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Short communication

Does North Appalachian agriculture contribute to soil carbon sequestration?

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ABSTRACT

Agricultural systems are important for world ecosystems. They can be managed to moderate CO_2 emissions. World soils can be both a sink and source of atmospheric CO_2, but it is a slow process. Data from long-term soil management experiments are needed to assess soil carbon (C) sink capacity through a complete life cycle analysis of direct and hidden C changes. Eight commonly used agricultural systems in northern Appalachia (OH, USA) were tested after 38 year to assess the magnitude of the soil C pool. Only a forest ecosystem and a no-tillage corn (*Zea mays* L.) crop plus manure increased soil organic carbon (SOC) by 37.3 and 33.3 Mg C ha^{-1}, respectively; meanwhile monoculture corn and/or no-tillage practices maintained the SOC level over the period. Thus, most of north Appalachian agriculture, with current practices, does not contribute to C sequestration. Improved agricultural practices for no-tillage continuous corn should include cultivars with higher residue production (above- and belowground) and slower decomposition rates in order to increase SOC sequestration.

1. Introduction

World soils represent a large organic C pool (1500 Gt to 1-m depth), which is more than the biotic (560 Gt) and atmospheric (780 Gt) pools combined (Lal, 2004). The atmospheric pool is increasing at the rate of 3.5 Gt C yr^{-1} (IPCC, 2007; WMO, 2008), primarily by fossil fuel combustion and land use conversion. The terrestrial pool, soil and biotic, have been a source of atmospheric CO_2 ever since the dawn of settled agriculture about 10 millennia ago. Soils represent a short to long-term C storage sink and have the potential to off-set anthropogenic emissions (Swift, 2001). Therefore, establishing long-term field experiments is important to study SOC dynamics in relation to land use and management. Several agricultural field experiments have run for more than 100 years; studies of about 20 years duration are also valuable. The turning point in the long-term field experiment history came in 1925 when Sir Ronald Aylmer Fisher established modern statistical science. The keys were the introduction of blocks (replications) in the experiment, type of design, and analysis of variance. This milestone in designing the field experiment has led to the pre-Fisher and post-Fisher eras. Whilst a post-Fisher replicated experimental design is appropriate for the majority of studies, there are numerous situations in which replication is simply impossible (Machado and Petrie, 2006). A relevant case is that of watershed experiments to study the impact of land use and management. One example is the North Appalachian Experimental Watersheds (NAEW) established in 1938 in OH, USA. The extent of the region of similar characteristics of NAEW covers hill land of southeastern Ohio, western Pennsylvania, and parts of West Virginia, Kentucky, southern Indiana, and Tennessee. The key issue is time, providing direct observations of changes in soil quality and functioning across time scales of decades as well as, indicating whether adoption of management practices (not necessarily comparing different treatments) changes the system performance over time. The NAEW research is based on the study of three important cultural practices (tillage systems, crop rotations, and fertilization), which strongly impact SOC dynamics. Results obtained from the NAEW in past studies (Blanco-Canqui et al., 2005; Puget et al., 2005) have also compared the SOC pool among some watersheds with different land use by simple pseudo-replication, being not valid from a statistical point of view.

The objective of the present study was to compare SOC measured in 1969 (Kelley et al., 1975) with data obtained in the same watersheds in 2007 by using the temporal pseudo-replication model (Hurlbert, 1984) in order to know if the typical agricultural systems in the area contribute to sequestration.

2. Materials and methods

The present investigation was conducted at the NAEW near the town of Coshocton in Northeast Ohio (40°22′N, 81°48′W, elevation: 300–600 m). This research station was established in 1938 by the US Department of Agriculture. Crop rotations, tillage systems, and

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Table 1
Land management practice and land management history (1969–2007) for eight watersheds at the North Appalachian Experimental Watershed.

Land management practice	Management history	
	Year	Agricultural practice[a]
No-tillage monoculture corn	1969–2007	No-tillage monoculture corn (continuous)
No-tillage rotation corn	1969–1970	Meadow (orchardgrass, *Dactylis glomerata* L., for hay)
	1971–1972	Moldboard plow corn
	1973–1975	No-tillage corn
	1976–1982	Meadow
	1983	Wheat (*Triticum aestivum* L.)/meadow strips
	1984–1993	No-tillage corn-soybean (*Glycine max* (L.) Merrill)
	1994–2004	No-tillage corn-soybean/rye (*Secale cereale* L.)
	2005–2007	No-tillage corn
No-tillage monoculture corn + manure	1969–2007	No-tillage monoculture corn + manure (6–11 Mg beef cattle manure ha^{-1} yr^{-1})(continuous)
Moldboard plow monoculture corn	1969–2007	Moldboard plow monoculture corn (continuous)
Disk rotation corn + manure	1969	Moldboard plow corn
	1970–1972	Meadow (orchardgrass for hay)
	1973–1974	No-tillage corn
	1975–1977	Meadow (orchardgrass for hay)
	1978–1982	No-tillage corn
	1983	Wheat/meadow strips
	1984–1989	Paraplowed corn-soybean
	1990	Wheat/meadow strips
	1991–2005	Disk soybean-wheat/red clover (*Trifolium pratense* L.)-corn + manure (5–9 Mg beef cattle manure ha^{-1} yr^{-1})
	2006–2007	Disked corn
Chisel rotation corn	1969–1974	No-tillage corn
	1975–1977	Meadow (orchardgrass for hay)
	1978–1982	Chisel corn
	1983	Wheat/meadow strips
	1984–1992	Chisel corn-soybean
	1993–2005	Chisel soybean/rye-corn
	2006–2007	No-tillage corn
Meadow	1969–2007	Meadow (orchardgrass for hay)(continuous)
Forest	1969–2007	Secondary perennial hardwood forest consisting of white (*Quercus alba* L.) and red oak (*Quercus rubra* L.) and yellow poplars (*Liriodendron tulipifera* L.)

[a] Crops separated by dash and slash mean one crop per season and two crops per season, respectively.

fertilization treatments have been practiced on watersheds since 1938. Treatments have varied with time according to experimental objectives and also to reflect the evolution of farming practices in the region. The agricultural land management practices of the eight watersheds (0.5–1 ha) selected for the study from 1969 to 2007 are showed in Table 1. With the mixed agriculture of the region and the variable adoption of improved practices, most of these practices are common. The exception is the moldboard plow monoculture corn. Corn, wheat, soybean, and rye residues were returned to the soil. Watershed slopes range from 6% to 23%. Soils are well-drained silt-loams developed from shale and sandstone bedrock. Two dominant soil series (and their corresponding taxonomic classification according to U.S. Soil Taxonomy) at the watersheds studied are Berks shaly silt loam (loamy-skeletal, mixed, mesic, Typic Dystrochrepts) and Rayne silt loam (fine loamy, mixed, mesic Typic Hapludult) (Kelley et al., 1975).

In 1969, Kelley et al. (1975) took three soil core samples in the top 60- or 76-cm depth (cores were separated into three sections) of each watershed (upper, middle, and lower position) in 1969. Sampling sites were selected so that the soil characteristics could be related to land management practices. These samples were analyzed by the Ohio Agricultural Research and Development Center, determining SOC by Walkely–Black method (Peech et al., 1947). In early November 2007, another soil sampling was carried out, by taking samples in 12 points in each watershed (grid pattern, covering the upper, middle, and lower watershed position). Samples were collected at depths 0–10, 10–20, 20–30, and 30–50 cm. Because 1969 depth intervals were different from 2007, signifi-

Table 2
Soil bulk density mean ± standard error measured in 2007 for eight agricultural land management practices in North Appalachian Experimental Watershed.

Land management practice	Soil bulk density ($Mg\,m^{-3}$) by depth (cm)			
	0–10	10–20	20–30	30–50
No-tillage monoculture corn	1.62 ± 0.01	1.74 ± 0.01	1.71 ± 0.02	1.75 ± 0.02
No-tillage rotation corn	1.64 ± 0.02	1.70 ± 0.02	1.72 ± 0.03	1.83 ± 0.02
No-tillage monoculture corn + manure	1.35 ± 0.01	1.66 ± 0.02	1.71 ± 0.03	1.76 ± 0.02
Moldboard plow monoculture corn	1.62 ± 0.05	1.67 ± 0.04	1.72 ± 0.03	1.84 ± 0.02
Disk rotation corn + manure	1.51 ± 0.02	1.66 ± 0.01	1.66 ± 0.02	1.67 ± 0.03
Chisel rotation corn	1.62 ± 0.02	1.68 ± 0.01	1.69 ± 0.02	1.76 ± 0.02
Meadow	1.35 ± 0.01	1.52 ± 0.02	1.67 ± 0.03	1.70 ± 0.02
Forest	1.36 ± 0.04	1.50 ± 0.04	1.55 ± 0.04	1.69 ± 0.03

Table 3
Temporal changes of soil organic carbon (SOC) concentration in four soil layers after 38 year (1969–2007) in North Appalachian Experimental Watershed for eight agricultural land management practices.

Land management practices	Year	SOC ($g\,kg^{-1}$) at 0–50 cm depth (cm)			
		0–10	10–20	20–30	30–50
No-tillage monoculture corn	1969	17.33a[1]	5.67a	3.42a	1.94a
	2007	15.52a	6.08a	5.11a	2.60a
No-tillage rotation corn	1969	21.77a	6.35b	3.59a	1.87a
	2007	14.92b	9.23a	3.92a	3.07a
No-tillage monoculture corn + manure	1969	26.49b	7.04b	3.81b	1.88b
	2007	35.87a	12.55a	6.20a	3.89a
Moldboard monoculture corn	1969	23.13a	6.03b	3.22b	1.57b
	2007	12.10b	9.73a	8.67a	3.27a
Disk rotation corn + manure	1969	27.46a	5.80a	2.83a	1.25a
	2007	17.17b	8.23a	3.70a	2.81a
Chisel rotation corn	1969	30.75a	6.28b	3.02a	1.30a
	2007	13.07b	9.45a	3.47a	2.46a
Meadow	1969	32.52a	8.81a	4.81a	2.41a
	2007	20.94b	10.33a	4.11a	2.65a
Forest	1969	18.06b	6.99b	4.68b	3.02b
	2007	30.00a	10.75a	10.49a	5.06a

[1] Within land management practice and depth, year means followed by the same letter are not significantly different at $P<0.05$ according to LSD.

cant SOC depth distribution functions were obtained (Mishra et al., 2009) for 1969 in order to compare both years for the same depth intervals. Intact soil cores were also taken for determination of soil bulk density by the core method (Blake and Hartage, 1986). Soil bulk density was not measured in 1969 (Kelley et al., 1975). Therefore, soil C stock to determine SOC sequestration for both years was calculated with the soil bulk density of 2007 (Table 2). No carbonates were detected in any samples. Soil organic C concentrations were determined by a dry combustion method (Nelson and Sommers, 1996) in a Vario Max CN analyzer (Elementar Instrument, Hanau, Germany). Soil organic C concentration was subjected to analysis of variance to compare data from 1969 and 2007 for each depth and total profile by temporal pseudo-replication model (Hurlbert, 1984). Effect of slope position on SOC concentration was analyzed for each watershed, but there were no significant differences. Analyses of variance were performed using SAS Version 8 program (SAS Institute, Cary, NC). Means were compared using Fisher's protected least significant difference (LSD) test at $P \leq 0.05$.

3. Results and discussion

The largest differences in SOC concentrations between the two sampling times (1969 and 2007) were in the 0–10 cm depth, although some cropping systems showed small differences in SOC content in other depths (Table 3). There was no change in the SOC concentration below 20 cm depth in most treatments, except for no-tillage monoculture corn + manure, moldboard monoculture corn, and forest. Total C accumulated by forest and no-tillage monoculture corn + manure was 37.3 and 33.3 $Mg\,ha^{-1}$, respectively (Fig. 1). No-tillage monoculture corn and moldboard tillage also increased soil C, but the magnitude was low (3.0 and 3.9 $Mg\,ha^{-1}$, respectively). Soil under other agricultural practices lost SOC, but this statement was not completely right because there was no statistical analysis for C sequestration, as a result of the same soil bulk density being used for both years. However, we can state that monoculture corn and/or no-tillage were the key practices that maintained the SOC concentration (0–50 cm), although disk rotation corn + manure (Fig. 1) nearly maintained SOC concentrations. This last treatment nearly maintained the SOC concentration level because manure was applied over 15 years. In fact, most cropping systems are maintaining the ecosystem C pool; only manure application increased the SOC pool. Schlesinger (2000) pointed out that manure application to increase SOC is a contradiction, calling it "The myth of manure". Thus, greater levels of SOC in manured fields are probably associated with inputs of biomass (plant residues) from a proportionally larger area of off-site lands and a reduction of SOC in those areas.

An explanation for SOC concentration decrease in the top layer could be that it is an erosion effect. However, we did not find any difference within each watershed for SOC concentration between upper, middle, and lower position. Hao et al. (2002) pointed out for six watersheds of this experiment that there was no difference in SOC relative to slope position; only under no-tillage continuous corn + manure did they find an increase in the lower position. Other studies carried out at the NAEW showed that C losses by erosion, averaged over 11 yr, in chisel rotation corn and no-tillage rotation

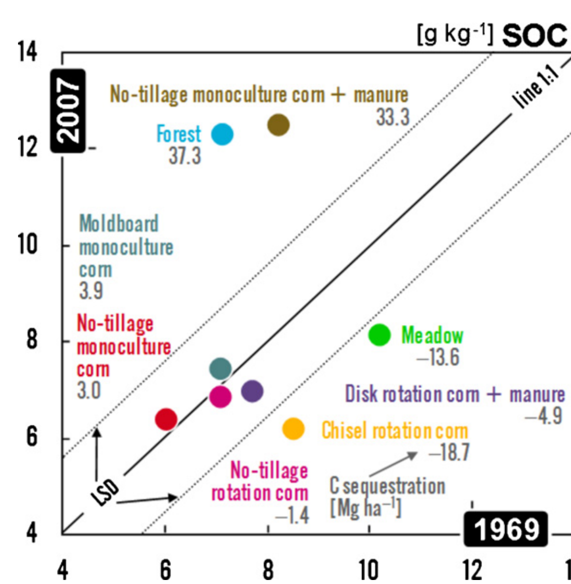

Fig. 1. Temporal changes of soil organic carbon (SOC) concentration and SOC sequestration in the 0–50 cm soil layer after 38 year (1969–2007) in North Appalachian Experimental Watershed for eight agricultural land management practices. Dotted line represents LSD at $P<0.05$ for comparison 1969 and 2007 SOC concentration within agricultural land management practices.

corn were 21.9 and 18.4 kg ha^{-1}, respectively (Starr et al., 2008). According to Owens et al. (2002), C concentrations on sediment lost from watersheds at the NAEW varied little with time, tillage practice, and weather. Therefore, the SOC decrease in the 0–10 cm layer must be more related to tillage system treatments. Moldboard, chisel, and disk treatments probably promoted a greater mineralization at top layer; but at the same time, increased SOC in the next layer due to burial (Table 3). According to Ussiri and Lal (2009), no-tillage increases SOC pool by lower decomposition of corn residues. Moreover, they stated that no-tillage practice reduced soil CO_2 emissions compared with moldboard plow tillage.

4. Conclusions

Most of North Appalachian agriculture is not contributing to increase SOC sequestration. Only monoculture corn and/or no-tillage practices maintained the soil organic C level after 38 year. In the long-term, it is necessary to identify new strategies of increasing the SOC pool in croplands. More research needs to be done on selection of corn cultivars with a higher production of belowground biomass and aboveground residues, residues more recalcitrant to decomposition, and soil C mineralization inhibition. Another consequence of these results is that removing crop residue for bioenergy production could have a negative effect on soil quality and functioning. Powlson et al. (2008) concluded that using wheat straw as a fuel for generation of electricity instead of fossil fuels had lower net CO_2 emissions. It would be an interesting comparison to use corn residues for these calculations. Nevertheless, to prevent deterioration of soil properties (Blanco-Canqui et al., 2006), most of the residues would need to be returned to the soil as long-term practices to maintain the SOC pool.

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