Crop Rotation and Tillage Impact on Carbon Sequestration in Saskatchewan Soils

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Abstract

Six field experiments from the Brown to Black soil zones and from light- to heavy-textured soils in Saskatchewan were conducted to quantify C sequestration under different tillage and crop rotations. Continuous cropping compared with crop rotations containing various frequency of fallow sequestered soil C ranging from 0.5 to 6.7 Mg C ha^{-1}, depending on the duration of experiments, frequency of fallow and soil texture. This increase in soil organic C under continuous cropping varied from 36 to 453 kg C $ha^{-1}yr^{-1}$. The potential for sequestering soil C with continuous cropping was greater in the Dark Brown and Black soil zones than in the Brown soil zone even through the frequency of fallow was greater in the Brown soil zone. No-tillage compared with conventional tillage also sequestered soil C ranging from 0.6 to 13.2 Mg C ha^{-1}. This increase in soil organic C under no-till varied from 50 to 528 kg C $ha^{-1}yr^{-1}$. With elimination of both tillage and fallow, the soil organic C increase was approximately 200 kg C $ha^{-1}yr^{-1}$ in the Brown soil zone regardless of soil texture, and from 600 to 800 kg C $ha^{-1}yr^{-1}$ in the Dark Brown and Black soil zones. Relative annual increase in soil organic C under no-till was approximately a linear function of clay content. This study also indicated that potential gains of soil organic C under no-till were not necessarily related to the level of soil organic C prior to adoption of no-till. Heavy-textured soils would have a greater potential for gains in soil organic C under no-till in the prairie soils.

Introduction

Agricultural soil is a source and a sink of atmospheric CO_2. Management practices that promote sequestration of soil organic C(SOC) will reduce CO_2 emission. The amount of SOC is a function of primary production and rate of decomposition of SOC. No-tillage (NT) has been known to sequester SOC compared with conventional tillage (CT), especially within the top 5- or 10-cm soil (Campbell et al., 1995; Campbell et al., 1996a; b). While the primary crop productivity between CT and NT is generally less pronounced (McConkey et al., 1996), C sequestration under NT is believed to result from reduced decomposition of SOC because of physical protection, even though direct evidence has been rarely provided.

Soil texture is known to affect both the amount of SOC and the retention of organic matter from crop residues. Linear correlations were found between soil texture and the SOC (Spain, 1990; Hassink, 1994). Additions of crop residues decompose more rapidly in sandy soils than in clay soils (Sörensen, 1981; Ladd et al., 1985). With the same input of organic material, clay soils usually contain more organic matter than sandy soils (Jenkinson, 1988). Differences in decomposition rates and amounts of SOC in various textured soils have been attributed to differences in physical protection of SOC. The stabilizing effect has been ascribed to adsorption of organics onto surfaces such as clays (Oades, 1989), encapsulation between clay particles (Tisdall and Oades, 1982) or entrapment in small pores in aggregates inaccessible to microbes (Elliott and Coleman, 1988). Liang et al. (1998) reported that soil texture directly controls the proportion of crop residue C retained in the soil. Other work has confirmed that aggregation and texture indirectly determine the level of C retained in soil by suppressing biological activity (Hassink, 1996).

Recent research suggest that gains in SOC under NT are related to clay content (Campbell et al., 1996a). Campbell et al. (1995) reported in a Swinton silt loam of the Brown Chernozem after 12 years that NT gained about 1.5 Mg ha^{-1} more C than CT with continuous wheat in the 0-15-cm soil, and NT gained about 0.5 Mg ha^{-1} more C than CT with fallow wheat. In a coarse-textured Hatton fine sandy loam of the Brown Chernozem, Campbell et al. (1996b) reported that NT gained about 1.4 Mg C ha^{-1} more than CT with continuous wheat in the 0-15-cm soil after 11 years. On a similar study conducted on a heavy-textured Sceptre clay of the Brown Chernozem, Campbell et al. (1996a) reported that both NT in the 0-15-cm soil gained 5 Mg C ha^{-1} more than their conventional tillage counterparts with both continuous and fallow wheat after 11 years. However, because of variations in the duration of experiments and limited number of soil types reported by Campbell et al. (1995; 1996a, b) it is not clear whether these increases in SOC under NT were quantitatively related to soil texture. This information may be important for providing a quantitative measure of C sequestration under NT for Canadian prairie soils. The objectives of this study were 1) to quantify the impact of crop rotations and tillage on C sequestration, and 2) to quantify the impact of soil texture on C increase under NT in six Saskatchewan soils.

Materials and Methods

Experimental design, crop systems and tillage practices were similar for the Swinton silt loam, Sceptre clay and Hatton fine sandy loam. Treatments that are relevant to this study are briefly described. Tillage systems for these studies consisted of minimum tillage (MT) and no-tillage (NT). Herbicides were used to control weeds on NT. Pre-seeding tillage with one operation of heavy-duty sweep cultivator with attached rodweeder, or mounted harrow, was used for MT. No-tillage fallow involved herbicides only while MT fallow used herbicides plus one or two operations with wide-blade cultivator and/ or heavy-duty cultivator. A combination of grasshoppers and dry weather produced severe wind erosion for MT in 1984, so NT was used on the fallow phase of MT fallow-wheat (F-W) until 1988, when there was adequate residue to control erosion. Planting was performed with an offset disc press drill (Dyck and Tessier, 1986) for NT and a conventional hoe drill for MT. Plots received approximately 10 kg P ha^{-1} as monoammonium phosphate, seed-placed. Until 1990, N fertilizer as ammonium nitrate was broadcasted before seed-bed preparation at a rate based on soil tests (Saskatchewan Agriculture, 1988). After 1990, up to 45 kg N ha^{-1} was applied with the seed and additional required N fertilizer was broadcast. Fall applications of 2,4-D ester were used to control winter annual broadleaf weeds in all treatments. Two crop rotations, continuous wheat (Cont W) and F-W were used. Each phase of F-W, the fallow phase \(F)-W] and the wheat phase \F-(W)] was presented each year. Other details of the management of experiments in the Brown soil zone are reported elsewhere (Campbell et al. 1995, Campbell et al. 1996 a, b).

On the Melfort silty clay loam site, three tillage systems (CT, MT and NT) under a F-W were used. The heavy-duty cultivator was used for tillage operations on summer-fallow; in some years a rodweeder replaced one or more of the cultivation operations for CT. The first summer-fallow tillage operation was performed usually in early June with subsequent operations performed on an as needed basis usually at 2 to 3 week intervals. Treatments of NT for weed control generally received a first spraying in late May or early June with repeat applications as required usually in July and August. Tillage operation for MT was similar to that of CT, but the number of tillage operation was reduced to twice a year by substituting herbicides for some weed control. From 1969 to 1976, all tillage systems including NT received tillage before seeding (Zentner et al., 1990). Other details of the experiment are reported (Zentner et al., 1990).

On the Indian Head clay site, crop systems consisted of three, 4-yr rotations. One crop rotation included 1 yr of fallow in four, fallow-spring wheat-spring wheat-winter wheat (FWWwW) while the other crop rotations were continuous cropping systems, pea-spring wheat-flax-winter wheat (PWXwW) and spring wheat-spring wheat-flax-winter wheat (WWXwW))(Lafond et al., 1992). Three tillage systems (CT, MT and NT) were used. Soil disturbance in NT occurred only during the seeding operation. Minimum tillage included only one tillage operation in the spring using a chisel plow equipped with 41-cm sweeps. Conventional tillage included fall tillage after harvest and spring tillage before seeding. In the NT system, weeds on fallow were controlled with herbicide applications. In the CT system, weed control on fallow was by mechanical means, with 2 to 4 cultivations and 0 to 3 rodweeder operations per year. Weed control on MT fallow was accomplished with herbicides and one operation with heavy duty cultivator followed by one operation with a rod weeder. Details of the experiment on the Indian Head clay can be found (Lafond et al., 1992).

On the Elstow clay loam, two crop rotations including a continuous cropped rotation of wheat-wheat-canola-wheat-wheat-flax \WW(C)WWX] and a rotation containing one fallow in three years, fallow-flax-wheat-fallow-canola-wheat (FXWFCW), were used. Two phases of fallow-containing rotations were sampled \FXWF(C)W] and \FX(W)FCW]. Tillage systems included CT and NT. Herbicides were used exclusively for weed control in the NT treatments. Normally this involved the use of phenoxy herbicides (2,4-D or MCPA) in late fall or early spring for control of broadleaved winter annuals. In the CT cropping system, tillage with a cultivator equipped with spikes or sweeps was performed on stubble in late fall. Early spring tillage was carried out with a cultivator equipped with mounted harrows followed by cultivating or rod weeding just prior to seeding for all CT treatments. The tillage fallow normally required three operations with a cultivator and mounted harrows, plus one or two operations with a cultivator or rod-weeder. Seeders were used including a double-disc press drill, an offset double disc press drill and a narrow hoe press drill. Management practices such as N and P fertilizers were reported (Brandt, 1992). Other information regarding soil types, duration of experiments, soil texture and crop rotations are reported (Table 1).

Soil samples were taken from the 0- to 7.5-cm and 7.5- to 15-cm depths for the Hatton fine sandy loam, Swinton silt loam and Sceptre clay in the fall of 1993, for the Melfort silty clay loam and Indian Head clay in the fall of 1994, and for the Elstow clay loam in the fall of 1995. Four soil cores per plot were extracted and composited by depth. The resulting samples were air-dried and sieved through a 2-mm sieve. Crop residues remaining on the sieve were discarded. Representative sub-samples were ground with a rollermill (<153 μm) and analyzed for SOC using an automated combustion technique (Carlo Erba™, Milan, Italy). To remove carbonates we pretreated soil with phosphoric acid in a tin capsule after weighing, then drying the sample for 16 h at 75^{o}C prior to analysis for C. Because of possible changes in soil bulk density as a result of crop rotations, especially tillage practices, the amount of SOC in the 0-7.5-cm and 7.5-15-cm depth was calculated on an equivalent mass basis within each layer (Ellert and Bettany, 1995).

For the Hatton fine sandy loam, Swinton silt loam and Sceptre clay, contrasts were used to separate treatment differences. For these three sites two contrasts were selected to compare crop rotation effect including Cont W versus F-W, and F-(W) versus (F)-W. Only one contrast was selected to compare tillage effect, MT versus NT. For the Melfort silty clay loam and Elstow clay loam experimental data were statistically analyzed as one or two-factor factorial, randomized complete block design, while for the Indian Head clay a split-plot design with tillage in main plots and crop rotations in sub-plots was used. For mean separations, the least significant differences were used at *P=0.05* level.

Results and Discussion

The SOC for the Hatton fine sandy loam, Swinton silt loam and Sceptre clay have been reported previously (Campbell et al., 1995, 1996 a, b). In general, there was no interaction effect of crop rotations and tillage on SOC at any site. Thus, tillage and crop rotation effect on SOC will be discussed separately. The specific phase of crop or fallow within the same rotation had no impact on SOC in either the 0-7.5-cm or 7.5-15-cm soil for the Hatton fine sandy loam, Swinton silt loam, Sceptre clay and Elstow clay loam soil (Tables 2 & 3). This was expected because one crop year would not produce in any significant change in SOC. However, continuous cropping, compared with fallow-containing rotations, had a higher amount of SOC in the 0-7.5-cm soil for all sites except for the Sceptre clay (Tables 2 & 3). This same effect was extended to the 7.5-15-cm soil for the Swinton silt loam and Elstow clay loam. Increase in SOC with continuous cropping varied from 0.5 to 6.7 Mg C ha^{-1} in the 0-15-cm soil, mainly depending on the duration of experiments and soil type. These increases in SOC were 36 kg C $ha^{-1}yr^{-1}$ for the Sceptre clay, 100 kg C $ha^{-1}yr^{-1}$ for the Hatton fine sandy loam, 212 kg C $ha^{-1}yr^{-1}$ for the Swinton silt loam, 300 kg C $ha^{-1}yr^{-1}$ for the Indian Head clay, and 453 kg C $ha^{-1}yr^{-1}$ for the Elstow clay loam. It is clear that the potential for sequestering soil C with continuous cropping was greater in the Dark Brown and Black soil zones than in the Brown soil zone even through the frequency of fallow was greater in the Brown soil zone. It should be seen that soils in the Dark Brown and Black soil zones also had higher levels of SOC than in the Brown soil zone. Greater amounts of SOC sequestered with continuous cropping in the Dark Brown and Black soil zones contradicted with the hypothesis of Janzen et al. (1998), who suggest that the ability to increase SOC would depend not only on the amount of residue C inputs, but also on the C content of the soil at the time of initiation with improved management practices. However, because we do not have SOC at the initiation of adoption of NT at the Dark Brown and Black soil zone sites we can not determine if the difference between cropping systems is due to increasing SOC with continuous cropping or to decreasing SOC with fallow-containing systems.

Tillage practices had significant impacts on SOC only in the 0-7.5-cm soil for all sites (Tables 4 & 5). Increase in SOC under NT in the 0-15-cm soil varied from 0.6 to 13.2 Mg ha^{-1}, depending mainly on the duration of field experiments and soil texture. Annual increase in SOC under NT amounted from 50 to 528 kg C ha^{-1} yr^{-1}. Carbon increase under NT in the Hatton fine sandy loam was greater than that in the Swinton silt loam. This greater increase in SOC may have been resulted from reduced wind erosion under NT. In general, wind erodible fraction (a fraction of soil dry aggregates in the fall less than 0.84 mm) rarely exceeded 60% in the Swinton silt loam and Sceptre clay (unpublished data). However, wind erodible fraction could exceed more than 60%, or even close to 80% in the coarse-textured soil. Anderson and Wenhardt (1966) considered that wind erodible fraction of greater than 60% would cause severe wind erosion on prairie soils. As noted in the methods, severe erosion was noted for MT in 1984. Wind erosion was not specifically noted in subsequent years but may have occurred. Carbon increase in coarse-textured soils under NT would be greater because of reduced wind erosion in the Brown soil zone.

It is of interest to note that MT was almost as effective as NT in sequestering SOC compared with CT in the Indian Head clay while the same treatment had no significant impact on SOC in the Melfort silty clay even though these two soils are in the same soil zone. These contrasting results between the two sites in the Black soil zone may be explained by frequency of fallow and associated frequency of tillage. At the Melfort site, MT had an average of 1.5 tillage per year with most tillage during fallow when the soil was moist that would promote SOC mineralization. At the Indian Head site MT had an average of one tillage per year.

It is very important to know other possible mechanisms that favor C sequestration under NT in addition to reduced wind erosion in light-textured soils. It was generally consistent that the difference in crop yields between CT and NT within each site was insignificant, with exceptions of the Indian Head clay and the Elstow clay loam, where grain yields were reported to be higher under NT (Brandt, 1992; Lafond et al., 1992). Assuming that the increase in yield under NT would directly translate to increase in crop residue returns to the soil, it would be unlikely that this alone would contribute to significant buildup of SOC.

No-tillage can improve soil aggregation and reduce losses of SOC that result from cultivation

(Havlin et al., 1990; Carter, 1992; Weill et al., 1989). Our observations from these tillage experiments confirmed that NT improve soil physical properties by increasing wet aggregate stability and mean weight diameter (unpublished data). Changes in these physical properties under NT would favor formation of macro-aggregates, reduce accessibility of substrates, especially within micro-aggregates, thus decrease decomposition of SOC.

In order to assess the effect of soil texture on SOC increase the relative annual increase in SOC was calculated as follows

where RAISOC (% yr^{-1}) was relative annual increase in SOC per year under NT, SOC_{NT} was the amount of SOC under NT (Mg C ha^{-1} in the 0-15-cm soil), SOC_{CT} was the amount of SOC under CT or MT (Mg C ha^{-1} in the 0-15-cm soil), and Year was number of years since the establishment of tillage experiments.

Relative annual increase in SOC under NT varied from 0.2 to 1.2% yr^{-1}, mainly depending on the clay content of soil (Fig. 1). If the value of RAISOC for the Hatton fine sandy loam was excluded because of probably additional C sequestration associated with reduced wind erosion under NT, there was a linear relationship between RAISOC and the clay content of soil, indicating the role of soil clay content in sequestering C under NT.

Conclusions

Elimination of fallow in a crop rotation increased SOC from 36 to 453 kg C $ha^{-1}yr^{-1}$. The potential for gains in SOC by extending crop rotation was greater in the Dark Brown and Black soil zones than in the Brown soil zone, even though the frequency of fallow in a crop rotation in the Dark Brown and Black soil zones was less than in the Brown soil zone. This shows that the detrimental impact of fallow in depleting SOC in the Dark Brown and Black soil zones was greater than in the Brown soil zone. Similarly, NT in comparison with CT increased SOC from 50 to 528 kg C $ha^{-1}yr^{-1}$. The potential for gains in SOC with conservation tillage was also greater in the Dark Brown and Black soil zones than in the Brown soil zone. However, relative annual increase in SOC under NT over CT or MT increased approximately linearly with increasing clay content. The combined impact of continuous cropping with adoption of NT resulted in increase in SOC by approximately 200 kg C $ha^{-1}yr^{-1}$ in the Brown soil zone regardless of soil texture, and from 600 to 800 kg C $ha^{-1}yr^{-1}$ in the Dark Brown and Black soil zones. This study also indicated that potential gains of SOC with elimination of fallow and tillage are not necessarily related to the SOC amount prior to adoption of the improved management practices. For instance, the Melfort silty clay loam contained the largest amount of SOC, and also gained the highest amount of SOC under NT. The concept of using relative annual increase of SOC under NT may be useful in determining C increase under NT without actual measurements of SOC change over time.

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References

Anderson, C.H. and A. Wenhardt. 1966. Soil erodibility, fall and spring. Can. J. Soil Sci. 46:255-299.
Brandt, S.A. 1992. Zero vs. conventional tillage and their effects on crop yield and soil moisture.

Can. J. Soil Sci. 72:679-688.
Campbell, C.A., B.G. McConkey, R.P. Zentner, F. Selles, and D. Curtin. 1996a. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Can. J. Soil Sci. 76:395-401.
Campbell, C.A., B.G. McConkey, R.P. Zentner, F. Selles, and D. Curtin. 1996b. Tillage and crop rotation effects on soil organic C and N in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. Soil & Tillage Research 37:3-14.
Campbell, C.A., B.G. McConkey, R.P. Zentner, F.B. Dyck, F. Selles, and D. Curtin. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. Can. J. Soil Sci. 75:449-458.
Carter M.R. 1992. Influence of reduced tillage systems on organic matter, microbial biomass, macro-aggregate distribution and structure stability of the surface soil in a humid climate. Soil Tillage Res. 23:361-372.
Dyck, F.B. and S. Tessier. 1986. Zero-till drill development at the Swift Current research station. Can. Soc. Agric. Engineering, Ottawa, ON. Pap. 86-210.
Ellert, B.H. and J.R. Bettany. 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Can. J. Soil Sci. 75:529-538.
Elliott, E.T. and D.C. Coleman. 1988. Let the soil work for us. In H. Eijsackers and A. Quispel (eds.) Ecological Implications of Contemporary Agriculture. Proceedings 4th European Ecology Symposium, Wageningen. Munksgaard, Copenhagen. pp. 23-32.
Hassink, J. 1996. Preservation of plant residues in soils differing in unsaturated protective capacity. Soil Sci. Soc. Am. J. 60:487-491.
Hassink, J. 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. Soil Biol. Biochem. 26:1221-1231.
Havlin, J.L., D.E. Kissel, L.D. maddux, M.M. Claasen and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448-452.
Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGill, and R.P. Zentner. 1998. Management effects on soil C storage in the Canadian prairies. Soil & Tillage Res. 47:181-195.
Jenkinson, D.S. 1988. Soil organic matter and its dynamics. In A. Wild (ed.) Soil Conditions and Plant Growth. 11th ed, Longman, New York. pp. 564-607.
Ladd, J.N., M. Amato and J.M. Odes. 1985. Decomposition of plant material in Australian soils: III. Residual organic and microbial biomass C and N from isotope-labelled legume material and soil organic matter, decomposing under field conditions. Australian. J. Soil Res. 23:603-611.
Lafond, G.P., H. Loeppky, and D.A. Derksen. 1992. The effects of tillage systems and crop rotations on soil water conservation, seeding establishment and crop yield. Can. J. Plant Sci. 72:103-115.
Liang, B.C., E.G. Gregorich, A.F. MacKenzie, M. Schnitner, R.P. Voroney, C.M. Monreal, and R.P. Beyaert. 1998. Retention and turnover of corn residue carbon. Soil Sci. Soc. Am. J. 62:1361-1366.
McConkey, B.G., C.A. Campbell, R.P. Zentner, F.B. Dyck, and F. Selles. 1996. Long-term tillage on spring wheat production on three soil textures in the Brown soil zone. Can. J. Plant Sci. 76:747-756.
Oades, J.M. 1989. An introduction to organic matter in mineral soils. In J.B. Dixon and S.B. Weed (eds.) Minerals in Soil Environments. Soil Sci. Soc. Am., Madison. pp. 89-159.
Saskatchewan Agriculture. 1988. Tillage practices that reduce soil erosion. Soil Conserv. Notes. ISSN 0829-5751.
Sörensen, L.H. 1981. Carbon-nitrogen relationships during the humification of cellulose in soils containing different amounts of clay. Soil Biol. Biochem. 13:313-321.
Spain, A. 1990. Influence of environmental conditions and some soil chemical properties on the

carbon and nitrogen contents of some tropical Australian rainforest soils. Australian J. Soil Res. 28:825-839.

Tisdall, J.M. and J.M. Oades. 1982. Organic matter and water stable aggregates in soils. J. Soil Sci. 33:141-163.

Weill, A.N., C.R. De Kimpe and E. McKyes. 1989. Effect of tillage reduction and fertiliser on soil macro- and microaggregates. Can. J. Soil Sci. 68:489-500.

Zentner, R.P., K.E. Bowren, W. Edwards, and C.A. Campbell. 1990. Effects of crop rotations and fertilization on yields and quality of spring wheat grown on a Black Chernozem in north-central Saskatchewan. Can. J. Plant Sci. 70:387-397.

Table 1. Soil types, locations, duration of tillage experiments, soil texture, crop rotations, tillage and soil organic C in six mid- to long-term tillage experiments in Saskatchewan

Soil	Taxonomy	Location	Years after initiation	Soil texture		Crop rotation[1]	Tillage system[2]
				Sand	Clay		
			--- yr ---	------ % ------			
Hatton fine sandy loam	Orthic Brown Chernozem	50°24'N 108°00'W	11	70.8	15.3	Cont W, F-(W), (F)-W	MT, NT
Swinton silt loam	Orthic Brown Chernozem	50°16'N 107°44'W	12	32.6	27.6	Cont W, F-(W), (F)-W	MT, NT
Sceptre clay	Rego Brown Chernozem	50°36'N 107°48'W	11	25.7	42.7	Cont W, F-(W), (F)-W	MT, NT
Indian Head clay	Rego Black Chernozem	50°32'N 103°40'W	8	16.3	63.1	W-W-X-wW, P-S-X-wW, F-W-W-wW	CT, MT, NT
Melfort silty clay loam	Orthic Black Chernozem	52°51'N 104°37'W	25	16.6	41.4	F-(W)	CT, MT, NT
Elstow clay loam	Orthic Dark Brown Chernozem	52°22'N 108°50'W	15	29.0	31.0	W-W-(C)-W-W-X F-X-W-F-(C)-W F-X-(W)-F-C-W	CT, NT

[1] Letters in the parenthesis indicate the rotation phase sampled, W=spring wheat, F=fallow, X=flax, wW=winter wheat, P=pea, C=canola.
[2] CT=conventional tillage (full tillage after crop, preseeding tillage, tillage as required for weed control during fallow)
MT=minimum tillage preseeding tillage, herbicides and tillage used for weed control during fallow)
NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

Table 2. Impact of crop rotations on soil organic C in the Hatton fine sandy loam, Swinton silt loam and Sceptre clay.

Crop rotation	Hatton fine sandy loam		Swinton silt loam		Sceptre clay	
	mg C g^{-1}	Mg C ha^{-1}	mg C g^{-1}	Mg C ha^{-1}	mg C g^{-1}	Mg C ha^{-1}
0-7.5 cm						
F-(W)	8.7	8.1	15.8	13.0	16.3	12.1
(F)-W	9.0	8.5	15.4	12.7	15.7	11.6
Cont W	10.0	9.4	17.7	14.6	17.2	12.8
Contrast “F-(W) vs (F)-W”	>0.10	>0.10	>0.10	>0.10	>0.10	>0.10
Contrast “Cont W vs F-W”	0.05	0.05	<0.001	<0.001	>0.10	>0.10
7.5- 15 cm						
F-(W)	7.8	8.7	14.9	13.6	14.1	13.8
(F)-W	9.2	10.0	14.7	13.9	13.7	13.5
Cont W	8.5	9.4	15.7	14.6	13.4	13.2
Contrast “F-(W) vs (F)-W”	>0.10	>0.10	>0.10	>0.10	>0.10	>0.10
Contrast “Cont W vs F-W”	>0.10	>0.10	<0.10	0.10	>0.10	>0.10

Table 3. Impact of crop rotation on soil organic C in the Elstow clay loam and Indian Head clay.

Soil	Crop rotations	Soil organic C	
		mg C g^{-1}	Mg C ha^{-1}
Elstow clay loam			
0-7.5 cm	W-W-(C)-W-W-X	41.2a	28.7a
	F-X-W-F-(C)-W	35.6b	24.8b
	F-X-(W)-F-C-W	35.4b	24.7b
7.5-15 cm	W-W-(C)-W-W-X	35.9a	28.0a
	F-X-W-F-(C)-W	31.9b	24.9b
	F-X-(W)-F-C-W	32.7b	25.5b
Indian Head clay			
0-7.5 cm	P-S-X-wW	32.2a	21.8a
	W-W-X-wW	32.8a	22.1a
	F-W-W-wW	29.9b	20.2b
7.5-15 cm	P-S-X-wW	23.9a	18.3a
	W-W-X-wW	23.6a	18.0a
	F-W-W-wW	23.1a	17.6a

Means followed by the same letters within the same column and the same depth of the same soil are not significantly different at *P=0.05* probability level.

Table 4. Impact of tillage on soil organic C in the Hatton fine sandy loam, Swinton silt loam and Sceptre clay.

Tillage	Hatton fine sandy loam		Swinton silt loam		Sceptre clay	
	mg C g^{-1}	Mg C ha^{-1}	mg C g^{-1}	Mg C ha^{-1}	mg C g^{-1}	Mg C ha^{-1}
0-7.5 cm						
MT	9.3	8.7	15.9	13.1	15.7	11.7
NT	10.7	10.0	17.2	14.1	17.8	13.3
Contrast “MT vs NT”	0.05	0.10	<0.01	0.01	0.05	0.05
7.5- 15 cm						
MT	8.5	9.3	15.6	14.5	13.6	13.2
NT	8.5	9.4	15.2	14.1	14.4	14.2
Contrast “MT vs NT”	>0.10	>0.10	>0.10	>0.10	>0.10	>0.10

Table 5. Impact of tillage on soil organic C in the Melfort silty clay loam, Elstow clay loam and Indian Head clay.

Soil	Tillage	Soil organic C	
		mg C g^{-1}	Mg C ha^{-1}
Elstow clay loam			
0-7.5 cm	CT	35.2b	24.6b
	NT	39.6a	27.6a
7.5-15 cm	CT	33.3a	26.0a
	NT	33.6a	26.2a
Melfort silty clay loam			
0-7.5 cm	CT	56.7b	38.7b
	MT	59.3b	40.5b
	NT	67.0a	45.7a
7.5-15 cm	CT	55.1a	47.9a
	MT	63.6a	55.3a
	NT	62.2a	54.1a
Indian Head clay			
0-7.5 cm	CT	28.7b	19.4b
	MT	33.0a	22.2a
	NT	33.3a	22.5a
7.5-15 cm	CT	23.0a	17.6a
	MT	24.1a	18.4a
	NT	23.4a	17.9a

Means followed by the same letters within the same column and the same depth of the same soil are not significantly different from each other.

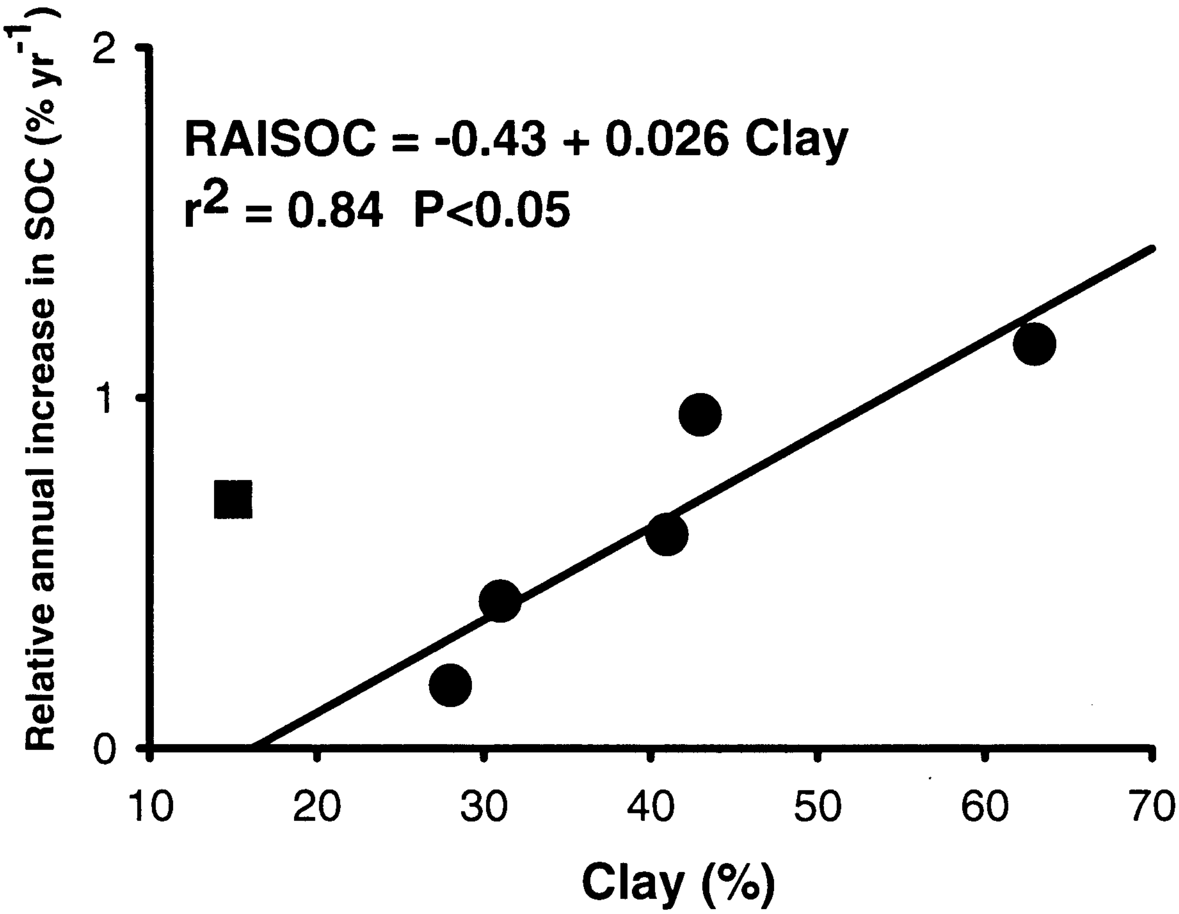

Figure 1. The relationship between relative annual increase in soil organic C under no-tillage over systems using tillage for some weed control and clay content of soil. ■ Observation was made for the coarse-textured soil of Hatton fine sandy loam and wasn't used for the regression analysis.