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Quantifying soil organic carbon stocks in herbaceous biomass crops grown in Ontario, Canada

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Abstract Nineteen farms growing herbaceous biomass crops, switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus* spp.), were sampled for soil organic carbon (SOC) across Ontario, Canada in 2016. Switchgrass and miscanthus fields were sampled in addition to nearby agricultural fields and woodlots to compare SOC in herbaceous biomass systems relative to alternative land-uses. The mean SOC concentration of the woodlots was 4.26 ± 0.29% and was significantly higher ($p < 0.05$) than in any other types of land-use. The mean SOC concentration in agricultural fields was 2.21 ± 0.31%, while switchgrass and miscanthus had a mean SOC concentration of 2.50 ± 0.29 and 2.50 ± 0.36%, respectively. The mean SOC stock (0–30 cm) was highest in woodlots at 103.55 ± 7.40 Mg C ha^{-1}. This was significantly higher than stocks quantified in agricultural and miscanthus land-uses, which contained 80.51 ± 7.74 and 83.36 ± 8.97 Mg C ha^{-1}, respectively. The mean SOC stock calculated for switchgrass was 85.30 ± 7.14 Mg C ha^{-1} and was not significantly different ($p > 0.05$) when compared with the SOC stocks quantified for the woodlot. The study recorded numerically higher SOC concentrations and stocks in biomass fields compared to agricultural fields. Therefore, biomass systems contribute to higher SOC sequestration. However, challenges associated with this study such as accurate bulk density measures and lack of baseline data need to be resolved in order to improve quantification of SOC sequestration.

Keywords Soil organic carbon · Biomass · Switchgrass · Miscanthus · Climate change · Land-use change

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Introduction

In Ontario, Canada, there is growing interest in producing biomass crops as a renewable biomass source for the creation of advanced biofuels, direct combustion for heating and electricity, the manufacturing of bioproducts, and their use as animal bedding (Kludze et al. 2013; Agri-Technology Commercialization Center 2015). The most common Ontario biomass crops include perennial warm-season grasses such as switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus* spp.). While woody species such as hybrid willow (*Salix* spp.) and poplar (*Populus* spp.) are also grown in Ontario (Marsal et al. 2016), herbaceous biomass species have garnered the most attention. Perennial warm-season grasses are of interest due to their high yields, low nutrient requirements, a broad range of environmental tolerances and environmental benefits in comparison to common Ontario field crops such as corn (*Zea mays*), soybean (*Glycine max*) and wheat (*Triticum aestivum*). They are also cultivated similarly to common Ontario hay and forage crops and thus, do not require highly specialized equipment (Deen 2017). Due to their perennial nature, high productivity and extensive root systems, warm-season grasses stabilize soil which reduces erosion and non-point source water pollution (McCalmont et al. 2017). Additionally, biomass crops also improve the quality of the soil by accumulating soil organic carbon (SOC). Previous research have indicated that herbaceous biomass crops can also increase SOC levels and provide long-term carbon storage on land where they have been introduced (Lemus and Lal 2005; Felten and Emmerling 2012; Gelfand et al. 2013; Agostini et al. 2015; Qin et al. 2016). With respect to agricultural lands with lower productivity, the accumulation of SOC will be enhanced since carbon emissions associated with land-use change are thought to be low with the introduction of biomass crops (Gelfand et al. 2013).

Through meta-analysis Agostini et al. (2015) have calculated mean values of SOC accumulation in switchgrass and miscanthus stands are approximately 1.59 and 1.21 Mg C ha^{-1} yr^{-1}, respectively. However, it is important to note that these rates can be highly variable and are influenced from study to study by many factors including crop management, sampling depth, duration, and previous land-use (Lemus and Lal 2005). Qin et al. (2016) found that cropland conversion to miscanthus resulted in a 14% increase in SOC stocks while conversion from grassland or forest to herbaceous biomass resulted in no SOC change. This stresses the importance to also consider land-use change with respect to biomass crops and SOC sequestration (Gelfand et al. 2013). Net changes in SOC for biomass systems are typically positive, but it is noted that this might not be the case in early years (Zatta et al. 2014). Upon conversion to biomass crops an initial resilience phase of SOC may be witnessed where gross inputs of organic carbon may not outweigh root respiration and the decay of existing SOC (Agostini et al. 2015). Overall, long-term trends indicate net gains of SOC in both switchgrass and miscanthus grown across North America, but the exact dynamics of how and when net gains occur is not completely understood.

Given the recent commitments made by both the Canadian Federal Government and the Provincial Government of Ontario to act against climate change, both agriculture and soil have come to the forefront of the carbon management discussion. The Government of Ontario's comprehensive "Climate Change Action Plan" includes "Agriculture, Forests and Lands" as one of the Ontario's key areas of action. Within this action area, the Government of Ontario is seeking to "maximize carbon storage from agriculture, enhance carbon storage in natural systems and increase our understanding of how agricultural and natural lands emit and store carbon" (Ontario Ministry of Environment and Climate Change 2017). Within this policy framework, biomass crops are a strong candidate for promotion in Ontario agricultural systems. Not only could these crops potentially enhance and maximize carbon storage, they could also improve the overall fertility, productivity, function and health of the soil. If verified to increase levels of SOC in Ontario, farmers such as those belonging to the Ontario Biomass Producers Cooperative (OBPC) could receive monetary compensation from the Ontario Government in the form of voluntary carbon offsets for sequestering carbon in the soil.

Worldwide, even though studies have looked at SOC dynamics in commercial biomass fields, none of these studies have looked at SOC sequestration in several locations in a given region. While research has indicated that switchgrass and miscanthus are likely to accumulate SOC, especially on less productive agricultural land, this has not been verified in Ontario. If Ontario policy is to reward farmers for SOC storage in biomass cropping systems, SOC accumulation must first be verified within the province. Therefore, it is the aim of this study to directly address this knowledge gap. Specifically, this study seeks to accomplish the following objectives: (1) create a database of current SOC levels in switchgrass and miscanthus fields in Ontario to facilitate long-term SOC monitoring, and (2) compare levels of SOC between herbaceous biomass, common agricultural and woodlot land-use systems to determine how much carbon is being stored in herbaceous biomass systems relative to alternative land-uses. Due to their high yield and extensive root systems, it is expected that both switchgrass and miscanthus will contain more SOC in the top 30 cm of soil than common agricultural crops but should contain less when compared to adjacent woodlots grown in the same regions and on similar soil types.

Methodology

Study locations

In 2016, nineteen farm sites across Ontario were identified for study and the selected sites can be seen in Fig. 1.

Of the nineteen sites, seventeen were commercial farms and two were research stations established and operated by the University of Guelph (sites 18 and 19). Traditionally seed sources for switchgrass in Ontario have been limited and therefore, all farms were growing a single cultivar; Cave In Rock (*P. virgatum* L.). For miscanthus, varieties found on each farm differed and included either *M.* × *giganteus* or clones of *M. sinensis* × *M. sacchariflorus* such as Nagara, Illinois, or M1 Select. At each farm location, biomass fields of varying ages were sampled for SOC content.

In addition, to compare differences in SOC based on land-use, woodlots and agricultural fields in proximity to the biomass fields were sampled at each farm where possible. Doing so, allowed for comparisons to be made between land-uses found at similar geographic locations and similar soil types influenced by the same climatic conditions. Due to limitations at each farm, such as availability and access permissions, not all four land-use types were able to be sampled at each farm location. In total, 21 switchgrass fields, 9 miscanthus fields, 15 agricultural fields and 16 woodlots were sampled. All agricultural fields were managed in some variation of either a corn, soy, wheat or a corn, soy rotation. There was only one exception (site 10) that had alfalfa (*Medicago sativa*) incorporated into a corn and soy rotation. In addition to the 17 commercial fields, switchgrass and miscanthus plots at the University of Guelph research stations in both

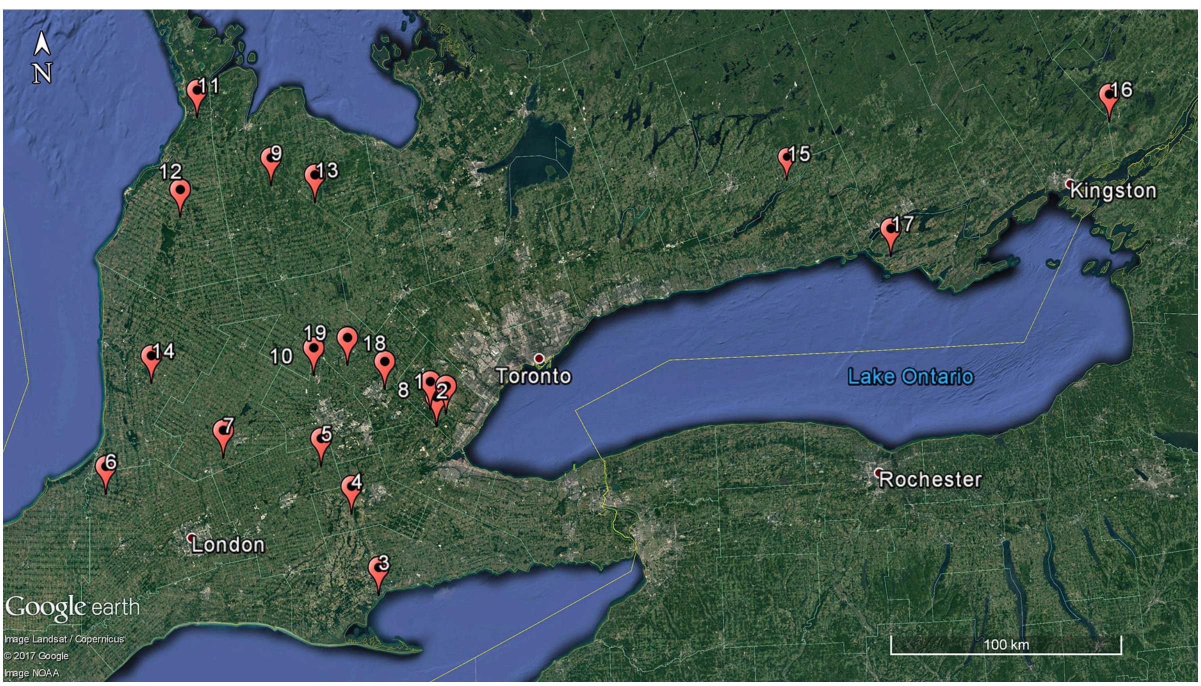

Fig. 1 Locations of the nineteen fields sites in Southern Ontario assessed for soil organic carbon content throughout the summer of 2016 created in Google Earth Pro. Numbers represent the unique farm identification number used throughout this study. Sites 18 and 19 represent research stations established and operated by the University of Guelph and are located in Guelph and Elora, respectively

Guelph ON (latitude 43°32′60″N, longitude 80°12′30″W) and Elora ON (latitude 43°38′50″N, longitude 80°24′03″W) were also examined for their SOC contents. Switchgrass and miscanthus have been growing at these two research sites since 2009.

Sample collection

At each field, top-soil samples from 0 to 30 cm were collected and examined for their SOC content ex situ. Soil samples were collected using a transect method with five sampling locations along the transect. The sampling locations were placed at evenly spaced intervals along the transect. Since the fields varied in size, sampling intervals were adjusted to fit the unique size of each field. For example, a field of 50 m in length would have received a sampling interval of 10 m while intervals for a field of 100 m in length would have been 20 m. The start of each transect was marked using a Garmin GPS unit, accurate to within 2 m, so that the transect could be found again for future sampling campaigns. Along with the GPS coordinates of each transect, the bearing of the transect was recorded with a compass. Moving along the bearing, the sampling interval was measured, and each sampling location was determined.

At each sampling location along the transect, 3 top-soil samples (0–30 cm), each weighing 500–700 g, were collected using a Dutch auger for SOC analysis. In addition, 2 samples were also collected for bulk density using a 250 mL UMS soil sampling ring (Meter Group AG, Munich, DE). The soil sampling rings had a height of 5 cm and an inner diameter of 8 cm. Since the rings did not extend throughout the entire 30 cm soil profile, one sample was collected from a depth of 0–15 cm and another from a depth of 15–30 cm. By doing so, changes in bulk density due to differences in depth below the plow layer were better captured. At each sampling location, all SOC and bulk density samples were collected within a 1 m radius of the marked sampling location.

Research plots of switchgrass and miscanthus in Guelph and Elora were smaller than the commercial fields surveyed. The dimensions of the Guelph plots were 10 m by 10 m and in Elora 3.05 m by 6.1 m. Instead of sampling by transect, each replicated plot was treated as a sampling point. As such, 3 SOC and 2 bulk density samples were collected for each replicate. In Guelph, plots were replicated 4 times which yielded a total of 12 SOC samples and 8 bulk density samples for each biomass crop, switchgrass and miscanthus. The agricultural field and woodlots in Guelph were sampled using the transect method (15 SOC and 10 bulk density samples). In Elora, plots were replicated 3 times. An agricultural control was built directly into the Elora plot design and thus, 9 SOC and 6 bulk density samples were collected for each switchgrass, miscanthus and agricultural land-use types. The woodlot in Elora was sampled using the transect method described above. Elora research plots had variable application rates of fertilizer and different biomass cultivars. Therefore, to maintain consistency, all samples were collected from the areas where Cave in Rock switchgrass and M1 Select miscanthus were grown and fertilized at 160 kg N ha^{-1}.

Soil organic carbon analysis

Soil samples for SOC analysis were air dried and subsequently passed through a 2 mm sieve. Rock and root material above the 2 mm sieve diameter were discarded so that only soil aggregates remained above the sieve. The large soil aggregates were then passed through a hammermill (Custom Laboratory Equipment, FL, USA) to break-up and homogenize the soil and again passed through a 2 mm sieve. After processing through the hammermill, approximately 15–20 g of soil was ground to < 0.450 mm and used for subsequent SOC analysis. SOC was determined using direct combustion method adapted from Wang and Anderson (1998) and further outlined by Wotherspoon et al. (2015). Each ground soil sample was divided up into 2 sub-samples. The first sub-sample was placed in a muffle furnace and heated to 575 °C for 24 h to remove all soil organic carbon (SOC) so that only the soil inorganic carbon remained (SIC). After SOC removal, the first sub-sample was analyzed for its remaining SIC content by combusting 0.2000–0.3000 g of soil in a Leco CR-412 carbon analyzer (LECO Corporation, MI, USA) at 1300 °C using a lance flow of 1.2 L min^{-1}. The second sub-sample was sent directly for C analysis in the Leco CR-412 using the same method to determine soil total carbon (STC). STC and SIC values from the two sub-samples were then used in Eq. 1 to calculate SOC (Tabatabi and Bramner 1970).

A moisture content correction factor (CFM) was applied to account for the moisture found within the air-dried STC sub-sample. Since the SIC sub-sample was analyzed directly after being treated in the muffle furnace, it was assumed that these samples did not contain any moisture and no CFM was applied. To determine the CFM, soil was placed in tins and weighed before and after oven-drying for 48 h at 105 °C. Equation 2 was then used to calculate the CFM where M_{tin} is the mass of the tin (g), M_{AD} (g) is the mass of air-dry soil (g) and M_{OD} (g) is the mass of oven-dry soil. Soils used in the CFM determination were not used for C analysis

$$SOC(\%) = [STC(\%) \times CFM] - SIC(\%) \quad (1)$$

$$\mathrm{CFM} = \frac{[\mathrm{M_{AD}(g) - M_{tin}(g)}]}{[\mathrm{M_{OD}(g) - M_{tin}(g)}]}. \quad (2)$$

Bulk density and soil organic carbon stocks

To calculate the total mass of SOC associated with each field, soil bulk density was used. For each field, bulk density samples were collected and analyzed separately from the SOC samples. Bulk density samples were first oven dried for 48 h at 105 °C and weighed to determine their oven dried mass (M_{OD}). Since root debris and rocks were present in the samples, bulk density was corrected to capture only the bulk density of the soil material (Hao et al. 2008). After oven-drying soil samples were passed through a 2 mm sieve. The mass (M_{debris}) and volume (V_{debris}) of the root and rock material that persisted above the 2 mm sieve was recorded and Eq. 3 was used to calculate bulk density. V_{debris} was obtained through water displacement (Hao et al. 2008). The total soil volume (V_{total}) was fixed at 250 cm^3 as this was the volume of the UMS soil sampling ring used. Finally, the mean bulk density and mean SOC (%) of each field was used in Eq. 4 to calculate the total Mg of organic carbon per hectare in each field for the top 30 cm of soil.

$$\text{Bulk density}\left(\text{g cm}^{-3}\right) = \frac{[\mathrm{M_{OD}(g) - M_{debris}(g)}]}{[\mathrm{V_{total}(cm^3) - V_{debris}(cm^3)}]} \quad (3)$$

$$\mathrm{SOC}\left(\text{Mg of C ha}^{-1}\right) = \left[10{,}000\,\mathrm{m}^2 \times 0.3\,\mathrm{m}\right] \times \left[\text{bulk density}\left(\text{g cm}^{-3}\right)\right] \times \left[\mathrm{SOC}(\%)\right]. \quad (4)$$

Statistical analysis

To determine the effect of land-use on SOC, a general linear mixed-effect model was fit using each field as an independent observation. SOC values for each field used within the model were the mean values of the 15 soil samples collected in each field. Ideally, bulk density is used to standardize the SOC (%) data and report results on a mass basis. However, some of the biomass and agricultural fields sampled were grown on marginal, rocky soil that damaged sampling equipment and thus, it was not possible to obtain bulk density for all fields. To include all the data within this study, two separate models were created for land-use comparisons; one with SOC given as a concentration (%) and one with SOC given in mass (Mg C ha^{-1}).

Each general linear mixed-effect model was fit in Rstudio using the “lme4” package. Land-use type was modeled as the fixed effect and farm location was treated as the random effect. To compare all land-use types (switchgrass, miscanthus, agriculture, and woodlot) against each other, the least square means were computed, and compared pairwise using a Tukey’s multiple range test within the “lsmeans” package. For each model, assumptions of variance and normality were examined using scatterplots and QQ plots of the Pearson residuals. Plots of the observed and predicted values for SOC were also examined for each model to ensure proper fit. One outlier was identified and removed in each model. The type 1 error for all statistical tests was 0.05.

Results and discussion

Soil organic carbon concentration

Mean SOC concentrations (%) across the different land-use types are presented in Fig. 2.

Pairwise comparisons between the various land-uses resulted in no statistical difference ($p \geq 0.05$) in mean SOC concentration between common agricultural, miscanthus or switchgrass crops. The mean SOC concentration of the woodlots was 4.26 ± 0.29% and was significantly higher ($p < 0.05$) than in any other types of land-use. The mean SOC values presented include biomass fields that ranged from 0 to 10 years of age. However, only a single field with an age of 0 (newly established in 2016) was sampled, and the

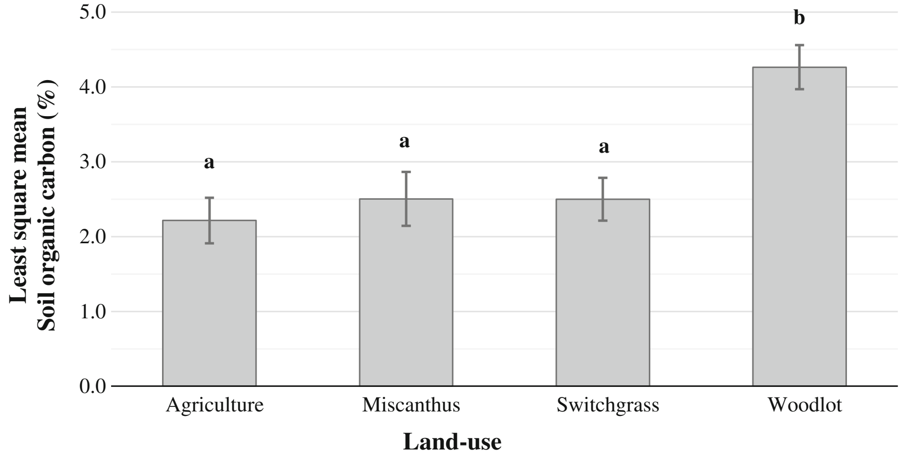

Fig. 2 Least Square mean soil organic carbon concentration (%) in fields of different land-uses sampled in Ontario, Canada in 2016. Different letters indicate statistical difference ($p < 0.05$)

mean age for all biomass fields was 4.23 years. Age is a key parameter governing the total inputs of carbon in biomass systems and thus, could have had influence on mean SOC in this analysis.

Although herbaceous biomass crops can produce high yields of plant material, not all these materials are decomposed each year, making the actual input of organic matter into the soil difficult to estimate. Depending on the management strategy it is conceivable that little to no aboveground biomass will remain on the field. The aboveground residues are also not incorporated into the field since these systems are not tilled. Therefore, it is typically thought that the root biomass is the main contributor of carbon influencing the SOM pool in herbaceous biomass cropping systems (de Graaff et al. 2013; Adkins et al. 2016). Total dry root biomass has been known to reach over 18 Mg ha^{-1} (Ma et al. 2000) in switchgrass and over 16 Mg ha^{-1} in miscanthus (Neukirchen et al. 1999). However, since these crops are perennial, not all this root mass is accumulated or turned over each year. It could take many years or multiple crop rotation of biomass, in which the entire root system is subject to decay, before changes in SOC can be witnessed. Robertson et al. (2017) reported that total SOC in the top 30 cm of soil in a commercial miscanthus field grown near Lincolnshire, UK did not change even after 7 years. Although miscanthus derived SOC was incorporated within the top 30 cm of soil at a rate of 0.86 Mg C ha^{-1} yr^{-1}, no net change in total SOC was observed. This is also in accordance with research by Zatta et al. (2014) who also recorded changes in miscanthus derived carbon but observed no net changes in SOC (0–30 cm) after 6 years. Zatta et al. (2014) attributed this result to both root respiration as well as rhizosphere priming effects whereby the newly added, labile miscanthus inputs accelerated the decomposition of previously existing SOC. However, studies examining rhizosphere priming in biomass systems have had mixed results (Robertson et al. 2017).

While results were not statistically significant, numerical difference between the agricultural and biomass land-uses were observed. Agricultural fields had a mean SOC concentration 2.21 ± 0.31%, while switchgrass and miscanthus had a mean SOC concentration of 2.50 ± 0.29 and 2.50 ± 0.36%, respectively. This coupled with the relatively young age of biomass plantations, could represent a trend in which both switchgrass and miscanthus will accumulate more SOC in the future in comparison to annual field crops grown in Ontario. Experiments examining SOC dynamics in switchgrass plantations report positive changes in SOC, even after recent establishment (Liebig et al. 2008). Data demonstrating positive SOC changes in young miscanthus stands, is sparse throughout the scientific literature. However, the studies reported indicate that young miscanthus stands do influence the SOC pool and that land-use change to miscanthus does not result in a loss of SOC (Zimmerman et al. 2013). Comparisons of SOC sequestration between species of biomass crops demonstrate higher SOC accumulation in switchgrass than miscanthus. Higher rates of root turnover and improved retention of switchgrass residues are likely factors contributing to greater SOC sequestration of switchgrass residues in comparison to miscanthus (Agostini et al. 2015). These findings support the numerical trends observed in this study.

Soil organic carbon stocks

Mean SOC stocks (Mg C ha^{-1}) for each land-use can be seen in Fig. 3.

Mean SOC stocks (Mg C ha^{-1}) for each land-use can be seen in Fig. 3. Mean SOC stocks in each land-use system was influenced by soil bulk density. Mean SOC was highest in woodlots at 103.55 ± 7.40 Mg C ha^{-1}. This was significantly higher ($p < 0.05$) than both agricultural and miscanthus land-uses which contained 80.51 ± 7.74 and 83.36 ± 8.97 Mg C ha^{-1}, respectively. Interestingly, the mean SOC stock calculated for switchgrass was 85.30 ± 7.14 Mg C ha^{-1} and was not significantly different to any land-use including the woodlot land-use system. This was likely due to a slightly larger standard error in miscanthus fields than in switchgrass even though overall carbon stocks in switchgrasss and miscanthus were very similar. However, these results support the numerical trend observed for the SOC concentrations across the different land-use types. They also further support the findings reported in the literature that both switchgrass and miscanthus have the tendency to accumulate more carbon in soils compared to annual agricultural row crops (Agostini et al. 2015). However, it is also important to note that the SOC stocks calculated were for the top 30 cm soil profile only. This does not include the carbon stored within the vegetation, or within the soil horizons deeper than 30 cm.

The roots of trees are significant contributors to the SOC pool and persist downwards of 30 cm (Oelbermann et al. 2004). The root systems of trees can be larger and extend deeper in the soil than perennial grasses, even though switchgrass and miscanthus roots can also extend well beyond 30 cm. In this study, woodlots that were sampled are all undisturbed soil systems for 50–100 years. Therefore, soils derived from these mature woodlots have significantly more carbon stored within them. In this context, it is also interesting to note that early research on native perennial grasses by Weaver and Darland (1949) witnessed switchgrass roots deeper than 3 m in various soils throughout Nebraska, USA and Northern Kansas, USA. Similar trends are observable in miscanthus. Neukirchen et al. (1999) documented miscanthus roots deeper than 2 m. As the sites selected for this study are in close proximity to the woodlots, in the long-term, both herbaceous biomass crops may hold the potential to enhance SOC to reach the levels that are recorded in this study in woodlots.

Further, positive changes in SOC stocks have been observed in biomass stands at depths greater than 60 cm (Zan et al. 2001; Liebig et al. 2008; Dondini et al. 2009; Felten and Emmerling 2012; Gauder et al. 2016). This is an important insight when considering carbon credits and carbon policy in Ontario. Quantifying SOC in the top 30 cm therefore may contribute an under estimation of SOC stock associated with herbaceous biomass crops. In addition, the SOC stored

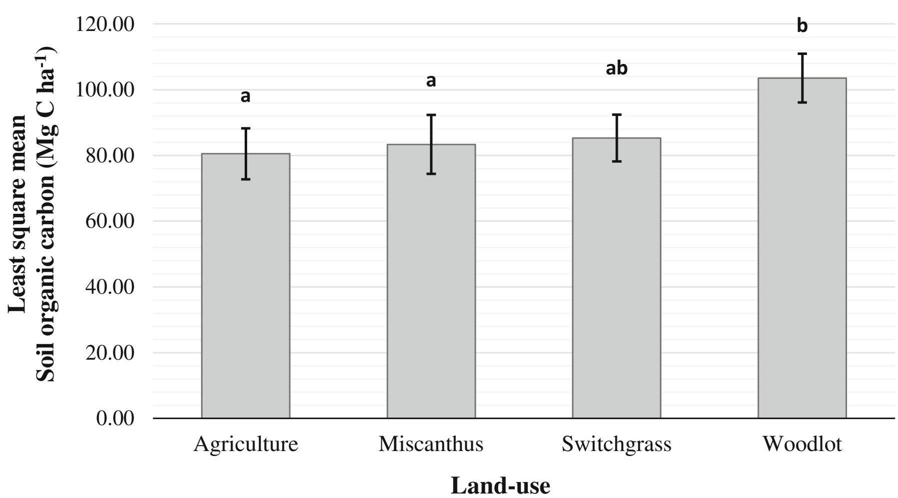

Fig. 3 Least square mean soil organic carbon stocks (Mg of C ha^{-1}) in fields of different land-uses sampled in Ontario, Canada in 2016. Different letters indicate statistical difference ($p < 0.05$)

deeper might also be more permanently retained since it is not as subject to erosion or soil disturbance (Lemus and Lal 2005).

Another pivotal part of calculating total SOC stocks in soils is the measurement of bulk density. Typical values of bulk density for Ontario agricultural fields range from 1.1 to 1.3 g cm^{-3}, although this is not always the case. Capturing an accurate measure of bulk density can be difficult. Typical methods of driving a sampling ring or tube of into the soil can cause soil fracturing that impact overall results. In addition, bulk density of the same soil has been known to change with season, moisture content and sampling depth (Stone 1991). This makes getting an accurate bulk density of the entire soil profile examined tedious. Since the sampling rings used in this study were only 5 cm tall, an attempt was made at each sampling point to take one bulk density reading for 0–15 cm depth and one below a 15 cm depth to 30 cm. In doing so, it would have better captured the total variability in bulk density within the top 30 cm of soil in this study. However, bulk density values for switchgrass and miscanthus appeared slightly high in comparison to typical agricultural soil values reported in Ontario. Abnormally dry conditions during the 2016 sampling year, sample compaction and partial sampling of the entire 0–30 cm profile may have influenced bulk density numbers. Having said the above, high bulk density values for biomass fields have been reported throughout the literature. Felten and Emmerling (2012), reported a bulk density of 1.54 ± 0.09 g cm^{-3} in the 0–15 cm depth and 1.73 ± 0.03 g cm^{-3} in the 15–30 cm depth in a 16-year-old German, miscanthus plantation. Similarly, Gauder et al. (2016) reported values ranging from 1.3 to 1.52 g cm^{-3} in switchgrass and miscanthus fields grown in Nebraska. Values reported by Gauder et al. (2016) as well as Felten and Emmerling (2012) are similar to those calculated for biomass fields sampled throughout this study.

Conclusion

Across the 19 farm sites sampled throughout Ontario, soils associated with herbaceous biomass crops did not contain significantly higher concentrations of SOC when compared to common agricultural land-use systems. Woodlots sampled under similar soil and climatic conditions and close proximity to biomass fields contained the highest mean SOC concentration and stocks indicating that biomass crops due to their perennial nature may have the capacity to enhance soil carbon sequestration into the future. Numerically higher SOC concentrations and SOC stocks recorded in switchgrass and miscanthus fields in comparison the agricultural reference fields shows that SOC sequestration potential is higher in biomass fields. Challenges associated with this study such as accurate bulk density measures and lack of baseline data need to be resolved in order to improve estimates of SOC sequestration. Contradictory evidence within the scientific literature on SOC in biomass crops demonstrates that the underlying mechanisms controlling changes in SOC are not fully understood. Important factors such as land-use change, sampling depth and site conditions can all influence overall results. The data collected throughout this study can be used in the future to track long-term changes in SOC within herbaceous biomass fields. This will help to explore underlying mechanisms controlling changes in SOC and potentially verify SOC storage in connection with the Ontario Government's new carbon policy initiatives.

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