Factsheet # 1

Title: SOIL ORGANIC CARBON SEQUESTRATION POTENTIALS BY BIOMASS CROPS (SWITCHGRASS & MISCANTHUS)

By

Sowthini Vijayakumar[1], Sayan Ladhani[1], Feloria Mohammadi[1], Amir Bazrgar[1], Mahendra Thimmanagari[2] and Naresh Thevathasan[1]*

*Corresponding author: nthevath@uoguelph.ca
[1]School of Environmental Sciences, University of Guelph
[2]Ontario Ministry of Agriculture and Rural Affairs (OMAFRA)

Sponsored by: OMAFRA KTT project initiative and the University of Guelph

Collaborator: Ontario Biomass Producer Cooperative (OBPC)

WHAT ARE PERENNIAL BIOMASS CROPS?

Perennial biomass crops (PBCs) are fast growing herbaceous grass species with the ability to contribute to the production of biomass energy. They are a renewable and carbon neutral energy source, where electric power is created by burning of organic material. (1) Perennial biomass crops, namely switchgrass and miscanthus, are becoming increasingly popular in Ontario due to their ability to produce high biomass yields with little inputs and low soil nutrients, while improving soil health. (2) The growing biomass and renewable energy sector have increased the demand for biomass crops, providing a sustainable economic avenue for farmers, especially on marginal or degraded lands. (2) The integration of biomass crops into Ontario's agricultural community is an economically and environmentally conscious decision.

Figure 1: Switchgrass crops (left) and miscanthus crops (right) growing in Ontario, Canada. (2)

ENVIRONMENTAL BENEFITS OF PBCs

Increasing global temperatures are proven to be associated with anthropogenic emissions; with 10% of Canada's greenhouse gas (GHG) emissions coming from crop and livestock production, the need for GHG mitigation strategies in agriculture is evident. (1) Carbon dioxide (CO_2) emissions are of particular concern, and with the integration of PBCs into agricultural lands, it is possible to reduce emissions and improve soil health through increasing carbon sinks. (3) Switchgrass and miscanthus mitigate GHG emissions in two ways: i) replacing fossil fuel combustion with renewable biomass energy and ii) sequestering carbon (C) into soils through above and below ground inputs, increasing total soil organic carbon (SOC) pools. (4,5,6,7 and,8). Biomass crops create net carbon sinks in agricultural soils such that for every 0.6kg of fossil fuel related emissions released throughout cultivation, 1kg of C is sequestered via the production of biomass crops. (4) The incorporation of C and organic matter into soils also has the ability to improve overall soil health, function and productivity. (5) These crops also provide many ecosystem services including erosion control, improved nutrient cycling and soil health, and increases in biodiversity in agricultural lands (4, 5). Therefore, the integration of PBCs into agricultural practices is both economically and environmentally sustainable.

SWITCHGRASS & MISCANTHUS

Benefits

Switchgrass and miscanthus are growing in popularity due to their rapid establishment, carbon sequestration abilities and high yield production in areas of low nutrient and water availability. These PBCs are suitable for Ontario, as they produce high yields and have similar management to other crops (soy, wheat, corn) grown in the region. Both crops establish well on most soil types and are adapted to Ontario's climatic conditions. Miscanthus is typically preferred over switchgrass due to more effective input use and higher potential to sequester C, caused by a slower rate of residue decay and more belowground biomass. However, in dry regions characterized by poor soil quality, switchgrass is more desirable. (4)

SOC Storage

Plants sequester carbon through the removal and storage of carbon dioxide (CO_2) from the atmosphere into soils via the addition of organic matter to C pools. PBCs are noted to have the ability to sequester large amounts of C into both above and below ground biomass. The integration of C into above ground plant matter (leaves, shoots) is considered above ground biomass, while the storage of C in soils and roots is belowground. (9) The extensive root systems of biomass crops allow them to store significant amounts of C below ground, but their potential to reduce CO_2 emissions is affected by the rate of C additions, stability of soil C and the long term ability of soil to store C. (10,11) Biomass crops are predicted to be able to offset 1000 to 2000 Mt C yr^{-1} globally through C sinks (12), with the potential to exceed the carbon storage rates of agricultural crops by 30 times. (13) The increases in SOC storage will be greater in soils with low SOC content to begin with, highlighting a need to address marginal and low productive agricultural lands for the integration of biomass crops.

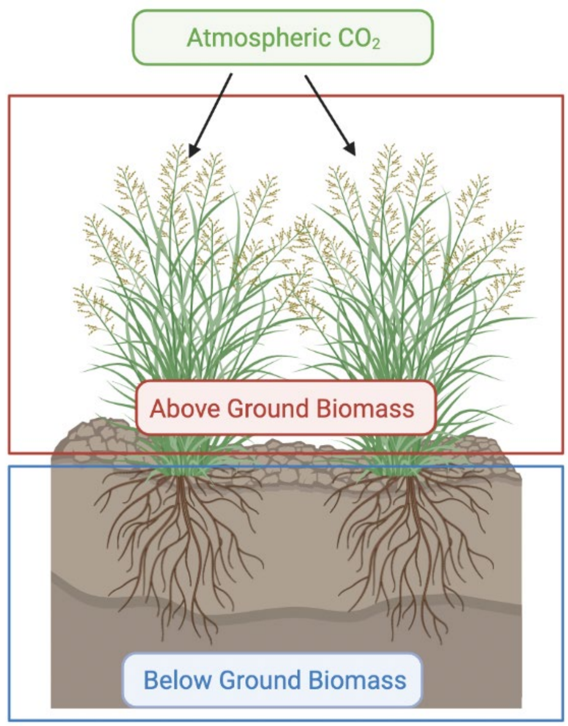

Figure 2: Carbon is sequestered from the atmosphere into soils via plants through above (shoots, leaves) and below (roots, soils) ground biomass.

SOC Potentials

Studies from the University of Guelph on the analysis of land use applications (miscanthus, switchgrass, woodlots, and agricultural fields) and SOC content have shown that there is a positive relationship for SOC present after the integration of switchgrass or miscanthus.

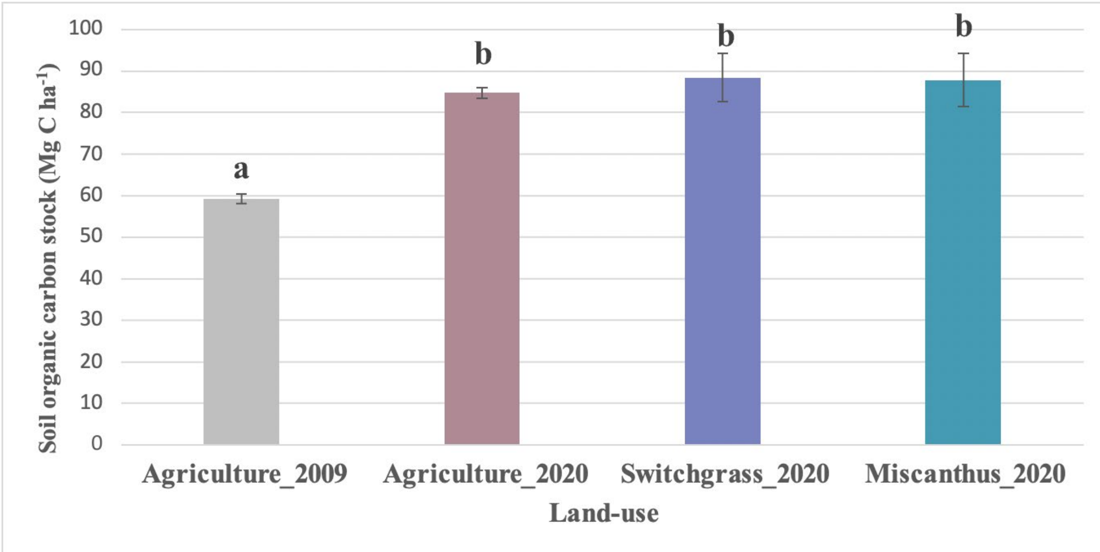

Figure 3: Mean soil organic carbon stock (Mg C ha^{-1}) of sampled fields for different land-uses. Fields sampled are non-fertile land located in Guelph, Ontario, Canada. The year of sampling is identified, and significance is compared to 2016 data. Different letters indicate statistical differences ($p \leq 0.05$).

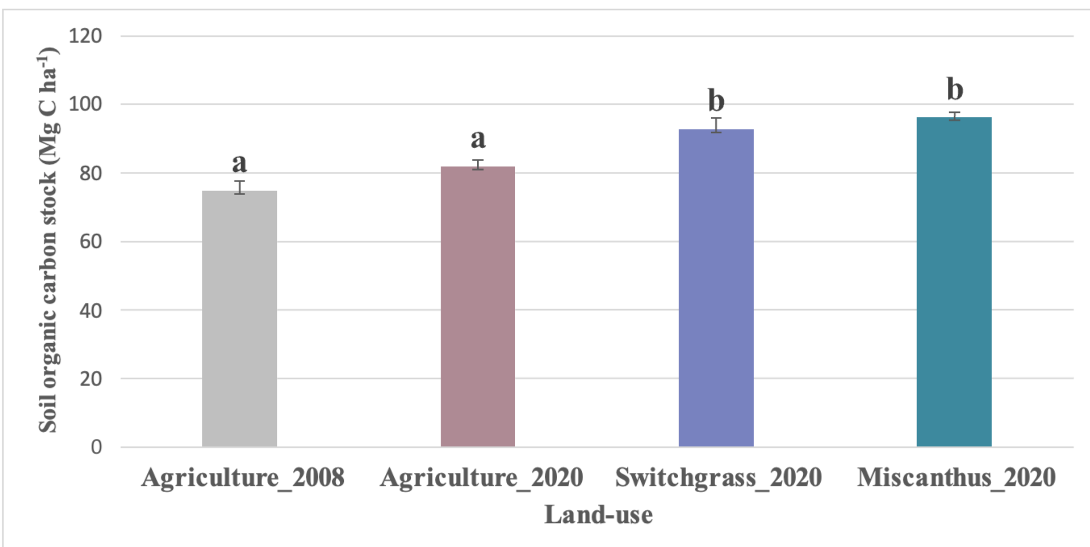

Figure 4: Mean soil organic carbon stock (Mg C ha^{-1}) of sampled fields for different land-uses. Fields sampled are located in Elora, Ontario, Canada in fertile land and the year of sampling is identified. Different letters indicate statistical differences ($p \leq 0.05$).

Studies performed on fertile Class 1 agricultural land in Elora, Ontario showed that the mean calculated values for SOC content in switchgrass soils was 92.9 Mg C ha^{-1} and was 96.4 Mg C ha^{-1} for miscanthus soils in 2020, whereas the baseline from the agricultural field soil in 2008 74.8 Mg C ha^{-1}. This is a statistically significant result for SOC in the PBC fields, while the agricultural fields showed no statistical differences in SOC content. Fertile Class 1 and 2 lands in Burlington, Ontario showed no statistical differences in SOC for agriculture, switchgrass, and miscanthus land use systems from 2016 - 2020. Low fertile Class 3 and 4 lands in Guelph, Ontario showed an agricultural baseline of 59.3 Mg C ha^{-1} in 2009, and statistically significant switchgrass and miscanthus values of 88.5 and 87.9 Mg C ha^{-1} in 2020. Woodlots in these studies did not show any significant changes in SOC over time but showed the greatest amounts of SOC. Miscanthus crops showed greater gains in SOC when fertilized by 80kg N ha^{-1} in both high- and low-class lands, with the potential to store significant levels of SOC in Class 3 soils. Switchgrass crops showed the ability to sequester C without fertilizer; switchgrass has the ability to sequester about 1.5 Mg C per ha/year, removing the equivalent of 6 tons of CO_2 per hectare from the atmosphere on an annual basis.

	Agriculture	Switchgrass	Switchgrass C Gain	Switchgrass CO_2 Value	Miscanthus	Miscanthus C Gain	Miscanthus CO_2 Value
Elora (2008)	74.8	92.8	18.0	66.2	96.4	21.5	79.2
Guelph (2009)	59.2	88.5	29.2	107.3	87.9	28.6	105.1
Burlington (2016)	84.1	87.4	3.33	12.2	101.4	17.3	63.5

Table 1: Differences in soil organic carbon (SOC) values between agricultural plots, Elora in 2008, Guelph in 2009, and Burlington in 2016, compared to their respective switchgrass and miscanthus samples in 2020 (Mg C ha^{-1}). Carbon (C) gain occurred in this study and equivalent CO2 mobilization values are also represented (Mg CO2 ha^{-1}).

Marginal lands that are converted to PBCs for more than 10 years show higher SOC gains than fertile lands. Despite short term conversion of agricultural crops in Burlington to biomass crops showing no statistical significance, there is evidence of SOC concentrations increasing over a 40-60 years period for PBC productivity(5). Further, the usage of best management practices, including low tillage and crop rotations, in lower productivity lands are linked to greater increases in SOC.

CONCLUSIONS

The positive relationship between the integration of perennial biomass crops on SOC in Ontario, Canada is a promising avenue for carbon sequestration on marginal agricultural lands. Converting marginal agricultural lands to biomass crops has the potential to improve the health and productivity of lands, while considerably reducing the GHG emissions from the agricultural sector. Encouraging farmers to convert unproductive agricultural lands to perennial biomass crop production is an important initiative to further enhance the economic and sustainable nature of perennial biomass crop production in Ontario. It is crucial to note that the mobilization of carbon from soils back to the atmosphere is possible when biomass fields are converted back to agricultural production (6). Therefore, maintaining the biomass fields for a longer period (greater than 20 years) could help SOC gains to match the SOC levels recorded in un-disturbed woodlot soils. It also appears that greater gains of SOC influenced by the perennial biomass crops were on poor or marginal lands. With approximately 1 million hectares of potentially usable marginal lands in Ontario that could be converted to biomass crops, results to-date suggest that it can be a successful mitigation method for greenhouse gas emissions produced by the agricultural sector.

Studies from the University of Guelph:

1. Graham J, P. Voroney, Brent Coleman, B. Deen, A. Gordon,. M. Thimmanagari and N. Thevathasan* (corresponding author) (2018). Quantifying soil organic carbon stocks in herbaceous biomass crops grown in Ontario, Canada. Agroforest Syst: https://doi.org/10.1007/s10457-018-0272-0
2. Bazrgar, B. A, Aeryn Ng, Brent Coleman , Muhammad Waseem Ashiq , Andrew Gordon and Naresh Thevathasan* (2020). Long-Term Monitoring of Soil Carbon Sequestration in Woody and Herbaceous Bioenergy Crop Production Systems on Marginal Lands in SouthernOntario, Canada. Sustainability: doi:10.3390/su12093901
3. Jarecki, M, K. Kariyapperuma, B. Deen, J.Graham, A. B. Bazrgar, S. Vijayakumar, M. Thimmanagari, A.Gordon , P.Voroney and N. Thevathasan* (2020). The Potential of Switchgrass and Miscanthus to Enhance Soil Organic Carbon Sequestration: Predicted by DayCent Model. Land 9: 509; doi:10.3390/land9120509
4. Ivany H, Thevathesan, N. Long-term SOC gains in Ontario grown perennial biomass crops. (2020). Unpublished.
5. Szatkowski M, Thevathesan, N. Biomass crop influence on soil organic carbon sequestration. (2020). Unpublished.

References

1. Government of Canada. Greenhouse gases and agriculture [Internet]. Government of Canada; 2020 [cited 2021 Jul]. Available from: https://agriculture.canada.ca/en/agriculture-and-environment/climate-change-and-air-quality/greenhouse-gases-and-agriculture
2. Samson R, Delaquis E, Deen B, Debruyn J, Eggiman U. Switchgrass agronomy [Internet]. 2016 [cited 2021 Jul]. Available from: https://www.agrireseau.net/documents/Document_93992.pdf
3. Government of Canada. Canada's adoption of renewable power sources – Energy market analysis [Internet]. Government of Canada; 2020 [cited Jul 2021]. Available from: https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/electricity/report/2017-canadian-adoption-renewable-power/canadas-adoption-renewable-power-sources-energy-market-analysis-biomass.html
4. Graham J, P. Voroney, Brent Coleman, B. Deen, A. Gordon,. M. Thimmanagari and N. Thevathasan* (corresponding author) (2018). Quantifying soil organic carbon stocks in herbaceous biomass crops grown in Ontario, Canada. Agroforest Syst: https://doi.org/10.1007/s10457-018-0272-0
5. Bazrgar, B. A, Aeryn Ng, Brent Coleman , Muhammad Waseem Ashiq , Andrew Gordon and Naresh Thevathasan* (2020). Long-Term Monitoring of Soil Carbon Sequestration in Woody and Herbaceous Bioenergy Crop Production Systems on Marginal Lands in SouthernOntario, Canada. Sustainability: doi:10.3390/su12093901

6. Jarecki, M, K. Kariyapperuma, B. Deen, J.Graham, A. B. Bazrgar, S. Vijayakumar, M. Thimmanagari, A.Gordon , P.Voroney and N. Thevathasan* (2020). The Potential of Switchgrass and Miscanthus to Enhance Soil Organic Carbon Sequestration: Predicted by DayCent Model. Land 9: 509; doi:10.3390/land9120509
7. Agostini F, Gregory AS, Richter GM. Carbon sequestration by perennial energy crops: Is the jury still out? Bioenerg. Res. [Internet]. 2015 Dec 15[cited 2021 Jul];8(3):1057–80. Available from: https://link.springer.com/article/10.1007/s12155-014-9571-0 doi:10.1007/s12155-014-9571-0
8. Qin Z, Dunn J, Kwon H, Mueller S, Wander M. Soil carbon sequestration and land use change associated with biofuel production: Empirical evidence. GCB Bioenergy. [Internet]. 2015 [cited 2021 Aug];8(1):66–80. Available from: doi 10.1111/gcbb.12237
9. Scordia D, Cosentino S. Perennial energy grasses: Resilient crops in a changing European agriculture. Agriculture [Internet]. 2019 Aug 1 [cited Jul 2021];9(8):169. Available from: https://www.mdpi.com/2077-0472/9/8/169/htm doi: 10.3390/agriculture9080169
10. Clifton-Brown JC, Breuer J, Jones MB. Carbon mitigation by the energy crop, Miscanthus. Glob Chang Biol. [Internet]. 2007 Aug 21[cited 2021 Jul];13(11):2296–307. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2007.01438.x doi:10.1111/j.1365-2486.2007.01438.x
11. Graham J, Voroney P, Coleman B, Deen B, Gordon A, Thimmanagari M, et al. Quantifying soil organic carbon stocks in herbaceous biomass crops grown in Ontario, Canada. Agroforest Syst. 2019 Oct 15 [cited 2021 Jun]; 93(5):1627–35. Available from: https://link.springer.com/article/10.1007%2Fs10457-018-0272-0 doi:10.1007/s10457-018-0272-0
12. Lorenz K, Lal R. Soil organic carbon sequestration in agroforestry systems - A review. Agron Sustain Dev. [Internet]. 2014;34(2):443–54. Available from: doi 10.1007/s13593-014-0212-y
13. McLaughlin SB, de la Torre Ugarte DG, Garten, CT, Lynd LR, Sanderson MA, Tolbert VR, et al. High-value renewable energy from prairie grasses. *Environ. Sci. Technol*. [Internet]. 2002 [cited 2021 Jun]; 36(10):2122–9. Available from: doi 10.1021/es010963d
14. Ingram JS, Fernandes EC. Managing carbon sequestration in soils: Concepts and terminology. Agric Ecosyst Environ.[Internet]. 2001[cited 2021];87(1):111–7. Available from: doi 10.1016/s0167-8809(01)00145-1
15. Cannell MG. Carbon sequestration and Biomass Energy Offset: Theoretical, potential and achievable capacities globally, in Europe and the UK. Fuel and Energy Abstracts [Internet]. 2003[cited 2021 Aug]; 44(3):163. Available from: doi 10.1016/s0140-6701(03)81845-3
16. Ferchaud F, Mary B, Rupngam T, Chenu C. Changes in soil carbon stocks and distribution under perennial and annual Bioenergy Crops. GCB Bioenergy. [Internet]. 2020[cited 2021 Aug];8:290–306. Available from: doi 10.5194/egusphere-egu2020-20118
17. Lemus R, Lal R. Bioenergy crops and carbon sequestration. Crit Rev Plant Sci [Internet]. 2007 Jan [cited 2021 Aug]; 24(1):1–21. Available from: doi 10.1080/07352680590910393