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Soil Organic Carbon Sequestration under Two Dedicated Perennial Bioenergy Crops

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Certain dedicated bioenergy crops, such as SRF willow and switchgrass, may have greater soil carbon storage potentials than conventional row crops, such as corn, due to their perennial nature and greater root biomass. The increased carbon sequestration with these crops may have positive ramifications in reducing CO_2 GHG emissions due to the soil acting as a carbon sink. In 1993, two sites in southwestern Quebec were established to assess the potential of two dedicated perennial bioenergy crops; switchgrass and SRF willow. The potential for soil carbon sequestration of these crops was assessed in the fall of 1996 and 1998 at a 0-60 cm depth. In 1996 the soil organic carbon values showed switchgrass and willow at the Ecomuseum site to have significantly higher amounts of soil organic carbon than corn. In 1998, at 0-15 cm, willow and switchgrass had higher soil organic carbon than corn (35, 33, and 27 Mg ha^{-1}, respectively), but not from 15-45 cm. At 45-60 cm, willow had the highest soil organic carbon compared to switchgrass and corn (18, 12, and 10 Mg ha^{-1}, respectively). At the Seedfarm site, which had inherently lower soil fertility, the perennial crops in 1996 and 1998 did not differ significantly in soil organic carbon content from the corn. From 1996 to 1998 a decline in soil organic carbon was measured (-15 Mg ha^{-1} at the Ecomuseum, and –9 Mg ha^{-1} at the Seedfarm), which is most likely a result of the low rates of fertilization in the perennial crops. Perennial bioenergy crops, such as SRF willow and switchgrass, have the potential to increase soil carbon levels compared to corn. However, further information is required on the impact of fertilization practices on productivity and the impact on maintaining or increasing soil carbon levels in these crops.

1. INTRODUCTION

Agricultural soils have long been recognised by soil scientists as potential carbon reserves. However, temperate agricultural soils are not a large source or sink of carbon under current agricultural practices (Cole et al., 1997). Key strategies to increasing the carbon sequestration potential of a soil include, increasing the time under which the soil is vegetated; reducing, or eliminating, soil tillage; boosting primary production and the return of organic matter to the soil; increasing the soil fertility; and increasing the use of perennial grasses and legumes. However, the greatest agricultural potential for mitigating CO_2 lies in increasing the amount and variety of plant biomass used directly for energy production as a substitute for fossil fuel energy (Cole et al., 1997).

2. MATERIALS AND METHODS

2.1 Experimental Layout

The two experimental sites (Seedfarm and Ecomuseum) were located at the Emile A. Lods Agronomy Research Centre of McGill University, in southwestern Quebec (42^{o}25'N lat., 75^{o}56'W long.). Both sites consisted of undulating landscapes, with soils of moderate moisture holding capacities. Aboveground and soil sampling was restricted to areas of Chicot sandy loam exclusively. Prior to the experimental layout, the Seedfarm site was under a corn-alfalfa rotation for 3 years. The Ecomuseum site was under continuous corn for over 4 years and in addition to mineral fertilizer, received regular applications of approximately 20 Mg ha^{-1} yr^{-1} of dairy manure.

In 1993, the sites were divided into 4 blocks with 3 treatments in each block as a randomized complete block design. The 3 treatments consisted of switchgrass (*Panicum virgatum* L.), short rotation forestry (SRF) willow (*Salix alba* sp.) and corn (*Zea mays* L.). In 1993, the SRF willows cuttings were planted at a rate of 11 000 ha^{-1}, in 0.92 m wide rows. The trees were coppiced in January 1996, and fertilized with 77 kg N ha^{-1} in 1996, and with 125 kg N ha^{-1} in 1998. Switchgrass was planted in May 1993 and fertilized with 45 kg N ha^{-1} in 1994, 1995, 1996, as well as with 75 kg N ha^{-1} in 1997 at the Seedfarm. At the Ecomuseum, the switchgrass was fertilized with 30 kg N ha^{-1}, and with 45 kg N ha^{-1} in June 1995, 1996, and 1997. In 1998, both sites received 50 kg N ha^{-1}. Each spring the overwintered switchgrass was harvested at a 15 cm height at both sites, and baled. In 1996, the corn at the Seedfarm was fertilized with 205 kg N ha^{-1}, and with 161 kg N ha^{-1} at the Ecomuseum. In 1997, the Seedfarm received 162 kg N ha^{-1} of fertilizer, and the Ecomuseum received 176 kg N ha^{-1}. In 1998, the corn received 148 kg N ha^{-1}at both sites.

2.2 Soil Sampling

At six locations (in 1996, and four locations in 1998) in each plot, a 15 cm x 6 cm diameter cylindrical metal soil core was manually driven into the soil. The procedure was repeated at 15 cm depth increments unto a depth of 60 cm. Soil samples were mechanically crushed and sieved to 2 mm to obtain a uniform subsample, then further ground with a mortar and pestle to pass through a 100 mesh sieve.

2.3 Organic Carbon Determination

In 1996, the soil samples were analysed for organic carbon content by using the modified Mebius procedure (Yeomans and Bremner, 1988). Carbon storage under different management systems was calculated on an equivalent mass basis (Mg ha^{-1}) (Ellert and Bettany, 1995). This was the average soil mass across all systems from 0-60 cm, which was 7090 Mg ha^{-1} in 1996, and 6910 Mg ha^{-1} in 1998.

In 1998 the organic carbon was measured using a LECO Carbon Analyser 1400 C. Due to the different methodologies used in the two sampling years, 60 randomly chosen 1996 soil samples (equally representing each cropping system and depths) were re-analysed using the LECO analyser. From these results a regression equation (r^2=0.99) was used to adjust the 1996 organic carbon values to enable comparisons to be made between years.

2.4 Statistical Analysis

Data was analysed as a randomized complete block design, with 4 blocks, the 3 crops as treatments, and the 2 sites as main factors. Statistical analyses were performed using SAS, GLM procedure. Data obtained from root biomass and soil carbon were analysed as repeated measure analyses of variance, using depth as a repeated factor. Significant ANOVA means were compared using the Student Newman Keuls (SNK) multiple range test.

3. RESULTS AND DISCUSSION

3.1 1996 Root Biomass Yields

The total switchgrass root production was greater at the Seedfarm site (8068 kg ha^{-1}) than at the Ecomuseum site (5965 kg ha^{-1}). The willow fine roots, root crown and total roots were not significantly different between the two sites. In contrast, the fine root yields for corn were significantly higher at the Seedfarm (522 kg ha^{-1}) than at the Ecomuseum (337 kg ha^{-1}) (Figure 1), as measured by Zan (1998).

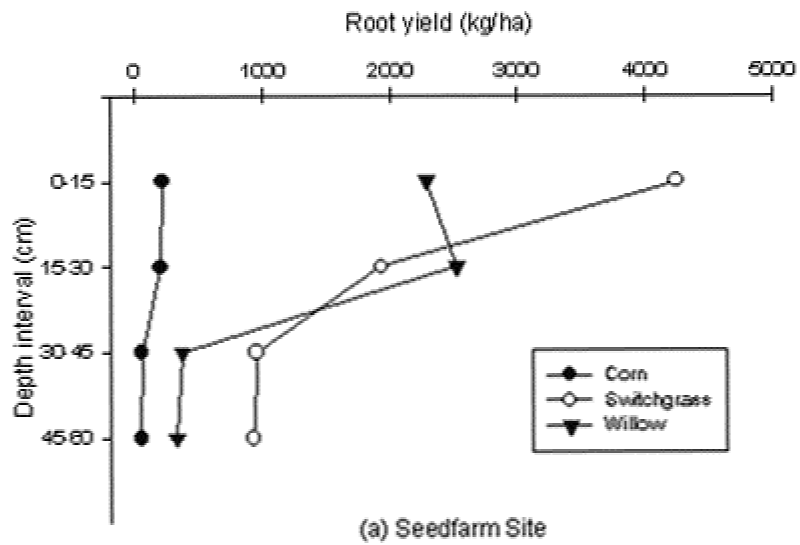
3.2 Soil Organic Carbon

In 1996, willow plots at the Ecomuseum had significantly higher amounts of soil organic carbon (138 Mg ha^{-1}), followed by switchgrass at the Ecomuseum (116 Mg ha^{-1}) which had significantly higher organic carbon compared to the remaining systems. The remaining systems were not found to differ in terms of organic carbon contents from 0-60 cm. Analysis were also conducted on individual depths, however, no significant differences were detected between any of the systems in any of the soil layers (Zan, 1998).

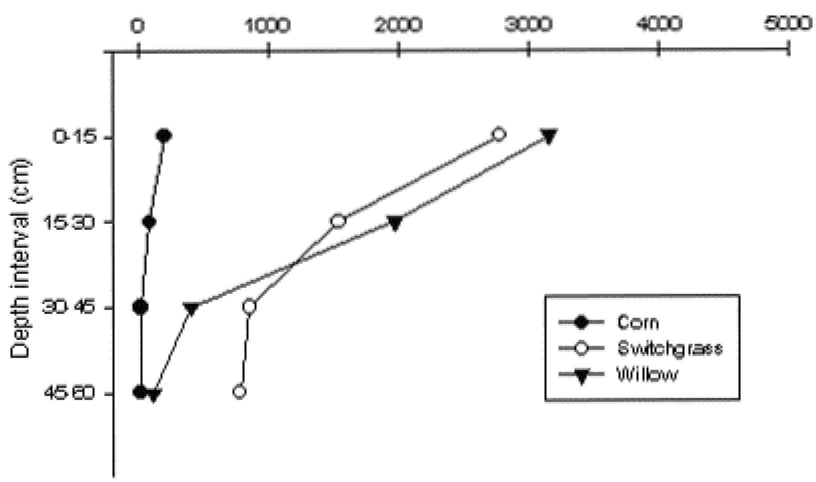
Table 1. 1998 Soil Organic Carbon values for Individual Depths and 0-60 cm, for each Site

	Soil Organic Carbon (Mg ha^{-1})				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	***0-60 cm**
Ecomuseum					
Willow	35 a	33 a	16 a	18 a	**98 a**
Switchgrass	33 a	27 a	15 a	12 b	**90 a**
Corn	27 b	27 a	14 a	10 b	**83 a**
Seedfarm					
Willow	33 a	27 a	14 a	19 a	**88 a**
Switchgrass	29 a	22 a	10 a	13 a	**77 a**
Corn	26 a	25 a	15 a	13 a	**84 a**

Means with different letters within each site are not significantly different at p=0.05 according to the SNK test. *Only the 0-60 cm column was calculated on an equivalent mass basis.



(a) Seedfarm Site



(b) Ecomuseum Site

In 1998 however, there were differences between the individual depths at the Ecomuseum only (Table 1). Willow and switchgrass had higher soil organic carbon than corn at 0-15 cm, which may be due to the incorporation of surface residue in the case of corn. At 45-60 cm, willow had significantly higher organic carbon than the other systems, possibly due to the greater root biomass. However, overall from 0-60 cm, there was no detectable difference between any of the crops, at either site.

Although an overall decrease in soil organic carbon was observed in 1998, by comparing individual cropping systems (Figure 2), willow at the Ecomuseum had significantly higher soil organic carbon than switchgrass at the Seedfarm. This indicates that willows may have greater potential to increase soil organic carbon levels, relative to switchgrass and corn.

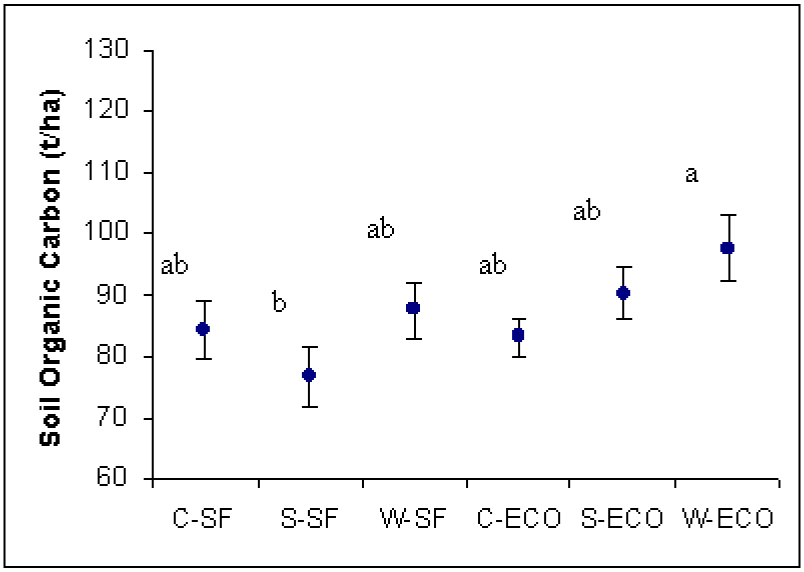


Figure 2. Mean 1998 soil organic carbon in willow, switchgrass and corn plots, in an equivalent soil mass basis (Mg ha^{-1}). Error bars represent standard errors of means. Means with different letters are not significantly different at p=0.05 according to the SNK test. C=corn; S=switchgrass, W=willow; SF=Seedfarm; Eco=Ecomuseum

In both 1996 and 1998, the Ecomuseum was found to have a significantly higher amount of organic soil carbon than at the Seedfarm (Table 2). However, the mean level of organic carbon in 1998 decreased from 1996 at both sites. From 0-60 cm, average organic carbon loss at the Ecomuseum was 15 Mg C ha^{-1} yr^{-1}, while at the Seedfarm, the average loss since 1996 was 9 Mg C ha^{-1} yr^{-1}.

Table 2. Mean soil organic carbon from 0-60 cm in each cropping system

		Organic Carbon (Mg ha^{-1})	
Site	Crop	1996	1998
Ecomuseum	Corn	105	83 (-11)*
	Switchgrass	119	90 (-14)
	Willow	137	98 (-20)
	Mean	**121 a**	**91 a (-15)**

Seedfarm	Corn	108	85 (-12)
	Switchgrass	93	77 (-8)
	Willow	103	88 (-8)
	Mean	**101 b**	**83 b (-9)**

*Values in brackets represent the amount of annual incremental organic C increase since the last sampling period (Mg C ha^{-1} yr^{-1})

The decrease in soil organic carbon from 1996 to 1998 was not anticipated. The conversion from annually tilled systems (prior to the plantation of switchgrass and willow), to a undisturbed system, coupled with the additions of litterfall of approximately 2.0 Mg ha^{-1} in switchgrass plots, and 1.8 Mg ha^{-1} in the willow, as well as the turn over of root carbon, was expected to significantly increase the soil organic carbon. The decline in soil organic C in corn may be explained by soil erosion, as well as by the moldboard plowing, which increases the organic matter decomposition rate.

Due to the continuous removal of switchgrass biomass each spring, there may have been a decrease in the microbial population due to the lack of organic input, thereby slowly reducing the microbial population, as their source of nutrients becomes depleted. Campbell et al. (1997) found soil organic matter to decrease from 1959 to 1996, at 0-15 cm when wheat straw was removed every two out of three years. Several studies point to the importance fertilization levels have on soil organic carbon sequestration (Campbell, 1997; Mahli et al., 1997). A study by Mahli et al. (1997) found the total C to increase with increasing N fertilizer application (rates varied from 0-336 kg ha^{-1}), by up to 64 g kg^{-1} in the 112 kg N ha^{-1} rate (from 50.33 g kg^{-1} in the control) over 27 years. Hay was grown on those plots with average dry matter yields of 1.17 Mg ha^{-1} on the no N fertilized plots to 5.45 Mg ha^{-1} on the 336 kg N ha^{-1} plots. In our study, switchgrass 1998 aboveground biomass yields averaged 12.7 Mg ha^{-1} at the Seedfarm, and 12.9 Mg ha^{-1} at the Ecomuseum, with fertilization rates of 50 kg N ha^{-1}.

The relatively low fertilization rates used were chosen to minimize the amount of switchgrass lodging, pest outbreaks in the willows, and input costs. Optimal rates of fertilization for economical biomass production may not be optimal for soil organic carbon storage. This study should not discredit previous work conducted on carbon sequestration with perennial crops. Rather, it should be cautioned that relatively high yielding biomass crops are efficient nutrient feeders and have significant nutrient demands.

REFERENCES

Campbell, C.A., F. Selles, G.P. Lafond, B.G. McConkey, and D. Hahn (1997) Effect of crop management on C and N in long-term crop rotations after adopting no-tillage management: Comparison of soil sampling strategies. Can. J. Soil Sci. 78:1-12.

Cole, C.V., J. Duxbury, J. Freney, O. Heinemeyer, K. Minami, A. Mosier, K. Paustian, N. Rosenberg, N. Sampson, D. Sauerbeck, and Q. Zhao (1997) Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling Agroecosyst. 49:221-228.

Ellert, B.H. and Bettany, J.R. (1995) Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Can. J. Soil Sci. 75:529-538.

Malhi, S.S., M. Nyborg, J.T. Harapiak, K. Heier, and N.A. Flore(1997) Increasing organic C and N in soil under bromegrass with long-term N fertilization. Nut. Cycl. Agroecosyst. 49:225-260

Yeomans, J.C., Bremner, J.M. (1998) A rapid and precise method for routine determination of organic carbon in soil. Commun. Soil Sci. Plant Anal. 19:1467-1476.

Zan, C. (1998) Carbon storage in two biomass energy plantations. [M.Sc Thesis] McGill University. 108 pp.

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