Long-term effects of tillage system and crop rotation on soil physical and chemical properties in a Brookston clay loam at Ridgetown, ON

UNIVERSITY of GUELPH RIDGETOWN CAMPUS

CHANGING LIVES IMPROVING LIFE

L. L. Van Eerd[1,2], K. A. Congreves[1], and D. C. Hooker[3]

[1]School of Environmental Sciences, University of Guelph, Ridgetown Campus, [3]Department of Plant Agriculture, University of Guelph, Ridgetown Campus. [2]*Corresponding and presenting author email:* lvaneerd@uoguelph.ca

Introduction

Maintaining and building soil quality is necessary to maintain crop yields and the competitiveness of Ontario's agricultural industry. Although there are many methods of assessing soil quality, ideal soil quality indicators encompass chemical, physical and biological components of a soil (Kennedy and Smith 1995; Arias et al. 2005). One such indicator is the Cornell Soil Health Assessment (CSHA), which provides one number to represent overall soil health by compiling over 17 soil parameters (Gugino et al. 2007; Idowu et al. 2008; 2009). In addition, soil organic carbon (SOC) is a sensitive indicator of soil quality (Bolinder et al. 1999) as it influences many chemical, physical and biological parameters and is essential for agro-ecosystem functioning. Long-term studies allow for quantification of the effects of crop production practices on changes to soil quality. A strong understanding of the effect of agricultural practices on soil quality is crucial for future prevention of soil and ecosystem degradation.

Objective: In two long-term trials at Ridgetown, the objective was to assess the impact of tillage and crop rotation on soil quality, using the CSHA, SOC, and total N.

Materials and Methods

Two long-term experiments at University of Guelph, Ridgetown Campus were established on Brookston clay loam soil in 1991 and 1995 and sampled in 2006 for SOC and in 2009 for CSHA.

Experimental Design: 1991 Tillage Trial

RCBD tillage trial with six replicates
Soybean-corn (S-C) rotation
Tillage: No-till (NT): no soil disturbance except trash whippers on planter
Conventional tillage (CT): fall mouldboard plough with spring tillage (2 or 3 passes with cultivator or disc)
Chisel plough (chisel-T): fall chisel plough with spring tillage

Experimental Design: 1995 Tillage-Crop Rotation Trial

Split-plot tillage-rotation trial with four replicates
Tillage: NT vs. CT
Rotation: S-C, continuous corn (cC), continuous soybean (cS), soybean-winter wheat (S-W), and soybean-wheat-corn (S-W-C).

Soil Sampling and Analysis:

November 2006: **Soil organic C (SOC), total C and total N**

- Methods according to Carter and Gregorich (2008)
- 3-4 intact cores (4 cm diameter) from each subplot using a Giddings soil corer with tube
- Sectioned into 5, 10, 20 cm increments to 120 cm depth
- Both trials
- Data expressed as content (Mg ha^{-1}) based on bulk density
- SOC and total N expressed as an equivalent soil mass basis (Ellert and Bettany 1995; Yang and Wander 1999) at surface layer (0-5 cm), depth of tillage (0-20 cm), and total profile (0-100 cm)

June 2009: **Cornell Soil Health Assessment (CSHA)**

- Methods according to Gugino et al. (2007)
- 30 soil cores (1.8 cm diameter) to 15 cm depth from each subplot
- Tillage-crop rotation trial only

Statistical Analysis:

Trials analysed separately with ANOVA in SAS (v9.3)
1991 Tillage Trial: PROC GLM with tillage, soil depth and tillage-by-depth in the model
1995 Tillage-Rotation Trial: PROC GLM with tillage, rotation, sample depth and all two-way and three way interactions in the model
CSHA: PROC MIXED with tillage, rotation and tillage-by-rotation interaction in the model

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Results

CORNELL SOIL HEALTH ASSESSMENT (CSHA):

For the CSHA, there was no tillage by rotation interaction for all 14 parameters except for permanent wilting point. Other than soil hardness score, all parameters and the CSHA overall soil quality score were higher in NT than CT (Table 1). The CSHA overall soil quality score was higher with S-W rotation than all other rotations expect for S-W-C (Table 2).

Table 1. Effect of tillage system[z] on Cornell soil health assessment (CSHA) parameters in 0-15 cm depth from a 14 yr long-term experiment initiated in 1995 and sampled in 2009

Parameter	Conventional	No till	Tillage Pr>F	Rotation x tillage Pr>F	Bluegrass fence row
CSHA soil quality score (%)	63.4 b	67.8 a	*	-	75.3
Root health	2.22	2.20	-	-	3.0
Aggregate stability (%)	28.0 b	46.1 a	***	-	69.0
Penetrometer reading (Mpa)	1.70 b	2.05 a	***	+	n/a[y]
Available water capacity (g g^{-1})	0.215	0.215	-	-	n/a
pH	6.85 a	6.45 b	***	-	6.78
Cation exchange capacity	24.4	24.5	-	-	15.3
Active carbon (mg kg^{-1})	689	701	-	-	693
Organic matter (%)	4.22 b	4.61 a	*	-	5.9
Nutrients (mg kg^{-1})					
Potentially mineralizable N	7.65 b	11.1 a	**	-	22
P	34.0	37.8	+	-	7.0
K	183 b	205 a	*	+	107
Ca	4070	4030	*	-	2390
Mg	227	248	+	-	205
Mn	35.6	33.2	-	-	9.5
Mn Index	21.8 b	24.9 a	**	-	14.6
Zn	2.00 b	2.26 a	*	-	6.45
Zn Index	21.4 b	25.2 a	**	-	41.3

[a-b] For each parameter, means followed by a different letter indicates a significant difference according to Tukey-Kramer means comparison (P<0.05). ***, **, *, + Indicates a significant effect at alpha = 0.001, 0.01, 0.05, 0.1.
[z] Conventional tillage was fall mouldboard plough with spring cultivation; No-till was no soil disturbance except trash whippers on planter
[y] n/a = not available

Table 2. Effect of crop rotation on Cornell soil health assessment (CSHA) parameters in 0-15 cm depth from a 14 yr long-term experiment initiated in 1995 and sampled in 2009

Parameter	Continuous Corn	Soy - corn	Continuous Soybean	Soy - wheat	Soy - wheat corn	Pr>F
CSHA soil quality score (%)	63.6 b	63.1 b	64.4 b	71.2 a	65.4 ab	**
Root health	2.27	2.06	2.41	2.20	2.12	+
Aggregate stability (%)	34.0 b	34.6 b	33.0 b	43.2 a	40.3 ab	*
Penetrometer reading (Mpa)	2.20 a	1.85 b	1.50 c	1.85 b	1.99 a	***
Available water capacity (g g^{-1})	0.208	0.213	0.208	0.227	0.218	-
pH	6.40	6.71	6.82	6.63	6.69	+
Cation exchange capacity	24.6	24.7	24.1	25.4	23.6	-
Active carbon (mg kg^{-1})	706	693	682	707	686	-
Organic matter (%)	4.59	4.21	4.13	4.87	4.28	+
Nutrients (mg kg^{-1})						
Potentially mineralizable N	10.4 ab	7.45 b	7.57 b	11.1 a	10.3 ab	*
P	44.0 a	40.3 ab	33.8 bc	30.4 c	30.9 bc	**
K	202	202	172	210	183	-
Ca	3930	4200	3820	4290	4010	-
Mg	234	236	227	265	226	-
Mn	37.5	41.6	29.3	31.3	32.4	-
Mn Index	27.2 a	25.0 a	20.7 b	21.6 b	22.2 b	**
Zn	2.25	2.14	1.93	2.28	2.03	-
Zn Index	25.7	23.0	21.6	23.6	22.4	+

[a-c] For each parameter, means followed by a different letter indicates a significant difference according to Tukey-Kramer means comparison (P<0.05). ***, **, *, +Indicates a significant effect at alpha = 0.001, 0.01, 0.05, 0.1.

Conclusions

Soil quality, SOC, and total N were higher after 11 and 15 years in 1) rotations with winter wheat and 2) no-till system than the conventional practice of fall moldboard plough with spring tillage. To improve soil quality and C sequestration, growers on clay loam soil in southwestern Ontario are recommended to include winter wheat in the rotation and adopt no-till production practices.

TILLAGE EFFECT ON SOIL ORGANIC CARBON:

In both long-term experiments, on an equivalent soil mass basis, total N (data not shown) and SOC were higher with NT compared to CT, with an intermediary response to chisel tillage (Table 3). Higher SOC with NT compared to CT was observed in all depths to 80 cm (Table 3) and there was no tillage by depth interaction (p=0.9996). The decomposition of organic matter may be more restricted in the NT vs CT soils, favoring the accumulation of SOC. Results at Ridgetown were similar to those in Indiana, where SOC and total N was higher in NT compared to CT (Gál et al. 2007) but contrast with those in Elora, Ontario, where there were no differences in SOC between NT, CT and chisel-T treatments to 60 cm depth (Deen and Kataki 2003).

Table 3. Impact of tillage[z] with depth on soil organic carbon (SOC) on an equivalent soil mass basis from two studies initiated in 1991 and 1995 and sampled in 2006

Depth (cm)	Soybean-corn 15 yr study (1991)				Crop rotation 11 yr study (1995)		
	Soil mass	------ SOC (Mg C ha^{-1}) ------			Soil mass	--- SOC (Mg C ha^{-1}) ---	
	(Mg ha^{-1})	Conventional	No till	Chisel	(Mg ha^{-1})	Conventional	No till
0-5	638.4	13.2 c	16.8 a	15.5 b	731.0	15.5 b	21.1 a
0-10	1226	25.7 b	30.5 a	28.8 ab	1367	28.7 b	36.3 a
0-15	1827	37.8 b	44.2 a	41.0 ab	2167	45.4 b	54.9 a
0-20	2443	48.7 b	57.6 a	51.5 ab	2795	57.3 b	68.4 a
0-30	3680	63.9 b	78.5 a	67.8 b	4235	76.0 b	89.4 a
0-40	5023	75.4 b	92.5 a	80.7 b	5600	86.8 b	103 a
0-50	6318	86.3 b	104 a	93.1 ab	6966	97.9 b	116 a
0-60	7593	97.5 b	116 a	106 ab	8330	111 b	131 a
0-80	10260	122 b	141 a	132 ab	11190	137 b	160 a
0-100	13050	147 a	168 a	160 a	14030	164 b	190 a

[a-c] In each row and study, means followed by a different letter indicates a significant difference according to Tukey-Kramer means comparison (P<0.05). There was no tillage x depth interaction (p=0.9996).
[z] Conventional tillage was fall mouldboard plough with spring cultivation; No-till had no soil disturbance except trash whippers on planter; Chisel tillage was fall chisel plough with spring cultivation

TILLAGE x ROTATION EFFECT ON SOC:

On an equivalent soil mass basis, there was a tillage by rotation effect (p<0.0001) for SOC (Table 4) and total N (data not shown), which followed SOC trends. There were no differences in SOC across crop rotations under NT. Continuous cropping with CT of either corn or soybean tended to produce the lowest SOC at 0-5 and 0-20 cm soil depths compared to other crop rotations. The S-W crop rotation produced the highest SOC of 21.5 and 79.0 Mg ha^{-1} at equivalent depths of 0-5 and 0-20 cm, respectively, possibly due more lignin in wheat residues which tends to be more recalcitrant to decomposition. In contrast to results at Ridgetown, in Indiana, there was no tillage by rotation effect and no differences in SOC and total N between cC and S-C crop rotations (Gál et al. 2007).

Table 4. Impact of tillage system[z] and crop rotation on soil organic carbon storage after 11 yr in a long-term experiment initiated in 1995

Crop rotation	Equivalent soil mass (Mg ha^{-1}) with corresponding soil depth (cm)											
	------------ 731 (0-5) -----------				------------ 2795 (0-20) ------------				---------- 14030 (0-100) ----------			
	CT	Contrast[y]	NT	Across Tillage	CT	Contrast	NT	Across Tillage	CT	Contrast	NT	Across Tillage
	----------- soil organic carbon content (Mg C ha^{-1}) -----------											
Continuous Corn	13.7 bc	*	21.2	17.0 ab	51.1	+	70.9	60.2	158	+	203	179
Soybean-Corn	16.7 b	ns	17.5	17.1 ab	60.7	ns	52.5	56.4	169	ns	162	166
Continuous Soy	11.9 c	*	17.9	14.6 b	45.2	ns	62.3	53.1	153	ns	181	166
Soybean-Wheat	21.5 a	ns	25.6	23.5 a	79.0	ns	79.8	79.4	190	ns	202	196
Soy-Wheat-Corn	14.1 b	**	22.6	17.8 ab	51.5	ns	69.6	59.9	156	+	191	173
Across Rotation	15.2	**	20.7	18.0	56.4	+	66.4	61.8	164	*	187	176
Difference[x]	*		ns	*	+		ns	+	ns		ns	ns
Effects	------------ P-value ------------											
Tillage	0.006				0.003				0.000			
Rotation	0.22				0.09				0.23			
Interaction	0.91				0.90				0.91			

**, *, +, ns represents statistical significance at p=0.01, 0.05, 0.10, >0.10, respectively.
[z] CT, conventional tillage was fall moldboard plough with spring cultivation; NT, no till system had no soil disturbance except at planting.
[y] Single degree of freedom contrasts between tillage system within crop rotation.
[x] Statistical differences across rotation, sliced by tillage according to Littell et al. (2006).

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