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Soil & Tillage Research 68 (2002) 133–142

Soil & Tillage Research

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Effect of cropland management and slope position on soil organic carbon pool at the North Appalachian Experimental Watersheds

Y. Hao [a], R. Lal [a,*], L.B. Owens [b], R.C. Izaurralde [c], W.M. Post [d], D.L. Hothem [b]

[a] School of Natural Resources, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210-1085, USA
[b] USDA-ARS, North Appalachian Experimental Watershed, P.O. Box 488, Coshocton, OH 43812, USA
[c] Battelle Pacific Northwest National Laboratory, 901 D St. SW, Washington, DC 20024, USA
[d] Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Received 9 January 2001; received in revised form 27 September 2002; accepted 30 September 2002

Abstract

Soil organic matter is strongly related to soil type, landscape morphology, and soil and crop management practices. Therefore, long-term (15–36-years) effects of six cropland management systems on soil organic carbon (SOC) pool in 0–30 cm depth were studied for the period of 1939–1999 at the North Appalachian Experimental Watersheds (<3 ha, Dystric Cambisol, Haplic Luvisol, and Haplic Alisol) near Coshocton, OH, USA. Six management treatments were: (1) no tillage continuous corn with NPK (NC); (2) no tillage continuous corn with NPK and manure (NTC-M); (3) no tillage corn–soybean rotation (NTR); (4) chisel tillage corn–soybean rotation (CTR); (5) moldboard tillage with corn–wheat–meadow–meadow rotation with improved practices (MTR-I); (6) moldboard tillage with corn–wheat–meadow–meadow rotation with prevalent practices (MTR-P). The SOC pool ranged from 24.5 Mg ha^{-1} in the 32-years moldboard tillage corn (*Zea mays* L.)–wheat (*Triticum aestivum* L.)–meadow–meadow rotation with straight row farming and annual application of fertilizer (N:P:K = 5:9:17) of 56–112 kg ha^{-1} and cattle (*Bos taurus*) manure of 9 Mg ha^{-1} as the prevalent system (MTR-P) to 65.5 Mg ha^{-1} in the 36-years no tillage continuous corn with contour row farming and annual application of 170–225 kg N ha^{-1} and appropriate amounts of P and K, and 6–11 Mg ha^{-1} of cattle manure as the improved system (NTC-M). The difference in SOC pool among management systems ranged from 2.4 to 41 Mg ha^{-1} and was greater than 25 Mg ha^{-1} between NTC-M and the other five management systems. The difference in the SOC pool of NTC-M and that of no tillage continuous corn (NTC) were 16–21 Mg ha^{-1} higher at the lower slope position than at the middle and upper slope positions. The effect of slope positions on SOC pools of the other management systems was significantly less (<5 Mg ha^{-1}). The effects of manure application, tillage, crop rotation, fertilizer rate, and soil and water conservation farming on SOC pool were accumulative. The NTC-M treatment with application of NPK fertilizer, lime, and cattle manure is an effective cropland management system for SOC sequestration.

Keywords: Soil organic carbon pool; Cropland management; Tillage; Crop rotation; Manure; North Appalachian Experimental Watershed

1. Introduction

Soil organic carbon (SOC) plays an important role in enhancing crop production (Stevenson and Cole, 1999) and mitigating greenhouse gas emissions (Lal et al., 1995a,b; Flach et al., 1997; Post and Kwon,

* Corresponding author. Tel.: +1-614-292-9069; fax: +1-614-292-7432.
E-mail address: lal.1@osu.edu (R. Lal).

0167-1987/02/$ – see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0167-1987(02)00113-7

2000). The SOC content in cropland is strongly correlated to crop and soil management practices. These practices include crop species and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation and drainage, and soil and water conservation (NRC, 1989; Paustian et al., 1997). They control SOC input from crop residue and addition of organic amendments, and SOC output through decomposition into gases and transportation into aquatic ecosystems via leaching, runoff, and erosion.

Conversion of plow tillage to no tillage can increase SOC pool by up to 10 Mg ha^{-1} during 5–20-years (Paustian et al., 1997). Due to more biomass production in corn (*Zea mays* L.) than soybean (*Glycine max* L.), SOC content under continuous corn is normally higher than that under corn–soybean rotation (Lal et al., 1997; Paustian et al., 1997). Application of N fertilizer and animal manure also increases SOC content (Paustian et al., 1997).

The SOC content also depends on landscape position due to soil erosion and leaching, which are predominant on sloping landscape. Increasing water content and soil deposition at lower slope position affects SOC decomposition and crop biomass production where the SOC content is often higher (Pennock et al., 1994; Fahnestock et al., 1995; Gregorich et al., 1998).

The effects of cropland management practices and landscape position on SOC pool depend on climate, soil type, and landscape morphology, and are thus site-specific. The North Appalachian Experimental Watershed Research Station near Coshocton, OH, is one of the ideal sites for studying the effects of cropland management practices and landscape position on SOC pool for three reasons: (1) soil management practices differ in crop rotation, tillage method, rate of fertilizer and manure application, and soil and water conservation practices have been maintained for more than 10-years making their long-term effects on SOC pool significant; (2) the slope gradient and length of the watersheds are normally above 6% (up to 35%) and 100 m, respectively (Kelley et al., 1975); (3) long-term data of water runoff and soil erosion are available.

The objective of this study was to determine the long-term effects of cropland management practices and slope position on SOC pool at the North Appalachian Experimental Watersheds.

2. Materials and methods

2.1. Site description

The North Appalachian Experimental Watershed Research Station was established in the late 1930s. It is located about 16 km northeast of Coshocton, OH (40°22′N, 81°48′W with elevation of 300–600 m). The climax vegetation is mixed oak (*Quercus* spp.) forest. The mean annual precipitation from 1939 to 1999 was 950 mm with good distribution throughout the growing season, and the mean annual ambient temperature was 10.3 °C and an average of 179 frost-free days (Kelley et al., 1975) (Table 1).

This study involves 12 watersheds that are used for corn, soybean, wheat (*Triticum aestivum* L.), and forage production. These watersheds are located within an area of 625 ha (2.5 km across), and the area of each watershed ranges from 0.26 to 0.79 ha, except for watershed 192, which is 3.07 ha. The slope gradient ranges from 2 to 25% and the slope length from 86 to 132 m, except for watershed 192, which is 223 m long. The dominant soil types include Berks shaly silt loam (USDA classification: loamy-skeletal, mixed, mesic, Typic Dystrochrepts; FAO classification: Dystric Cambisol), Clarksburg silt loam (fine loamy, mixed, mesic Oxyaquic Fragiudlaf; Stagnic Luvisol), Coshocton silt loam (fine loamy, mixed, mesic Aquic Hapludalf; Haplic

Table 1
Mean monthly temperature and precipitation from 1939 to 1999 at the North Appalachian Experimental Watershed Research Station near Coshocton, OH, USA

	Temperature (°C)	Precipitation (cm)
January	−3.0	6.5
February	−1.5	5.4
March	3.4	8.1
April	9.8	8.8
May	15.6	9.8
June	20.4	10.7
July	22.6	11.1
August	21.8	8.2
September	18.0	7.0
October	11.8	5.9
November	5.2	7.1
December	−0.6	6.4
Year	10.3	95.0

Table 2
Characteristics of the North Appalachian Experimental Watersheds

Watershed	Area (ha)	Slope gradient (%)	Slope length (m)	Aspect[a]	Shape	Soil type[b]
103	0.26	2–18	86	W	Fan	Co, Re
106	0.63	6–25	117	E	Triangle	Br, Re
109	0.68	6–18	110	E	Pentagonal	Br, Re
110	0.51	2–18	107	E	Triangle	Ke, Re
113	0.59	2–18	118	NW	Triangle	Cl, Ke, Re
115	0.65	2–12	119	ES	Triangle	Co, Ke, Re
118	0.79	6–12	132	E	Triangle	Cl, Co
121	0.58	6–25	106	S	Fan	Br, Cl, Re
123	0.55	2–12	107	S	Pentagonal	Ke, Re
188	0.83	2–12	134	S	Pentagonal	Re
191	0.49	2–12	109	S	Pentagonal	Re
192	3.07	2–25	223	EN	Pentagonal	Br, Cl, Re

[a] E: east, W: west, N: north, S: south.
[b] Br: Berks shaly silt loam, Cl: Clarksburg silt loam, Co: Coshocton silt loam, Ke: Keene silt loam, Re: Rayne silt loam.

Luvisol), Keene silt loam (fine-silty, mixed, mesic Aquic Hapludalf; Haplic Luvisol), and Rayne silt loam (fine loamy, mixed, mesic Typic Hapludult; Haplic Alisol). These soils are developed from the sandstone and shale bedrocks (Kelley et al., 1975). The detailed description of each watershed is shown in Table 2.

2.2. Agricultural management

2.2.1. From 1939 to 1970

Two contrasting cropland management systems (five prevailing watersheds and eight improved watersheds) were practiced with conventional tillage corn–wheat–meadow–meadow rotation (Table 3) (MTR-P)

Table 3
Agricultural management practices at the North Appalachian Experimental Watersheds from 1939 to 1999

Period	Watershed	Crop[a]	Tillage[b]	NPK ($kg\,ha^{-1}$)[c]	Soil pH[d]	Manure ($Mg\,ha^{-1}$)[e]	Treatment symbol
1939–1970	103, 109	C	Moldboard	202		13	MTR-I
	113, 121	W	Disking	202		13	
	123, 188	M1	No tillage	225			
		M2	No tillage		6.8		
1939–1970	106, 110	C	Moldboard	56		9	MTR-P
	115, 118	W	Disking	112			
	192	M1	No tillage				
		M2	No tillage		5.4		
1984–1999	109	C	Chisel	170–225 N, P, K	6–7		CTR
		S	Chisel				
1984–1999	118	C	No tillage	170–225 N, P, K	6–7		NTR
		S	No tillage				
1971–1999	188	C	No tillage	170–225 N, P, K	6–7		NTC
1964–1999	191	C	No tillage	170–225 N, P, K	6–7	6–11	NTC-M

[a] C: corn, S: soybean, W: wheat, M1: first year meadow, M2: second year meadow.
[b] Tillage rows were contour for all watersheds except for the second group of watersheds (straight rows).
[c] During 1939–1970, NPK fertilizer was 5:9:17 (N:P:K). After 1970, N, P, and K were urea or NH_4NO_3, superphosphate, and KCl, respectively. After 1970, the amounts of P and K are determined by soil test for obtaining corn grain yield of $10\,Mg\,ha^{-1}$.
[d] Lime used for adjusting soil pH was dolomite $CaMg(CO_3)_2$.
[e] Manure was beef cattle manure with straw bedding and $<70\%$ of water content.

(Kelley et al., 1975). Improved cropland management involved maintaining higher soil pH (6.8 versus 5.4), higher application rates of NPK fertilizer (N:P:K = 5:9:17) (170–225 kg ha^{-1} versus 56–112 kg ha^{-1}) and beef cattle (*Bos taurus*) manure (13 versus 9 Mg ha^{-1}), and using soil and water conservation farming (contour versus straight row across slope) (MTR-I). The details of the farming operations are described by Kelley et al. (1975) and in Ohio Agronomy Guide (1995).

In late April to early May, the soil was plowed with a moldboard plow to a depth of 20 cm and then disked twice and harrowed once prior to planting corn. Weeds were controlled by 2 or 3 mechanical cultivations before 1960, and by herbicides after 1960. Within 2 weeks of corn harvest, the soil was lightly disked and winter wheat was planted into 3–5 cm depth of soils. Following the corn harvest, stover was chopped and left on the soil surface. Timothy (*Phleum pratense* L.) was seeded along with wheat in early October, and red clover (*Trifolium pratense* L.) and alsike clover (*Trifolium hybridum* L.) were seeded in March. Hay was harvested twice per year (in June and August). The 10-years averages of corn yields (Mg ha^{-1}) for improved and prevailing practices were 3.26 and 2.76 from 1941 to 1950, 5.96 and 4.08 from 1951 to 1960, and 7.65 and 5.46 from 1961 to 1970, respectively.

2.2.2. From 1971 to 1999

Four contrasting cropland management systems were studied. These were: (1) no tillage continuous corn (NTC) starting in 1971; (2) no tillage continuous corn with application of beef cattle manure (NTC-M) starting in 1964; (3) no tillage corn–soybean rotation (NTR) starting in 1984; (4) chisel tillage corn–soybean rotation (CTR) starting in 1984 (Table 3). Management techniques are described by Owens and Edwards (1993), Shipitalo and Edwards (1998), and in Ohio Agronomy Guide (1995). For watersheds 109 and 118, the agricultural management practices from 1971 to 1983 went through several changes and thus were not included in this study.

Corn and soybean were planted on the contour with a planter or no tillage drill. Ryegrass (*Lolium perenne* L.) was aerially seeded into the soybean prior to leaf drop, and later killed with herbicides in April/May before the corn was planted in the spring. Corn and soybean were combine-harvested in October. Intact (not chopped) crop residue covered more than 80% of soil surface after harvest. Chisel tillage was operated once during April/May at 25 cm depth and 30 cm spacing.

For the continuous corn and corn–soybean rotation, N fertilizer (urea or NH_4NO_3) was broadcast at the rate of 170–225 kg N ha^{-1} in spring before corn was planted. Fertilizers P (superphosphate) and K (KCl) were applied in fall at rates depending on soil test for obtaining corn grain yield of 10 Mg ha^{-1}. Lime ($CaMg(CO_3)_2$) was applied during fall to reach soil pH of 6–7. Beef cattle manure (straw bedding and less than 70% of water content) was applied annually to the NTC watershed 191 since 1964. Manure was applied at the rate of 6–11 Mg ha^{-1} by top-dressing during spring before corn was planted.

The average annual corn grain yields (Mg ha^{-1}, dry weight with 15.5% moisture) from 1971 to 1999 ranged from 7.1 to 8.6 and were in the order: NTR (118) < NTC (188) < NTC-M (191) < CTR (109). The average annual soybean grain yields (Mg ha^{-1}, dry weight with 14% moisture) from 1985 to 1999 were 2.4 for watershed 118, and 2.8 for watershed 109. The coefficient of variation (CV) ranged from 18 to 33% for corn yield and from 33 to 39% for soybean yield. The average annual above-ground corn residue production (Mg ha^{-1}) measured from 1984 to 1996 was 6.38 for CTR (109) and 6.24 for NTR (118), with CV 26–33%.

2.3. Soil sampling

Soil samples were obtained in 1970 and in November 1999. Three to four soil cores in 1970 and nine cores in 1999 were taken at the upper, middle and lower slope positions (1–3 cores at each position) of each watershed. The core diameter of 2.54 cm was used in 1970 and 7.6 cm in 1999. Soil cores were divided into three generic horizons of the top Ap and two B horizons in 1970 and into three depth profiles of 0–10, 10–20, and 20–30 cm in 1999. Visible crop residue at the soil surface was removed before soil samples were collected. Soil samples were air-dried and ground to pass through a 2 mm sieve.

2.4. Soil bulk density

Dry soil bulk density was determined by the core method (Blake and Hartge, 1986) using 7.6 cm diameter and 7.6 cm long cores. The water content was determined by oven-drying the soil samples at 105 °C for 24 h. Soil bulk density was not measured in 1970 and was assumed to be the same as that measured in 1975 for watershed 103 whose land use changed from conventional moldboard till, corn–wheat–meadow–meadow rotation to pasture in 1975.

2.5. SOC concentration and pool

The SOC concentration was determined by the Walkely-Black method for the soil samples taken in 1970 and by the dry combustion method for the soil samples taken in 1999 (Nelson and Sommers, 1996). The instruments were either a CE Instrument NC 2100 soil analyzer (ThermoQuest Italia S.p.A., Rodano, MI) or a PE 2400 Series II CHN analyzer (Perkin Elmer Co., Norwalk, CT), both of which were equipped with a thermoconductivity detector. Ten grams of air-dried (<2 mm) soil samples were ground to pass 0.15 mm sieve and approximately 100 mg of ground soil sample was analyzed for total C content. The content of inorganic C in the soil sample was determined by the method of Dreimanis (1962) and subtracted from the total C to obtain the SOC content.

The SOC content of 1970 soil samples was determined for a 7.5 cm layer for each of the three generic horizons, which involved 5–12.5 cm depth for the Ap horizon, 15–30 cm depth for the first B horizon, and below 45 cm depth for the second B horizon. Soil samples obtained in 1970 were normalized into 0–15 and 15–30 cm depths, and the third horizon was discarded. The SOC pool was computed by multiplication of soil bulk density, SOC content, and soil volume and expressed as Mg ha^{-1} for specific soil depths.

2.6. Statistical analysis

Student *t*-test and least significant difference test were conducted for single pair and multiple pair comparisons, respectively.

3. Results and discussion

3.1. Effect of cropland management on SOC pool from 1939 to 1970

In comparison with the prevailing (P) practice of moldboard tillage with corn–wheat–meadow–meadow rotation (MTR-P), use of the improved (I) practice (MTR-I) increased the SOC pool by 5 Mg ha^{-1} (significant at $P = 0.05$) in 0–15 and 0–30 cm depths and by 0.1 Mg ha^{-1} in 15–30 cm depth (Table 4). The increase in SOC pool might be due to the increase in C input through high amounts of manure application and crop residue production under high fertilizer application rate and optimum soil pH, and the decrease in SOC loss through an effective soil erosion control

Table 4
Effect of soil fertility management on SOC in 0–30 cm depth for conventional tillage corn–wheat–meadow–meadow rotation from 1939 to 1970

Management[a]	Depth (cm)	Bulk density (g cm^{-3})[b]	SOC content (g per 100 g)	SOC pool (Mg ha^{-1})	Pool range (Mg ha^{-1})	Pool CV (%)
MTR-P	0–15	1.22	1.04	19.2	15.9–25.5	13
	15–30	1.34	0.27	5.4	3.5–8.2	26
	0–30	1.28	0.64	24.6	20.5–30.2	12
LSD (0.05)		NS	0.08			
MTR-I	0–15	1.22	1.31	24.2	15.9–38.3	23
	15–30	1.34	0.27	5.5	2.3–9.3	31
	0–30	1.28	0.77	29.7	18.3–47.6	21
LSD (0.05)		NS	0.06			

[a] MTR: moldboard tillage with corn–wheat–meadow–meadow rotation, P: prevailing practice, I: improved practice. Comparing with MTR-P, MTR-I had higher soil pH, higher amounts of fertilizer and cattle manure application, and contour row instead of straight row.

[b] Bulk density was not measured in 1970 and taken to be equal to those measured in 1975 at watershed 103. NS: not significant at 5% probability level.

under contour farming. The average annual corn yield of MTR-I was 1.5 Mg ha^{-1} higher than that of MTR-P during 1941–1970 (Kelley et al., 1975). The annual soil erosion rates (Mg ha^{-1}) in the corn cycles from three MTR-I watersheds (109, 113, 123) were only 30–50% of those from two MTR-P watersheds (115 and 118) (Shipitalo and Edwards, 1998).

The SOC pools in 0–15 cm depth were much higher than those in 15–30 cm depth (Table 4), reflecting a predominant role of tillage depth in vertical distribution of SOC. The range and CV of SOC pool were larger for MTR-I than for MTR-P (Table 4), which may be caused by contour versus straight row farming.

3.2. *Effect of cropland management on SOC pool from 1964 to 1999*

The SOC pools of all depths (Table 5) were the highest in the 36-years NTC with annual application of 170–225 kg N ha^{-1}, the amounts of P and K for reaching 10 Mg ha^{-1} corn grain yield, the amount of lime for maintaining soil pH 6–7, and 6 and 11 Mg ha^{-1} of cattle manure (NTC-M). The differences in SOC pools between NTC-M and any of the other three management systems were significant for all but 20–30 cm depth and were 15–23 Mg ha^{-1} for 0–10 cm depth, 6–9 Mg ha^{-1} for 10–20 cm depth, 1.8–3.7 Mg ha^{-1} for 20–30 cm depth, and 26–33 Mg ha^{-1} for 0–30 cm depth. The lowest SOC pools occurred in one of the three management systems depending on soil depth (Table 5).

Without application of cattle manure the SOC pool of NTC decreased dramatically (Table 5). However, the changes in crop rotation from corn–soybean rotation to continuous corn or in tillage from chisel to no tillage did not dramatically increase SOC pools at different depths (Table 5, generally insignificant). This indicated significance of the manure application and importance of crop rotation and tillage methods in reaching high SOC pool of NTC-M.

The higher SOC pool in continuous corn than corn–soybean rotation may be due to increased resistance to microbial degradation of corn residue than soybean residue. Paustian et al. (1997) indicated that

Table 5
Effect of tillage, crop rotation, and manure application on SOC in 0–30 cm depth from 1964 to 1999

Watershed	Management[a]			Depth (cm)	Bulk density (g cm^{-3})	SOC content (g per 100 g)	SOC pool (Mg ha^{-1})	Pool range (Mg ha^{-1})	Pool CV (%)
	Tillage	Rotation	Manure						
109	CT	CS	NM	0–10	1.10	1.32	14.3	11.3–18.5	15
				10–20	1.28	0.83	10.6	9.1–13.1	13
				20–30	1.44	0.52	7.3	4.0–13.5	47
				0–30	1.28	0.89	32.1	26.1–37.9	13
LSD (0.05)					0.10	0.19			
118	NT	CS	NM	0–10	1.15	1.63	18.1	15.1–20.4	11
				10–20	1.30	0.95	12.3	9.1–14.2	13
				20–30	1.41	0.46	6.5	2.8–8.8	29
				0–30	1.29	1.01	36.8	31.2–42.4	10
LSD (0.05)					0.04	0.16			
188	NT	CC	NM	0–10	1.11	2.14	21.8	15.7–25.6	14
				10–20	1.38	0.69	9.4	5.4–11.4	19
				20–30	1.39	0.60	8.4	4.9–11.3	27
				0–30	1.29	1.14	39.6	34.8–45.9	10
LSD (0.05)					0.07	0.22			
191	NT	CC	M	0–10	0.96	3.99	37.1	29.9–44.0	12
				10–20	1.29	1.43	18.3	13.2–23.6	21
				20–30	1.34	0.76	10.2	7.3–16.0	30
				0–30	1.20	2.06	65.5	55.4–83.4	14
LSD (0.05)					0.06	0.41			

[a] CT: chisel tillage, NT: no tillage, CS: corn–soybean rotation, CC: continuous corn, M: cattle manure, NM: no cattle manure.

SOC pool is generally higher under continuous corn than under corn–soybean rotation.

Reducing tillage intensity normally leads to a higher SOC pool due to the effect of tillage on SOC mineralization through breakup of soil aggregates and soil aeration (Powlson and Jenkinson, 1981; Balesdent et al., 1990, 2000; Havlin et al., 1990; Franzluebbers et al., 1995; Paustian et al., 1997; Reicoky et al., 1997; Dick et al., 1998; Six et al., 1999; Watts et al., 2000). The higher SOC pool of NTR than that of CTR was indicated only in the top 20 cm layer (Table 5). Frye and Blevins (1997) observed that the effect of 20-years of no tillage in Kentucky, USA, increased the SOC pool compared with conventional tillage and occurred only in 0–5 cm depth. Similar observations were made by Lyon et al. (1997) with their 20-years wheat–fallow experiment in Sidney, NE, USA.

The SOC pool decreased with depth especially in no tillage treatments (Table 5). Although, the variation in SOC pool generally increased with soil depth (Table 5). The range of SOC pool indicated the normal differences of 50–100% between the minimum and maximum values for any depth.

3.3. Comparison of SOC pools in 0–30 cm depth

The SOC pool in 0–30 cm depth ranged from 24.5 to 65.5 Mg ha^{-1} and increased in the order: MTR-P < MTR-I < CTR < NTR < NTC < NTC-M (Table 6). The SOC pool of no tillage continuous corn with manure application (NTC-M) was significantly higher than those of the other five management systems by 25.9 (65%) to 41 (167%) Mg ha^{-1} (Table 6). The SOC pool of NTC was significantly higher than those of the conventional and chisel tillage management systems. The SOC pool of NTR was insignificantly higher than those of the conventional and chisel tillage management systems. Furthermore, the SOC pools of the CTR were not significantly higher than those of conventional tillage corn–wheat–meadow–meadow rotation (MTR-P and MTR-I) (Table 6).

No till, continuous corn, and a combination of high amounts of soil amendments (fertilizer, manure, and lime) with contour farming increased the SOC pools by 5.2 Mg ha^{-1} (21%) (Table 6). Manure application, however, increased the SOC pool by 25.9 Mg ha^{-1} (65%). The effect of the above practices on the increases in SOC pool were accumulative (Table 6).

3.4. Effect of slope position on SOC pool and its comparison

The SOC pools at upper slope position were normally lowest for different soil depths, but the differences from the middle or lower slope positions were often insignificant (Table 7). The highest SOC pools

Table 6
Comparison of the SOC pools in 0–30 cm depth between the soil management practices for 1939–1999

Management[a]	Duration (year)	SOC (Mg ha^{-1})[b]	SOC difference (Mg ha^{-1})[c]					
			MTR-P	MTR-I	CTR-H	NTR-H	NTC-H	NTC-M
MTR-P	32	24.5c		*21*[d]	31[d]	50[d]	62[d]	167[d]
MTR-I	32	29.7c	*5.2***		8[d]	24[d]	33[d]	121[d]
CTR	16	32.1c	7.6	2.4		*15*[d]	23[d]	104[d]
NTR	16	36.8bc	12.3	7.1	*4.7**		*8*[d]	78[d]
NTC	30	39.6b	15.1	9.9	7.5	*2.8* NS		*65*[d]
NTC-M	36	65.5a	41.0	35.8	33.4	28.7	*25.9****	

[a] CTR: chisel tillage corn–soybean rotation, MTR: conventional tillage corn–wheat–meadow–meadow rotation, P: prevailing practice, I: improved practice, NTR: no tillage corn–soybean rotation, NTC: no tillage continuous corn, M: cattle manure. Comparing with MTR-P, MTR-I had higher soil pH, higher amounts of fertilizer and cattle manure application, and contour row instead of straight row.

[b] The numbers followed by the same letters are not significantly different from each other at $P = 0.05$ of least significant test.

[c] The numbers in the lower triangle = SOC pool in column − SOC pool in row. Numbers in the upper triangle = 100 × numbers in the lower triangle/SOC pool in column. The italic numbers are the SOC pool differences between the two soil management practices which differed in only one of the four management practices: manure application, tillage, crop rotation, and soil fertility (fertilizer, lime, manure, and contour versus straight row). NS: not significant with $P > 0.05$ of *t*-test.

[d] The values were given in %.

Table 7
Effect of slope position on SOC pool at different depths of the North Appalachian Experimental Watersheds

Watershed	Management[a]	Slope	SOC ($Mg\,ha^{-1}$)[b]			
			0–10 cm	10–20 cm	20–30 cm	0–30 cm
109	CTR	Upper	14.2a	10.1a	4.2b	28.6b
		Middle	13.5a	10.5a	11.5a	35.6a
		Lower	15.1a	11.1a	6.1b	32.3ab
118	NTR	Upper	16.1b	12.1a	5.0a	33.3b
		Middle	18.9a	12.6a	7.5a	39.0a
		Lower	19.3a	12.2a	6.8a	38.3ab
188	NTC	Upper	23.2a	8.9a	9.5a	41.5a
		Middle	22.0a	10.1a	6.5a	38.6a
		Lower	20.3a	9.3a	9.2a	38.7a
191	NTC-M	Upper	35.8ab	14.5b	8.6a	58.9b
		Middle	34.0b	17.8b	8.8a	60.5b
		Lower	41.7a	22.5a	13.0a	77.2a

[a] CTR: chisel tillage corn–soybean rotation, NTR: no tillage corn–soybean rotation, NTC: no tillage continuous corn, M: cattle manure.
[b] The numbers followed by the same letters are not significantly different from each other at $P = 0.05$ of least significant test.

Table 8
Effect of slope positions on differences in SOC pool in 0–30 cm depth among soil management practices

Management[a]	Slope	SOC difference ($Mg\,ha^{-1}$)			
		0–10 cm	10–20 cm	20–30 cm	0–30 cm
NTR-CTR (118–109)	Upper	1.9	2.0	0.8	4.7
	Middle	5.3	2.1	−4.0	3.4
	Lower	4.2	1.1	0.8	6.0
NTC-NTR (188–118)	Upper	7.1	−3.2	4.4	8.3
	Middle	3.1	−2.5	−1.1	−0.4
	Lower	1.0	−2.9	2.4	0.5
NTC-M-NTC (191–188)	Upper	12.6	5.6	−0.8	17.4
	Middle	12.0	7.7	2.3	22.0
	Lower	21.4	13.2	3.9	38.5

[a] NTR: no tillage corn–soybean rotation, CTR: chisel tillage corn–soybean rotation, NTC: no tillage continuous corn, M: cattle manure.

were indicated at the lower slope positions for all soil depths only at watershed 191 (NTC-M) most likely due to downslope transportation of manure during runoff. The SOC pool of 0–30 cm depth at the lower slope position of watershed 191 was higher than that of the upper slope position by 18.6 $Mg\,ha^{-1}$. The differences in SOC pools between the three slope positions were generally insignificant and less than 5 $Mg\,ha^{-1}$ for the other three management systems (Table 7).

The effect of the slope positions on SOC pool differences between no tillage and chisel tillage of corn–soybean rotation and between continuous corn and corn–soybean rotation of no tillage was generally less than 5 $Mg\,ha^{-1}$ (Table 8). The effect was, however, up to 21 $Mg\,ha^{-1}$ for the SOC pool differences in 0–30 cm depth between manure and no manure application of NTC.

4. Conclusion

The SOC pool at the North Appalachian Experimental Watersheds can be increased by applying cattle manure, reducing tillage intensity, converting corn–soybean rotation to continuous corn, and increasing soil fertility through combination of increased amounts of soil amendments (fertilizer, manure, and lime) with contour farming. A combination of these cropland management practices can increase SOC pool in 0–30 cm depth accumulatively by 41 Mg ha^{-1} and lead to SOC pool level of 65 Mg ha^{-1}. Slope position of the watersheds can exert a significant effect on SOC pool where cattle manure was constantly applied.

Acknowledgements

This research is funded by the United States Department of Energy.

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