DIVISION S-6—SOIL & WATER MANAGEMENT & CONSERVATION

Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis

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ABSTRACT

Changes in agricultural management can potentially increase the accumulation rate of soil organic C (SOC), thereby sequestering CO_2 from the atmosphere. This study was conducted to quantify potential soil C sequestration rates for different crops in response to decreasing tillage intensity or enhancing rotation complexity, and to estimate the duration of time over which sequestration may occur. Analyses of C sequestration rates were completed using a global database of 67 long-term agricultural experiments, consisting of 276 paired treatments. Results indicate, on average, that a change from conventional tillage (CT) to no-till (NT) can sequester 57 ± 14 g C m^{-2} yr^{-1}, excluding wheat (*Triticum aestivum* L.)-fallow systems which may not result in SOC accumulation with a change from CT to NT. Enhancing rotation complexity can sequester an average 20 ± 12 g C m^{-2} yr^{-1}, excluding a change from continuous corn (*Zea mays* L.) to corn-soybean (*Glycine max* L.) which may not result in a significant accumulation of SOC. Carbon sequestration rates, with a change from CT to NT, can be expected to peak in 5 to 10 yr with SOC reaching a new equilibrium in 15 to 20 yr. Following initiation of an enhancement in rotation complexity, SOC may reach a new equilibrium in approximately 40 to 60 yr. Carbon sequestration rates, estimated for a number of individual crops and crop rotations in this study, can be used in spatial modeling analyses to more accurately predict regional, national, and global C sequestration potentials.

ORGANIC C in agricultural soils contributes positively to soil fertility, soil tilth, crop production, and overall soil sustainability (Bauer and Black, 1994; Lal et al., 1997; Reeves, 1997). Changes in agricultural management can increase or decrease SOC. Optimizing agricultural management for accumulation of SOC can result in the sequestration of atmospheric CO_2, thereby partially mitigating the current increase in atmospheric CO_2 (Sampson and Scholes, 2000). In addition to the environmental benefits of soil C sequestration, consideration has also been given to the implementation of a C credit trading system which may provide economic incentives for C sequestration initiatives (Marland et al., 2001a; 2001b).

Changes in agricultural practices for the purpose of increasing SOC must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter (SOM) and oxidation of SOC, or a combination thereof (Follett, 2001; Paustian et al., 2000). These practices include, but are not limited to, reducing tillage intensity, decreasing or ceasing the fallow period, using a winter cover crop, changing from monoculture to rotation cropping, or altering soil inputs to increase primary production (e.g., fertilizers, pesticides, and irrigation). Implementing practices that sequester C can reverse the loss of SOC that may have occurred under intensive cultivation thereby increasing SOC to a new equilibrium (Johnson et al. 1995).

A global analysis of soil C loss following cultivation of forests or grasslands indicated a 20% reduction of the initial SOC, or approximately 1500 g m^{-2} in the top 30 cm of soil (Mann, 1986). A similar analysis by Davidson and Ackerman (1993) estimated a 30% SOC loss from the entire soil column within 20 yr following cultivation, with the majority of this loss occurring within the first 5 yr.

Loss of SOC can be reversed by ceasing cultivation and returning to the original land cover or other perennial vegetation. Average global C sequestration rates, when changing land use from agriculture to forest or grassland, were estimated to be 33.8 or 33.2 g C m^{-2} yr^{-1}, respectively (Post and Kwon, 2000). Silver et al. (2000) estimated that reforestation of abandoned tropical agricultural land and pasture sequesters C in the soil at a rate of 130 g C m^{-2} yr^{-1} for the first 20 yr, and then at an average rate of 41 g C m^{-2} yr^{-1} for the following 80 yr.

Loss of SOC can also be reversed by using less intensive cultivation practices or by changing from monoculture to rotation cropping. In an analysis of 17 experiments (n = 38), Kern and Johnson (1993) concluded that a change from CT to NT sequesters the greatest amount of C in the top 8 cm of soil, a lesser amount in the 8- to 15-cm depth, and no significant amount below 15 cm. They also concluded that, unlike NT, no significant change in SOC was realized in response to reduced tillage (RT). Kern and Johnson (1993) assumed the duration of C sequestration to be between 10 and 20 yr. Paustian et al. (1997) compared 39 paired tillage experiments, ranging in duration from 5 to 20 yr, and estimated that NT resulted in an average soil C increase of 285 g m^{-2} with respect to CT. Using an average experiment duration of 13 yr implies an approximate C sequestration rate of 22 g m^{-2} yr^{-1}.

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Abbreviations: CT, conventional tillage; IPCC, Intergovernmental Panel on Climate Change; NT, no-till; RT, reduced tillage; SOC, soil organic C; SOM, soil organic matter.

In an analysis of 17 European tillage experiments, Smith et al. (1998) found that the average increase of SOC, with a change from CT to NT, was 0.73 ± 0.39% yr^{-1}, and that SOC may reach a new equilibrium in approximately 50 to 100 yr. Analysis of some long-term experiments in Canada (Dumanski et al., 1998) indicated that SOC can be sequestered for 25 to 30 yr at a rate of 50 to 75 g C m^{-2} yr^{-1}, depending on soil type, in well fertilized Chernozemic and Luvisolic soils cropped continuously to cereals and hay. Analysis of these Canadian experiments focused on crop rotations, as opposed to tillage, and is unique in that it considered rates of C sequestration with regard to soil type.

The Intergovernmental Panel on Climate Change (IPCC) has developed guidelines for accounting of greenhouse gases, including C sinks in forest and agricultural ecosystems (Houghton et al., 1997). The IPCC suggests using a multiplication factor of 1.1 for a change from CT to NT (Houghton et al., 1997; Land-use change & forestry section), essentially corresponding to a 10% increase in SOC. Moving from CT to RT, factors of 1.05 and 1.0 are recommended for agricultural lands in temperate and tropical climate regimes, respectively. The IPCC suggests these factors be applied to a depth of 30 cm and over a period of 20 yr. Additional factors are provided for residue management, soil inputs (e.g., mulching and manure), and fallow frequency. The IPCC approach has recently been applied in a national inventory of C in agricultural soils (Eve et al., 2001).

In an effort to integrate data from previous regional analyses and improve estimates of agricultural C sequestration rates, we developed a global data set based on a review of long-term experiments in the published literature that recorded the response of SOC to changes in agricultural management. Soil organic C measurements and auxiliary data were specifically compiled to (i) quantitatively estimate the response of SOC to changes in tillage intensity and crop rotation, (ii) quantitatively estimate the duration of C sequestration rates, and (iii) provide confidence intervals for estimates of C sequestration rates that could be used in policy and C cycle modeling analyses. This analysis was intended to provide increased accuracy over past estimates of potential C sequestration by increasing the number of experiments (sample size) and stratifying the analysis by cropping practice (e.g., continuous corn, soybean-sorghum [*Sorghum* spp.] rotation, etc.).

MATERIALS AND METHODS

Database Compilation and Organization

Experiments from the published literature that recorded the response of SOC to changes in tillage or crop rotation, and that were greater than 5 yr in duration, were used in this study. A total of 67 global, long-term agricultural experiment sites, consisting of 276 paired treatments, were compiled (Table 1).

Measurements for SOC were recorded as mass per unit area (e.g., g m^{-2} 30-cm $depth^{-1}$). Reported estimates that did not include SOC measurements to a 30-cm depth were not normalized to a depth of 30 cm. In many cases, little or no change in SOC was found to occur between 20 and 30 cm; hence, extrapolating SOC measurements from higher in the soil profile to represent SOC changes in the lower profile would incorrectly inflate C sequestration estimates. Therefore, when experimental results indicated SOC measurements, for example, to a depth of 15 cm, it was assumed that changes in SOC below 15 cm were negligible. Values reported for SOM were converted to SOC through division by 1.72 (Soil Survey Division Staff, 1993).

Data that were presented in terms of SOC percentage were converted to mass per unit area by multiplying the fraction of SOC by respective measurements of soil bulk density (g cm^{-3}) and depth of soil sampled (cm). In experiments where SOC concentration was provided without data on soil bulk density, bulk density was calculated according to equations provided by Chen et al. (1998). Chen et al. (1998) provide regression equations for estimating soil bulk density with respect to tillage practice and soil depth, based on clay- and sand-particle fractions and the percentage of SOM.

A more direct approach for estimating soil bulk density (Adams, 1973) has been used by Post and Kwon (2000) in an analysis of C accumulation in forest and grassland ecosystems. A separate analysis was performed on the data compiled for use in this study, between SOC under CT and SOC under NT, using soil bulk density estimates based on both Chen et al. (1998) and Adams (1973). Analyses included soil samples at varying depths from experiments only where soil bulk density was measured ($n = 202$), thus allowing a comparison between changes in SOC with both measured and estimated bulk density values. A linear regression analysis (Fig. 1) indicated that calculated changes in SOC based on equations from Chen et al. (1998) had a slightly higher correlation ($r^2 = 0.87$) with changes in SOC using actual soil bulk density measurements than did estimates based on Adams (1973) ($r^2 = 0.81$).

Analysis of Experimental Data

Rates of Carbon Sequestration

Carbon sequestration rates were calculated for (i) a decrease in tillage intensity, and (ii) an enhancement of rotation complexity. A decrease in tillage intensity refers to a change in tillage practice that reduces soil disturbance and generally results in increased surface residue. In this analysis, CT included the use of a moldboard plow, RT consisted of practices that used tillage operations other than plowing (e.g., disking), and NT included practices that did not till the soil. Crop systems (e.g., continuous corn, corn–soybean, and wheat–fallow) were grouped separately in the tillage analysis to determine whether a statistically significant amount of C was sequestered within each group in response to a reduction in tillage intensity.

Enhancement of rotation complexity refers to (i) a change from monoculture to continuous rotation cropping, (ii) a change from crop–fallow systems to continuous monoculture or rotation cropping, and (iii) an increase in the number of crops used in a rotation cropping system. In this analysis, continuous cropping is a cropping system without a fallow season, monoculture is a system with only one crop grown, and rotation cropping indicates two or more crops rotated over time on the same unit of land. Most of the monoculture and rotation systems in this analysis are cropped continuously, with the exception of wheat–fallow systems.

Carbon sequestration rates were estimated by calculating the mean difference between the initial and alternative practices, using soil sample data from the latest year available (e.g., comparing C measurements for NT and CT in Year 20,

Table 1. Agricultural experiments used in this study.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Ås, Norway	N/A (low N)	N/A	31	3 yr cereal-3 yr row crop vs. cereal	20	−199	Uhlen (1991)
Ås, Norway	N/A (low N)	N/A	31	2 yr ley-4 yr row crop vs. 3 yr cereal-3 yr row crop	20	199	Uhlen (1991)
Ås, Norway	N/A (low N)	N/A	31	4 yr ley-2 yr row crop vs. 3 yr cereal-3 yr row crop	20	881	Uhlen (1991)
Ås, Norway	N/A (medium N)	N/A	31	3 yr cereal-3 yr row crop vs. cereal	20	−171	Uhlen (1991)
Ås, Norway	N/A (medium N)	N/A	31	2 yr ley-4 yr row crop vs. 3 yr cereal-3 yr row crop	20	711	Uhlen (1991)
Ås, Norway	NA (medium N)	N/A	31	4 yr ley-2 yr row crop vs. 3 yr cereal-3 yr row crop	20	597	Uhlen (1991)
Athens, GA	Summer grain-winter rye	Old field, 10 yr	16	NT vs. CT	20	158	Hendrix (1997)
Auburn, AL	CT	N/A	100	Cn-C vs. Cn	10	37	Entry et al. (1996), Mitchell et al. (1996, 2000)
Auburn, AL	CT	N/A	100	Cn-C-S vs. Cn	10	701	Entry et al. (1996), Mitchell et al. (1996, 2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	S-Sf vs. S	17	798	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	W-S vs. S	17	1393	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	C-Sf vs. C	17	−45	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	C-S vs. C	17	−663	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	W-C vs. C	17	101	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	S-Sf vs. S	17	1404	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	S-C vs. S	17	1921	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	C-Sf vs. C	17	−101	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	W-C vs. C	17	112	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	C-S vs. C	17	−393	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	W-S (avg. seq.) vs. W	17	112	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (no fert.)	Pasture, 4 yr	11	W-Sf (avg. seq) vs. W	17	595	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	W-S (avg. seq.) vs. W	17	168	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	W-Sf (avg. seq.) vs. W	17	483	Studdert and Echeverría (2000)
Balcarce, Argentina	CT (N fert.)	Pasture, 4 yr	11	W-C (avg. seq.) vs. W	17	651	Studdert and Echeverría (2000)
Buenos Aires, Argentina	N/A (no fert.)	N/A	15	W-G vs. W	21	310	Miglierina et al. (2000)
Buenos Aires, Argentina	N/A (fert.)	N/A	15	W-G vs. W	21	180	Miglierina et al. (2000)
Buenos Aires, Argentina	N/A (no fert.)	N/A	15	W-G/legume vs. W	21	390	Miglierina et al. (2000)
Buenos Aires, Argentina	N/A (fert.)	N/A	15	W-G/legume vs. W	21	760	Miglierina et al. (2000)
Bushland, TX	RT	CT, W or W-F, ~30 yr	10	Sm vs. W-Sm-F	20	100	Potter et al. (1997)
Bushland, TX	RT	CT, W or W-F, ~30 yr	10	W vs. W-Sm-F	20	20	Potter et al. (1997)
Bushland, TX	RT	CT, W or W-F, ~30 yr	10	W vs. W-F	20	100	Potter et al. (1997)
Bushland, TX	NT	CT, W or W-F, ~30 yr	10	Sm vs. W-Sm-F	20	80	Potter et al. (1997)
Bushland, TX	NT	CT, W or W-F, ~30 yr	10	W vs. W-Sm-F	20	280	Potter et al. (1997)
Bushland, TX	NT	CT, W or W-F, ~30 yr	10	W vs. W-F	20	420	Potter et al. (1997)
Bushland, TX	Sm	CT, W or W-F, ~30 yr	10	NT vs. RT	20	280	Potter et al. (1997)
Bushland, TX	W	CT, W or W-F, ~30 yr	10	NT vs. RT	20	560	Potter et al. (1997)
Bushland, TX	W-Sm-F (avg. seq.)	CT, W or W-F, ~30 yr	10	NT vs. RT	20	300	Potter et al. (1997)
Bushland, TX	W-F (avg. seq.)	CT, W or W-F, ~30 yr	10	NT vs. RT	20	240	Potter et al. (1997)
Canterbury, New Zealand	W-B-peas	W-B-peas, >10 yr	9	NT vs. CT	15	2607	Hermawan and Cameron (1993)
Canterbury, New Zealand	W-peas-B-white clover	Ryegrass-white clover, ~5 yr	10	NT vs. CT	15	640	Francis and Knight (1993)
Cantuar, SK, Canada	W	Cereal-fallow, 70–80 yr	15	NT vs. CT	15	192	Campbell et al. (1996b)
Cantuar, SK, Canada	W-F	Cereal-fallow, 70–80 yr	15	NT vs. RT	15	59	Campbell et al. (1996b)
Cantuar, SK, Canada	NT	Cereal-fallow, 70–80 yr	15	W vs. W-F	15	−6	Campbell et al. (1996b)
Columbia, MO	C	Grassland	100	NT vs. CT	20	853	Buyanovsky and Wagner (1998), Balesdent et al. (1988), Buyanovsky et al. (1997)
Columbia, MO	CT (fert.)	Grassland	100	C-W-Cl vs. C	20	1112	Buyanovsky and Wagner (1998), Balesdent et al. (1988), Buyanovsky et al. (1997)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Columbia, MO	CT (0 fert.)	Grassland	100	C-W-Cl vs. C	20	1655	Buyanovsky and Wagner (1998), Balesdent et al. (1988), Buyanovsky et al. (1997)
Columbia, MO	CT (fert.)	Grassland	100	C-W-Cl vs. W	20	1112	Buyanovsky and Wagner (1998), Balesdent et al. (1988), Buyanovsky et al. (1997).
Columbia, MO	CT (0 fert.)	Grassland	100	C-W-Cl vs. W	20	1520	Buyanovsky and Wagner (1998), Balesdent et al. (1988), Buyanovsky et al. (1997)
Condobolin, Australia	W	Cultivated, >50 yr	14	NT vs. RT	10	227	Fettell and Gill (1995)
Cordoba, Argentina	S	Crop-meadow rotation	15	NT vs. CT	15	834	Chagas et al. (1995)
Cordoba, Argentina	S	Crop-meadow rotation	15	NT vs. RT	15	675	Chagas et al. (1995)
Cordoba, Argentina	S	Crop-meadow rotation	15	RT vs. CT	15	159	Chagas et al. (1995)
Corpus Christi, TX	4 yr [C]-4 yr Cn	CT, many yr	12	NT vs. CT	20	560	Potter et al. (1998)
Corpus Christi, TX	4 yr [C]-4 yr Cn	CT, many yr	12	NT vs. RT	20	200	Potter et al. (1998)
Corpus Christi, TX	4 yr [C]-4 yr Cn	CT, many yr	12	RT vs. CT	20	360	Potter et al. (1998)
Corpus Christi, TX	4 yr C-4 yr [Cn]	CT, many yr	12	NT vs. CT	20	340	Potter et al. (1998)
Corpus Christi, TX	4 yr C-4 yr [Cn]	CT, many yr	12	NT vs. CT	20	340	Potter et al. (1998)
Corpus Christi, TX	4 yr C-4 yr [Cn]	CT, many yr	12	RT vs. CT	20	110	Potter et al. (1998)
Crossville, AL	S	CT, row crop, >50 yr	10	NT vs. CT	20	1006	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	C	CT, row crop, >50 yr	10	NT vs. CT	20	1603	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	C-S	CT, row crop, >50 yr	10	NT vs. CT	20	1191	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	CT	CT, row crop, >50 yr	10	C-S vs. S	20	−122	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	NT	CT, row crop, >50 yr	10	C-S vs. S	20	64	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	CT	CT, row crop, >50 yr	10	C-S vs. C	20	−259	Edwards et al. (1992), Wood and Edwards (1992)
Crossville, AL	NT	CT, row crop, >50 yr	10	C-S vs. C	20	−671	Edwards et al. (1992), Wood and Edwards (1992)
Culbertson, MT	W	Cropped, 4 yr	9	NT vs. CT	15	55	Aase and Pikul (1995), Pikul and Aase (1995), J.L. Pikul, personal communication, 2001.
Culbertson, MT	W	Cropped, 4 yr	9	NT vs. RT	15	−248	Aase and Pikul (1995), Pikul and Aase (1995), J.L. Pikul, personal communication, 2001.
Culbertson, MT	W	Cropped, 4 yr	9	RT vs. CT	15	303	Aase and Pikul (1995), Pikul and Aase (1995), J.L. Pikul, personal communication, 2001.
Culbertson, MT	CT	Cropped, 4 yr	9	W-B vs. W	15	33	Aase and Pikul (1995), Pikul and Aase (1995), J.L. Pikul, personal communication, 2001.
Dawson Creek, BC, Canada	B	N/A	10	NT vs. CT	7.5	901	Arshad et al. (1990)
Edinburgh, Scotland	B	N/A	24	NT vs. CT	30	2898	Soane and Ball (1998), Ball et al. (1997)
Edinburgh, Scotland	B	N/A	24	NT vs. CT	30	2735	Soane and Ball (1998)
Eldorado do Sul, Brazil	O-C	CT, 15 yr	9	NT vs. CT	30	460	Bayer et al. (2000)
Eldorado do Sul, Brazil	O/V-C/Cp	CT, 15 yr	9	NT vs. CT	30	640	Bayer et al. (2000)
Eldorado do Sul, Brazil	CT	CT, 15 yr	9	O/V-C/Cp vs. O-C	30	560	Bayer et al. (2000)
Eldorado do Sul, Brazil	NT	CT, 15 yr	9	O/V-C/Cp vs. O-C	30	740	Bayer et al. (2000)
El Reno, OK	W-F	CT, W, 9 yr	11	NT vs. CT	20	1270	Dao (1998)
Elwood, IL	C-S	N/A	6	NT vs. CT	30	592	Mielke et al. (1986)
Essone, France	C	CT, W, ~10 yr	15	NT vs. CT	30	721	Balesdent et al. (1990)
Fargo, ND	S-B-Sf-B	N/A	10	NT vs. CT	30	2285	Deibert and Utter (1989)
Fargo, ND	S-B-Sf-B	N/A	10	NT vs. RT	30	2107	Deibert and Utter (1989)
Fargo, ND	S-B-Sf-B	N/A	10	RT vs. CT	30	179	Deibert and Utter (1989)
Florence, SC	C	N/A	7	NT vs. RT	15	452	Karlen et al. (1989)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Giessen, Germany	C-C-beet	N/A	17	NT vs. CT	25	107	Tebrügge and Düring (1999)
Hoytville, OH	C	CT, C-O, 6 yr	18	NT vs. CT	30	2397	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	C-S	CT, C-O, 6 yr	18	NT vs. CT	30	1538	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	C-O-G	CT, C-O, 6 yr	18	NT vs. CT	30	2187	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	NT	CT, C-O, 6 yr	19	C-S vs. C	30	−1722	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	CT	CT, C-O, 6 yr	19	C-S vs. C	30	−863	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	NT	CT, C-O, 6 yr	19	C-O-G vs. C	30	−14	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Hoytville, OH	CT	CT, C-O, 6 yr	19	C-O-G vs. C	30	224	Dick et al. (1997), Dick (1983), W.A. Dick, personal communication, 2000.
Indiana, USA	C	N/A	7	NT vs. CT	10	307	Kladivko et al. (1986)
Indiana, USA	C-S	N/A	7	NT vs. CT	7.5	653	Kladivko et al. (1986)
Indian Head, SK, Canada	CT (0 fert.)	CT, F-W	15	W vs. W-F	40	−111	Campbell et al. (1991a, 1997), Campbell (2001a)
Indian Head, SK, Canada	CT (fert.)	CT, F-W	15	W vs. W-F	40	162	Campbell et al. (1991a, 1997), Campbell (2001a)
Indian Head, SK, Canada	CT (0 fert.)	CT, F-W	15	W vs. W-W-F	40	368	Campbell et al. (1991a, 1997), Campbell (2001a)
Indian Head, SK, Canada	CT (fert.)	CT, F-W	15	W vs. W-W-F	40	−106	Campbell et al. (1991a, 1997), Campbell (2001a)
Kanawha, IA	CT	N/A	36	C-S vs. C	15	−234	Robinson et al. (1996)
Kanawha, IA	CT	N/A	36	C-C-O-G vs. C	15	527	Robinson et al. (1996)
Kanawha, IA	CT	N/A	36	C-A-G-G vs. C	15	566	Robinson et al. (1996)
Lethbridge, AB, Canada	N/A	Cultivated for ~3 yr	78	W vs. W-F	15	230	Monreal and Janzen (1993), Janzen et al. (1997)
Lethbridge, AB, Canada	N/A	Cultivated for ~3 yr	78	W vs. W-W-F	15	147	Monreal and Janzen (1993), Janzen et al. (1997)
Lethbridge, AB, Canada	N/A	Cultivated for ~44 yr	41	W vs. W-F	30	112	Janzen (1987), Janzen et al. (1997)
Lethbridge, AB, Canada	N/A	Cultivated for ~44 yr	41	W vs. W-W-F	30	244	Janzen (1987), Janzen et al. (1997)
Lethbridge, AB, Canada	Fert. with manure	Cultivated for ~44 yr	41	W vs. W-W-F	30	−255	Janzen (1987), Janzen et al. (1997)
Lethbridge, AB, Canada	N/A	Cultivated for ~44 yr	41	W vs. F-W-W-H-H-H	30	−360	Janzen (1987), Janzen et al. (1997)
Lethbridge, AB, Canada	W-F	Cultivated for ~61 yr	24	NT vs. CT	20	−320	Miller et al. (1999)
Lexington, KY	C (0 N)	Bluegrass, 50 yr	20	NT vs. CT	30	788	Blevens et al. (1983a), Ismail et al. (1994)
Lexington, KY	C (84 N)	Bluegrass, 50 yr	20	NT vs. CT	30	383	Blevens et al. (1983a), Ismail et al. (1994)
Lexington, KY	C (168 N)	Bluegrass, 50 yr	20	NT vs. CT	30	392	Blevens et al. (1983a), Ismail et al. (1994)
Lexington, KY	C (336 N)	Bluegrass, 50 yr	20	NT vs. CT	30	696	Blevens et al. (1983a), Ismail et al. (1994)
Lincoln, NE	Sm-S	N/A	10	NT vs. CT	8	−160	Dickey et al. (1994)
Lincoln, NE	Sm-S	N/A	10	RT vs. CT	8	633	Dickey et al. (1994)
Lincoln, NE	Sm-S	N/A	10	NT vs. RT	8	−793	Dickey et al. (1994)
Lincoln, NE	Sm-S	N/A	10	NT vs. CT	8	301	Dickey et al. (1994)
Lincoln, NE	Sm-S	N/A	10	RT vs. CT	8	688	Dickey et al. (1994)
Lincoln, NE	Sm-S	N/A	10	NT vs. RT	8	−388	Dickey et al. (1994)
Mandan, ND	W-F (0 N)	N/A	7	NT vs. CT	30	−109	Black and Tanaka (1997)
Mandan, ND	W-F (0 N)	N/A	7	NT vs. RT	30	419	Black and Tanaka (1997)
Mandan, ND	W-F (0 N)	N/A	7	RT vs. CT	30	−528	Black and Tanaka (1997)
Mandan, ND	W-F (20 N)	N/A	7	NT vs. CT	30	−634	Black and Tanaka (1997)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Mandan, ND	W-F (20 N)	N/A	7	NT vs. RT	30	−423	Black and Tanaka (1997)
Mandan, ND	W-F (20 N)	N/A	7	RT vs. CT	30	−211	Black and Tanaka (1997)
Mandan, ND	W-F (40 N)	N/A	7	NT vs. CT	30	−1074	Black and Tanaka (1997)
Mandan, ND	W-F (40 N)	N/A	7	NT vs. RT	30	−332	Black and Tanaka (1997)
Mandan, ND	W-F (40 N)	N/A	7	RT vs. CT	30	−741	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (34 N)	N/A	7	NT vs. CT	30	892	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (34 N)	N/A	7	NT vs. RT	30	890	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (34 N)	N/A	7	RT vs. CT	30	2	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (67 N)	N/A	7	NT vs. CT	30	1246	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (67 N)	N/A	7	NT vs. RT	30	55	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (67 N)	N/A	7	RT vs. CT	30	1191	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (101 N)	N/A	7	NT vs. CT	30	1690	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (101 N)	N/A	7	NT vs. RT	30	914	Black and Tanaka (1997)
Mandan, ND	W-W-Sf (101 N)	N/A	7	RT vs. CT	30	777	Black and Tanaka (1997)
Mandan, ND	CT (low N)	N/A	7	W-W-Sf vs. W-F	30	562	Black and Tanaka (1997)
Mandan, ND	CT (medium N)	N/A	7	W-W-Sf vs. W-F	30	−234	Black and Tanaka (1997)
Mandan, ND	CT (high N)	N/A	7	W-W-Sf vs. W-F	30	−425	Black and Tanaka (1997)
Mandan, ND	NT (low N)	N/A	7	W-W-Sf vs. W-F	30	1563	Black and Tanaka (1997)
Mandan, ND	NT (medium N)	N/A	7	W-W-Sf vs. W-F	30	1646	Black and Tanaka (1997)
Mandan, ND	NT (high N)	N/A	7	W-W-Sf vs. W-F	30	2339	Black and Tanaka (1997)
Manhatten, KS	S	N/A	11	NT vs. CT	30	307	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	Sm-S	N/A	11	NT vs. CT	30	399	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	Sm	N/A	11	NT vs. CT	30	54	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	S	N/A	12	NT vs. CT	30	−57	Havlin et al. (1990)
Manhatten, KS	Sm-S	N/A	12	NT vs. CT	30	468	Havlin et al. (1990)
Manhatten, KS	Sm	N/A	12	NT vs. CT	30	578	Havlin et al. (1990)
Manhatten, KS	CT	N/A	11	S-Sm vs. S	30	344	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	NT	N/A	11	S-Sm vs. S	30	436	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	CT	N/A	11	Sm-S vs. Sm	30	−384	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	NT	N/A	11	Sm-S vs. Sm	30	−39	Havlin et al. (1990), Havlin and Kissel (1997)
Manhatten, KS	CT	N/A	12	S-Sm vs. S	30	−933	Havlin et al. (1990)
Manhatten, KS	NT	N/A	12	S-Sm vs. S	30	−408	Havlin et al. (1990)
Manhatten, KS	CT	N/A	12	Sm-S vs. Sm	30	−1050	Havlin et al. (1990)
Manhatten, KS	NT	N/A	12	Sm-S vs. Sm	30	−1159	Havlin et al. (1990)
Manhatten, KS	CT (0 N)	N/A	8	C-S vs. S	30	69	Havlin et al. (1990)
Manhatten, KS	CT (252 N)	N/A	8	C-S vs. S	30	293	Havlin et al. (1990)
Manhatten, KS	CT (0 N)	N/A	8	C-S vs. C	30	−263	Havlin et al. (1990)
Manhatten, KS	CT (252 N)	N/A	8	C-S vs. C	30	−266	Havlin et al. (1990)
Mead, NE	CT (0 N)	N/A	10	C-S vs. C	30	248	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	Sm-S vs. S	30	−553	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-S vs. S	30	−160	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	Sm-S vs. Sm	30	−428	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-O-Sm-S vs. C	30	645	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-O-Sm-S vs. S	30	237	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-O-Sm-S vs. Sm	30	362	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-S-Sm-O vs. C	30	92	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-S-Sm-O vs. S	30	−316	Varvel (1994)
Mead, NE	CT (0 N)	N/A	10	C-S-Sm-O vs. Sm	30	−191	Varvel (1994)
Mead, NE	CT (90 N)	N/A	10	C-S vs. C	30	209	Varvel (1994)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Mead, NE	CT (34 N)	N/A	10	C-S vs. S	30	−208	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	Sm-S vs. S	30	−606	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	Sm-S vs. Sm	30	−429	Varvel (1994)
Mead, NE	CT (90 N)	N/A	10	C-O-Sm-S vs. C	30	479	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	C-O-Sm-S vs. S	30	62	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	C-O-Sm-S vs. Sm	30	240	Varvel (1994)
Mead, NE	CT (90 N)	N/A	10	C-S-Sm-O vs. C	30	142	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	C-S-Sm-O vs. S	30	−275	Varvel (1994)
Mead, NE	CT (34 N)	N/A	10	C-S-Sm-O vs. Sm	30	−97	Varvel (1994)
Mead, NE	CT (180 N)	N/A	10	C-S vs. C	30	−2	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	C-S vs. S	30	−271	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	Sm-S vs. S	30	−476	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	Sm-S vs. Sm	30	−322	Varvel (1994)
Mead, NE	CT (180 N)	N/A	10	C-O-Sm-S vs. C	30	443	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	C-O-Sm-S vs. S	30	174	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	C-O-Sm-S vs. Sm	30	328	Varvel (1994)
Mead, NE	CT (180 N)	N/A	10	C-S-Sm-O vs. C	30	73	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	C-S-Sm-O vs. S	30	−176	Varvel (1994)
Mead, NE	CT (68 N)	N/A	10	C-S-Sm-O vs. Sm	30	−22	Varvel (1994)
Mead, NE	RT (fert., herbicide)	N/A	16	C-S-C-O/Cl vs. C	15	276	Lesoing and Doran (1997)
Melfort, SK, Canada	CT (0 fert.)	CT, F-W	30	W vs. W-F	15	390	Campbell et al. (1991b, 1997)
Melfort, SK, Canada	CT (fert.)	CT, F-W	30	W vs. W-F	15	420	Campbell et al. (1991b, 1997)
Melfort, SK, Canada	CT (0 fert.)	CT, F-W	30	W vs. F-W-W-H-H-W	15	3	Campbell et al. (1991b, 1997)
Melfort, SK, Canada	CT (fert.)	CT, F-W	30	W vs. F-W-W-H-H-W	15	183	Campbell et al. (1991b, 1997)
Nashua, IA	CT	N/A	12	C-S vs. C	15	164	Robinson et al. (1996)
Nashua, IA	CT	N/A	12	C-C-O-G vs. C	15	614	Robinson et al. (1996)
North Yorkshire, England	B	N/A	9	NT vs. CT	20	330	Chaney et al. (1985)
Palmerston North, New Zealand	C-O	N/A	10	NT vs. CT	20	549	Horne et al. (1992)
Palmerston North, New Zealand	C-O	N/A	10	RT vs. CT	20	584	Horne et al. (1992)
Palmerston North, New Zealand	C-O	N/A	10	NT vs. RT	20	−35	Horne et al. (1992)
Pendleton, OR	W-F (0 N)	N/A	44	RT vs. CT	30	324	Rasmussen and Smiley (1997), Rasmussen and Rohde (1988)
Pendleton, OR	W-F (90 N)	N/A	44	RT vs. CT	30	434	Rasmussen and Smiley (1997), Rasmussen and Rohde (1988)
Pendleton, OR	W-F (135 N)	N/A	44	RT vs. CT	30	579	Rasmussen and Smiley (1997), Rasmussen and Rohde (1988)
Pendleton, OR	W-F (180 N)	N/A	44	RT vs. CT	30	548	Rasmussen and Smiley (1997), Rasmussen and Rohde (1988)
Quebec, Canada	C	Grass meadow, >20 yr	11	NT vs. CT	24	216	Angers et al. (1993)
Quebec, Canada	C	Grass meadow, >20 yr	11	NT vs. RT	24	208	Angers et al. (1993)
Quebec, Canada	C	Grass meadow, >20 yr	11	RT vs. CT	24	8	Angers et al. (1993)
Rycroft, AB, Canada	Canola-W-B-F	N/A	6	NT vs. CT	20	190	Franzluebbers and Arshad (1996)
Rycroft, AB, Canada	Canola-W-B-F	N/A	6	NT vs. RT	20	13	Franzluebbers and Arshad (1996)
Rycroft, AB, Canada	Canola-W-B-F	N/A	6	RT vs. CT	20	177	Franzluebbers and Arshad (1996)
Senatobia, MS	C	Pasture	8	NT vs. CT	15.2	354	Rhoton (2000)
Senatobia, MS	CnS	Pasture	8	NT vs. CT	15.2	268	Rhoton (2000)
Senatobia, MS	S	Pasture	8	NT vs. CT	15.2	488	Rhoton (2000)
Sidney, NE	W	Native grassland	22	NT vs. CT	20	673	Lyon et al. (1997)
Sidney, NE	W	Native grassland	22	NT vs. RT	20	234	Lyon et al. (1997)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Sidney, NE	W	Native grassland	22	RT vs. CT	20	439	Lyon et al. (1997)
Sidney, NE	W	Native grassland	22	NT vs. CT	20	350	Lyon et al. (1997)
Sidney, NE	W	Native grassland	22	NT vs. RT	20	385	Lyon et al. (1997)
Sidney, NE	W	Native grassland	22	RT vs. CT	20	−35	Lyon et al. (1997)
Sidney, NE	W-F	Cultivated for ~47 yr	11	NT vs. CT	30	10	Doran et al. (1998)
Sidney, NE	W-F	Cultivated for ~47 yr	11	RT vs. CT	30	−80	Doran et al. (1998)
Sidney, NE	W-F	Cultivated for ~47 yr	11	NT vs. RT	30	90	Doran et al. (1998)
South Charleston, OH	C	CT, C-S	18	NT vs. CT	30	2392	Karlen et al. (1989), Hunt et al. (1996)
South Charleston, OH	C	CT, C-S	18	NT vs. RT	30	2623	Karlen et al. (1989), Hunt et al. (1996)
South Charleston, OH	C	CT, C-S	18	RT vs. CT	30	−231	Karlen et al. (1989), Hunt et al. (1996)
Stewart Valley, SK, Canada	W	N/A	15	NT vs. CT	15	192	Campbell et al. (1996a)
Stewart Valley, SK, Canada	W-F	N/A	16	NT vs. RT	16	404	Campbell et al. (1996a)
Stewart Valley, SK, Canada	NT	N/A	15	W vs. W-F	15	92	Campbell et al. (1996a)
Sutherland, IA	CT (200 N)	Cultivated for ~36 yr	34	C-S vs. C	15	95	Robinson et al. (1996)
Sutherland, IA	CT (135 N)	Cultivated for ~36 yr	34	C-C-O-G vs. C	15	760	Robinson et al. (1996)
Sutherland, IA	CT (135 N)	Cultivated for ~36 yr	34	C-A-G-G vs. C	15	892	Robinson et al. (1996)
Swift Current, SK, Canada	RT (no N)	CT, F-W, ~60 yr	23	W vs. W-W-F	15	130	Biederbeck et al. (1984), Campbell and Zentner (1997)
Swift Current, SK, Canada	RT (N)	CT, F-W, ~60 yr	23	W vs. W-W-F	15	−120	Biederbeck et al. (1984), Campbell and Zentner (1997)
Swift Current, SK, Canada	NT	CT, F-W, ~70 yr	14	W vs. W-F	15	154	Campbell et al. (1995)
Swift Current, SK, Canada	CT	CT, F-W, ~70 yr	14	W vs. W-F	15	−29	Campbell et al. (1995)
Swift Current, SK, Canada	W-F	CT, F-W, ~70 yr	14	NT vs. CT	15	109	Campbell et al. (1995)
Swift Current, SK, Canada	W	CT, F-W, ~70 yr	14	NT vs. CT	15	292	Campbell et al. (1995)
Temple, TX	[W]-Sm-C (28 N)	CT many yr	10	NT vs. RT	20	140	Potter et al. (1998)
Temple, TX	[W]-Sm-C (112 N)	CT, many yr	10	NT vs. RT	20	−110	Potter et al. (1998)
Temple, TX	W-Sm-[C] (28 N)	CT, many yr	10	NT vs. RT	20	300	Potter et al. (1998)
Temple, TX	W-Sm-[C] (112 N)	CT, many yr	10	NT vs. RT	20	290	Potter et al. (1998)
Tune, Norway	B-O	Cultivated ~14 yr	13	RT vs. CT	20	191	Børresen and Njøs (1993)
Urbana, IL	C-S	N/A	9	RT vs. CT	30	65	Yang and Wander (1999)
Urbana, IL	C-S	N/A	9	NT vs. RT	30	−312	Yang and Wander (1999)
Urbana, IL	C-S	N/A	9	RT vs. CT	30	377	Yang and Wander (1999)
Urbana, IL	CT (0 N)	N/A	69	C-O-S vs. C	15	733	Darmondy and Peck (1997), Odell et al. (1984)
Urbana, IL	CT (M, L, P)	N/A	69	C-O-S vs. C	15	534	Darmondy and Peck (1997), Odell et al. (1984)
Urbana, IL	CT (0 N)	N/A	69	C-O-H vs. C	15	1267	Darmondy and Peck (1997), Odell et al. (1984)
Urbana, IL	CT (M, L, P)	N/A	69	C-O-H vs. C	15	1959	Darmondy and Peck (1997), Odell et al. (1984)
Vienna, IL	C-S	Tall fescue, >10 yr	7	NT vs. CT	15	617	Kitur et al. (1994), Hussain et al. (1998), Hussain et al. (1999)
Vienna, IL	C-S	Tall fescue, > 10 yr	7	RT vs. CT	15	−253	Kitur et al. (1994), Hussain et al. (1998), Hussain et al. (1999)
Vienna, IL	C-S	Tall fescue, >10 yr	7	NT vs. RT	15	870	Kitur et al. (1994), Hussain et al. (1998), Hussain et al. (1999)
Wagga Wagga, Australia	W-lupin	Pasture, 2 yr	10	NT vs. CT	20	569	Chan et al. (1992)
Wagga Wagga, Australia	W-lupin	Pasture, 2 yr	10	RT vs. CT	20	−62	Chan et al. (1992)
Wagga Wagga, Australia	W-lupin	Pasture, 2 yr	10	NT vs. RT	20	631	Chan et al. (1992)
Warra, Australia	W (0 N)	Cultivated, cereal, 50 yr	10	NT vs. CT	10	97	Dalal et al. (1995), Hossain et al. (1996)
Warra, Australia	W (25 N)	Cultivated, cereal, 50 yr	10	NT vs. CT	10	190	Dalal et al. (1995), Hossain et al. (1996)
Warra, Australia	W (75 N)	Cultivated, cereal, 50 yr	10	NT vs. CT	10	262	Dalal et al. (1995), Hossain et al. (1996)

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Table 1. Continued.

Location	Crop or Tillage†	Prior history	Duration	Treatment‡	Depth	ΔSOC§	References
			yr		cm	g m^{-2}	
Warra, Australia	CT, W (0 N)	Cultivated, cereal, 50 yr	10	W-Legume vs. W	10	138	Dalal et al. (1995), Hossain et al. (1996)
Warra, Australia	CT, W (0 N)	Cultivated, cereal, 50 yr	10	W-G/legume vs. W	10	234	Dalal et al. (1995), Hossain et al. (1996)
Warwick, Australia	W-B	CT, 13 yr	20	NT vs. CT	10	413	Dalal (1989), Dalal et al. (1991)
Warwick, Australia	W-B	CT, 13 yr	20	NT vs. CT	10	433	Dalal (1989), Dalal et al. (1991)
Warwick, Australia	W-B	CT, 13 yr	20	NT vs. CT	10	374	Dalal (1989), Dalal et al. (1991)
Waseca, MN	C-A	N/A	11	NT vs. CT	15	650	Mielke et al. (1986)
Waseca, MN	C	N/A	6	NT vs. CT	30	−2	Mielke et al. (1986)
Woodslee, ON, Canada	CT (No N)	Maize, alfalfa, and red clover, >15 yr	35	C-O-A-A vs. C	70	1390	Gregorich et al. (2001)
Woodslee, ON, Canada	CT (N)	Maize, alfalfa, and red clover, >15 yr	35	C-O-A-A vs. C	70	2450	Gregorich et al. (2001)
Wooster, OH	C	Grass meadow, 6 yr	19	NT vs. CT	30	1236	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000
Wooster, OH	C-S	Grass meadow, 6 yr	19	NT vs. CT	30	1568	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000
Wooster, OH	C-S	Grass meadow, 6 yr	19	NT vs. RT	30	1317	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000
Wooster, OH	C-S	Grass meadow, 6 yr	19	RT vs. CT	30	251	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.
Wooster, OH	C-O-G	Grass meadow, 6 yr	19	NT vs. CT	30	1603	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.
Wooster, OH	NT	Grass meadow, 6 yr	19	C-S vs. C	30	366	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.
Wooster, OH	CT	Grass meadow, 6 yr	19	C-S vs. C	30	33	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.
Wooster, OH	NT	Grass meadow, 6 yr	19	C-O-G vs. C	30	−45	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.
Wooster, OH	CT	Grass meadow, 6 yr	19	C-O-G vs. C	30	−412	Dick et al. (1997), Mahboubi et al. (1993), Lal et al. (1994), W.A. Dick, personal communication, 2000.

† Values in parentheses represent N application rate in kg ha^{-1} yr^{-1}. Brackets represent the crop during or after which the soil samples were taken. CT, RT, and NT refer to conventional tillage, reduced tillage, and no-till, respectively. Treatments with varying fertilizer application rates or crop sequences were averaged prior to analysis. Abbreviations: A, alfalfa (*Medicago sativa* L.); B, barley (*Hordeum vulgare* L.); C, corn or maize; Cl, clover (*Trifolium* sp.); Cn, cotton; Cp, cowpea (*Vigna unguicalata* L.); F, fallow; Fert., unspecified fertilizer rate; G, grass; H, hay; L, lime; M, manure; O, oats (*Avena* spp.); Ps, pasture, P, phosphorus; S, soybean; Sf, sunflower; Sm, sorghum; V, vetch (*Vicia sativa* L.); W, wheat. N/A is not available.

‡ Treatments are arranged as the management intended to sequester soil organic C versus the conventional management (e.g., NT vs. CT; soybean–sunflower vs. continuous soybean).

§ Calculated using soil organic matter (SOM) to SOC conversion factor of 0.58 and estimates of soil bulk density where necessary (see text for further explanation).

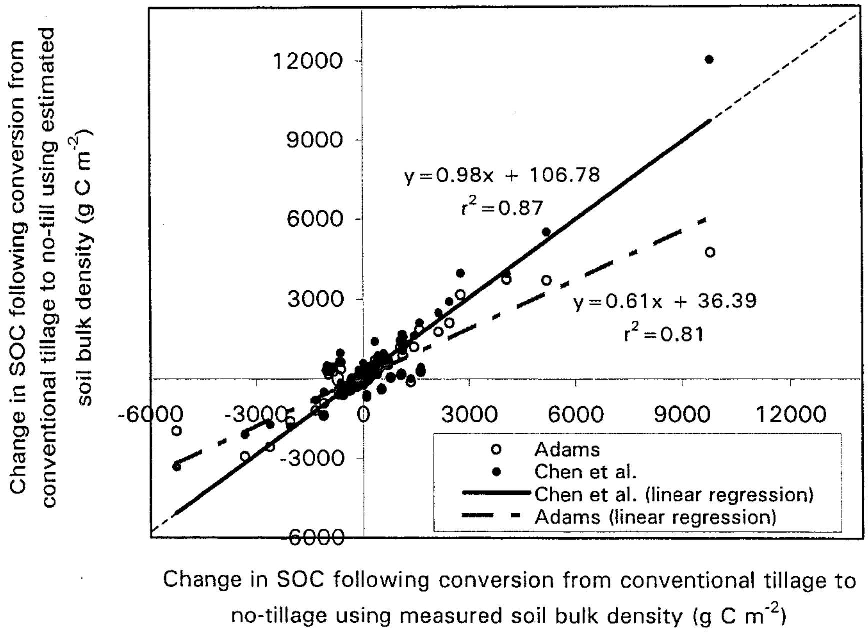

Fig. 1. Comparison between changes in soil organic C (SOC) based on measured soil bulk densities and soil bulk densities estimated using equations from Adams (1973) and Chen et al. (1998). Dashed line indicates 1:1 relationship.

as opposed to comparing NT in Year 20 to CT in Year 1). This method of analysis was intended to reduce the variability in C sequestration estimates caused by deviations in annual precipitation and temperature from the average annual mean, which has been shown to cause significant gain or loss of SOC in any particular year (Campbell et al., 2001b). For example, if changes in mean annual weather conditions cause changes in productivity and C input to the soil, these changes will be observed in both the CT and NT treatments in any given year and will counterbalance each other when the difference between the two treatments is calculated. In using this method, it is possible that a calculated change in SOC could be caused, not only by an increase in SOC under the new management, but by a decrease in SOC over time under the initial management regime. However, for this study we are primarily interested in the overall benefit of changing from conventional management to the new mode of operation, and this method satisfies that purpose.

A paired *T*-test, using Minitab v. 12.23 (Minitab, 1999), was used on all groups of paired treatments to determine whether the new management scenario was significantly different than the baseline scenario (e.g., NT vs. CT; corn–soybean–cotton [*Gossypium hirsutum* L.] rotation vs. continuous cotton). A 95% confidence interval of the mean was determined for all estimates of C sequestration, regardless of whether the mean difference in SOC between treatments was statistically significant. Treatments that were replicated using different fertilizer application rates or different crop sequence orders were averaged prior to statistical analyses, so multiple replications from one experiment would not overly influence the results or mask the results of other experiments. The effects of regional climate (i.e., annual temperature and precipitation) on C sequestration rates are not presented here, because preliminary analysis using all treatments indicated no significant correlation between climate variables and C sequestration rates.

Duration of Carbon Sequestration Rates

Soil organic C is expected to reach a new equilibrium at some period following adoption of a new management practice (Johnson et al., 1995). The most accurate method to quantify the mean duration of C sequestration rates would be to calculate the change in SOC, following a new management practice, from those experiments that have a documented land-use history that coincides with the baseline condition or treatment control (e.g., land-use history is CT, as opposed to NT). Most experiments, however, fail to meet this criteria. Instead, we used all experiments that had three or more sampling times documented throughout the experiment duration ($n = 42$) and estimated the percentage change in the annual rate of SOC sequestration ($\Delta SOC_R\%\ yr^{-1}$) using the following equation:

$$\Delta SOC_R\%\ yr^{-1} = |[(NT_2 - CT_2) - (NT_1 - CT_1)]/(NT_1 - CT_1)/(t_2 - t_1)| \times 100 \quad [1]$$

where $NT_{1\ and\ 2}$ and $CT_{1\ and\ 2}$ is SOC under NT and CT during the first and second years in which SOC was measured, respectively; SOC_R is the estimated annual rate of soil C sequestration; and t_1 and t_2 are the number of years following initiation of the experiment in which SOC was measured. Equation [1] was repeated for consecutive years in each experiment and results were plotted against respective experiment durations. As the percentage annual difference in SOC decreased with time, it was inferred that SOC was approaching a new equilibrium and C sequestration had either decreased significantly or ceased.

As noted by Huston (2001), the biological response (e.g., change in SOC) to a specific environmental condition (e.g., NT) can be difficult to detect because of the many additional conditions or confounding variables that also affect the biological response. In this study, it is possible that deficiencies in soil macro and micronutrients, fluctuations in mean annual temperature and precipitation, and other common agronomic variables act as limiting factors to C sequestration. This phenomenon is supported by experiments with different wheat rotations in Canada that indicate little or no C sequestration with a change to NT when crops were not adequately fertilized (Campbell et al., 2001a).

In an effort to reduce the effects of confounding variables, and thereby reduce the variability in estimates of C sequestration rates, a quantile regression procedure (Koenker and Bassett, 1978) was used. Quantile regression algorithms have previously been used to estimate the effect of limiting factors within ecological experiments (Cade et al., 1999). In the case of C sequestration rates, a nonlinear quantile regression algorithm will usually be most representative of the nonlinear nature of SOC dynamics over time. While such an algorithm has been developed (Koenker and Park, 1996), it is not yet available in common statistical packages. In following the theory of nonlinear quantile regression analysis, we calculated the 75% quantile of mean annual changes in sequestration rates, and subsequently applied a nonlinear regression algorithm. Algorithms that provided the best fit (highest correlation) with the data were identified using Sigma Plot v. 4 (SPSS, 1997). Both the nonlinear quantile regression equations and the traditional nonlinear regression equations are presented for comparison.

RESULTS

Vertical Distribution of Sequestered Carbon

Vertical distribution of C sequestered in the soil profile was analyzed based on a change from CT to NT (Fig. 2). Measurements of SOC best fit into four categories of sampling depth: 0 to 7, 7 to 15, 15 to 25, and 25 to 35 cm. A significant increase in SOC of 482 ± 87 g m^{-2} ($P \leq 0.000$, $\alpha = 0.05$, $n = 59$) and 73 ± 57 g m^{-2} ($P \leq 0.013$, $\alpha = 0.05$, $n = 55$) was found for the 0- to 7- and 7- to 15-cm depths, respectively. The 15- to 25-cm ($n = 41$) and the 25- to 35-cm depths ($n = 19$) did not show a significant increase in SOC when changing from CT to NT. Therefore, it is estimated that approximately 85% of the C sequestered in soil, with a change from CT to NT, occurs in the top 7 cm. Regression equations for the 0- to 7-cm depth (Eq. [2]) and 7- to 15-cm depth (Eq. [3]) are:

$$SOC_{NT} = 1.20(SOC_{CT}) + 255.12 \qquad r^2 = 0.85 \qquad [2]$$

$$SOC_{NT} = 0.93(SOC_{CT}) + 181.36 \qquad r^2 = 0.93 \qquad [3]$$

where SOC_{NT} and SOC_{CT} is SOC in grams per square meter under NT and CT, respectively.

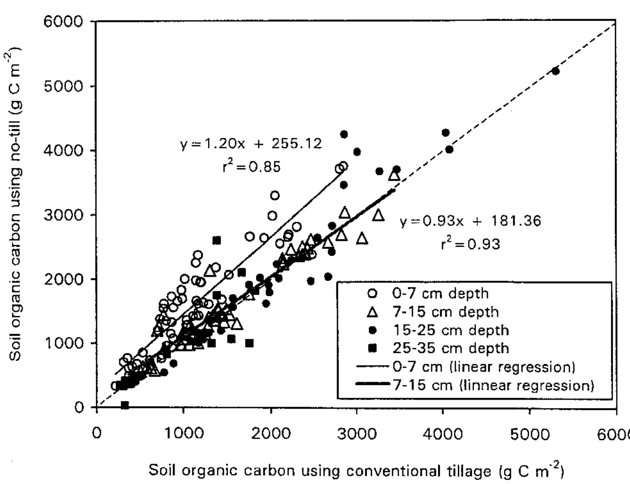

Fig. 2. Soil organic C (SOC) at different soil depths as a result of changing from conventional tillage to no-till. Dashed line indicates 1:1 relationship.

Influence of Tillage Intensity on Carbon Sequestration

A comparison of the amount of C sequestered was conducted between CT, RT, and NT to determine whether the three treatments resulted in significantly different amounts of SOC. Only experiments that included measurements for all three tillage treatments were included in the analysis ($n = 29$). Soil organic C levels under NT were significantly different from SOC levels under CT ($P \leq 0.002$, $\alpha = 0.05$) and RT ($P \leq 0.016$, $\alpha = 0.05$), while SOC levels under CT and RT were not significantly different from each other ($P \leq 0.142$, $\alpha = 0.05$). Therefore, CT and RT treatments were grouped together and referred to collectively as CT in all analyses hereinafter.

A comparison between all CT and NT paired treatments ($n = 93$) indicated that, on average, a move from CT to NT can sequester 48 ± 13 g C m^{-2} yr^{-1} (Table 2). Moving to NT in wheat–fallow rotations showed no significant increase in SOC and therefore may not be a recommended practice for sequestering SOC. Excluding wheat–fallow treatments from the analysis resulted in an average potential C sequestration rate of 57 ± 14 g C m^{-2} yr^{-1}, when changing from CT to NT (Fig. 3).

Mean C sequestration rates, with a change to NT, for rotation cropping systems were significantly greater than for continuous monocultures ($P \leq 0.087$, $\alpha = 0.1$) (Table 2). Corn–soybean rotations, with a change from CT to NT, resulted in the highest C sequestration (90 ± 59 g C m^{-2} yr^{-1}) of all monoculture and rotation cropping systems. Since corn–soybean rotations make up the majority of the rotation corn and rotation soybean categories, analyses of rotation corn and rotation soybean data were also completed with the exclusion of corn–soybean treatments (Table 2).

Influence of Enhanced Rotation Complexity on Carbon Sequestration

Enhancing rotation complexity (i.e., changing from monoculture to continuous rotation cropping, changing

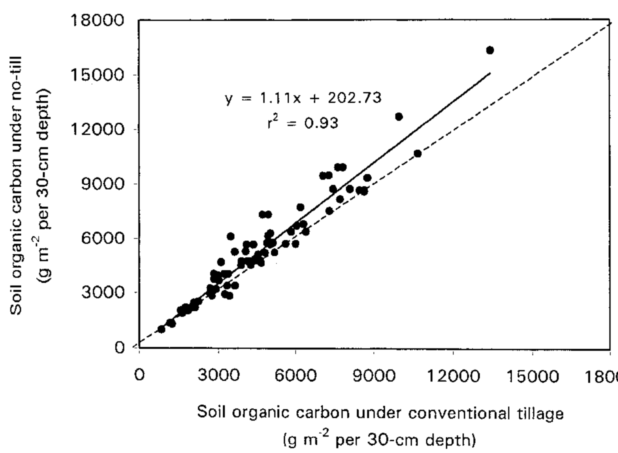

Fig. 3. Comparison of soil organic C (SOC) between conventional tillage and no-till. This analysis includes all tillage experiments except those involving wheat-fallow rotation systems (see text for explanation). Dashed line indicates 1:1 relationship.

Table 2. Soil organic C (SOC) sequestered in response to changing from conventional tillage to no-till.

Crop systems	Number of paired treatments	Average soil depth	Average duration of experiments	Mean increase in SOC		Linear regression between CT and NT‡	Mean C sequestration rate§	
		cm	yr	g m^{-2}	g kg C^{-1}†		g m^{-2} yr^{-1}	g kg C^{-1} yr^{-1}†
All crop systems	93	22	15	624 ± 157*	147 ± 31	$y = 1.10x + 158.35$	48 ± 13	12 ± 3
All crop systems (no wheat–fallow)¶	79	22	14	710 ± 175*	163 ± 35	$y = 1.11x + 202.73$	57 ± 14	14 ± 3
All continuous monocultures	39	21	16	704 ± 274*	169 ± 49	$y = 1.13x + 145.31$	44 ± 14	13 ± 4
All rotations (no wheat–fallow)	40	22	13	716 ± 233*	156 ± 51	$y = 1.07x + 357.89$	69 ± 25	15 ± 5
All corn systems	35	23	18	812 ± 271*	188 ± 51	$y = 1.01x + 744.27$	55 ± 21	14 ± 5
Continuous corn	14	25	23	932 ± 559*	211 ± 119	$y = 0.97x + 1090.65$	44 ± 27	12 ± 9
Rotation corn	21	23	15	731 ± 300*	173 ± 65	$y = 1.07x + 426.84$	62 ± 32	15 ± 7
Rotation corn (no corn–soybean)#	10	22	16	603 ± 521*	142 ± 103	$y = 1.14x + 0.70$	32 ± 19	8 ± 4
Corn–soybean rotation	11	23	14	847 ± 402*	200 ± 97	$y = 0.82x + 1676.70$	90 ± 59	21 ± 13
All wheat systems	36	19	14	347 ± 181*	108 ± 47	$y = 1.00x + 340.22$	32 ± 21	9 ± 5
Continuous wheat	10	15	12	293 ± 287*	121 ± 72	$y = 1.15x - 90.83$	25 ± 26	11 ± 7
Rotation wheat (no wheat–fallow)	12	20	10	630 ± 451*	154 ± 126	$y = 0.95x + 911.43$	74 ± 52	16 ± 13
Wheat–fallow	14	23	19	142 ± 192	59 ± 51	$y = 0.88x + 600.02$	2 ± 19	3 ± 4
All soybean systems	22	22	12	760 ± 325*	173 ± 68	$y = 1.08x + 384.06$	78 ± 38	18 ± 8
Continuous soybean	6	21	10	542 ± 402*	195 ± 144	$y = 0.88x + 1023.75$	61 ± 46	22 ± 16
Rotation soybean	16	22	13	842 ± 439*	165 ± 87	$y = 1.19x - 143.67$	84 ± 52	17 ± 10
Rotation soybean (no corn–soybean)	6	23	11	790 ± 1210	94 ± 181	$y = 1.4x - 1467.98$	77 ± 121	9 ± 18

* Indicates significant difference between SOC under conventional till (CT) and no-till (NT) at the $P = 0.05$ level.
† Represents an increase in SOC per kg SOC, as opposed to SOC per kg soil.
‡ CT and NT are denoted in the regression equations as x and y, respectively.
§ Sequestration rate was calculated as an average of sequestration rates from each experiment, not by division of the mean increase in SOC with the average duration of experiments.
¶ Wheat–fallow rotations were not shown to sequester a significant amount of C, with a change from CT to NT, and were therefore excluded from some analyses.
# Since corn–soybean rotations constituted a large part of the rotation corn and rotation soybean categories, these categories were also analyzed with the exclusion of corn–soybean rotations.

crop–fallow to continuous monoculture or rotation cropping, or increasing the number of crops in a rotation system), did not result in sequestering as much SOC (15 ± 11 g C m^{-2} yr^{-1}) on average as did a change to NT (Table 3). Changing from continuous corn to a corn–soybean rotation did not result in increased C

Table 3. Soil organic carbon sequestered in response to enhancing crop rotation.†

Enhanced crop rotation	Number of paired treatments	Average soil depth	Average duration of experiments	Mean increase in SOC		Linear regression between initial system and enhanced rotation§	Mean C sequestration rate¶	
		cm	yr	g m^{-2}	g kg C^{-1}‡		g m^{-2} yr^{-1}	g kg C^{-1} yr^{-1}‡
All rotations	97	22	25	218 ± 118*	56 ± 24	$y = 0.98x + 320.12$	15 ± 11	4 ± 2
All rotations (no c to c-s)#	85	21	26	293 ± 118*	70 ± 25	$y = 1.00x + 286.29$	20 ± 12	5 ± 2
All CT rotations (no c to c-s)	48	21	28	280 ± 167*	75 ± 40	$y = 0.95x + 527.84$	16 ± 14	4 ± 3
All NT rotations (no c to c-s)	14	25	15	171 ± 377	47 ± 56	$y = 0.93x + 524.14$	26 ± 56	6 ± 8
All rotations with grass, hay, or pasture	18	33	20	538 ± 243*	108 ± 64	$y = 1.02x + 382.69$	19 ± 8	5 ± 4
All corn rotations	35	23	30	163 ± 212	58 ± 44	$y = 0.84x + 1021.40$	6 ± 11	2 ± 2
All corn rotations (no c to c-s)	23	22	34	412 ± 209*	97 ± 53	$y = 0.89x + 966.94$	19 ± 11	4 ± 2
Continuous corn to corn-soybean	12	24	21	−311 ± 367	−46 ± 51	$y = 0.77x + 904.24$	−19 ± 19	−3 ± 4
All wheat rotations	32	19	24	271 ± 139*	64 ± 28	$y = 1.10x - 142.5$	27 ± 22	6 ± 4
All wheat rotations (no w-f to cont. w)††	15	20	20	446 ± 274*	97 ± 50	$y = 1.09x - 13.83$	51 ± 47	11 ± 8
Wheat–fallow to continuous wheat	11	17	25	104 ± 100*	33 ± 38	$y = 1.02x + 54.73$	6 ± 8	2 ± 3
All soybean rotations	13	25	11	253 ± 473	57 ± 82	$y = 0.85x + 1081.52$	26 ± 46	6 ± 8

* Indicates significant difference between soil organic carbon (SOC) under baseline condition and rotation enhancement at the $P = 0.05$ level.
† Consists of changing from monoculture to continuous rotation cropping, crop-fallow to continuous monoculture or rotation cropping, and increasing the number of crops in a rotation system.
‡ Represents an increase in SOC per kg SOC, as opposed to SOC per kg soil.
§ Initial and enhanced rotation systems are denoted in regression equations by x and y, respectively.
¶ Sequestration rate was calculated as an average of sequestration rates from each experiment, not by division of the mean increase in SOC with the average duration of experiments.
# A change from continuous corn (c) to corn–soybean (c-s) rotation was not shown to sequester a significant amount of C, and was therefore excluded from some analyses.
†† A change from wheat–fallow (w-f) to continuous wheat (w) was not shown to sequester a significant amount of C, and was therefore excluded from some analyses. Treatments with a change from wheat–fallow to non-fallow, wheat rotations were included.

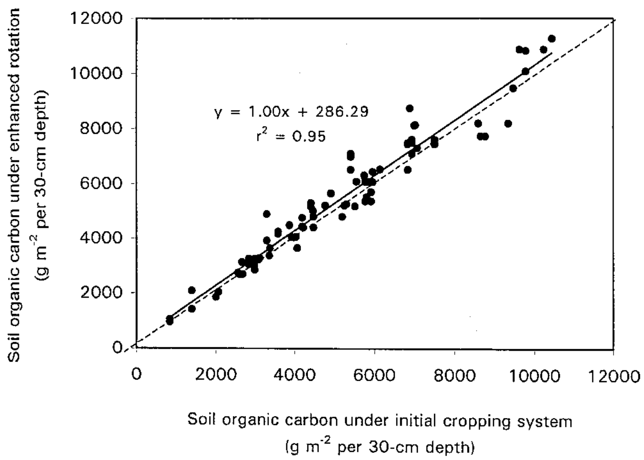

Fig. 4. Comparison of soil organic C (SOC) between initial and enhanced rotation cropping systems, which include comparisons between (i) monoculture and continuous rotation, (ii) wheat–fallow and continuous monoculture or rotation cropping, and (iii) rotation with two crops and rotation with three or more crops. This analysis includes all rotation enhancement experiments except those involving a change from continuous corn to corn–soybean rotation (see text for explanation). Dashed line indicates 1:1 relationship.

sequestration. Continuous corn generally produces more residue and C input than a corn–soybean rotation system. The decrease in residue C input may be the cause of lower C sequestration rates or possible SOC loss, as indicated by correlations found between SOC and soil residue inputs (Clapp et al., 2000; Duiker and Lal, 1999; Rasmussen et al., 1980). An analysis of all rotation enhancements, not including a change from continuous corn to corn–soybean rotations (Fig. 4), resulted in a mean C sequestration rate of 20 ± 12 g C m^{-2} yr^{-1} (Table 3).

Enhancing rotation complexity, while already using NT, did not result in a significant increase in SOC. It is possible that SOC under NT is closer to a maximum

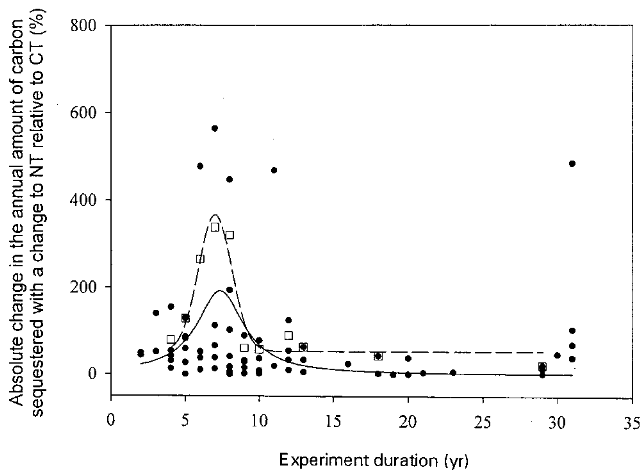

Fig. 5. The percentage change in annual soil organic C (SOC) sequestration rates under NT, relative to CT. Solid line represents data (solid circles) using a nonlinear regression equation (see Eq. [4] in text). Dashed line represents the 75% quantile of mean values (open squares) using a nonlinear regression equation (see Eq. [5] in text). A data point at Year 8 and 1236% has been excluded from the graph, for easier visual interpretation, but was included in the analysis.

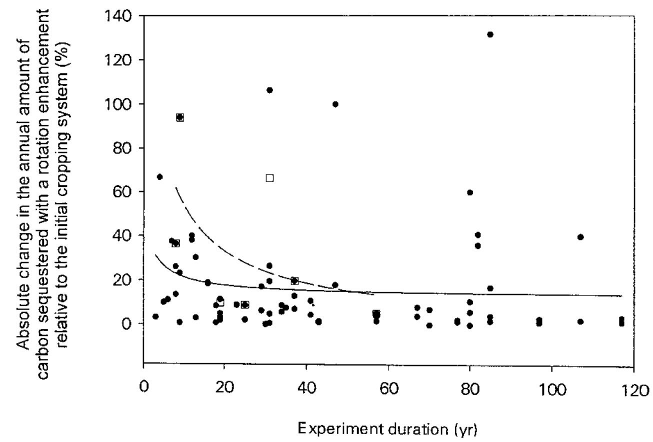

Fig. 6. The percentage change in annual soil organic C (SOC) sequestration rates under enhanced rotation, relative to monoculture or rotation with a lesser number of crops (see text for further explanation). Solid line represents data (solid circles) using a hyperbolic decay regression equation (see Eq. [6] in text). Dashed line represents the 75% quantile of mean values (open squares) using a hyperbolic decay regression equation (see Eq. [7] in text).

steady-state level than that of CT, and therefore stands to gain less SOC under a rotation enhancement. This explanation is supported by the observation that SOC accumulation in response to changes in agricultural management is likely to be greatest on lands with a history of intensive cultivation, because soils that have lost the most C stand to gain the greatest (see Johnson et al. 1995).

Many of the wheat experiments consisted of decreasing the fallow period (e.g., changing from a wheat–fallow rotation to a wheat–wheat–fallow rotation) or rotating wheat with one or more different crops (e.g., wheat–sunflower [*Helianthus annuus* L.] or wheat–legume rotations). These practices appeared to be more successful in sequestering C (51 ± 47 g C m^{-2} yr^{-1}) than moving from a wheat–fallow rotation to continuous wheat (6 ± 8 g C m^{-2} yr^{-1}). Therefore, while moving from wheat–fallow to continuous wheat may increase C residue inputs, it does not appear to increase SOC as effectively as a continuous cropping system that either rotates wheat with other crops or reduces the fallow period.

Duration of Carbon Sequestration

An analysis of the annual rate of change in SOC in response to a change to NT, reveals that the majority of SOC change occurs within the first 10- to 15-yr following implementation of NT (Fig. 5). The highest correlation ($r^2 = 0.12$) between $\Delta SOC_R\%\ yr^{-1}$ and time, using a traditional nonlinear regression analysis, was obtained using the following nonlinear regression equation:

$$y = \frac{192.39}{1 + \left(\frac{x - 7.36}{1.95}\right)^2} \qquad r^2 = 0.12 \qquad [4]$$

where y is $\Delta SOC_R\%\ yr^{-1}$ and x is the number of years the land has been in NT. Applying quantile regression techniques resulted in a higher correlation between

$\Delta SOC_R\%\ yr^{-1}$ and time ($r^2 = 0.92$), using the following nonlinear regression equation on the 75% quantile of mean values:

$$y = 52.85 + 313.54 \times \exp\left[-0.5\left(\frac{x - 7.02}{1.13}\right)^2\right] \qquad r^2 = 0.92 \qquad [5]$$

where y is $\Delta SOC_R\%\ yr^{-1}$ and x is the number of years the land has been in NT.

The correlation between $\Delta SOC_R\%\ yr^{-1}$ and time in response to enhancing rotation complexity (Fig. 6) was less explicit than that for a reduction in tillage intensity (Fig. 5). This was expected since the average C sequestration rates for rotation improvements were lower than those for a reduction in tillage intensity (Tables 2 and 3). The data for rotation enhancements were more variable than those for a reduction in tillage intensity, and there was no indication of a delayed response to sequestering SOC. In terms of nonquantile regression analysis, the following hyperbolic decay equation best fit the data ($r^2 = 0.02$):

$$y = 13.07 + \frac{109.82}{3.07 + x} \qquad r^2 = 0.02 \qquad [6]$$

where y is $\Delta SOC_R\%\ yr^{-1}$ and x is the number of years in which an enhanced rotation system has been in use. The quantile regression technique again resulted in a higher correlation between $\Delta SOC_R\%\ yr^{-1}$ and time ($r^2 = 0.30$), using the following hyperbolic decay equation on the 75% quantile of mean changes in C sequestration rates:

$$y = \frac{861.38}{5.92 + x} \qquad r^2 = 0.30 \qquad [7]$$

where y is $\Delta SOC_R\%\ yr^{-1}$ and x is the number of years in which an enhanced rotation system has been in use. With a relatively low correlation coefficient, little can be concluded regarding the duration of C sequestration rates for improvements in rotation management. However, it can be speculated that while C sequestration rates are lower for an enhancement in rotation complexity, as compared with a decrease in tillage intensity, the rate of sequestration may continue for a longer period of time (~40–60 yr).

DISCUSSION AND CONCLUSIONS

The results presented here indicate that a change from CT to NT can sequester an average 57 ± 14 g C m^{-2} yr^{-1}, excluding a change to NT in wheat–fallow systems. This average value is higher than previous estimates of 24 to 40 g C m^{-2} yr^{-1} (Lal et al., 1999) and 10 to 50 g C m^{-2} yr^{-1} (Lal et al., 1998), and is within the higher range of values (approximately 10–60 g C m^{-2} yr^{-1}) cited in a recent review by Follett (2001). An enhancement in rotation complexity, with the exception of a change from continuous corn to corn–soybean, can sequester an average 20 ± 12 g C m^{-2} yr^{-1}. This value is similar to that of 10–30 g C m^{-2} yr^{-1}, with an average of 20 g C m^{-2} yr^{-1}, estimated by Lal et al. (1998, 1999) for an improvement in rotation management. The IPCC provides a multiplication factor of 1.10, corresponding to a 10% increase in SOC, to be used in calculations of C sequestration with a change to NT (Houghton et al., 1997). Results from this study indicate that a factor of 1.16 and 1.07 may be more appropriate for a change to NT and an enhancement in rotation complexity, respectively.

Soil C sequestration rates, with a change to NT practices, can be expected to have a delayed response, reach peak sequestration rates in 5 to 10 yr, and decline to near zero in 15 to 20 yr, based on regression analyses (Fig. 5). This agrees with a review by Lal et al. (1998), based on results from Franzluebbers and Arshad (1996), that there may be little to no increase in SOC in the first 2 to 5 yr after a change in management practice, but will be followed by a large increase in the next 5 to 10 yr. Campbell et al. (2001b) concluded that wheat rotation systems in Canada will reach an equilibrium, following a change to NT, after 15 to 20 yr, provided that average weather conditions remain constant. Lal et al. (1998) estimate that rates of C sequestration may continue over a period of 25 to 50 yr. While this estimate does not coincide with our estimates of sequestration duration with a change to NT, the extended C sequestration projected by Lal et al. (1998) may be consistent with projected sequestration rates for an enhancement in rotation complexity (Fig. 6).

While estimated changes in SOC are due to either an increase in C inputs or a decrease in CO_2 efflux from the soil, it is not possible from this study, nor is it the intention, to determine which factor is responsible for the change in SOC. The position taken here is that all flows of C to and from the soil are inherently accounted for by the change in SOC (West and Marland, 2002). However, it is noted that SOC can be transported by erosional forces and deposited elsewhere in the watershed. Ignoring displacement and redistribution of SOC by erosion may lead to smaller estimates of C sequestration than actually exist.

Data used in this analysis was stratified separately with regard to a change in tillage or a change in crop rotation. In practice, these changes could occur simultaneously. It can be inferred from our results that if a decrease in tillage and an enhancement in rotation complexity occur simultaneously, the short-term (~15–20 yr) increase in SOC will primarily be caused by the change in tillage and subsequent decrease in the rate of SOC decomposition, while the long-term (~40–60 yr) increase in SOC will be primarily caused by the rotation enhancement and subsequent change in residue input and composition.

When assessing the potential for C sequestration in agricultural soils, it is particularly important to consider the crop rotation being used, in addition to tillage operations and inputs to production. Soil C sequestration rates estimated from this analysis provide increased resolution over previous analyses because of the disaggregation of data by crop type, estimates of sequestration duration, and the inclusion of confidence intervals. Estimates of C sequestration rates and the delineation of rates between cropping systems presented here may have a substantial impact on estimates of potential C storage at regional and global scales.

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