and increasing organic C inputs can enhance transformation of soil organic C from the labile into stable pools, promote soil C accumulation, improve soil fertility and while mitigate atmospheric CO_2 rise.

1. Introduction

Soils represent the largest global carbon (C) stock (1550 Pg), containing nearly three times as much C as vegetation and twice that of the atmospheric pool (Lal, 2003; Schlesinger and Andrews, 2000). It is estimated that the C sink capacity of the earth's soil is about 1 Pg C year^{-1}, which could offset 0.47 μmol mol^{-1} of atmospheric CO_2 annually (Jagadamma and Lal, 2010). Enhanced C sequestration in agricultural soils not only has the potential to help reduce atmospheric CO_2 concentrations (Sperow et al., 2003), but also promotes the productivity and sustainability of agricultural systems (Lal, 2004). It has been well documented that increasing soil C enhances soil fertility, reduces erosion and

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nutrient runoff, and improves water quality (Kurkalova et al., 2004; Lubowski et al., 2006; Feng et al., 2007). For example, Kurkalova et al. (2004) estimated that increasing C sequestration by 100 kg C ha^{-1} $year^{-1}$ in Iowa agricultural soils would reduce soil erosion by water by 350 kg ha^{-1} $year^{-1}$, soil erosion by wind by 0.4 kg ha^{-1} $year^{-1}$, and soil N runoff by 0.14 kg ha^{-1} $year^{-1}$. Increased C stocks in agricultural soils also enhance soils' ability to support sustainable crop growth while bringing farmers or landowners additional incomes. Nordhaus and Yang (1996) estimated that C sequestration would yield economic benefit of 6–21 US dollars per ton of C. Currently, the Chicago Climate Exchange (CCX) will pay land managers about $2 per ton of CO_2 reduction for adopting management practices for sequestering CO_2 (http://www.chicagoclimatex.com). Soil C can be enhanced through increasing organic C inputs and reducing organic C decomposition via agricultural management decisions (Lal, 2004; Paustian et al., 2000).

Soil microbes are the living part of soil organic matter and play critical roles in soil C and N cycling and ecosystem functioning (Doran, 1987). They serve as both source and sink of plant nutrients (Dalal, 1998). The activity of soil microbes greatly influences short-term dynamics and long-term stability of organic matter in soil. Microbes are usually C-limited in agricultural soils (Smith and Paul, 1990), and microbial biomass and activities are thus closely related to labile organic C in soil. It is well-known that soil microbial biomass and activity respond sensitively to changes in organic C levels or quality resulting from agronomic practices and other disturbances (Powlson et al., 1987; Lundquist et al., 1999; Tu et al., 2006). High microbial activities are inherently coupled to high C turnover and CO_2 release; thus management practices that reduce microbial access to organic matter should promote soil C accumulation.

Public concerns over high-energy inputs or use of synthetic chemicals (pesticides and fertilizers) have led to an increasing interest in alternative farming practices (also known as sustainable production practices) that are less dependent on energy-intensive technology in agriculture (Lichtfouse et al., 2009). In the past decades, a multitude of sustainable crop production practices have been developed and adopted at varying spatial scales; they commonly include no-tillage or reduced tillage practices (Triplett and Dick, 2008), integrated pest management, crop rotations/intercropping and/or cover cropping (Lichtfouse et al., 2009). These practices can directly or indirectly affect soil microbes and soil C dynamics by increasing C inputs and reducing C loss (Chen et al., 2009; Alvarez et al., 1995; Pascault et al., 2010; Jacobs et al., 2010). Many studies have shown that production systems that minimize soil disturbance (reduced tillage, minimum tillage, and no tillage) generally increase soil organic C, and microbial biomass and activity compared to conventional tillage in various soil types and climatic regions (Paustian et al., 2000; Kushwaha et al., 2001; Triplett and Dick, 2008; Jacobs et al., 2010). However, there is a concern that reducing tillage may only have limited short-term effects through facilitating organic C redistribution to the top layer and therefore the long-term potential for C sequestration is still debatable (Baker et al., 2007; Luo et al., 2010).

In humid and warm regions of the world, such as the southeast USA, decomposition rates of organic C are increased because of high soil microbial activity levels during much of the year. The effectiveness of various agricultural practices in facilitating soil C accumulation is less studied in these regions. We hypothesized that a combination of sustainable production practices will result in greater microbial biomass and activity and soil organic C than any individual practice. To test this hypothesis, we investigated the cumulative effects of various production practices on soil microbial biomass and activity, and soil organic C and N after continuous treatments for 15 years in a long-term field experiment established in fall 1994 with aims at examining long-term effects of different sustainable production practices on yield and pest and disease pressures in vegetable crops in the mountains of western North Carolina.

2. Materials and methods

2.1. The field experiment

The field experiment was established in fall 1994 at the Mountain Horticultural Crops Research Station (N 35°25′39″, W 82°33′21″, elevation 624 m) in Mills River, NC. The monthly rainfall and air temperature of the site are provided in Table 1. Prior to the beginning of this experiment, this site was continuously cultivated with moldboard plow tillage and fumigated annually for over 30 years. The soil parent material was alluvial deposits. The soil pH was 6.2 (0–15 cm depth). The soil contained 560 g sand kg^{-1} soil, 260 g silt kg^{-1} soil, and 180 g clay kg^{-1} soil. The soil type is a Delanco fine sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult), equivalent to Acrisol in FAO (Overstreet et al., 2010).

Six production practice systems were established in fall 1994, i.e., tillage with no chemical or organic inputs (Control, TN), tillage with chemical inputs (TC), tillage with organic inputs (TO), no-tillage with chemical inputs (NC), no-tillage with organic inputs (NO), and fescue grasses (FG). A detailed description for the six production practices and the sequence of vegetables grown is given in Tables 2a and 2b, respectively. Winter cover crops of wheat (*Triticum aestivum* L.) or rye (*Secale cereale*, M.Bieb) and crimson clover (*Trifolium incarnatum* L.) or hairy vetch (*Vicia villosa* Roth.) were fall planted in the synthetic treatments and the organic treatments, respectively.

Table 1
The monthly rainfall and maximum and minimum air temperatures for the experimental and long-term periods.

Month	Experiment (June, 2009–May, 2010)			Long-term (1995–2010)		
	Rainfall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)	Maximum temperature (°C)	Minimum temperature (°C)
January	138	5.4	−5.5	101	8.9	−3.1
February	80	4.6	−4.0	79	10.3	−1.9
March	52	12.5	1.2	87	14.9	1.4
April	52	22.4	5.6	83	20.0	5.4
May	135	24.7	12.7	86	24.1	10.3
June	125	28.2	15.4	120	27.3	14.8
July	59	27.0	15.8	109	28.9	16.9
August	99	27.8	16.8	105	28.9	16.7
September	170	24.1	14.6	108	25.1	12.7
October	90	18.4	7.0	65	20.4	6.4
November	138	15.9	2.7	91	15.0	1.0
December	193	7.9	−2.8	89	9.7	−2.4