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Soil carbon changes in cultivated and excavated land converted to grasses in east-central Saskatchewan

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Abstract. The conversion of annually cultivated or disturbed marginal land to forage grasses has the potential to accrete soil organic carbon (SOC) in the surface 0–15 cm depth. Soil organic carbon mass (Mg ha^{-1}) was measured in ten side-by-side cultivated versus forage grass seed-down restoration treatments on catenae at various sites in east-central Saskatchewan, Canada. Treatments were imposed for time periods ranging from five to twelve years. It was found that SOC mass was usually significantly higher in the grassland restorations versus the paired cultivated equivalents. Estimated SOC gain rates (0–15 cm) from grass seed-down in the region was estimated to be 0.6 to 0.8 Mg C ha^{-1} yr^{-1}. Light fraction organic carbon (LFOC), the labile component of SOC, was more variable in the comparisons than SOC. Measured ^{13}C natural abundance values in selected equivalent comparisons revealed a possible contribution from seeded warm season C_4 grasses and soil carbonate ^{13}C to the C pools in upslope positions of the landscape. Overall, grassland restoration in this region appears to result in increased carbon storage in the surface soil.

Introduction

Most of the carbon in agroecosystems is found in soils, and agricultural practices can alter the amount of carbon stored in soils (Schlesinger et al. 1995). The soil is therefore one of the ecosystem components that can play a key role in the global C budget due to its role as a net sink or source of CO_2. Land use approaches that will enhance CO_2 incorporation into biomass or soil C reserves can contribute to a substantial and sustainable reduction in atmospheric CO_2. Several studies have examined the impact of forages on soil organic carbon. For example, in Alberta, Canada, the use of a forage-based rotation has markedly increased soil organic carbon (SOC) content for over 70 years, despite removal of C in forage and crop residues (Juma et al. 1997). Studies on the conversion of cultivated land to perennial grass through the Conservation Reserve Program (CRP) in the US have also documented increases in SOC from conversion to grass cover (Staben et al. 1997; Robles and Burke 1998)). Gebhart et al. (1995) reported a mean soil carbon accumulation rate of 0.02 to 0.4 Mg C ha^{-1} yr^{-1} after five years in grassland seeded for the set-aside program in the US. However, information on the effect of conversion to grass cover in the northern Great Plains of Canada is lacking.

This study examined changes in soil carbon resulting from seeding perennial grasses into long-term cultivated systems and land disturbed by excavation in east-central Saskatchewan. The objectives were to use differences in SOC mass, light fraction organic carbon mass/proportions in SOC and ^{13}C natural abundance to estimate net C gain rates and provide insight into the carbon dynamics associated with grassland restoration.

Materials and methods

Sites

The restored grasslands are Ducks Unlimited dense nesting cover (DNC) units, with the intended purpose of providing nesting cover for waterfowl, and are only lightly grazed or hayed. The restored grassland treatments consisted of seed-downs to species mixes of wheat grasses (*Agropyron* spp.), blue grama grass (*Bouteloua gracilis*), and alfalfa (*Medicago sativa*), for 5–12 years. The treatments were dominated by grass species at the time of sampling. The twelve sites are located in the Dark Brown (Typic Boroll) and Thin Black (Udic Boroll) soil zones around Meacham and Dana, Saskatchewan (52°07′ N, 105°45′ E and 52°20′ N, 105°54′ E respectively) and in the transition between the Black (Udic Boroll) and Gray (Boralfic Boroll) soil zones around Gronlid (53°04′ N, 104°37′ E) and Pleasantdale (52°34′ N, 104°31′ E) Saskatchewan. At ten sites, the cultivated treatment pairs in the toposequences consisted of crop rotations such as Wheat (*Triticum aestivum*)-Wheat-Canola (*Brassica napus*)-Pea (*Pisum sativum*) and Wheat-Wheat-Fallow-Canola maintained for the last 15–20 years and before that a cereal-fallow rotation. Predominant native vegetation on these soils prior to breaking for cultivation about 80 years ago was rough fescue (*Festuca* spp.), a cool season C_3 grass. Slopes of the toposequences ranged from 2% to 16%. Two recently disturbed (surface soil excavated for road construction) and grass seed-down restoration comparisons were made on level landscapes in the Gronlid area.

Sampling and analysis

In the spring of 1999, five soil cores were taken randomly over an area of 25 m^2 within individual landscape positions (shoulder, backslope and footslope) identified in each paired cultivated and restored landscape, for a total of thirty cores per site. At all sites in the study, the cores were taken using 10-cm diameter by 15-cm length PVC pipes pressed into the soil. Soil cores were sectioned into 0–5, 5–10, and 10–15 cm depth increments and air-dried at 30 °C for a week for bulk density determination. Soil organic carbon (SOC) was determined from sub-samples ground to < 100 mesh after passing a 2 mm sieve, using a LECO CR-12 automated com-

Table 1. Mean SOC mass (Mg ha^{-1}) across the landscape (0–5 cm depth) in selected cultivated versus seed-down equivalents.

Restoration Site	Cultivated Treatment	Restored Grassland Treatment	p-value
Hanuschak	15.2	22.7	0.000
Bergren	5.8	21.3	0.000
Fontaine	10.7	14.8	0.001
Totzke	12.8	13.9	0.233
Gayowski	12.8	14.8	0.062

bustion carbon determinator set at 840 °C (Wang and Anderson 1998). Organic carbon mass (Mg ha^{-1}) was determined using a modification of the equivalent mass method (Ellert and Bettany 1995). Light fraction organic carbon (LFOC), the labile pool of soil organic matter, was obtained by the method of flotation of light debris in 25 g soil samples in NaI (Gregorich and Ellert 1993). The ^{13}C natural abundance ($\delta^{13}C$) values were determined by automated mass spectrometry (Europa Scientific, Crewe, England) using a mass spectrometer equipped with a single inlet and triple collectors.

Data analysis

Data was analyzed with MINITAB™ statistical software, using one-way ANOVA and Tukey's pairwise comparison for means separation. A significance level of α = 0.05 was chosen for detecting significant differences. Normal distribution plots of data, and Bartlett's tests of homogeneity of variances indicated unequal variances, so unequal variances were assumed in the analysis. Since the analysis involved a pairwise comparison, a two-sample t-test assuming unequal variances was also used to analyze the same data, to compare significance at the chosen confidence interval. The results of both methods of analysis were found to be similar. A two-way ANOVA was also done on two factors; treatments (cultivated vs. seed-down), and slope position (shoulder, backslope, and footslope).

Results and discussion

SOC mass among treatments

The results from selected sites for the surface layer (0–5 cm) on a site-by-site basis within the study areas are presented in Table 1. Across the landscape, the SOC mass in the surface 0–5 cm was higher in the restored grassland treatments at nearly all sites, but as indicated in Table 1, the differences were not always significant at a 5% probability level.

Table 2. The distribution of SOC mass (Mg ha^{-1} 0–5 cm depth) within the landscape (averaged across treatments) at various slope positions (shoulder (SH), backslope (BS), and footslope (FS)) at selected sites.

Restoration Site	SH	BS	FS	p-value
Gayowski	7.2	11.7	19.4	0.000
Totzke	8.9	14.4	16.7	0.000
Fontaine	8.3	13.8	16.2	0.000
Hanuschak	13.5	17.5	25.9	0.000

The greater SOC mass in the surface soil of grass seed-downs at the time of measurement indicated an impact of the grass seed-down on increasing stores of SOC. However, the magnitude of the effect varied, depending on site and slope position. For example, at some sites, grass seed-down increased SOC throughout the entire sampling depth (0–15 cm) at all landscape positions while in others, the difference in SOC was not significant at certain landscape positions or depth increments. Due to perennial forages and native grassland species having a longer growing season and generally deeper rooting depth than annual crops, they return more residue to the soil. Perennials also allocate more C from photosynthate to belowground parts in order to extend the growing season and keep reserves for the next growing season (Smith et al. 1997). Thus, SOC may cycle more slowly and result in a more secure net amount in the sub-soil (Paustian et al. 1997). Perennials also form an extensive network of roots that may enhance stable soil aggregate formation in the absence of tillage or disturbance and thus protect SOC from excessive oxidation.

Trends in the distribution of SOC mass according to landscape position showed highly significant differences in SOC mass at different slope positions, with the lowest SOC amounts at shoulders and highest in footslopes (Table 2). Due to greater moisture available for biomass production and the depositional effect of erosion in depressions, SOC and plant nutrients are accumulated at a greater rate and may be protected from extensive losses due to burial and reduced rates of decomposition (Gregorich et al. 1995).

LFOC distribution in the surface 0–5 cm depth

Mean percentage of SOC comprised of light fraction organic carbon (LFOC) did not show any significant differences among sites. Data for selected sites is presented in Table 3. Mean % LFOC was expected to be consistently significantly higher in the surface 0–5 cm depth of the seed-down treatment than in the cultivated equivalent, reflecting greater inputs of recent carbon from grass litter and roots. However, high inherent spatial and analytical variability in this measurement made it difficult to show significant differences. Therefore, LFOC proportion or mass in SOC may not always be a reliable predictor of SOC mass and accretion rate.

Table 3. Mean light fraction organic carbon proportions (%LFOC) in SOC (0–5 cm depth) for selected treatments.

Restoration Site	Treatment	Mean %LFOC	p-value
Gayowski	Cultivated	10.6 ± 2.3	0.220
	Restored	14.2 ± 0.6	
Borrow pit	Excavated	13.9 ± 1.2	0.630
	Restored	14.9 ± 2.2	
Totzke	Cultivated	8.3 ± 0.6	0.580
	Restored	9.4 ± 1.6	
Fontaine	Cultivated	15.3 ± 5.1	0.980
	Restored	15.5 ± 2.7	

LFOC amounts generally followed trends similar to SOC. There was typically higher LFOC in treatments with significantly higher SOC. This trend is consistent with the results of other workers (Biederbeck et al. 1994).

^{13}C natural abundance in samples from selected sites

In this region, the original native grass vegetation and the cropping systems that followed are dominated by C_3 photosynthetic pathway plants. The C_3 species have $\delta^{13}C$ values of the organic carbon ranging from −32‰ to −22‰, with a mean of −27‰, whereas C_4 plants have values ranging from approximately −17‰ to −9‰, with a mean of −13‰. These differences are maintained in plant litter (Ludlow et al. 1976). On the other hand, the inorganic carbon in primary carbonate minerals in Saskatchewan soils has less negative $\delta^{13}C$ values, approaching 0‰ (Rask and Schoenau 1993). The $\delta^{13}C$ values of the total soil carbon (organic + inorganic) for one site are shown in Table 4. The mean $\delta^{13}C$ values tended to be higher (less negative) in the cultivated treatments at all depths in the shoulder and backslope positions compared to the restored grassland equivalents, except at lower depths in the footslopes. The mixing of subsoil, which contains soil carbonates, with top soil as a result of cultivation as well as losses of top soil by erosion may explain this, as carbonate carbon has a less negative $\delta^{13}C$ than organic carbon in these soils (Wang and Anderson 1999). In the restored grassland, the data may also reflect some contribution to SOC from seeded C_4 species such as blue grama grass, which have a less negative $\delta^{13}C$ than C_3 species. The C_4 species were identified to be more abundant in the relatively warmer and drier upper slopes.

The mean $\delta^{13}C$ values in the Borrow Pit site, where SOC-rich topsoil has been removed by excavation, were higher than that in the restoration equivalent (Table 5). Less negative $\delta^{13}C$ values in the disturbed treatment may be due to the near absence of plant residue input, and the dilution with soil carbonate C. The trend in more negative $\delta^{13}C$ values with increasing depth in both treatment equivalents may indicate less carbonate C, as well as the dominance of C_3 vegetation prior to disturbance.

Table 4. Mean $\delta^{13}C$ (‰) values for total soil carbon at various slope positions and depths at the Fontaine site.

Slope position	Depth (cm)	Cultivated Mean $\delta^{13}C$ (‰)	Restored Grassland Mean $\delta^{13}C$ (‰)	p-value
Shoulder	0–5	−13.8 ± 0.4	−17.6 ± 0.4	0.000
	5–10	−10.3 ± 0.7	−14.8 ± 0.6	0.002
	10–15	−7.9 ± 0.4	−8.5 ± 0.3	0.300
Backslope	0–5	−14.8 ± 0.5	−23.1 ± 0.1	0.000
	5–10	−17.0 ± 1.9	−22.4 ± 0.5	0.510
	10–15	−4.9 ± 1.4	−23.4 ± 0.8	0.002
Footslope	0–5	−20.6 ± 0.3	−22.5 ± 0.4	0.001
	5–10	−20.5 ± 0.5	−19.7 ± 0.2	0.190
	10–15	−22.6 ± 0.6	−14.9 ± 0.7	0.000

Table 5. Mean $\delta^{13}C$ (‰) values for total soil carbon at various depths at Borrow Pit site.

Slope position	Depth (cm)	Excavated Mean $\delta^{13}C$ (‰)	Restored Mean $\delta^{13}C$ (‰)	p-value
Level	0–5	−16.0 ± 2.5	−24.1 ± 0.4	0.031
	5–10	−18.9 ± 2.1	−25.0 ± 0.6	0.052
	10–15	−23.9 ± 0.6	−25.2 ± 0.3	0.110

Estimation of SOC gain rates in the study areas

The combined analysis of the total average SOC mass (0–15 cm) in cultivated versus grassland restoration treatment sites in the Dark Brown/Thin Black Soil Zone study area were 52.6 ± 2.6 Mg C ha^{-1} for the cultivated treatment, and 59.4 ± 4.1 Mg C ha^{-1} for the restoration treatments across the landscape. The SOC mass in the cultivated treatment was used as a reference point. Using this data, we estimated a net C gain rate of 0.6 to 0.8 Mg C ha^{-1} yr^{-1} (0–15 cm) from managed forage seed-down of annually cultivated land over periods of five to twelve years. A similar value for C gain rate was calculated for unmanaged seeded restorations at the excavated sites. These estimates fall within the range of net C gain rates estimated by various workers such as Jastrow (1996) and Gebhart et al. (1995) of 0.4 to 1.0 Mg C ha^{-1} yr^{-1} over similar time periods in conversions of cultivated land to grass in the US.

Conclusions

It is evident from this study that seed-down of marginal cultivated land to perennial forage grass mixes has an impact of increasing SOC in the surface layer after five to twelve years. The effect on SOC storage is likely to vary under different conditions, such as in different soil textural classes and climatic zones. In this study area which consisted predominantly of loams and clay-loams in the Dark Brown/Thin Black and Black/Gray Zones of east central Saskatchewan, net C gain rates (0–15 cm depth) were estimated to be 0.6–0.8 Mg C ha^{-1} yr^{-1}. The accumulation of C at depths greater than 15 cm over longer time periods should also be considered, especially when the forage cover includes a preponderance of deeper-rooted forage species, such as alfalfa and clover. Efforts to increase plant production and residue return in marginal lands converted to perennial cover should result in greater net C storage in soils.

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