Residual effects of topsoil replacement depths and organic amendments on soil organic carbon levels of reclaimed wellsites

Francis J. Larney, Andrew F. Olson and Paul R. DeMaere

Agriculture & Agri-Food Canada, Research Centre, 5403 1st Avenue South, Lethbridge, Alberta, Canada T1J 4B1, Email francis.larney@agr.gc.ca

Abstract
The reclamation success of abandoned wellsites in agricultural areas depends on their capacity to sustain levels of soil quality similar to those which existed prior to soil disturbance. A study conducted from 1997-2000 examined the effect of four (0, 50, 100 and 150%) topsoil replacement depths (TRD) and five amendment treatments [compost, manure, alfalfa (*Medicago sativa* L.) hay, wheat (*Triticum aestivum* L.) straw, check) in the reclamation of three natural gas wellsites in south-central Alberta. In 2007 (10 yr after establishment) the three wellsites were sampled to examine the residual effects of reclamation treatments on soil organic carbon (SOC). The compost-amended plots (averaged over all TRDs) in 2007 maintained higher SOC than the straw and check plots (by 11-15%). The results showed that where topsoil is scarce (e.g. in the reclamation of older wellsites) initial investment in organic amendments can have a residual effect on soil quality, as indicated by SOC.

Key Words
Soil reclamation, organic amendments, soil organic carbon, natural gas wellsites.

Introduction
In mid-2009, Alberta=s oil and gas infrastructure included over 212,000 capable wells (Energy Resources Conservation Board 2009). As these wells are depleted and abandoned over time, the wellsites, many of which are leased from agricultural landowners, need to be returned to >equivalent land capability= (Alberta Environment, 1995, 2008), i.e. to levels of production similar to those which existed prior to soil disturbance. A study conducted from 1997-2000 examined the effect of four (0, 50, 100 and 150%) topsoil replacement depths (TRD) and five amendment treatments [compost, manure, alfalfa (*Medicago sativa* L.) hay, wheat (*Triticum aestivum* L.) straw, check) in the reclamation of three wellsites in south-central Alberta (Strathmore, Hesketh and Rosedale). Larney *et al.* (2003) looked at crop response to the various reclamation treatments. Of the 20 treatments (four TRD x five amendments), the reclamation capacity of the 100% TRD-compost treatment ranked highest, being 19% higher than the baseline treatment (100% TRD-check). The lowest-ranking treatment overall, was the 0% TRD-straw treatment which yielded 64% of the baseline treatment. Crop yield responses to organic amendments were larger when the recipient soil was lower in organic matter.

Changes in soil properties reflect the success or failure of reclamation practices on abandoned wellsites. Larney *et al.* (2005) examined the effect the four TRD treatments and five amendment treatments on soil properties. TRD treatment differences were consistent across all wellsites, with 30 to 32% higher soil organic carbon (SOC) on the 150% TRD compared to the 0% TRD. After 40 mo (June 1997–October 2000), the average amounts (n = 3 wellsites) of added C conserved near the soil surface were: compost (65 ±10% SE) > manure (45 ±16% SE) > alfalfa (28 ±11% SE) > straw (23 ± 6% SE). Zvomuya *et al.* (2006) found that low carbon to nitrogen (C/N) ratio amendments, particularly compost and alfalfa, were the most effective for improving grain N concentration and uptake.
The above results point to enhanced crop performance and soil quality as a result of reclamation treatments over the short-term duration of the initial study (4 yr, 1997-2000). However, questions remained about the longevity of the soil treatment (TRD, organic amendments) effects on these wellsites. To answer this question, we carried out a follow-up study in 2007 which involved returning to the three wellsites, relocating the plots and taking soil samples. Our objective was to examine, 10 yr after establishment, the residual effects on soil organic carbon (SOC) of the initial reclamation treatments.

Methods

Study sites and design

This study is described in greater detail by Larney *et al*. (2003, 2005). Briefly, three abandoned natural gas wellsites (Strathmore, Hesketh and Rosedale) were selected in south-central Alberta in the spring of 1997. The soils were Orthic Dark Brown or Black Chernozems. Surface soil texture was loam to clay loam. The experimental design was a split-plot, with topsoil replacement depth (TRD, at 0%, 50%, 100% and 150%) as the main treatment and organic amendment (compost, manure, straw, alfalfa and check) as the sub-treatment, replicated four times. Each main plot was 8 x 10 m in area with sub-plots of 8 x 2 m.

Topsoil replacement depths and amendments

Two-lift soil stripping was carried out on all three sites by an experienced operator on a bulldozer. This is the selective recovery and stockpiling of all available topsoil (mostly Ap horizon material) in the first lift and 'good quality' subsoil (mostly B horizon material, some Ap horizon material, minimal C horizon material) in the second lift. Soils were redistributed uniformly (subsoil followed by topsoil) across the sites to meet the required replacement depth for topsoil of 60% of the control soil depth (Alberta Environment 1995). It was assumed that the depth of topsoil existing following replacement represented the 100% TRD treatment. The 0% TRD was achieved by removing and stockpiling all of the topsoil layer. The 50% and 150% TRD treatments were accomplished by removing half of the topsoil layer depth from the 50% TRD plots and spreading it evenly over the 150% TRD plots. After TRD main plot treatments were established, amendments were applied as one-time sub-treatments in late June/early July 1997 as follows: (1) compost derived from straw-bedded cattle feedlot manure; (2) fresh feedlot manure; (3) straw (wheat); (4) alfalfa hay and (5) check (unamended). Compost and manure were applied at 40 t/ha (dry wt.), and straw and alfalfa at 14.6-17.0 t/ha (dry wt). Amendments were with two passes of a rototiller to 10 cm depth. Apart from manure at Strathmore (15.6 t/ha of C), the amendments added similar amounts of C (6.6-9.9 t/ha).

Management and soil sampling

Spring wheat (*Triticum aestivum*) was the test crop at all three sites throughout the initial four year study period (1997-2000). After harvest in 2000, the wellsites were land-farmed in the same manner as the adjacent field area by the owners. In 2007, soil samples were taken from each plot to determine SOC at 0-15 cm, 15-30 cm, and 30-60 cm. Total C was measured on fine-ground material in an elemental analyzer (Carlo Erba, Milan, Italy). Inorganic carbon was measured by the method of Amundson *et al*. (1988). Organic carbon was determined as the difference between the total carbon and the inorganic carbon. Statistical analyses were performed using the GLM procedure (SAS Institute Inc., 2006).

Results

Soil organic carbon (SOC) was significantly affected by TRD in 2007 for all three depths at Strathmore, the 0-15 cm depth at Hesketh and the 0-15 cm and 30-60 cm depths at Rosedale (Table 1). The trend was for lower SOC in the 0% TRD compared to the others. The lack of topsoil on the 0% TRD resulted in lower SOC at the 0-15 cm depth and this extended deeper in the profile since a deeper layer (inherently lower in SOC) would be sampled for the 30-60 cm depth on the 0% TRD compared to the 100% or 150% TRDs due to the lack of topsoil.

Residual effects of the organic amendments were significant for the 0-15 cm depth at all three sites (Table 1), but did not extend to deeper layers. At Strathmore, the compost treatment (20.4 g/ kg) was significantly higher than the straw and check treatments (17.8-18.1 g/kg) but not the manure or alfalfa. At Hesketh, the compost and manure treatments (24.0-24.5 g/kg) were significantly higher than the straw (21.7 g/kg) treatment but not the alfalfa or check. At Rosedale, the compost treatment (19.9 g/kg) was significantly higher than the straw, alfalfa and check treatments (17.5-17.6 g/kg) but not the manure treatment. Residual effects of compost and manure were not significantly different from each other at any of the three sites, while alfalfa was as good as both manure and compost at two (Strathmore, Hesketh) of the three sites. The check treatment was as good as manure and compost at the Hesketh site only (the one with the highest background level of SOC). SOC on the straw treatment was significantly lower than compost at all three sites. None of the TRD x amendment interaction effects were significant (Table 1).

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Table 1. Effect of topsoil replacement depth and amendment on organic carbon concentrations at Strathmore, Hesketh and Rosedale, 2007.

	Strathmore			Hesketh			Rosedale		
	Depth (cm)								
	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
	g/kg								
	Topsoil replacement depth (TRD) (%)								
0	16.9c†	9.9b	5.5ab	21.4c	13.5a	10.8a	16.1b	8.2a	6.6ab
50	18.6b	9.6b	4.5b	22.5bc	13.6a	11.2a	18.5a	8.1a	4.2c
100	20.0a	11.6a	6.8a	26.0a	14.8a	11.5a	18.8a	8.6a	7.8a
150	20.4a	12.1a	5.8ab	23.4b	13.5a	11.3a	19.8a	9.1a	4.5bc
	Amendment								
Compost	20.4a	11.3a	5.5a	24.0a	14.2a	10.9a	19.9a	8.4a	6.3a
Manure	19.1ab	11.0a	5.9a	24.5a	13.6a	11.6a	18.9ab	8.8a	5.6a
Straw	18.1b	10.4a	5.5a	21.7b	14.0a	10.9a	17.5b	8.6a	6.0a
Alfalfa	19.3ab	10.9a	5.7a	23.4ab	14.0a	11.4a	17.6b	8.3a	5.5a
Check	17.8b	10.3a	5.6a	23.1ab	13.5a	11.1a	17.6b	8.5a	5.5a
	P-value								
TRD	<0.001	<0.001	0.009	<0.001	0.32	0.87	<0.001	0.37	0.004
Am	0.005	0.32	0.97	0.05	0.94	0.86	0.007	0.97	0.96
TRD xAm	0.54	0.36	0.12	0.96	0.71	0.82	0.79	0.96	1.00

TRD = topsoil replacement depth; Am = amendment. †Within TRD or amendment, means followed by different letters are significantly different according to LSD (0.05).

Soil organic matter content is considered one of the most important soil quality indicators (Gregorich *et al*. 1994). Although C mass additions were not that different among amendments, the C added as compost or manure raised SOC levels and, more importantly, maintained them for 10 yr, while C added as straw or alfalfa was less effective. Cox *et al*. (2001) also reported that compost was of greatest benefit in improving soil quality on an eroded soil in Washington compared to straw or coal ash. They found that compost significantly increased SOM and plant available P, as well as reducing bulk density and improving water infiltration.

The status of C on the decomposition spectrum is important in the ability of organic amendments to enhance SOC levels. Compost- or manure-C is in a much more stable form than straw- or alfalfa-C. Most of the readily decomposable C had already left the compost and manure before they were soil-incorporated, leaving mostly stable C, which was able to raise SOC levels significantly. In contrast, the greater part of organic C in straw and alfalfa was readily decomposable, rapidly breaking down once mixed with soil, and the remaining C was less capable of raising SOC.

Conclusion

The study demonstrated that residual effects of one-time applications of organic amendments (e.g. compost, manure, alfalfa) on SOC were found 10 yr after application. It is hoped that results from this research will promote increased use of organic amendments (particularly compost) in wellsite reclamation in Alberta. The livestock industry produces large volumes of manure and its return to the soil as compost in reclamation scenarios in the oil and gas industry is a good fit.

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