Factsheet #4

Soil organic carbon sequestration potential of perennial biomass crops as determined by soil isotopic carbon ($\delta^{13}C$) signature

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Sowthini Vijayakumar[1], Amir Bazrgar[1], Paul Voroney[1] and Naresh Thevathasan*[1]

*Corresponding author: nthevath@uoguelph.ca
[1]School of Environmental Sciences, University of Guelph

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Perennial biomass crops (PBCs) and ^{13}C natural abundance

Perennial biomass crops (PBCs) are characterized by their ability to quickly establish and produce annual biomass yields, accumulate and sequester carbon (C) in aboveground, belowground biomass and in soil, despite low volumes of accessible water, along with their C_4 photosynthetic abilities (Clifton-brown *et al*., 2007). Switchgrass (*Panicum virgatum*, SG) and miscanthus (*Miscanthus spp*., Mis) are two commonly grown C_4 perennial warm-season biomass crops in Ontario, Canada (Graham et al., 2019). Graham et al. (2019), in their study in Ontario, reported that SG and Mis are capable of sequestering C in soil when low productive agricultural land is converted to PBCs. However, to what extent these C_4 PBCs can sequester C in soil is not known. This can be elucidated by quantifying the ^{13}C natural abundance of stable isotopes in soil organic matter (SOM).

Natural abundance of stable carbon isotopes can be used as a quantitative tool to study soil SOM dynamics (referred to as the ^{13}C natural abundance technique). The term "natural abundance" refers to the concentration of a stable isotope as it occurs in nature. ^{12}C and ^{13}C are the two most abundant stable isotopes of C with an average natural abundance of 98.89% and 1.11%, respectively (Rundel et al., 2012; Ehleringer and Rundel 1989). Natural abundance isotopic studies utilize the difference in ^{13}C values ($\delta^{13}C$) of C_3 and C_4 plants to identify the source, pools and fate of organic C in soils (Derrien et al., 2006; Gerzabek et al., 2001; Balesdent et al., 1987). Soils developed under C_3 or C_4 vegetation contain SOM with $\delta^{13}C$ of −27‰ or −13‰, respectively. This contrast in isotopic signature of plant residues is maintained throughout the continuum of decomposition processes and transferred to residue-derived SOM (Derrien et al., 2006; Balesdent et al. 1987). Therefore, the inherent $\delta^{13}C$ values allow either group of plants to act as a tracer in carbon cycling studies (Ehleringer et al., 2000; Boutton, 1996).

Contribution of perennial biomass crops on soil organic carbon sequestration

Studies from the University of Guelph discovered the potential of PBCs on soil organic C (SOC) sequestration by estimating the amount of ^{13}C natural abundance in SOM in three different locations, namely Guelph, Elora and Burlington, Ontario in 2020. The Guelph (GTI-Guelph Turfgrass Institute) site is classified as class 3 land whereas, the Elora (ERS-Elora Research Station) and Burlington sites are classified as class 1 land under Canada Land Inventory (CLI) classification. Prior to PBC establishment on a certain portion of the land, the land was under agriculture crop production with annual crop rotation of C_4 [corn (*Zea mays*) and C_3 species [soybean (*Glycine max*) and wheat (*Triticum aestivum*)] (used as a reference field). The change in ^{13}C values in SOM in two different years (2016 and 2020) after land use conversion was captured in SG and Mis fields along with ^{13}C values in SOM in the remaining portions of agricultural field, which provided the proportion of the newly derived C from the C_4 crops.

In Guelph, SOC in the agricultural reference field had a $\delta^{13}C$ value of -24.21 ‰ and values for SG and Mis were -22.70 ‰ and -22.58 ‰, respectively. In Elora, SOC in the agricultural reference field had a $\delta^{13}C$ value of -23.05 ‰ and values for SG and Mis were -21.08 ‰ and -19.83 ‰, respectively (Table 1). The $\delta^{13}C$ of SOC in agricultural soils was slightly more negative than those measured for SOC in the adjacent SG and Mis fields, indicating a C_4 biomass enrichment of SOC. Since corn is also a C_4 crop, different management strategies such as residue removal or crop rotations could have influenced initial C_4 SOC levels and ultimately the inferences made.

Table 1: δ^{13}C (‰) signatures, soil organic carbon stocks and calculated contribution of C_4 biomass to the soil in Guelph, Elora and Burlington, Ontario in 2020.

Farm location	Land-use	Establishment (year)	δ^{13}C$_{SOC}$ (‰)	Total SOC (Mg C ha^{-1})	C_4 SOC (Mg C ha^{-1})	C_4 SOC (%)	C_3 SOC (Mg C ha^{-1})
Guelph, ON	Agriculture	<1989	-24.21	83.1 (± 10.36)	15.5 (± 0.34)	19	67.0 (± 0.34)
Guelph, ON	Miscanthus	2009	-22.58	91.7 (± 3.13)	28.1 (± 0.17)	31	63.7 (± 0.17)
Guelph, ON	Switchgrass	2009	-22.70	88.2 (± 2.08)	26.3 (± 0.08)	30	61.9 (± 0.08)
Elora, ON	Agriculture	2009	-23.05	97.5 (± 3.76)	26.0 (± 0.05)	27	71.5 (± 0.05)
Elora, ON	Miscanthus	2009	-19.83	99.1 (± 0.50)	49.6 (± 0.23)	50	49.8 (± 0.23)
Elora, ON	Switchgrass	2009	-21.08	91.9 (± 1.67)	37.8 (± 0.09)	41	54.2 (± 0.09)
Elora, ON	Woodlot	-	-26.97	133.8 (± 2.63)	0	0	133.8 (± 2.63)
Burlington, ON	Agriculture	-	-24.53	104.1 (± 2.42)	17.3 (± 0.08)	17	86.8 (± 0.08)
Burlington, ON	Miscanthus	2016	-25.30	135.4 (± 3.30)	17.7 (± 0.13)	12	119.6 (± 0.13)
Burlington, ON	Switchgrass	2016	-25.59	94.7 (± 3.47)	9.1 (± 0.16)	10	8.6 (± 0.16)

In Guelph, total SOC in SG and Mis were 88.2 and 91.78 Mg C ha^{-1} and the proportions of C_4 derived SOC were 30 % in SG and 31 % in Mis. Total SOC in SG and Mis were 91.9 and 99.1 Mg C ha^{-1} and the proportions of C_4 derived SOC were 41 % in SG and 50 % in Mis in Elora. However, about 19 % and 27 % of SOC in agricultural reference fields were derived from C_4 vegetation inputs in Guelph and Elora, respectively (Table 1). This suggests that residues from the herbaceous C_4 biomass crops are being incorporated into the soil and thereby have influenced the SOC pool over an 11-year period. However, this trend was not observed in 4 years of biomass production in Burlington, where C_4 derived SOC were 10 %, 12 % and 17 % in SG, Mis and agriculture, respectively.

Figures 1 and 2 show the C_4 SOC (Mg C ha^{-1}) contribution from agriculture, Mis and SG in sampled years 2016 and 2020 (4 years) in Guelph and Elora, respectively. In Guelph, C_4 SOC contribution in 2020 was significantly higher in SG compared to C_4 SOC contribution in 2016. Though no statistical significances were observed in agriculture and Mis in C_4 SOC contribution between 2016 and 2020, values were numerically higher in 2020. However, in Elora, C_4 SOC contribution in 2020 was significantly higher in all three land-uses: SG, Mis and agriculture, compared to C_4 SOC contribution in 2016. It should be noted that the contribution of C_4 SOC was comparatively higher in biomass crop fields (SG and Mis) than agricultural fields after 4 years. This shows the potential of biomass crops on SOC sequestration compared to agriculture.

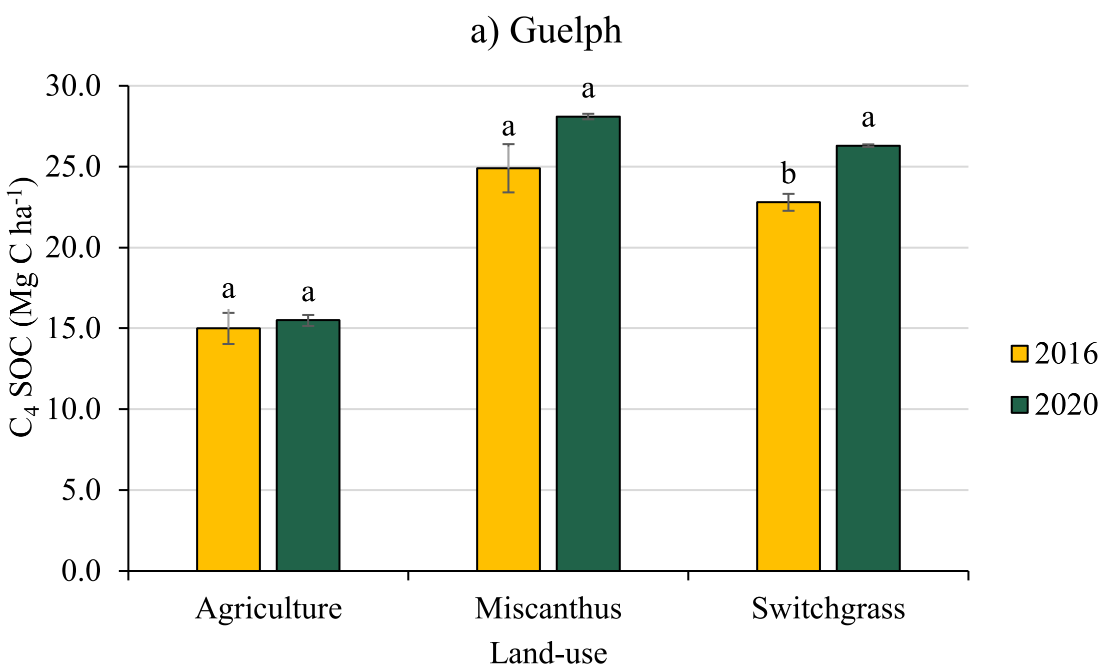

Figure 1: Comparison of C_4 SOC (Mg C ha^{-1}) contribution from agriculture, Miscanthus and switchgrass in sampled years 2016 and 2020 (4 years) in Guelph, Ontario.

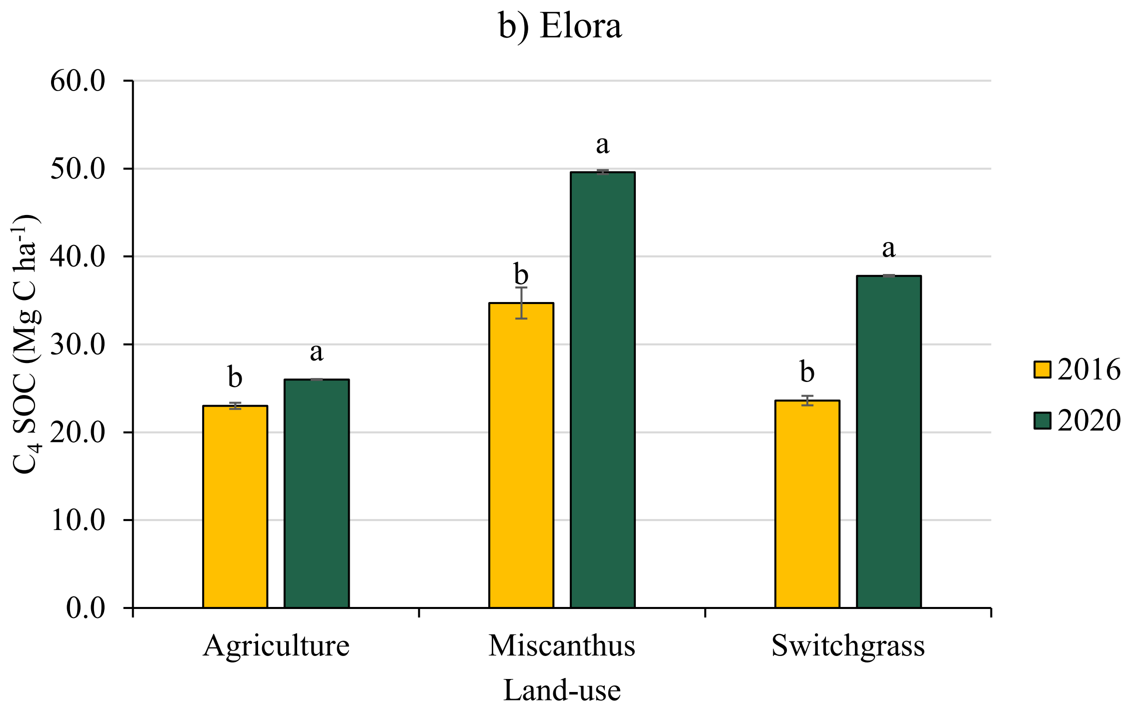

Figure 2: Comparison of C_4 SOC (Mg C ha^{-1}) contribution from agriculture, Miscanthus and switchgrass in sampled years 2016 and 2020 (4 years) in Elora, Ontario.

Conclusion

The research looked at the proportional contribution of PBCs to the above SOM gains by analyzing $\delta^{13}C$ signatures in SOM. The results clearly indicate that the PBC (switchgrass and miscanthus) contribution to total SOC ranged from 30 to 41% for switchgrass and 31 to 50% for miscanthus, whereas the agricultural crop (mainly corn – C_4 plant) contribution to total SOC was only 19 to 27%. The $\delta^{13}C$ analysis of SOC confirms the SOC contribution by PBCs in the 4-year study period and it was higher in PBCs compared to agricultural fields in both class 1 (ERS site) and class 3 (GTI site) lands. This clearly indicates that converting low productive agricultural lands to PBCs increases SOC.

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