EFFECT OF TILLAGE ON SELECTED SOIL BIOCHEMICAL CHARACTERISTICS IN A COARSE- AND MEDIUM-TEXTURED SOIL IN SOUTHWESTERN SASKATCHEWAN

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ABSTRACT

Characterization of soil organic matter is valuable for identifying the overall quality of soils. Crop management will influence soil quality. Some changes may become apparent more quickly than others and may depend upon soil texture and environmental conditions under which production is conducted. We assessed the impact of tillage [no-tillage (NT) vs conventional mechanical tillage (CT)] and fallow frequency [continuous wheat (*Triticum aestivum* L.)(Cont W) vs fallow-wheat (F-W)] on selected soil quality attributes on a Hatton fine sandy loam soil at Cantuar and a silt loam soil at Swift Current, in semiarid southwestern Saskatchewan. Measurements made in the O-7.5 cm depth at 4-year intervals after the study was initiated are discussed. In the coarse-textured soil, significant treatment effects on total organic C and N were only observed after 11-12 years. In the coarse-textured soil, labile organic constituents, such as C and N mineralization (C_{min} and N_{min}), showed treatment effects in 7 years, but microbial biomass-C (MB-C) and specific respiratory activity (SRA) (ratio C_{min}/MB-C) only showed significant effects after 11 years. In the medium-textured soil, total organic C and N and MB-C were not significantly affected by treatment even after 12 years, and Crnin and SRA were only significantly affected after 12 years; N_{min} was affected after 8 years. In the coarse-textured soil, soil quality attriiutes were generally greater in no-tillage (NT) systems than in conventional mechanical tillage (CT) or minimum tillage (MT), and greater in Cont W than in F-W systems. However, in the medium-textured soil, tillage did not influence the soil quality attriiutes, but cropping more frequently resulted in higher C_{min}, N_{min} and SRA. In both soils the response of the labile soil attriiutes was generally a function of crop residues returned to the land. Of the soil quality attriiutes tested, C_{min} and N_{min} were the most sensitive to the agronomic treatments. More research is required to determine why changes in soil quality become apparent more quickly in the coarser-textured soil.

INTRODUCTION

Throughout the Canadian prairies, producers are adopting reduced tillage practices for grain production (Lafond et al. 1990, Larney et al. 1994). This trend may result in changes in soil quality (Soil and Water Conserv. Soc. 1995). Soil organic matter is an important soil quality attribute which influences the productivity and physical well-being of soils. Thus, it is important, both from an economics and environmental standpoint, to determine how this change in tillage practice will influence soil quality.

Based on long-term studies conducted in southwestern Saskatchewan, we recently showed that, over an 11 - 12 year period, increases in C storage in the 0- 15 cm depth due to adoption of no-tillage (NT) were small (0 to 3 t ha^{-1}) and directly related to clay content (Campbell et al. 1996b).

Most of the differences were observed in the O-7.5 cm depth with little change in the 7.5-15 cm depth. It is well known that the labile components of soil organic matter change, and will reach a new steady state more quickly than does total organic matter (McGill et al. 1988). In the USA, Doran (1980) reported that microbial biomass (MB) and potential mineralizable N were greater for NT than for CT in the O-7.5 cm depth. Most workers report that soil biochemical characteristics decrease as the frequency of fallowing increases (Campbell et al. 1997).

The objective of this study was to determine the influence of tillage management and fallow frequency on changes in selected soil quality attributes over an 11-12 year period for a coarse-textured and medium-textured soil in the Brown soil zone, under monoculture spring wheat (Triticum aestivum L.) systems.

MATERIALS AND METHODS

The two experimental sites (at Cantuar and Swift Current) and the experimental methods used are described elsewhere (Campbell et al. 1995, 1996a, b). In all cases there were two rotations, a Cont W and a fallow wheat (F-W) system each with two tillage treatments, no-tillage (NT) vs either conventional tillage (CT) or minimum tillage (MT). For the soil biochemical analyses we only analyzed the cropped phase of F-W and only 3 replicates.

Soil samples were taken from the O-7.5 and 7.5-15 cm depth in April 1986, 1990 and 1994, but only the results for the O-7.5 cm depth (main depth showing significant differences) are discussed. We determined total organic C and total N on air-dry soil using Carlo Erba combustion method, net N mineralization on air-dry soil by incubating at 35°C at optimum moisture for 16 wk; C_{min} and microbial biomass on field moist soil. The description of methods used for soil biochemical analyses are presented by Biederbeck et al. (1994).

RESULTS AND DISCUSSION

Coarse-textured soil at Cantuar

It took 11 years before we observed significant treatment effects on total organic C or N, microbial biomass-C (MB-C), and specific respiratory activity (SRA); however, changes in C_{min} and N_{min} were apparent after 7 years whether expressed on an absolute or relative (to organic matter) basis (Table 1). Generally, soil quality attributes were greater in no-tillage (NT) systems than in tilled systems, and greater in Cont W than in F-W systems. After 11 years there was a close direct association between the labile attributes (e.g., C_{min}, N_{min} and MB-C) in the O-7.5 cm depth and the estimated mean annual straw produced, but total organic C and N and SRA were not closely associated with straw (Fig. 1).

We estimated the relative responsiveness of the soil quality attributes to fallow frequency and to tillage by calculating the ratios shown in Table 2. We assumed that the higher the ratio the more sensitive was the index. The sensitivity of most attributes to tillage was higher for F-W than for Cont W, perhaps because soil moisture was closer to optimum for microbial activity more frequently in F-W, and also because the F-W system was tilled more often than Cont W. We expected the more labile soil quality attributes to be more sensitive than the less labile total organic

C and N, and this was true for F-W, but for Cont W this was only true for N_{min}. The sensitivity of the soil quality attributes to fallow frequency was generally greater in tilled than in NT systems (Table 2). Most of the more labile attributes were more sensitive than total organic C and N to fallow frequency.

Medium-textured soil at Swift Current

The silt loam soil at Swift Current has about 60-80% more organic matter than the fine sandy loam at Cantuar (Tables 1 and 3). Perhaps this is one reason why we rarely observed significant treatment effects on even the more labile soil quality attributes until year 12 (Table 3). By year 4 there was some indication that C_{min} (and possibly N_{min}) were lower in the tilled F-W system than in the other treatments, but after 8 years these effects were no longer apparent. Thus, they may have been spurious variations after year 4. After 12 years there was a tendency for tilled F-W to have the lowest total organic C and N. Among the labile attributes, C_{min}, N_{min} and SRA were significantly greater for Cont W than for F-W, but there was no consistent effect of tillage on these characteristics. The response of the more labile attributes to cropping frequency was probably associated with the higher crop residues produced in Cont W (Table 4). Thus, correlation between C_{min} or N_{min} and mean annual straw production was 0.95, significant at $P = 0.05$. Tillage did not influence straw production in this soil.

Sensitivity analysis conducted as for the coarse-textured soil showed that the more labile attributes were more sensitive than total organic C and N to fallow frequency (Table 5). However, the converse was true in the case of sensitivity to tillage treatment. The latter was surprising and warrants further study.

Overall, our results suggest that, even for the more labile and dynamic soil attributes, it might take several years before the influence of crop management becomes apparent. Further, they show that evidence of an effect will be more quickly apparent in low organic matter soils where the relative difference is likely to be larger. It is also possible that we discern treatment effects on the labile constituents less readily in heavier textured soils because the biochemical constituents become complexed by colloidal material. In any event, more research is required into the impact of soil texture on the disposition of labile and less labile components of soil organic matter.

Figure 1. Relationship between selected soil quality attributes in the 0 to 7.5-cm depth and mean annual straw production after 11 years.

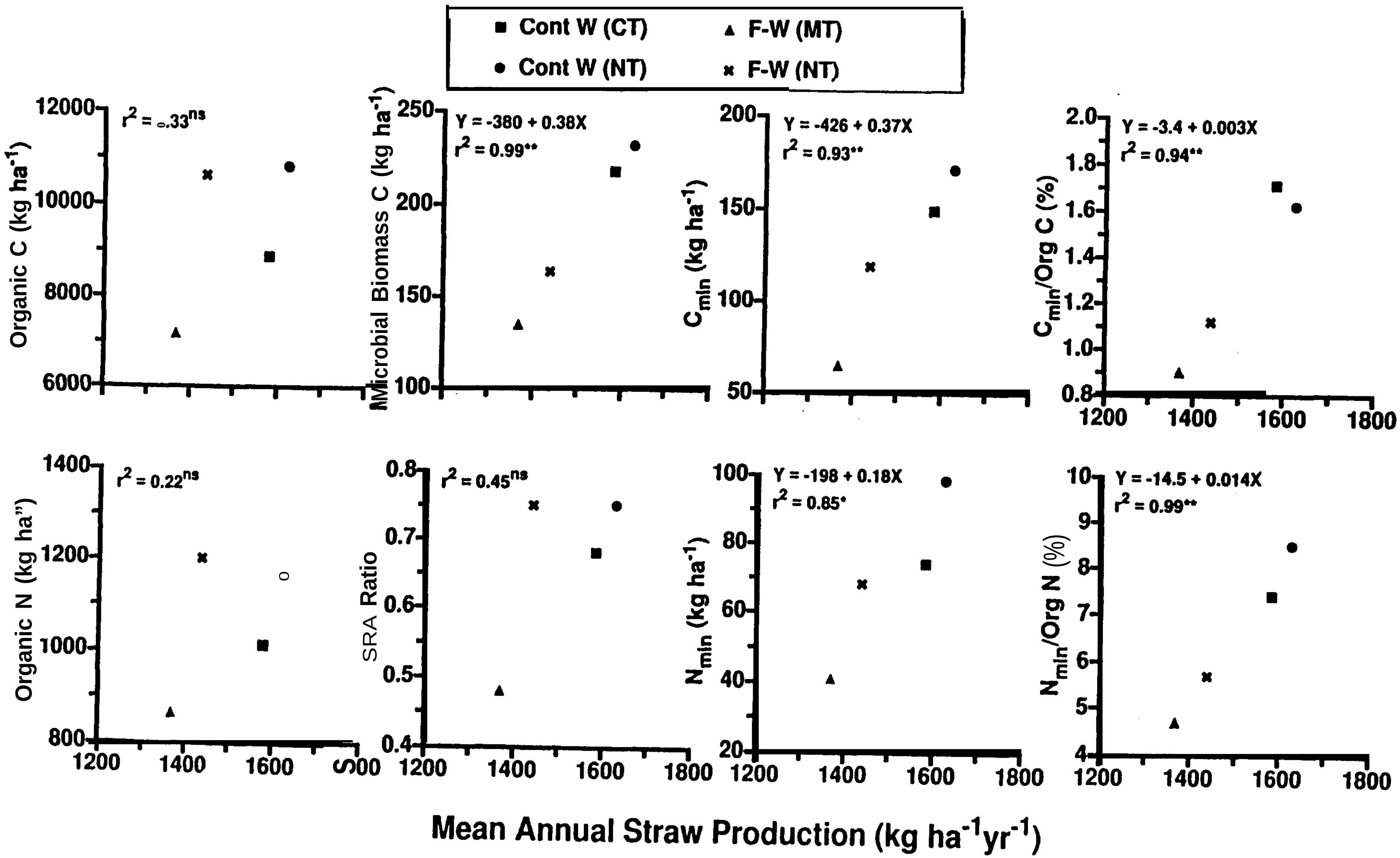

Table I. Effect of fallow frequency and tillage method on selected soil quality attributes in the top 7.5 cm of Hatton fine sandy loam after 3,7 and 1 I years at Cantuar

Treatment		Organic C (kg ha")	Organic N (kg ha")	MB-C[z] (kg ha^{-1})	MB-C / Org C (%)	C_{min}[y] (kg ha")	C_{min} / Org C (%)	N_{min}[x] (kg ha")	SRA[w]	N_{min} / OrgN (%)
					After 3 years (April 1986)					
Cont W	CT	7878	857	545	7.3	as	ND	66	ND	7.7
	NT	7997	894	587	a.2	88	ND	97	ND	10.9
F-W	MT	8105	893	782	9.5	116	ND	a4	ND	9.4
	NT	9035	990	632	7.2	73	ND	79	ND	8.0
Signif. of F ratio"		ns	ns	+	ns	*	ND	ND	ND	ND
S_x				53	-	a.1	ND		ND	ND
					After 7 years (April 1990)					
Cont W	CT	8509	910	107	1.3	120	1.41	50	1.22	5.5
	NT	8497	974	128	1.5	156	1.83	70	1.23	7.2
F-W	MT	7411	830	97	1.3	98	1.32	32	1.08	3.9
	NT	9335	992	a3	0.9	96	1.03	54	1.19	5.4
Signif. of F ratio[v]		ns	m.	ns	ns	*	•	• •	ns	• *
S_x		-				13	0.16	4		0.23
					After 11years (April 1994)					
Cont W	CT	8846	1011	218	2.48	149	1.71	74	0.68	7.4
	NT	10785	1163	232	2.18	171	1.62	98	0.75	8.5
F-W	MT	7158	865	135	1.89	65	0.90	41	0.48	4.7
	NT	10607	1202	164	1.55	119	1.12	68	0.75	5.7
Signif. of F ratio"		• *	•	+	• *	• • •	• .	• •	+	• *
S_x		578	58	23	0.13	7	0.08	6	0.07	0.5

z Microbial biomass (MB) determined by fumigation-incubation method in 1986 and 1990 and fumigation-extraction in 1994, using field-moist soil wetted to field capacity.

Y Cumulative C_{min} measured over 14 days at 20°C in 1986, but 30 days in 1990 and 1994. C_{min} measured on field-moist soil wetted to field capacity.

I Soil from the three replicates were composited befon N_{min} was determined in 1986. but done on each replicate in 1990 and 1994. Values arc accumulated over I6 weeks. Mineralization conducted on rewetted air-dry soil with incubation at 35%.

w SRA = specific respiratory activity or ratio of C_{min}/MB-C.

v ns, +, ● , ● *. • ** denote not significant. significant at P < 0.10. P < 0.05. P < 0.01 and P < 0.001. respectively; ND = not determined.

Table 2. Sensitivity of the various soil quality attributes to tillage method and fallow frequency assessed in the O-7.5 cm depth of fine sandy loam after 11 years at Cantuar

Treatment	org c	Org N	MB-C	C_{min}	N_{min}	MB-c / Org C	SRA	C_{min} / Org C	N_{min} / Org N
				Tillaee sensitivitv ratio (NT/CT or MT)					
Cont W	1.22	1.15	1.06	1.15	1.32	0.88	1.10	0.95	1.15
F-W	1.48	1.39	1.21	1.83	1.66	0.82	1.56	1.22	1.21
				Fallow freauencv sensitivitv ratio (Cont W/F-W)					
CT or MT	1.24	1.17	1.61	2.29	1.80	1.31	1 .42	1.90	1.57
NT	1.02	0.97	1.41	1.44	1.44	1.41	1.00	1.45	1.49

Table 3. Effect of fallow frequency and tillage method on selected soil quality attributes in the top 7.5 cm of a silt loam soil after 4.8 and l2 years at Swift Current

Treatment		Organic c (kg ha")	Organic N (kg ha")	MB-C' (kg ha-')	MB-C / Org C (%)	C_{min} [y] (kg ha^{-1})	C_{min} / Org C (%)	N_{min} [x] (kg ha-')	SRA	N_{min} / ORGN (%)
					After 4 years (April 1986)					
Cont W	CT	14396	1434	496	3.43	163	ND	98	ND	ND
	NT	13992	1403	448	3.2 l	156	ND	100	ND	ND
F-W	CT	12850	1305	499	3.90	110	ND	83	ND	ND
	NT	15286	1504	433	2.82	164	ND	108	ND	ND`
Signif. of F ratio [w]		·	us	ns	ns	•	ND	ND	ND	ND
$S_{\bar{x}}$		365				12	ND		ND	ND
					After 8 years (April 1990)					
Cont W	CT	15052	1530	221	1.47	187	1.24	108	0.85	7.09
	NT	16911	1655	174	1.03	198	1.17	105	1.15	6.43
F-W	CT	13987	1412	262	1.87	166	1.18	89	0.64	6.25
	NT	14809	1490	193	1.34	151	1.03	79	0.83	5.40
Signif. of F ratio'		+	ns	ns	+	ns	ns	·	ns	ns
$S_{\bar{x}}$		682			0.19			5		
					After 12 years (April 1994)					
Cont W	CT	14357	1420	243	1.70	208	1.45	90	0.86	6.25
	NT	16838	1622	179	1.06	201	1.20	95	1.12	5.75
F-W	CT	13430	1342	220	1.53	152	1.06	79	0.73	5.59
	NT	14851	1537	285	1.93	165	1.12	69	0.59	4.60
Signif. of F ratio'		+	+	• *	• .	.	+	• *	• *	. .
$S_{\bar{x}}$		712	61	15	0.1 l	12	0.09	4	0.07	0.23

z Microbial biomass (MB) determined by fumigation-incubation method in 1986 and 1990 and fumigation-extraction in 1994, using field-moist soil rewetted to field capacity.

y Cumulative C mineralization (C_{min}) measured over 14 days at 20°C in 1986. but 30 days in 1990 and 1994. Mineralization conducted on field-moist soil rewetted to field capacity.

x Soil from replicates l-3 were composited before net N mineralization was determined in 1986, but done on each replicate in 1990. Values are accumulated (N_{min}) over 16 weeks. Mineralization conducted on rewetted air-dry soil with incubation at 35°C.

w ns = not significant. + = significant at $P < 0.$ l, • = significant at $P < 0.05$, • * = significant at $P < 0.01$. and ND = not determined.

Table 4. Straw production' at the two sites during the sampling periods

Total for period	Straw production (kg ha^{-1} yr^{-1})			
	Cont W (CT)	Cont W (NT)	F-W (MT)	F-W (NT)
		Hatton fine sandv loam		
1983-1985	3499	3069	2853	292 1
1986-1989	4222	3998	4521	4909
1990-1993	9684	10830	7681	8002
Mean annual	1582	1627	1369	1439
		Swinton silt loam		
1982-1985	6365	5466	4037	3914
1986-1989	7063	7688	4784	4653
1990- 1993	9551	9779	6060	5539
Mean annual	1915	1911	1240	1176

Straw production for Cont W = straw yields for the years, but for F-W the yields are divided by 2 to account for a fallow year in every two years.

Table 5. Sensitivity of selected soil quality attributes to tillage and to fallow frequency in the O-7.5 cm depth after 12 years at Swift Current

Treatment	Org C	Org N	MB-C	C_{min}	C_{min} / Org C	SRA	N_{min}	N_{min} / Org N
				Tillage sensitivitv ratio (NT/CT)				
Cont W	1.17	1.14	0.74	0.97	0.83	1.30	1.06	0.92
F-W	1.11	1.15	1.30	1.09	1.06	0.81	0.87	0.82
				Fallow freauencv sensitivitv ratio (Cont W/F-W)				
CT	1.07	1.06	1.10	1.37	1.37	1.18	1.14	1.12
NT	1.13	1.06	0.62	1.22	1.07	1.90	1.38	1.25