Available online at www.sciencedirect.com

SCIENCE DIRECT®

Soil & Tillage Research 81 (2005) 173–181

Soil & Tillage Research

www.elsevier.com/locate/still

Erosional effects on soil organic carbon stock in an on-farm study on Alfisols in west central Ohio

M.K. Shukla, R. Lal*

Carbon Management and Sequestration Center OARDC/FAES, School Of Natural Resources, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210, USA

Abstract

Soil erosion and depositional processes in relation to land use and soil management need to be quantified to better understand the soil organic carbon (SOC) dynamics. This study was undertaken on a Miamian soil (Oxyaquic Hapludalfs) under on-farm conditions in western Ohio with the objectives of evaluating the effects of degree of erosion on SOC stock under a range of tillage systems. Six farms selected for this study were under: no-till (NT) for 15, 10, 6 and 1.5 years; chisel till every alternate year with annual manure application (MCT); and annual chisel till (ACT). A nearby forest (F) site on the same soil was chosen as control. Using the depth of A horizon as an indicator of the degree of erosion, four erosion phases identified were: uneroded (flat fields under F, NT15, and on the summit of sloping fields under NT10, NT6, NT1.5 and MCT); deposition (NT10, NT6, NT1.5 and ACT); slight (NT10, MCT and ACT); and moderate erosion (NT10 and ACT). Core and bulk soil samples were collected in triplicate from four depths (i.e., 0–10, 10–20, 20–30 and 30–50 cm) for each erosional phase in each field for the determination of bulk density, and SOC concentrations and stocks. SOC concentration in NT fields increased at a rate of 5% $year^{-1}$ for 0–10 cm and 2.5% $year^{-1}$ for 10–20 cm layer with increasing duration under NT. High SOC concentration for NT15 is indicative of SOC-sequestration potential upon conversion from plow till to NT. SOC concentration declined by 19.0–14.5 g kg^{-1} in MCT and 11.3–9.7 g kg^{-1} in NT10 between uneroded and slight erosion, and 12.0–11.2 g kg^{-1} between slight and moderate erosion in ACT. Overall SOC stock was greatest in the forest for each of the four depths. Total SOC stock for the 50 cm soil layer varied in the order F (71.99 Mg ha^{-1}) > NT15 (56.10 Mg ha^{-1}) > NT10 (37.89 Mg ha^{-1}) = NT6 (36.58 Mg ha^{-1}) for uneroded phase ($P < 0.05$). The lack of uneroded phase in ACT indicated high erosion risks of tillage, as also indicated by the high SOC stock for deposition phase from 0 to 50 cm soil layer (ACT (56.56 Mg ha^{-1}) > NT1.5 (42.70 Mg ha^{-1}) > NT10 (30.97 Mg ha^{-1})). Tillage increased soil erosion and decreased SOC stock for top 10 cm layer for all erosional phases except deposition.

Keywords: SOC stock; Erosion; Deposition; Bulk density; No-till; Tillage; Farm; Manure

1. Introduction

Soil erosion refers to the displacement of soil from the place of its formation by causative agents, including raindrops, runoff, wind and gravity (Lal,

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

0167-1987/$ – see front matter
doi:10.1016/j.still.2004.09.006

2003). Soil erosion can occur on both no-till (NT) and tilled soils depending upon the soil, topography and climate; essentially removing the topsoil and truncating the A horizon. Wind and water erosion and tillage can redistribute considerable amounts of soil and soil organic carbon (SOC), which is concentrated near soil surface and has low bulk density (Gregorich et al., 1998). The range of SOC lost by erosion in the top 25 cm of moderately and severely eroded soils can be as much as 19–51% for Mollisols and 15–65% for Alfisols (Kimble et al., 2001). Water-eroded soil usually deposits in depression at the footslope or toeslope of a landscape and erosional/depositional history at each landscape position influences the SOC dynamics (VandenBygaart et al., 2002). The eroded and deposited soils differ from the original soils, therefore translocation and redistribution of sediments and SOC is a pedogenic process (Lal, 2003).

The SOC stock is a function of tillage practices with higher SOC stock in soil managed by reduced (i.e., minimum till, conservation till or no-till) than plow till systems (Rasmussen et al., 1998; Halvorson et al., 2002; Shukla et al., 2003). Conventional tillage, especially on sloping soils, reduces the SOC stock by (1) exposure of the soil organic carbon to the oxidation process and it's emission as CO_2, (2) rapid decomposition of crop residues, (3) erosion and transport of SOC with the sediments, (4) disruption of aggregates and exposure of physically protected SOC to microbial and enzyme activity, and (5) leaching of dissolved organic carbon. Some soil specific data are available about the magnitude of SOC loss from mineralization and erosion, which shows that mineralization predominates in the first year after tillage and erosion becomes predominant on sloping lands thereafter (Gregorich and Janzen, 1995; Gregorich et al., 1998). Decline in SOC with degree of erosion is reported by McDanial and Hajek (1985) for all soils except Vertisols in Alabama, Langdale et al. (1985) for Piedmont soils in Georgia, Nizeyimana and Olson, 1988 for loess soils (Mollisols and Alfisols) in Illinois, and Fahnestock et al. (1995) for Alfisols in Ohio. Frye et al. (1982) also observed less SOC in Ap horizon of two moderately eroded Kentucky soils, relative to uneroded phases.

Erosion results in loss of productivity with attendant decline in the plant biomass and residues returned to the soil (Lal et al., 2000). Conversion from plow till to NT (Ketcheson and Webber, 1978) or conservation tillage (Bauer and Black, 1981), bare fallow to cover crops (Lowrance and Williams, 1988) and crop rotations (Webber, 1964) result in reducing erosion and loss of SOC. It is important to quantify erosion—SOC relationship under different land use and management systems in order to understand the sustainability of a management system. Therefore, the objectives of this study were to evaluate SOC stock under on-farm conditions with regard to (1) degree of erosion and (2) interaction between erosion phase and tillage system.

2. Materials and methods

2.1. Site description

The study area is located in the west central Ohio, in South Charleston and Springfield, Clark County (Table 1). The area lies in the tillage plains division of the central lowlands province, also known as major Land Resource Area 111, Indiana–Ohio tillage plain. Farming is the major enterprise with most soils well suited to field crops, pasture and trees. Major portion

Table 1
Management options and locations of selected fields in South Charleston, OH

Treatment	Tillage operation	Frequency (years)	Crops	Location
F	Forest	Natural	Trees	39°51.11′N 83°37.30′W
NT15	No-till	15	Soybean	39°53.65′N 83°46.78′W
NT10	No-till	10	Soybean	39°53.40′N 83°40.79′W
NT6	No-till	6	Corn	39°51.50′N 83°43.82′W
NT1.5	No-till	1.5	Soybean	39°50.76′N 83°35.44′W
MCT[a]	Chisel till	Alternate	Corn	39°50.92′N 83°37.57′W
ACT	Chisel till	Annual	Soybean	39°51.39′N 83°43.58′W

Experimental fields are listed in the table in the increasing order of intensity of tillage operation.
[a] Manure was also applied annually.

Table 2
The soil types and map units according to the soil survey of Clark County (USDA-NRCS, 1999)

Treatment	Soil type	Slope (%)	Map symbol	Erosion phase
F	Miamian silt loam	0–2	MhB2	–
NT15	Miamian silt loam	0–2	MhA	–
NT10	Miamian silty clay loam	6–12	MkC2	Eroded
NT6	Miamian silt loam	6–12	MhC2	Eroded
NT1.5	Miamian silt loam	2–6	MhB2	Eroded
MCT	Miamian silt loam	2–6	MhB2	Eroded
ACT	Miamian clay loam	6–12	MmC3	Severely eroded

of the county is flat, however, moderate to severe erosion is observed on some sloping lands and stream valleys. The study area was mostly under corn (*Zea mays* L.) soybean (*Glycine max*) rotation and soil was classified as Miamian (fine, mixed, active, mesic Oxyaquic Hapludalfs). A nearby natural forested site (F) located on similar soil type was selected as control. Six different fields selected were owned by three farmers and were under different land use and management systems including chronosequence of NT for 15, 10, 6 and 1.5 years; alternate year chisel tillage with manure (MCT); annual chisel tillage (ACT) (Table 1). Prior to being chiseled in October 2001, the NT1.5 was also under NT for at least 2 years (1999–2001). However, since October 2001, it is continuously under NT for the last 1.5 years. The MCT was chisel tilled after the harvest of corn whereas ACT was tilled every year. Both fields were chisel tilled for more than 5 years. Broadcast application of diammonium phosphate (DAP) was made in NT15, NT10, NT1.5 and ACT at the rate of 390 kg ha^{-1}, and in MCT at the rate of 700 kg ha^{-1} during April 2002. DAP was applied in NT6 at the rate of 334 kg ha^{-1} in April 2003. Liquid manure (12 Mg ha^{-1}) was applied in only MCT once annually during April.

The predominant soil type on four farms (NT15, NT6, NT1.5 and MCT) is Miamian silt loam; in NT10 and ACT farm soil types are Miamian silty clay loam and Miamian clay loam, respectively. The specific soil types and soil map units for each field are presented in Table 2. The average temperature for the study area is −2.3 °C in winter and 22 °C in summer. The average annual rainfall for the county is 960 mm. A detailed description of soils for each of the experimental fields is provided in soil survey of Clark County (USDA-NRCS, 1999).

Profile samples were obtained from each farm, using a push–probe to determine the depth of A horizon. Soil pits were dug wherever push–probe samples were inadequate for distinguishing between A and B horizons. Carbonate layer mostly occurred below 50 cm depth and was identified by the dilute HCl solution (0.12N) drop test on push probe samples during field sampling. Since erosion truncates the A horizon, the experimental plots were divided into different erosional phases (i.e., uneroded: 0, slight: 1, moderate: 2, severe: 3 and depositional: D) depending upon the remaining depth of the A horizon (Table 3).

The slope of the entire study area was nearly flat in F, NT15, and on the summit of NT10, NT6 and NT1.5. The maximum slopes (backslopes) of 6–12% were in NT6 and ACT. All the study area was identified as eroded except ACT, which was reported as severely eroded by USDA-NRCS (1999). Uneroded phase was detected in F, NT15, and on the summit slope of NT10, NT6, NT1.5 and MCT; deposition on the toeslope in NT10, NT6, NT1.5 and ACT (almost flat); slight in NT10, MCT and ACT; moderate in NT10 and ACT, with both phases located on back slope (Table 4).

Core and bulk soil samples were collected in triplicate from four depths (i.e., 0–10, 10–20, 20–30 and 30–50 cm) from each erosional phase given in Table 4. Soil bulk density (ρ_b) was measured on 6 cm

Table 3
Criteria for selecting erosional phases on Miamian soils of South Charleston, OH

Depth of A horizon (cm)	Erosional Class
>20	0: uneroded
15–20	1: slight erosion
10–15	2: moderate erosion
<10	3: severe erosion
>20 (at the toeslope)	D: deposition

Table 4
Erosion phases identified using the criteria in Table 3 for various land uses

	NT (Yrs)				MCT	ACT	Forest
	1.5	6	10	15			
Erosional phases	0 D	0 D	0 1 2 D	0	0 1	1 2 D	0

Land uses were chronosequence of no-till (NT), manured and chisel till (MCT) every alternate year, annual chisel till (ACT) and forest. The erosional phases were uneroded (0), slight (1), moderate (2), and deposition (D).

long and 6 cm diameter stainless steel cores (Blake and Hartge, 1986). Total carbon (TC) and total nitrogen (TN) concentrations were determined by the dry combustion method at 900 °C (Elementar, GmbH, Hanau, Germany). Since carbonate content was insignificant on 0–50 cm layer, it was assumed that TC was equal to soil organic carbon. The SOC stocks were calculated by multiplying bulk density and depth of soil layer with TC.

2.2. Statistical analysis

The analysis of means was done for the SOC concentration or stock in age chronosequence of NT for each depth and erosional phase, and among treatments under similar erosional phases using Statistical Analysis System (SAS Institute, 1989). Linear regression analysis between SOC concentration or stock and duration under NT was also performed using SAS Institute (1989).

3. Results and discussion

3.1. Land use and soil bulk density

The uneroded phase (depth of A horizon > 20 cm) was found on F, NT15, and on summit of NT10, NT6, NT1.5 and MCT. The ρ_b for uneroded phase varied in the order NT10 = NT1.5 > F for 0–10 and 10–20 cm layers, NT1.5 > MCT for 20–30 cm, and NT6 > MCT for 30–50 cm layer ($P < 0.01$; Table 5). The ρ_b for uneroded phase among four NT fields and MCT did not vary for 0–10 and 10–20 cm layers ($P < 0.01$; Table 5).

Table 5
The mean soil bulk density (Mg m^{-3}) for uneroded phase for each of the four depths (cm)

Treatments	Farm	0–10	10–20	20–30	30–50
1	F	1.01	1.06	1.17	1.21
2	NT15	1.15	1.2	1.2	1.18
3	NT10	1.23	1.3	1.24	1.25
4	NT6	1.16	1.2	1.25	1.28
5	NT1.5	1.21	1.25	1.26	1.27
6	MCT	1.15	1.2	1.14	1.18
LSD (all six treatments)		0.18	0.15	0.12	0.09
LSD (treatments 2–6)		NS	NS	0.12	0.08

F: forest; NT15: no-till for past 15 years; NT10: no-till for past 10 years; NT6: no-till for past 6 years; NT1.5: no-till for past 1.5 years; MCT: chisel tilled every alternate year with manuring; LSD: least significant difference at $P < 0.05$.

For depositional phase (at toeslope), the ρ_b varied in the order NT10 = MCT > NT6 for 0–10 cm layer, NT10 = NT1.5 = MCT < NT6 for 10–20 cm ($P < 0.05$; Table 6). Significant differences in ρ_b in slight erosion phase were observed between NT10 and ACT only for 20–30 cm depth ($P < 0.05$; Table 6). In general the ρ_b was the lowest for the F in the uneroded phase. The higher ρ_b for NT fields than forest can be attributed to lack of soil loosening, compaction caused by seeding and harvesting machinery. Year 2003 received above average rainfall with about 1287 mm of annual precipitation as against the normal annual

Table 6
The mean soil bulk density (Mg m^{-3}) for deposition and slight erosion phases for four depths (cm)

Treatments	Farm	0–10	10–20	20–30	30–50
Deposition					
1	NT10	1.22 a	1.32 a	1.21	1.21
2	NT6	1.03 b	1.10 c	1.19	1.20
3	NT1.5	1.13 ab	1.25	1.24	1.25
4	MCT	1.21 a	1.29 ab	1.14	1.18
	LSD	0.14	0.16	NS	NS
Slight					
1	NT10	1.31	1.38	1.29 a	1.28
2	MCT	1.23	1.30	1.25 ab	1.27
3	ACT	1.09	1.19	1.13 b	1.25
	LSD	NS	NS	0.15	NS

NT10: no-till for past 10 years; NT6: no-till for past 6 years; NT1.5: no-till for past 1.5 years; MCT: chisel tilled every alternate year with manuring; ACT: chisel tilled every year; LSD: least significant difference at $P < 0.05$.

precipitation of 1036 mm. The ρ_b generally increased with increase in depth and degree of erosion in all fields (Tables 5 and 6). The ρ_b for MCT was similar to that in other NT fields under uneroded, depositional and slightly eroded phase, which indicated the influence of manure on soil structure improvement.

3.2. Land use and soil organic carbon concentration

The forested control involved trees; leaf litter and detritus material, which contributed to high SOC concentration. The topography of forested control was almost flat with no observed erosion and SOC loss due to erosional processes. Therefore, average SOC concentration for the uneroded phase was high in the forest and was in the order F > NT15= MCT = NT6 = NT1.5 = NT10 for the upper 10 cm layer ($P < 0.05$; Fig. 1). The SOC concentration varied in the order F > NT15 > NT6 but the MCT, NT1.5 and NT10 did not differ significantly with NT15 or NT6 for 10–20 cm layer ($P < 0.05$). The SOC concentration varied in the order F = NT15 > NT6 for 20–30 cm layer but was similar for all treatments in uneroded phase for 30–50 cm layer ($P < 0.05$). The high SOC concentration in NT15 was in accord with nearly flat terrain and no observed erosion. The SOC concentration in MCT (on summit) was similar to NT15 for the uneroded phase, which can be attributed to the low tillage intensity and high rates of fertilizer and manure application to the field.

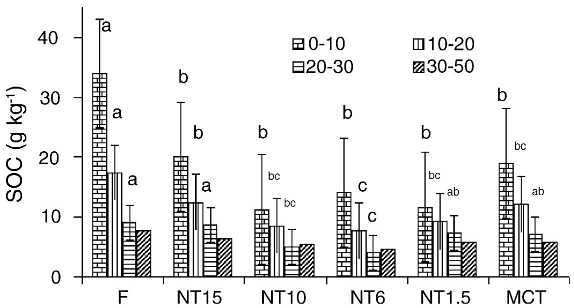

Fig. 1. Soil organic carbon (SOC) concentration for four depths and five land uses (e.g., F: forest; NT: no-till; 15, 10 and 1.5 years; MCT: alternate chisel till with manure) under uneroded phase. The bars are the LSD values for treatment vs. erosion phase for each depth separately.

Comparing SOC concentrations in uneroded phase on summit among NT fields indicated that SOC concentration was in the order NT15 > NT6 = NT1.5 = NT10 for 0–10 cm, NT15 > NT1.5 > NT6 for 10–20 cm, and NT15 = NT1.5 > NT10 = NT6 for 20–30 cm layer ($P < 0.05$). However, no differences in SOC concentration were obtained among NT fields for 30–50 cm layer ($P < 0.05$). A higher SOC concentration for NT15 demonstrated the C-sequestration potential of this conservation-effective measure (Fig. 1). In the last 4 years NT1.5 was chiseled only once in October 2001. Therefore, NT1.5 can be considered to be under NT for last 4 years, which may be the reason of SOC concentration being similar for NT1.5, NT10 and NT6 for 0–10 and 20–30 cm soil layers.

The SOC concentration in deposition phase varied in the order NT6 > NT10 for 0–10 cm layer, ACT > NT1.5 = NT6 > NT10 for 10–20 cm layer, ACT > NT1.5 = NT6 = NT10 for 20–30 cm, and ACT > NT6 > NT10 for 30–50 cm layer ($P < 0.05$; Fig. 2). Although both fields in NT6 and NT10 were on sloping lands with back slope having 6–12% gradient, still SOC concentration for deposition was higher in NT6 than in NT10. After the harvest of corn, the stover was left behind in the NT10 field, whereas row cleaners were used and residues removed in NT6 field, which probably led to a slight increase in erosion upslope and subsequent deposition on toeslope with attendant increase in SOC concentration. The ACT was also on sloping land with 6–12% gradient, and intense tillage coupled with high slope gradient led to more erosion and subsequently high deposition at the

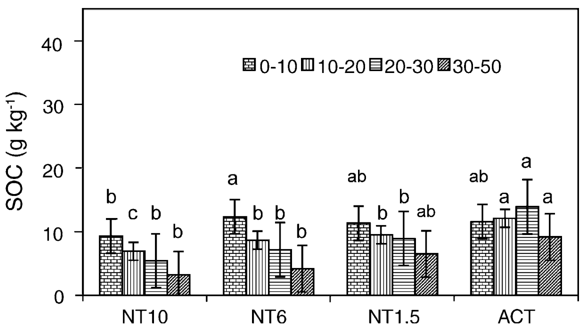

Fig. 2. Soil organic carbon (SOC) concentration for four depths and four land uses (NT: no-till; 10, 6 and 1.5 years; ACT: annual chisel till) under deposition phase (D). The bars are the LSD values for treatment vs. erosion phase for each depth separately.

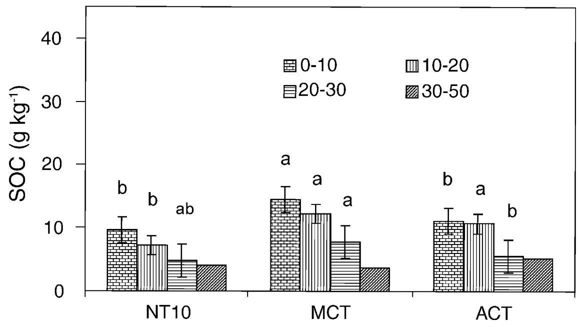

Fig. 3. Soil organic carbon (SOC) concentration for four depths and three land uses (NT: no-till; 10 year; MCT: alternate chisel till with manure; ACT: annual chisel till) under slight erosion phase (1). The bars are the LSD values for treatment vs. erosion phase for each depth separately.

toeslope. The high SOC concentration in the sub-soil layers for ACT showed the mixing effects of tillage operations.

The SOC concentration in slight erosion phase was similar among NT6, MCT and ACT treatments for 0–10 and 30–50 cm layers ($P < 0.05$; Fig. 3). It was MCT = ACT > NT6 and MCT > NT6 for 10–20 and 20–30 cm soil layer, respectively, in the slight erosion phase ($P < 0.05$; Fig. 3). The high SOC concentration for MCT may be due to the annual manure application irrespective of the crop in the rotation.

3.3. Soil erosion and soil organic carbon concentration

Review of the data on the effect of degree of erosion on average SOC concentration for 0–10 cm layer showed that in general SOC concentration decreased with the severity of erosion (Figs. 1–3). The SOC concentration declined from 19.0 to 14.5 g kg^{-1} (18%) in MCT and 11.3 to 9.7 g kg^{-1} (14%) in NT10 between uneroded and slight erosion, and 12.0 to 11.2 g kg^{-1} (7%) between slight and moderate erosion in ACT. However, no change in SOC concentration was detected in NT10 between slight and moderate erosion phases. The SOC concentration was similar between uneroded and deposition phases for NT1.5 and smaller for deposition than uneroded phase in NT6. The SOC concentration was higher for deposition than slight or moderate phase in NT10 and ACT treatments. This was possible as biologically active organic matter is light and a significant amount can be transported even with relatively small amounts of soil loss. The deposition sites generally have higher nutrient concentration and act as C sinks due to reduced decomposition of organic matter (Schimel et al., 1985). This was partially supported by our study, as the soil N concentration for 50 cm layer in ACT was significantly higher for deposition (4.8 g kg^{-1}) than slight (3.6 g kg^{-1}) or moderate erosion phase (3.2 g kg^{-1}) ($P < 0.05$). However, soil N concentration was similar in NT10 for moderate, slight, deposition and uneroded phases (3.0 g kg^{-1} for moderate to 3.4 g kg^{-1} for uneroded phase).

3.4. Effect of no-till duration on soil organic carbon concentration

The total SOC concentration in uneroded phase increased with increasing number of years under NT for all depths (Fig. 4a–d). A linear relationship provided adequate fit between SOC concentration and duration under NT. The linear relationship was significant for 0–10 and 10–20 cm layers only, and explained 33 and 41% of variability in SOC concentration, respectively ($P < 0.05$; Fig. 4a and b). The intercept of the best-fit line was at 10.02 g kg^{-1} and slope was 0.53 g kg^{-1} for the 0–10 cm layer, which indicated that the SOC concentration increased from a base value of 10.02 g kg^{-1} at the rate of 0.53 g kg^{-1} year^{-1}. The SOC concentration increased at a rate of 0.25 g kg^{-1} year^{-1} from a baseline value of 7.5 g kg^{-1} for the 10–20 cm layer.

3.5. Land use and soil organic carbon stocks

The SOC stock was highest for control-forested site for 0–10, 10–20 and 20–30 cm soil layers ($P < 0.05$; Table 7). The SOC stock was not significantly different between control-forested site and NT15 for 10–20 and 20–30 cm layers. The SOC stock was similar for MCT and NT15 for all depths in uneroded phase, which showed the important contribution of manure towards enhancing SOC stock. The total SOC stock for 0–50 cm soil layer for uneroded phase was similar among forested control, NT15 and MCT and varied in the order NT15 > NT10 = NT6 in NT fields ($P < 0.05$; Table 7). A comparison among five farms showed that total SOC stock for 0–50 cm layer was highest for NT15 for uneroded phase and ACT for

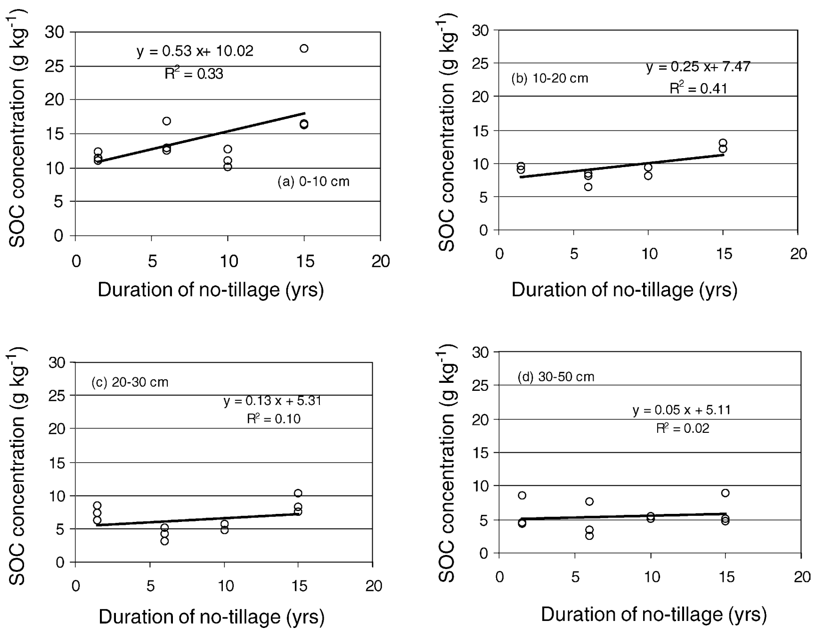

Fig. 4. Effect of age chronosequence of NT on soil organic carbon (SOC) concentrations for various depths in uneroded phase. All data is from summit for NT10, NT6 and NT1.5 treatments.

deposition phase ($P < 0.05$; Tables 7 and 8). No significant differences in total SOC stock occurred among NT10, MCT and ACT for 0–50 cm layer in the slight erosion phase ($P < 0.05$; Table 8).

3.6. Soil erosion and soil organic carbon stock

The review of total SOC stock for 0–50 cm layer under different erosional phases showed that total SOC stock varied in the order uneroded (37.9 Mg ha^{-1}) > deposition (31.0 Mg ha^{-1}) = moderate erosion (31.4 Mg ha^{-1}) ($P < 0.05$) in NT10 and deposition (56.6 Mg ha^{-1}) > slight (40.4 Mg ha^{-1}) = moderate (39.7 Mg ha^{-1}) in ACT. The slope gradient

Table 7
The mean soil organic carbon (SOC) stock (Mg ha^{-1}) for uneroded phase for each of the four depths and total SOC stock for 50 cm layer

Treatments	Farm	0–10	10–20	20–30	30–50	Total
1	F	33.8	18.4	10.6	9.2	72.0
2	NT15	23.2	15.0	10.5	7.5	56.1
3	NT10	13.9	11.0	6.3	7.4	37.9
4	NT6	16.3	9.2	5.2	6.8	36.6
5	NT1.5	14.1	11.5	9.3	6.7	42.2
6	MCT	20.4	14.6	8.2	5.9	50.0
LSD (all six treatments)		9.6	5.1	3.0	NS	16.1
LSD (treatments 2–6)		6.4	3.2	2.3	NS	8.4

F: forest; NT15: no-till for past 15 years; NT10: no-till for past 10 years; NT6: no-till for past 6 years; NT1.5: no-till for past 1.5 years; MCT: chisel tilled every alternate year with manuring; LSD: least significant difference at $P < 0.05$.

Table 8
The mean soil organic carbon (SOC) stock (Mg ha^{-1}) for each of the four farms in deposition and slight erosion phase for four depths and total SOC stock for 50 cm layer

No.	Farm	0–10	10–20	20–30	30–50	Total
Deposition						
1	NT10	11.3	9.2 b	6.6 c	3.9 c	31.0 c
2	NT6	12.7	9.6 b	8.5 bc	5.0 bc	35.8 bc
3	NT1.5	12.8	10.9 b	10.9 ab	8.1 ab	42.7 b
4	ACT	17.0	15.7 a	14.0 a	10.0 a	56.6 a
	LSD	NS	1.7	3.3	3.6	11.7
Slight						
1	NT10	12.7	10.1 b	6.4	5.3	34.4
2	MCT	15.8	14.6 a	9.7	4.8	44.9
3	ACT	13.8	16.9 ab	6.3	6.5	40.4
	LSD	NS	3.8	NS	NS	NS

NT10: no-till for past 10 years; NT6: no-till for past 6 years; NT1.5: no-till for past 1.5 years; MCT: chisel tilled every alternate year with manuring; ACT: chisel tilled every year; LSD: least significant difference at $P < 0.05$.

for both of these fields is 6–12%. No differences in SOC stock for NT10 among deposition, slight or moderate phase indicated reduced erosion or redistribution with reduced tillage intensity. For ACT, these results showed increased erosion–deposition with increasing tillage intensity.

3.7. Rate of change in soil organic carbon stock for no-till

The SOC stocks increased with duration under NT for 0–10 and 10–20 cm soil layers and explained 33 and 38% of variability in SOC stocks, respectively ($P < 0.05$; Fig. 5a and b). The SOC stock increased from a base value (or intercept) of 12.15 Mg ha^{-1} at a rate of 0.58 Mg ha^{-1} year^{-1} for 0–10 cm and 9.36 Mg ha^{-1} at the rate of 0.28 Mg ha^{-1} year^{-1} for 10–20 cm layer. Increasing trends were observed for 20–30 and 30–50 cm depths also but were not statistically significant ($P < 0.05$; Fig. 5c and d). The total SOC stock increased from 35.0 Mg ha^{-1} at the rate of 1.01 Mg ha^{-1} year^{-1} for 0–50 cm soil layer in the uneroded phase ($R^2 = 0.35$; $P < 0.05$; Fig. 5e). The significant and high total SOC stock for NT15 for the 0–50 cm layer showed the sequestration potential upon conversion from plow to NT.

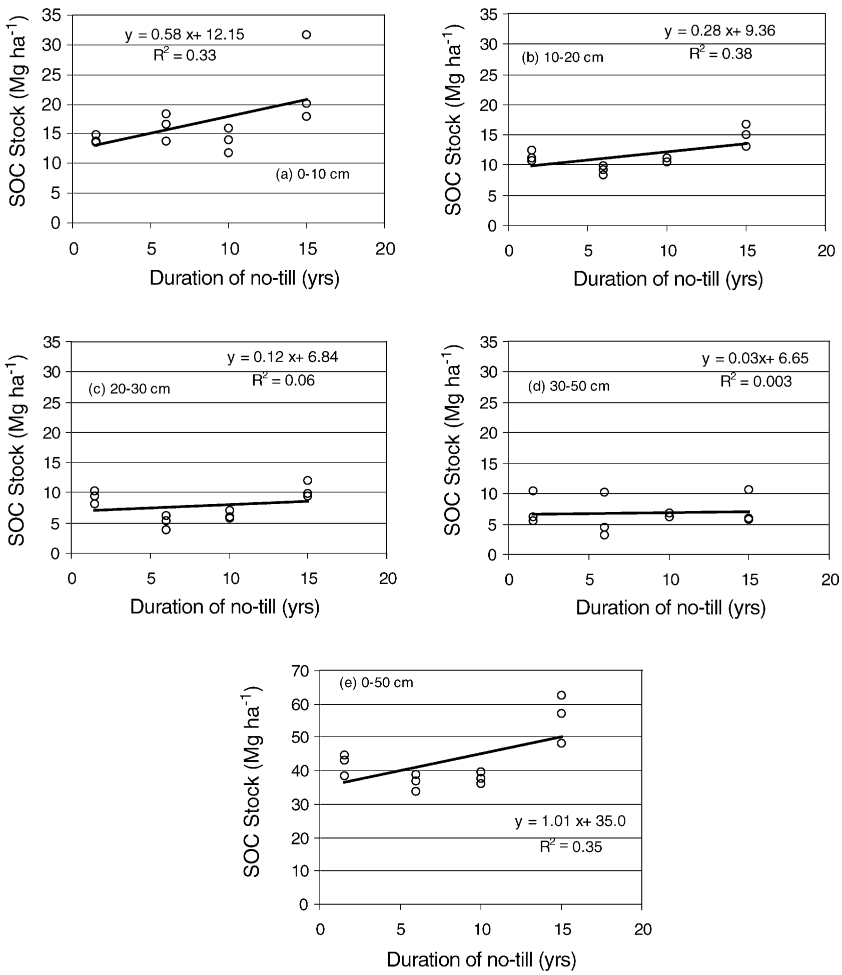

Fig. 5. Effect of age chronosequence of NT on soil organic carbon (SOC) stocks for various depths in uneroded phase. All data is from summit for NT10, NT6 and NT1.5 treatments.

4. Conclusions

The SOC concentration and stock were highest in the forested control for each depth followed by NT15 and NT6. The SOC concentration for uneroded phase in NT fields increased at a rate of 5% $year^{-1}$ for 0–10 cm layer and 3% $year^{-1}$ for 10–20 cm layer with increasing duration under NT. The SOC stocks in NT farms increased at a rate of 0.58 Mg ha^{-1} $year^{-1}$ for 0–10 cm and 0.28 Mg ha^{-1} $year^{-1}$ for 10–20 cm layer. Manure application increased SOC concentration whereas erosion decreased it. Uneroded phase was not detected in ACT indicating more erosion and deposition due to high tillage intensity. Overall, SOC stocks increased with increasing age of no-till chronosequence and decreased with increasing intensity of tillage.

Acknowledgements

Authors express deep appreciation for Sandy Jones, School of Natural Resources, and Joseph Davline, Western Branch of Ohio State University. Authors are thankful to the landowners Allan Armstrong, Arthur Hohenstein, Brain Herbage, Kevin Spears and Gene Farroll for allowing us to collect soil samples from their farms for this project.

References

Bauer, A., Black, A.L., 1981. Soil, carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin islands. Soil Sci. Soc. Am. J. 45, 1166–1170.

Blake G.R., Hartge K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. I. ASA Monograph No. 9. Madison, WI, pp. 363–376.

Fahnestock, P., Lal, R., Hall, G.F., 1995. Land use and erosional effects on two Ohio Alfisols II Crop yields. J. Sustain. Agric. 7, 85–100.

Frye, W.W., Ebelhar, S.A., Murdock, L.W., Blevins, R.L., 1982. Soil erosion effects on properties and productivity of two Kentucky soils. Soil Sci. Soc. Am. J. 46, 1051–1055.

Gregorich, E.G., Greer, K.J., Anderson, D.W., Liang, B.C., 1998. Carbon distribution and losses: erosion and depositional effects. Soil Till. Res. 47, 291–302.

Gregorich, E.G., Janzen, H.H., 1995. Storage of soil carbon in the light fraction and macroorganic matter. In: Carter, M.R., Steward, B.A. (Eds.), Structure and Organic Matter Storage in Agriculture Soils. Lewis Publishers, CRC Press, Boca Raton, FL, USA, pp. 167–190.

Halvorson, A.D., Wienhold, B.J., Black, A.L., 2002. Tillage, nitrogen and cropping systems effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66, 906–912.

Ketcheson, W.R., Webber, L.R., 1978. Effects of soil erosion on yield of corn. Can. J. Soil Sci. 58, 459–463.

Kimble, J.M., Lal, R., Mausbach, M., 2001. Erosion effects on soil organic carbon pool in soils of Iowa. In: Stott et al. (Eds.), Proceedings of the 10th International Soil Conservation Organization meeting on Sustaining the Global Farm, May 24–29, 1999. Purdue University, Indiana, pp. P474–477 (http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/iscodisc/Sustaining%20the%20Global%20Farm/).

Lal, R., Ahmadi, M., Bajracharya, R.M., 2000. Erosional impacts on soil properties and corn yield on Alfisols in central Ohio. Land Degrad. Dev. 11, 575–585.

Lal, R., 2003. Soil erosion and global carbon budget. Environ. Int. 29, 437–450.

Langdale, G.W., Denton, H.D., White Jr., A.W., Giliam, J.W., Frye, W.W., 1985. Effects of erosion on crop productivity of southern soils. In: Follett, R.F., Steward, B.A. (Eds.), Soil Erosion and Crop Productivity. ASA, Madison, WI, pp. 252–267.

Lowrance, R., Williams, R.G., 1988. Carbon movement in runoff and erosion under simulated rainfall conditions. Soil Sci. Soc. Am. J. 52, 1445–1448.

McDanial, T.A., Hajek, B.F., 1985. Soil erosion effects on crop productivity and soil properties in Alabama. In: McCool, D.K. (Ed.), Erosion and Soil Productivity, New Orleans, LA, December 10–12, 1984. ASAE, St. Joseph, MI, pp. 48–58.

Nizeyimana, E., Olson, K.R., 1988. Chemical, mineralogical, and physical property differences between moderately and severely eroded Illinois soils. Soil Sci. Soc. Am. J. 52, 1740–1748.

Rasmussen, P.E., Albrecht, S.L., Smiley, R.W., 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil Till. Res. 47, 197–205.

SAS Institute, 1989. SAS/STAT User's Guide, Version 6, vol. 1 and 2, 4th ed., SAS Institute, Cary, NC.

Schimel, D.S., Kelly, E.F., Yonker, C., Aguilar, R., Heil, R., 1985. Effects of erosional processes on nutrient cycling in semiarid landscapes. In: Caldwell et al. (Eds.), Planetary Ecology. Van Nostrand Reinhold, New York, pp. 571–580.

Shukla, M.K., Lal, R., Ebinger, M.H., 2003. Tillage effects on physical and hydrological properties of a typic Argiaquolls in central Ohio. Soil Sci. 168 (11), 802–811.

USDA-NRCS, 1999. Soil Survey of Clark County, Parts I and II. United States Department of Agriculture, Natural Resources Conservation Services, Washington, DC.

VandenBygaart, A.J., Yang, X.M., Kay, B.D., Aspinall, J.D., 2002. Variability in carbon sequestration potential in no-till soil landscapes of southern Ontario. Soil Till. Res. 65, 231–241.

Webber, L.R., 1964. Soil physical properties and erosion control. J. Soil Water Conserv. 19, 28–30.