# Soil Organic Carbon Dynamics for Different Land Uses and Soil Management Practices at the North Appalachian Experimental Watersheds in Ohio

Y. Hao[1], R. Lal[1], L.B. Owens[2], R.C. Izaurralde[3], and W.M. Post[4]

1. School of Natural Resources, The Ohio State University, Columbus, OH 43210
2. USDA-ARS, North Appalachian Experimental Watersheds, P.O. Box 478, Coshocton, OH 43812
3. Battelle Pacific Northwest National Laboratory, 901 D St. SW, Washington, DC 20024
4. Oak Ridge National Laboratory, Oak Ridge, TN 37831

## Introduction

Sequestration of atmospheric $CO_2$ into soil organic carbon (SOC) dictates acquisition of research data on equilibrium level of SOC pool under different land uses and associated soil management practices and the rate of change of SOC pool with change in land use and management. Important land uses and practices with the potential to sequester SOC include conversion of cropland to pastoral and forest lands, conventional tillage to conservation and no tillage, no manure use to regular addition of manure, and to soil-specific fertilization rate (Martel and Paul, 1974; Jenkinson and Rayner, 1977; Rasmussen et al., 1980; Ismail et al., 1994; Campbell et al., 1997; Paustian et al., 1997; Smith et al., 1997; Rasmussen et al., 1998; Dick et al., 1998; Huggins et al., 1998; Collins et al., 1999; Post and Kwon, 2000).

The majority of the above studies were conducted on the flat landscape where SOC erosion and decomposition caused by rainfall and runoff water are the predominant processes affecting SOC pool dynamics. Effects of land use and soil management practice on SOC pool dynamics on a sloping landscape need to be studied on a watershed scale.

At the north Appalachian experimental watersheds located near Coshocton, Ohio, slope gradient ranges normally from 6 to 35% and slope length from 86 to 539 m. Changes in land use and soil management practice occurred during 1930 to 2000, which allowed observation of temporal dynamics of SOC pool due to these changes at the sloping landscape of the watersheds.

## Objective

The objective of this study is to determine the effects of different land uses and soil management practices on SOC pool dynamics on the sloping landscape of the north Appalachian experimental watersheds in Ohio.

## Approach and Project Description

*Site Description*

The North Appalachian Experimental Watershed research station was established in the late 1930s. It is located about 16 km northeast of the city of Coshocton, Ohio ($40^0$ 22' N, $81^0$ 48' W, within elevation of 300 to 600 m). The climax vegetation is mixed oak (*Quercus* spp.) forest. The mean annual precipitation is about 944 mm with a good distribution throughout the growing season. The mean annual ambient temperature is 10.1 $^0$C with an average of 179 frost-free days (Kelley et al., 1975).

This study involves a native forest area, a grass revegetation area, a afforested watershed, and 13 watersheds used for corn, soybean, wheat, and forage production. The study site covers an area of 625 ha (2.5 km across). The geophysical characteristics of the watersheds are detailed in Kelley et al. (1975) and shown in Table 1.

*Land Use and Soil Management*

<u>Non-cropped sites from 1939 to 2000.</u> The earliest year for land use and agricultural management records available at the research station is 1939. Afforestation on watershed 172 occurred before 1939 and is assumed to start in 1930 in this study. One area next to watershed 118 had conventional moldboard till corn-wheat-meadow-meadow (CWMM) rotation from 1939 to 1970 and was converted to grassland in 1971. A meadow for hay production was practiced on watershed 130 since 1939.

There was essentially no management for watershed 130 after 1960, for watershed 172 from 1939 to 2000, and for grassland area after 1970. From 1939 to 1960, lime, fertilizer, and disk till were periodically applied to the watershed 130. The predominant vegetation is white pine (*Pinus strobus* L.) in watershed 172, mixed grass species such as Kentucky bluegrass (*Poa pratensis* L.) and orchardgrass (*Dactylis glomerata* L.) in grassland area, and tall fescue (*Festuca arundinacea* Schreb) and legumes such as alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), and timothy (*Phleum pratense* L.) before 1960 and smooth bromegrass (*Bromus inermis* L.) after 1960 in watershed 130.

<u>Cropped sites from 1939 to 1970</u>. Agricultural management practices on cropped watersheds are shown in Table 2 for the period from 1939 to 2000 and more details can be found in Kelley et al. (1975) for the period from 1939 to 1970. The CWMM rotation was practiced on 11 watersheds from 1939 to 1970 and continued until 1975 on watershed 106 and until 1973 on watershed 110. Two contrasting agricultural management, prevailing (5 watersheds) and improved (6 watersheds), were practiced. Improved management involved maintaining higher soil pH (6.8 versus 5.4), higher application rates of N-P-K fertilizer (5-20-20) (202-225 kg $ha^{-1}$ versus 56-112 kg $ha^{-1}$) and beef cattle manure (13 versus 9.0 Mg $ha^{-1}$), and using conservation farming (contour versus straight row across slope). The detailed farm operations are described below.

Corn was planted in late April or early May. Before planting corn, the soil was plowed with a moldboard plow to a depth of 20 cm and then disked twice and harrowed once. Corn was planted at a spacing of 90 to 100 cm between and 12 to 15 cm within rows. Fertilizer (5-20-20) was banded beside the seed row during planting. Cattle manure was top-dressed onto the soil. Weeds were controlled by two or three mechanical cultivation before 1960 and by using herbicides since 1960. Corn was harvested in early October with a mechanical picker, and the stover was chopped and left on the soil surface.

Winter wheat was seeded by drilling across slope after lightly disking the soil within two weeks of corn harvest. Fertilizer (5-20-20) was applied at the recommended rates (Table 2). Timothy was seeded along with wheat in early October and red clover and alsike clover (*Trifolium hybridum* L.) were seeded in March. Wheat was harvested in early July.

During the two meadow years, hay was harvested in late June and early August. Lime was broadcast on the second-year meadow to raise soil pH to the desired levels before the corn cycle (Table 2).

<u>Cropped sites from 1971 to 2000.</u> Five contrasting agricultural management systems were studied. These were: (1) no till corn-soybean rotation (NTR) starting in 1984; (2) chisel till corn-soybean rotation (CTR) starting in 1984; (3) conventional moldboard till continuous corn (MTC) starting in 1984, (4) no till continuous corn (NTC) starting in 1971, and (5) no till continuous corn with application of cattle manure (NTC-A) starting in 1964 (Table 2). The management practices from 1971 to 1983 were: 5 years of MTC followed by 8 years of meadow for the two NTR watersheds (113 and 118); 8 years of MTC followed by 7 years of NTC for one of the two CTR watersheds (109) and 8 years of NTC followed by 6 years of MTC for the other CTR watersheds (123). Management techniques are described below, and additional details are given by Owens and Edwards (1993) and Shipitalo and Edwards (1998).

Corn and soybean were planted on the contour with a planter or no till drill in late April or early May with a row spacing of 76 cm for corn and 18 cm for soybean. Rye (*Lolium perenne* L.) was aerially seeded into the soybean prior to leaf drop, and later killed with herbicides in April/May prior to planting corn 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. The depth of chisel tillage was 25 cm.

For the corn cycle in continuous corn and corn-soybean rotation, N fertilizer (urea or $NH_4NO_3$) was broadcast at the rate of 170 to 225 kg ha$^{-1}$ in spring before planting corn, P and K fertilizers (superphosphate and KCl) were applied in fall at rates depending on soil test value for obtaining corn grain yield of 10 Mg ha$^{-1}$, and lime ($CaMg(CO_3)_2$) was applied during fall to obtain soil pH of 6 to 7. Cattle manure (<70% water content) was applied at the rate of 6 to 11 Mg ha$^{-1}$ by top-dressing only in watershed 191 during spring before planting corn.

*Soil Sampling and Analysis*

The earliest soil samples were taken in 1970 for all CWMM watersheds (low or high fertilities). Soil samples were taken for all land uses and management practices in either 1998, or 1999, or 2000. Soil samples were taken several times from 1984 to 1999 only for the land uses and management practices adopted in 1984 except for MTC.

Soil samples were taken using 2.5 to 7 cm diameter soil cores or by digging soil pit of 0.25 $m^2$. Three to nine replicates of the soil samples were taken with at least one sample from each of the upper, middle, and lower slope positions. Soil bulk density was determined by the core method (Blake and Hartage, 1986). The concentration of SOC was determined by Walkley-Black method in 1970 (Peech et al., 1947). The concentration of total carbon was determined by dry combustion method (Nelson and Sommers, 1996) after 1970 and taken as SOC concentration due to negligible amounts of inorganic carbon. The SOC pool was computed by multiplying soil volume, soil bulk density, and SOC concentration and expressed as Mg $ha^{-1}$.

The bulk density was not determined for the soil samples taken in 1970 and taken to be equal to that determined in 1975 for CWMM watershed 103. The SOC pool in 1930 for afforested watershed 172 was taken to be equal to the average of the SOC pools determined in 1970 for all the CWMM watersheds with prevailing practice. These calculations were based on the assumptions that deforestation occurred around 1850 and that the land use and soil management practice from 1850 to 1939 was CWMM of prevailing practice, leading to stabilization of the SOC pool by 1930.

The rates of change in SOC pool were obtained by regression of SOC pool values with time using general linear model and expressed as Mg $ha^{-1}$ $yr^{-1}$. Based on the statistical significance of the rates, the stable SOC pool values of different land uses and soil management practices were determined either as ranges, minimum (greater than certain values), or maximum (less than certain values) attainable.

## Results

The SOC pool (Mg $ha^{-1}$) increased by 24.0 (98%) during 70 years of white pine afforestation (F), by 33.2 (144%) during 29 years of mixed grass revegetation (G), by 23.6 (60%) during the recent 30 years of 60-year meadow for hay (M), by 19.3 (88%) during 30 years of no till continuous corn (NTC), by 31.5 (89%) during the recent 30 years of 36-year no till continuous corn with 6 to 11 Mg $ha^{-1}$ $yr^{-1}$ of cattle manure application (NTC-A), by -5.8 (-18%) to +4.5 (12%) during 11 to 16 years of no till corn-soybean rotation (NTR), and by –2.3 (-6.8%) to +2.1 (5.8%) during 12 to 15 years of chisel till corn-soybean rotation (CTR) (Table 3).

The significant ($P < 0.05$) linear rates of SOC pool changes (Mg $ha^{-1}$ $yr^{-1}$) were 0.83 over 70 years for F, 1.19 over 29 years for G, 0.82 over 30 years for M, 0.66 over 30 years for NTC, and 1.09 over 30 years for NTC-A. The linear rates were insignificant for NTR and CTR (Table 3).

The stable SOC pools in the managed soils of 0-15 cm depth could be from a low 39%, for conventional moldboard till continuous corn (MTC), to a high 106%, for NTC-A, of the SOC pool (46.1 Mg $ha^{-1}$) of the undisturbed native forest (Table 3). For 0-30 cm depth, the values were from a low 47%, for CTR and MTC, to a high 91%, for NTC-A, of the SOC pool (73.3 Mg $ha^{-1}$) of the undisturbed native forest.

## Application and Benefits

The above results indicate that converting conventional moldboard till CWMM to forest, grassland, and no till continuous corn with cattle manure application has a strong potential to sequester carbon in soils of the sloping north Appalachian watersheds in Ohio. The average sequestration rates over 29 to 70 years can reach 0.66 to 1.19 Mg $ha^{-1}$ $yr^{-1}$. The other benefits of no tillage compared with conventional tillage are tillage fuel saving and soil erosion reduction.

The research data obtained in this study are useful in directing farming practice and policy making process for SOC sequestration, especially for the north Appalachian region in Ohio possessing sloping landscape.

## Future Activity

There is an uncertainty in determining the rates of SOC pool change over time based on linear regression of SOC pool values over two time points, although linearity of SOC pool change with time occurred in this and other studies (Fig. 1 in this study; Donigian et al., 1995; Campbell et al., 1997; Christensen and Johnston, 1997). Therefore, the changes in the SOC pools need to be continuously monitored in the future with a sampling time interval of 3 to 5 years. This will also give more conclusive determination regarding stable SOC pool values under different land uses and soil management practices.

In addition, a few other soil management practices need to be added into this study to determine the potential of manure application to sequester SOC. These practices include conventional moldboard tillage continuous corn, conservation tillage corn-soybean-wheat rotation, and pasture.

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Table 1. Characteristics of the experimental watersheds.

| Watershed[a] | Area | Slope gradient | Slope length | Aspect[b] | Shape | Soil type[c] |
|---|---|---|---|---|---|---|
| Non-cropped | ha | % | m | | | |
| 130 | 0.66 | 6-35 | 162 | E | Triangle | Br, Co, Re, Dk |
| 172 | 18.7 | 6-35 | 539 | S | Rectangle | Br, Co, Dk, Re |
| Cropped | | | | | | |
| 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 |
| 118 | 0.79 | 6-12 | 132 | E | Triangle | Cl, Co |
| 123 | 0.55 | 2-12 | 107 | S | Pentagonal | Ke, Re |
| 128 | 1.09 | 2-25 | 120 | E | Triangle | Br, 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] Native forest and grassland sites are parallel and next to watershed 118 and have similar characteristics to the watershed and thus not included in the table.

[a] E = east, W = west, N = north, S = south.

[b] Br = Berks shaly silt loam, Cl = Clarksburg silt loam, Co = Coshocton silt loam, Dk = Dekalb channery sandy loam, Ke = Keene silt loam, Re = Rayne silt loam. Br and Dk are Typic Dystrochrepts; Cl, Co, and Ke are Aquic Hapludalf; and Re is Typic Hapludult.

Table 2. Land uses and soil management practices in the experimental watersheds from 1930 to 2000.

| Land use & soil management[a] | Period | Watershed[b] | Vegetation[c] | Tillage | Manure[d] | Soil pH[e] | NPK[f] |
|---|---|---|---|---|---|---|---|
| | | | | | Mg $ha^{-1}$ | | kg $ha^{-1}$ |
| MTR-H | 1939-70 | 103, 109, | C | Moldboard | 13 | | 202 |
| | | 113, 121, | W | Disking | 13 | | 202 |
| | | 123, 188 | M1 | No | | | 225 |
| | | | M2 | No | | 6.8 | |
| MTR-L | 1939-70 | 106, 110, | C | Moldboard | 9 | | 56 |
| | | 115, 118, | W | Disking | | | 112 |
| | | 192 | M1 | No | | | |
| | | | M2 | No | | 5.4 | |
| CTR | 1984-95 | 109, 123 | C | Chisel | | 6-7 | 170-225 N, P&K |
| | | | S | Chisel | | | |
| NTR | 1984-95 | 113, 118 | C | No | | 6-7 | 170-225 N, P&K |
| | | | S | No | | | |
| MTC | 1984-98 | 128 | C | Moldboard | | 6-7 | 170-225 N, P&K |
| NTC | 1971-99 | 188 | C | No | | 6-7 | 170-225 N, P&K |
| NTC-A | 1964-99 | 191 | C | No | 6-11 | 6-7 | 170-225 N, P&K |
| M | 1939-00 | 130 | SB | | | | |
| G | 1971-98 | Plot | MG | | | | |
| F | 1930-00 | 172 | WP | | | | |

[a] MTR-H and MTR-L = conventional moldboard till (20 cm) corn-wheat-meadow-meadow rotation with high and low amounts of fertilizer, respectively; MTC = conventional moldboard till continuous corn; CTR = chisel till (25 cm) corn-soybean rotation; NTR = no till corn-soybean rotation; NTC and NTC-A = no till continuous corn without and with manure application, respectively; M = meadow for hay; G = grassland; F = forest. There was essentially no management for M after 1960 and for F. The management practice for M before 1960 involved occasional disking, plowing, and reseeding.

[b] MTR was practiced on watershed 103, 106, and 110 until 1975.

[c] C = corn (*Zea mays* L.), S = soybean (*Glycine max* L.), W = wheat (*Triticum aestivum* L.), M1 = first year meadow, M2 = second year meadow, SB = smooth bromegrass (*Bromus inermis* L.), MG = mixed grass species, and WP = white pine (*Pinus strobus* L.).

[d] Manure was beef cattle manure with straw bedding and water content of $<70\%$.

[e] Lime used for adjusting soil pH was dolomite $CaMg(CO_3)_2$.

[f] NPK fertilizer was 5-20-20 before 1971. Thereafter, N, P, and K were urea or $NH_4NO_3$, superphosphate, and KCl, respectively. The amounts of P and K are determined by annual soil test for obtaining corn grain yield of 10 Mg $ha^{-1}$.

Table 3. Change of soil organic carbon pool in 0-30 cm depth under different land uses and soil management practices.

| Land use & soil management[a] | | Watershed[b] | Period | SOC[c] | | Change[d] | Rate | Significance | |
|---|---|---|---|---|---|---|---|---|---|
| Study period | Prior to study | | | Initial | Final | | | $R^2$ | P value |
| | | | | ---------------Mg ha$^{-1}$ | | --------------- | Mg ha$^{-1}$ yr$^{-1}$ | | |
| F(70) | MTR-L | 172 | 1930-99 | 24.5 (12) | 48.5 (18) | 24.0 (98%) | 0.83 | 0.82 | <0.0001 |
| G(29) | MTR-L(30) | Plot | 1970-98 | 23.1 (12) | 56.3 (22) | 33.2 (144%) | 1.19 | 0.66 | 0.0014 |
| M(30) | M(30) | 130 | 1970-99 | 39.3 (13) | 62.9 (12) | 23.6 (60%) | 0.82 | 0.84 | 0.0105 |
| NTC(30) | MTR-H(30) | 188 | 1970-99 | 22.0 (22) | 41.3 (11) | 19.3 (88%) | 0.66 | 0.8 | <0.0001 |
| NTC-A(30) | NTC-A(6) | 191 | 1970-99 | 35.2 (18) | 66.7 (15) | 31.5 (89%) | 1.09 | 0.72 | 0.0005 |
| NTR(16) | M(8) | 118 | 1984-99 | 39.1 (36) | 36.8 (10) | -5.8 (-18%) | -0.06 | 0.00 | 0.7753 |
| NTR(11) | M(8) | 113 | 1985-95 | 36.5 (9) | 41.0 (6) | 4.5 (12%) | 0.45 | 0.43 | 0.0392 |
| CTR(12) | MTC(6) | 123 | 1984-95 | 36.1 (17) | 38.2 (14) | 2.1 (5.8%) | 0.40 | 0.10 | 0.1138 |
| CTR(15) | NTC(7) | 109 | 1985-99 | 33.7 (29) | 31.4 (15) | -2.3 (-6.8%) | -0.18 | 0.03 | 0.4797 |

[a] F = forest, G = grassland; M = meadow; MTR-L and MTR-H = conventional moldboard till corn-wheat-meadow-meadow rotation with low and high fertility level, respectively; NTC and NTC-A = no till continuous corn without and with cattle manure application, respectively; CTR and NTR = chisel and no till corn-soybean rotation; MTC = conventional moldboard till continuous corn; the numbers in parenthesis = the minimum numbers of years for the soil management practices being practiced (MTR-L was assumed before afforestation).

[b] The plot is parallel and next to watershed 118.

[c] The numbers in parenthesis are coefficient variation in percentage.

[d] The numbers = final SOC – initial SOC, and the numbers in parenthesis = 100% * (final SOC – initial SOC) / initial SOC.

Table 4. The levels of stable SOC pools under different land uses and soil management practices.

| Land use & soil Management[a] | Watershed[b] | Period | Trend | SOC pool[c] (Mg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-15 cm | | | 0-30 cm | | |
| | | | | Average | Range | CV% | Average | Range | CV% |
| Native forest | Plot | -1998 | Stable | 46.1 (100%) | 30.9-52.5 | 14 | 73.3 (100%) | 54.8-87.1 | 12 |
| F | 172 | 1930-99 | Min | 27.7 (60%) | 20.2-39.1 | 34 | 48.5 (66%) | 36.0-60.2 | 18 |
| M | 130 | 1970-2000 | Min | 45.4 (98%) | 41.4-48.5 | 8 | 62.9 (86%) | 55.2-69.8 | 12 |
| G | Plot | 1970-98 | Min | 36.9 (80%) | 26.9-56.7 | 23 | 56.3 (77%) | 41.4-73.3 | 22 |
| NTC-A | 191 | 1964-99 | Min | 48.8 (106%) | 40.5-59.5 | 13 | 66.7 (91%) | 56.9-84.3 | 15 |
| NTC | 188 | 1970-99 | Min | 28.4 (62%) | 20.9-32.7 | 13 | 41.3 (56%) | 35.6-47.6 | 11 |
| NTR | 113, 118 | 1984-99 | Stable | 24.7 (54%) | 13.2-47.5 | 22 | 36.8 (50%) | 24.5-55.2 | 16 |
| CTR | 109, 123 | 1984-99 | Stable | 21.4 (46%) | 12.0-27.6 | 17 | 34.7 (47%) | 21.0-44.0 | 17 |
| MTC | 128 | 1984-99 | Max | 18.0 (39%) | 15.4-21.8 | 13 | 34.1 (47%) | 30.5-37.5 | 9.2 |

[a] F = forest; G = grassland; M = meadow; NTC and NTC-A = no till continuous corn without and with cattle manure application, respectively; CTR and NTR = chisel and no till corn-soybean rotation; MTC = conventional moldboard till continuous corn.

[b] The plot is parallel and next to watershed 118.

[c] The numbers in parenthesis = 100% * SOC pool of soil management system / SOC pool of native forest.

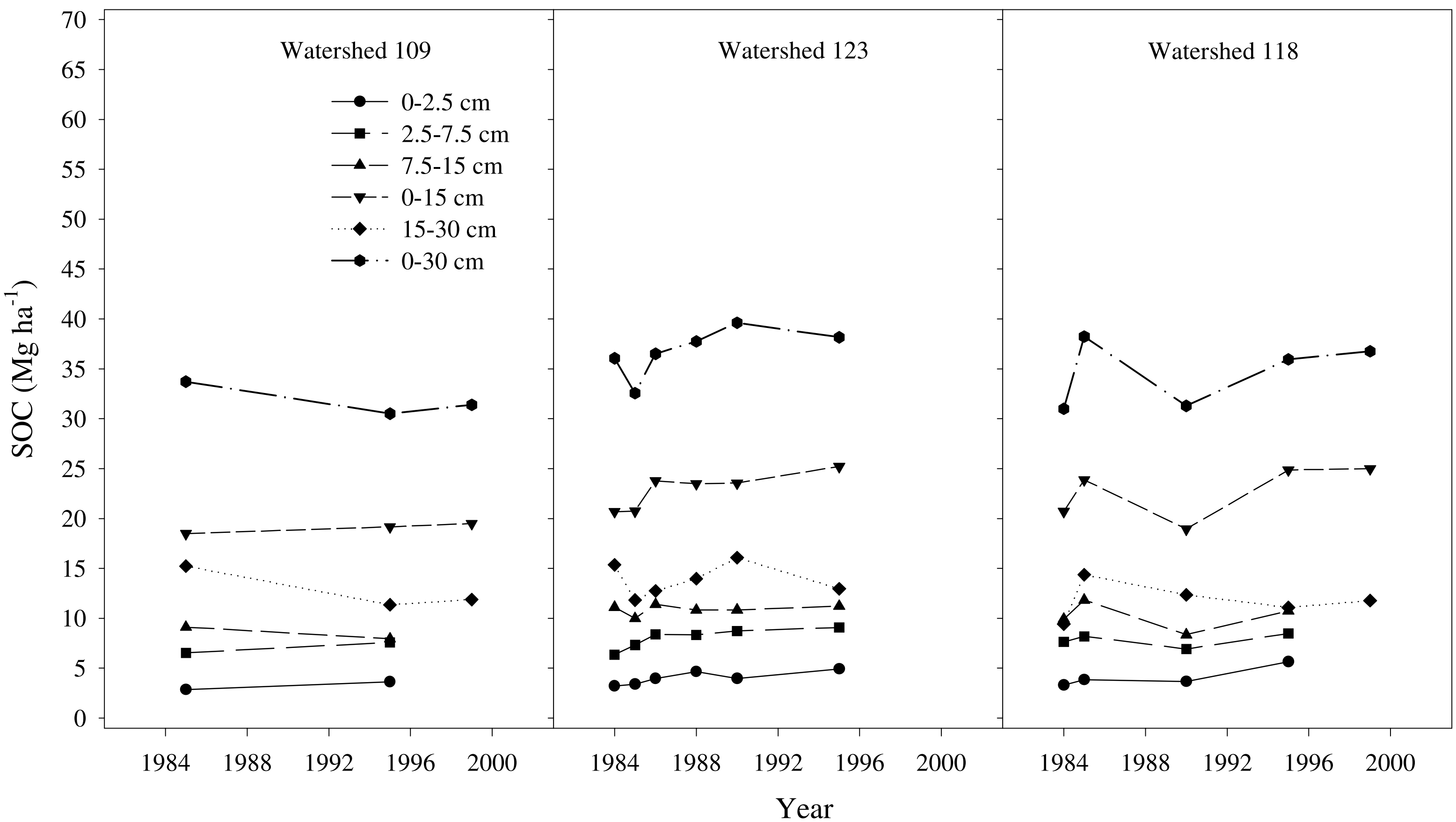


Fig. 1. Change with time of soil organic carbon pools in different depths for chisel (watershed 109&123) and no (watershed 118) till corn-soybean rotation from 1984 to 1999.