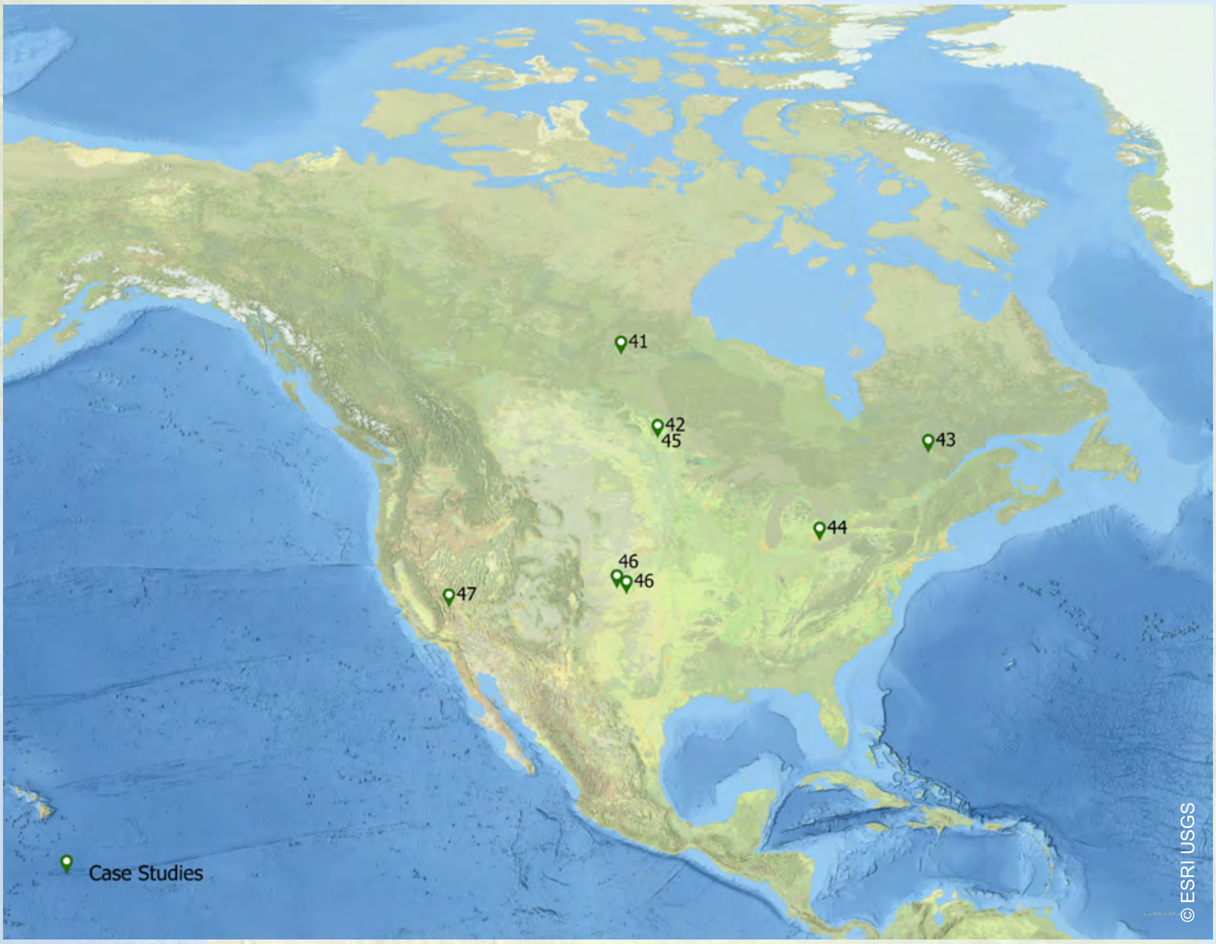
North America



41. Biochar as a soil amendment for carbon sequestration in Canada

Maren Oelbermann

School of Environment, Resources and Sustainability, University of Waterloo, Canada

1. Related practices

Biochar, manure applications, mineral fertilization, integrated soil fertility management

2. Description of the case study

Biochar has been used for thousands of years in the Amazon, and to date most of the research on biochar as an agricultural soil amendment concerned tropical soil. However, amending intensively managed temperate soils with biochar is a more recent approach to Canadian agriculture. Canadian field studies on how biochar impacts soil properties are mostly concentrated in Newfoundland & Labrador and Quebec (Table 168). This case study focuses on the impact of biochar on SOC and other soil chemical, physical and biological properties at the east-west and north-south field-scale across Canada. It consists of a replicated field trial established with biochar as a soil amendment combined with poultry manure or poultry manure and N fertilizer in southern Ontario **(this case study)**. This study was unique because of its location on a farm and managed under commercial farming operations. It was the largest longer-term commercial farming-based biochar field trial (with appropriate statistical design and replication), and demonstration site in Ontario focusing on soil health, C sequestration, greenhouse gas emissions and climate change resilience. A concurrent study on agricultural producer's knowledge of biochar and its adoption and an economic analysis was also conducted. This study was unique because all management operations at the field-scale were implemented so that they could be easily scaled-up to commercial farming operations in southern Ontario and/or regions with a similar soil type and climate. This allowed producers interested in commercial biochar application to use standard operating procedures, eliminating the need for additional or special equipment.

Table 168. Summary of field-scale studies across Canada that have evaluated the impact of biochar as an agricultural soil amendment

Location (Soil Type)	Biochar Feedstock	Experimental Details	Biochar Application Rate (t/ha)	Study Results
Newfoundland & Labrador (sandy)[1]	Sugar maple-yellow birch	Sugar beet	15	Biochar significantly increased crop yield; biochar enhanced macro- and micro-nutrient uptake by crop
Newfoundland & Labrador (loamy sand)[2]	Sugar maple-yellow birch	Sugar beet	0, 10, 20, 40 & 80	Biochar had positive effects on soil hydrological properties, especially at a 40 t/ha application rate
Quebec (loamy sand)[3]	Pine wood chips	Maize, soybean & switchgrass	0, 10 & 20	Biochar addition did not significantly increase SOC for all crops
Quebec (sandy clay loam)[3]	Pine wood chips	Maize, soybean & switchgrass	0, 10 & 20	SOC increased significantly under maize and switchgrass
Quebec Namur (sandy loam)[4]	Maple-oak-birch	Maize	1 + 170 kg/ha UAN	No significant increase in SOC. Significantly greater maize biomass; significantly greater N use efficiency Note: biochar was preconditioned with urea ammonium nitrate (UAN) to decrease application rates (c.f. Dil *et al.*, 2014)
Ontario[5]	Spruce-pine	Maize-soybean	3	SOC increased significantly under maize in the first year of application but then decreased sharply by 3rd year

[1]Abedin and Unc (2020); [2]Altdorff *et al.* (2019); [3]Backer *et al.* (2016); [4]Dil (2011); [5]Mechler *et al.*, 2018

3. Context of the case study

The study site was located in Bayfield (43°34′45.8′N, 81°39′52.2″W), Ontario, Canada on a commercial poultry-cash crop farm, situated 183 m above sea level with a slope of 1.5 percent. The soil was classified as a uniform grey-brown Luvisol with a loam texture. The 30 year mean weather data was obtained from a nearby weather station located in Goderich (43°74′28′N, 81°71′39″W), Ontario, Canada, which recorded a mean annual temperature of 8 °C and an annual precipitation of 991 mm. Commercial farming practices included the production of maize (*Zea mays* L.) in rotation with soybean (*Glycine max* (L.) Merr.). Poultry manure, based on switchgrass (*Panicum virgatum* L.) bedding, was added on a 3-year rotation at a rate of 6 t/ha and was topped-off with urea N fertilizer at 135 kg N/ha only in the years maize was produced. The site was tilled using a disc harrow and weeds were controlled by N-phosphonomethyl glycine (Glyphosate).

The experimental design was a randomized complete design with three replications (Figure 39). The treatments were: 6 t/ha poultry manure plus 135 kg N/ha N fertilizer (MN); 3 t/ha poultry manure plus 3 t/ha biochar (MB); and 3 t/ha poultry manure, 135 kg/ha N fertilizer and 3 t/ha biochar (MNB). The plot size for each treatment replicate was 10 m × 10 m, with a 3 m border between plots. Biochar in MB and MNB treatments was added using a drop spreader and worked into the soil using a Salford RTS vertical tillage unit to ensure uniform distribution. Commercial farm management operations including herbicide additions and N fertilizer application rates were standard agronomic practices for this region of southern Canada. The biochar was added to the respective treatment replicates only once over the duration of this study. Sample collection began in May and terminated in November of each year. The biochar was provided by Titan Carbon Smart Technologies (Saskatoon, Saskatchewan, Canada). The feedstock of the biochar was a 50/50 mix of pine (*Pinus* spp.) and spruce (*Picea* spp.), and the resultant biochar was produced using slow pyrolysis (550 °C, 15 min). Biochar chemical and physical properties are described in detail in Mechler *et al.* (2018).

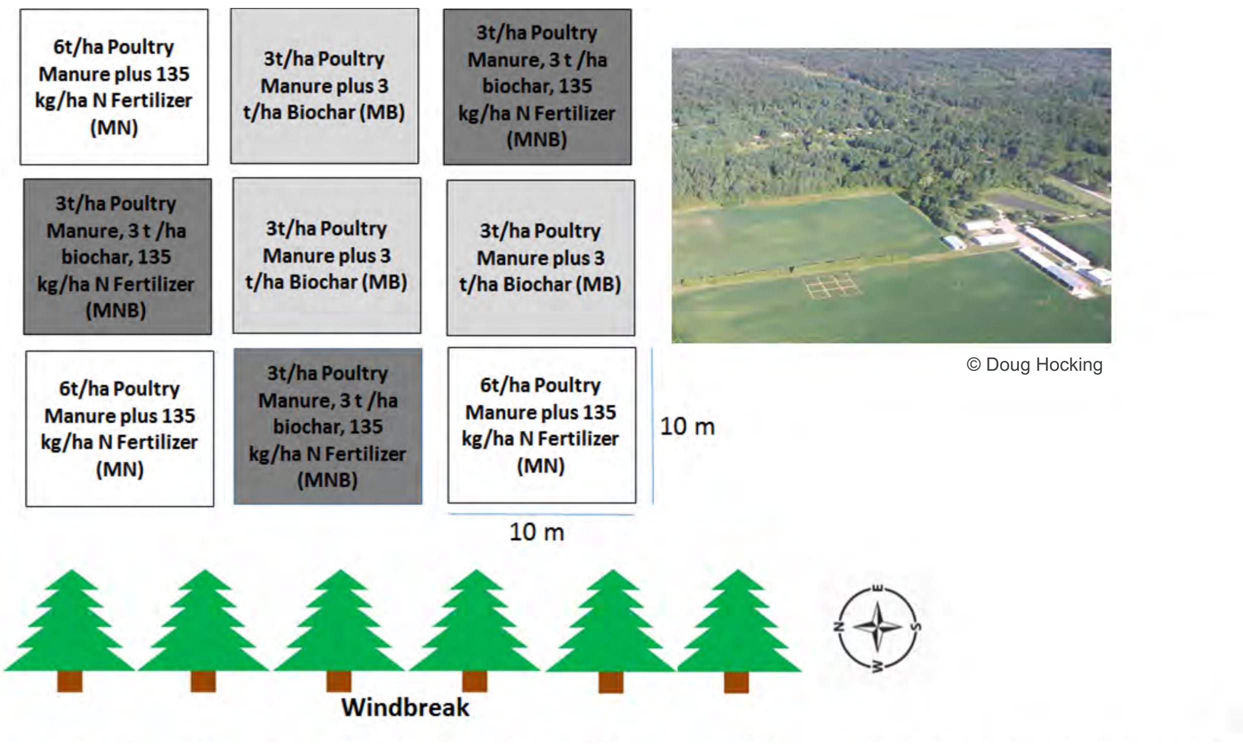


Figure 39. Complete randomized design of field-scale commercial farming operations in southern Ontario

4. Possibility of scaling up

This case study can be scaled-up to other regions if soil texture, climate, and the type of biochar (c.f. Mechler *et al.*, 2018) are the same.

5. Impact on soil organic carbon stocks

On the loam textured Luvisol in southern Canada, the addition of biochar plus poultry manure (MB treatment) in the first year of the study led to a 117 percent increase in SOC, whereas adding biochar plus poultry manure and N fertilizer (MNB treatment) increased SOC by 33 percent. However, 3 years after adding biochar SOC was 5 percent and 12 percent greater in the MB and MNB treatments, respectively. The control treatment without biochar (MN) showed no change (year 1) or a 3 percent loss (year 3) of SOC (Table 169). Increasing SOC in biochar treatments may be explained by the carbon input due to the biochar itself, as plant production has not changed.

Dil and Oelbermann (2014) simulated the effect of biochar addition on soil organic C stocks over 150 years in Ontario using coarse and medium textured soil. They found that a one-time application of maple-oak-birch derived biochar at 2 t/ha and preconditioned with urea ammonium nitrate led to a greater increase and long-term stabilization of SOC. They also found that the quantity of C stabilized was influenced by soil texture. Soil texture also determined if the C was stabilized in the active, slow, or passive C fractions.

Table 169. Change in SOC stocks in a grey-brown Luvisol (loam texture) in the moist, cool temperate climate of southern Canada

Baseline C stock (tC/ha)	Additional C storage (tC/ha/yr)	Duration (years)	Depth (cm)	Amendment application
15.6	0	1	10	3 t/ha poultry manure & 150 kg/ha N fertilizer
15.6	-2.6	3	10	3 t/ha poultry manure & 150 kg/ha N fertilizer
13.2	15.4	1	10	3 t/ha poultry manure and 3 t/ha biochar
13.2	0.7	3	10	3 t/ha poultry manure and 3 t/ha biochar
11.7	3.9	1	10	3 t/ha poultry manure & 150 kg/ha N fertilizer
11.7	1.4	3	10	3 t/ha poultry manure & 150 kg/ha N fertilizer

Source: Mechler et al. (2018); Mechler (2018); Jiang, (2019)

This when soil was amended with poultry manure and nitrogen fertilizer, poultry manure and biochar, or poultry manure, nitrogen fertilizer and biochar in year 1 and 3 under a maize crop

6. Other benefits of the practice

6.1. Improvement of soil properties

The following soil properties are improvement when biochar was added to temperate soil in southern Canada (Mechler *et al.*, 2018; Mechler, 2018; Jiang, 2019). Increases/decreases are significant at $p<0.05$ in treatments with biochar (MB and/or MNB):

- Increased water infiltration
- decreased bulk density
- increased water stable aggregates (> 250µm)
- decreased soil water content
- moderation of soil temperature extremes: maintenance of soil temperature under warmer than usual growing season. May provide greater resilience under projected climate change.
- maintenance of soil pH
- increased ammonium, decreased nitrate, decreased phosphorus
- increased soil microbial biomass carbon
- increased number of macrofauna
- changes in microbial community composition and substrate utilization
- increased mycorrhizal fungal colonization

6.2 Minimization of threats to soil functions

Table 170. Soil threats

Soil threats	
Nutrient imbalance and cycles	Nitrate and phosphorus adsorbed to biochar decreasing the leaching of these nutrients to ground and surface waters. Adsorption of these nutrients has not affected crop productivity.
Soil acidification	Maintenance of soil pH. Southern Ontario soil is calcareous but can tend towards acidity from heavy N fertilizer input. Biochar can moderate acidification from N fertilizer use.
Soil biodiversity loss	Biochar changes the composition and the carbon sources utilized by a more active microbial community. Biochar also provides habitat for micro and macro fauna.
Soil compaction	Decreases soil bulk density, increases water infiltration, and increases water stable aggregates.
Soil water management	Decreases soil water content. This did not affect crop yield, even in a drier than normal growing season.

Source: Mechler et al. (2018); Mechler (2018); Jiang, (2019)

6.3 Increases in production (e.g. food/fuel/feed/timber)

Adding biochar to temperate agricultural soil is a relatively new concept and results from longer-term field studies when biochar is combined with poultry manure are still limited. However, results from this case study showed that adding biochar when combined with poultry manure or with poultry manure and mineral N fertilizer caused no negative effects on SOC sequestration, soil health or crop productivity relative to commercial farming practices using poultry manure and mineral N fertilizer as a soil amendment. It was observed that during a drier than average growing season, treatments amended with biochar exhibited a greater resilience which was exhibited by an increased productivity in maize root and shoots.

6.4 Mitigation of and adaptation to climate change

The goal of this case study was to determine the impact of biochar on soil health and greenhouse gas emissions using conventional agroecosystem management practices. However, life-cycle assessment (LCA) is necessary to determine the actual impact of greenhouse gas emissions and carbon sequestration starting with biochar generation to its final use as a soil amendment.

To test for climate change adaptation potential, a macrocosm study, where soil collected from the three field treatments and seeded with soybean was exposed to single (ambient, elevated temperature or elevated CO_2) or multifactor (elevated temperature and CO_2), was conducted to evaluate the impact of climate change on soil amended with and without biochar. The response to climate effects on soil and soybean properties were substantially greater compared to that of amendment types. The absence of interactive effects indicated that soil amended with biochar functioned independently of single or multicomponent climate effects. Soil microbial biomass C and N, a short-term indicator for changes in land management, showed that amendment type MNB led to a lower SMB-C. However, the microbial biomass was not affected by climate effects, but climate effects influenced the way C and N were accessed by microbes in all amendment types, shifting the species richness and diversity, and the structure of the microbial community (Jiang, Galo and Oelbermann, 2021).

6.5 Socio-economic benefits

Regional or local biochar generation from regionally or locally sourced feedstocks enhances rural economics by providing job opportunities if high-quality biochar application becomes economically viable. Assuming a cost of $2 800 per t (in 2018) of high-quality biochar (Titan Carbon Smart Technologies), it is currently not economically viable for field application, even when considering a reduction in N fertilizer application, carbon credits, and generous yield increases. Despite the currently high cost, prices are expected to decline to $300/tonne (Garcia-Perez, 2017 pers. comm.) with an increase in the number of high quality biochar producers and the available supply over time will make the addition of biochar more economically realistic (Figure 40 and Figure 41).

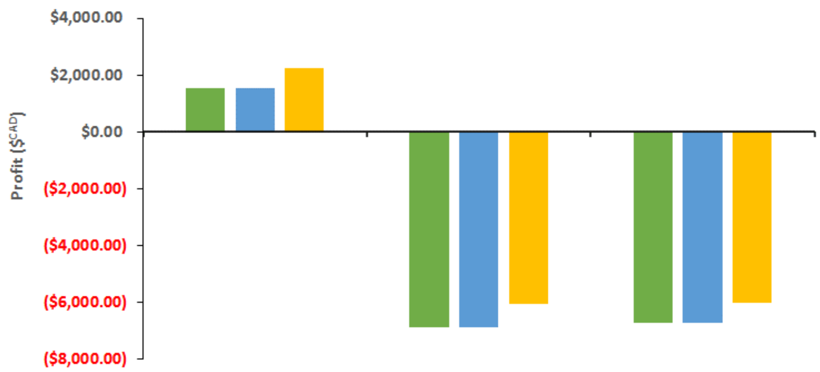
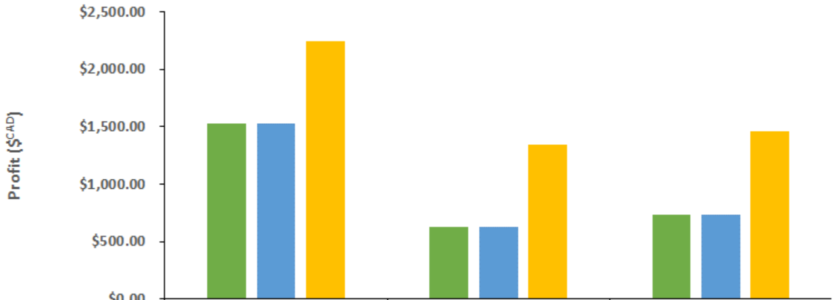


Figure 40. Economic analysis of biochar as a soil amendment at $2,800/t in southern Ontario, Canada. Data provided by M.Suta



	Profit(CAD)/ha	Profit/ha with Biochar	Profit/ha with Biochar, Carbon Credit & N fertilizer elimination
Winter Wheat	$1,526.39	$626.39	$737.59
Soybeans	$1,526.32	$626.32	$737.52
Grain Corns	$2,245.64	$1,345.64	$1,456.84

Figure 41. Economic analysis of biochar as a soil amendment at $300/t in southern Ontario, Canada. Data provided by M.Suta

The present case study showed that cost was the leading factor when considering the addition of biochar to agricultural soils, followed by a lack of research, unknown/confirmed benefits of biochar as a soil amendment and the need for a distinct economic benefit (Figure 42 and Figure 43). Because of this, farmers are wary of investing in anything without applicable and convincing research that show positive economic results. The economic analysis quantified the viability of biochar application using yield statistics from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) for winter wheat, soybeans, and grain corn, and fertilizer pricing from Syngenta Canada, and carbon pricing from the government of Ontario's proposed cap and trade program.

Figure 42. Word cloud of agricultural producer's perception of biochar as an agricultural soil amendment in southern Ontario, Canada

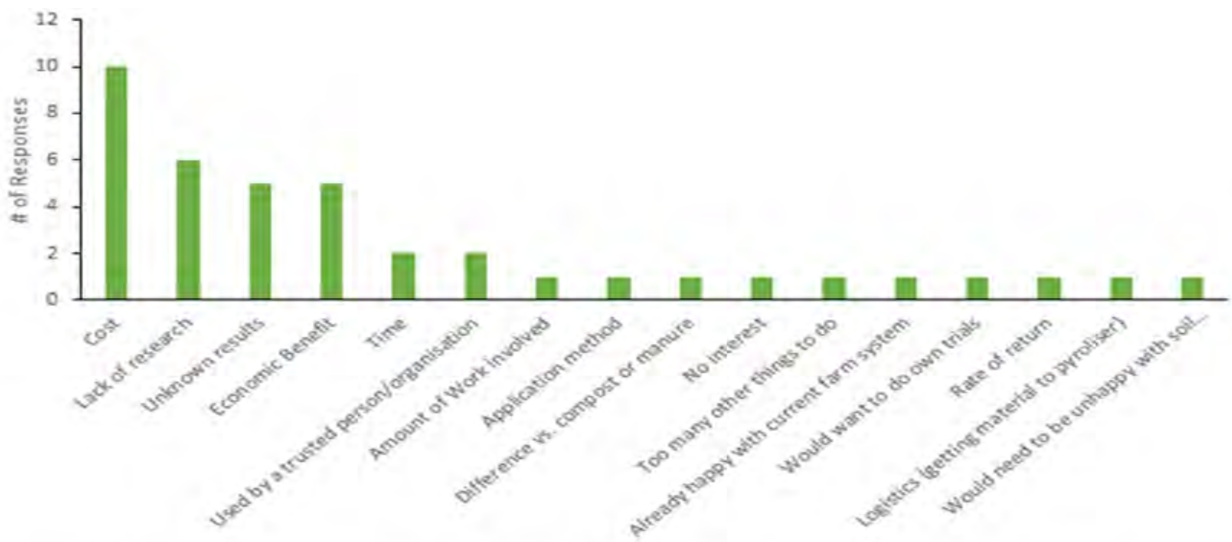


Figure 43. Factors affecting agricultural producers' willingness to apply biochar on their fields in southern Ontario, Canada. Data provided by M.Suta

7. Potential drawbacks to the practice

7.1 Tradeoffs with other threats to soil functions

Table 171. Soil threats

Soil threats	
Soil water management	Soil water content is frequently lowered in biochar amended soil. It did not impact crop productivity.

7.2 Increases in greenhouse gas emissions

Mean greenhouse gas emissions over 3 field seasons were not statistically different among treatments with and without biochar

Table 172. Mean greenhouse gas emissions for treatments with and without biochar over 3 field seasons

	MN	MB	MNB
CO_2 (mg CO_2-C /m/h)	127	118	122
N_2O (µg N_2O-N/m/h)	74	68	72

MN: 6 t/ha poultry manure plus 135 kg N/ha fertilizer; MB: 3 t/ha poultry manure plus 3 t/ha biochar; MNB: 3 t/ha poultry manure, 135 kg N/ha fertilizer plus 3 t/ha biochar

7.3 Decreases in production (Food/fuel/feed/timber/fibre

Crop productivity was not negatively affected in treatments with or without biochar.

8. Recommendations before implementing the practice

It is necessary to ensure addition of a high-quality biochar. This includes the use of a high-quality feedstock. Feedstock containing heavy metals (e.g. lead, zinc, arsenic) and other contaminants will generate a low-quality biochar containing heavy metals, polycyclic aromatic hydrocarbons and dioxins, which will negatively affect the soil, plants and environment. Therefore, it is important to use biochar produced from high quality feedstock and through a consistent pyrolysis process. Adding biochar without other amendments will increase carbon but may compromise crop productivity. Additionally, the performance and stability of biochar in soil is dependent on soil type, plant/crop species, and climate. Growers interested in using biochar on their property should apply it to a small area of their farm and then monitor results in subsequent years.

9. Potential barriers for adoption

Table 173. Potential barriers to adoption

Barrier	YES/NO	
Biophysical	No	Biochar improves soil biophysical characteristics (Lehmann and Josef, 2015).
Cultural	No	Biochar has been used for thousands of years in tropical and temperate environments (Lehmann and Josef, 2015).
Economic	Yes	Biochar is currently expensive and research on the most effective application rate is not yet confirmed (Suta, 2018, pers. comm.).
Institutional	Yes	In Canada, before applying biochar it must be approved by the Canadian Food Inspection Agency. Biochar must be of high quality and not contain contaminants.
Knowledge	Yes	Most agricultural producers do not have an understanding of what biochar is and its effect on soil (Suta, 2018, pers. comm.).
Natural resource	Yes	High quality feedstock may be limited in certain regions. Biochar production currently occurs at low capacity therefore increasing its price. Production at higher capacity will reduce its price to $300/t (Garcia-Perez, 2017, pers. comm.).

Photos

Photo 88. Spruce-pine biochar used in this case-study and applied at 3 t/ha in the first year of the field study

Photo 89. Biochar field-scale trials

Biochar field-scale trials in southern Ontario (A + B) under a maize crop in 2017; (C) maize crop with six-month-old biochar; (D) biochar 15 months after its addition under a soybean crop; (E) greenhouse gas measurements in early autumn 2017 under a maize crop; (F) biochar field-scale trial in southern Ontario shortly before maize harvest

References

Abedin, J. & Unc, A. 2020. Addition of biochar to acidic boreal podzolic soils enhances micronutrient availability and crop productivity. *Open Agriculture*, 5(1): 188–201. https://doi.org/10.1515/opag-2020-0021

Altdorff, D., Galagedara, L., Abedin, J. & Unc, A. 2019. Effect of biochar application rates on the hydraulic properties of an agricultural-use boreal Podzol. *Soil Systems,* 3(3): 53-68. https://doi.org/10.3390/soilsystems3030053

Backer, R.G.M., Schwinghamer, T.D., Whalen, J.K., Seguin, P. & Smith, D. 2016. Crop yield and SOC responses to biochar application were dependent on soil texture and crop type in southern Quebec, Canada. *Journal of Plant Nutrition and Soil Science*, 179: 399-408. https://doi.org/10.1002/jpln.201500520

Dil, M. & Oelbermann, M. 2014. Evaluating the long-term effects of nitrogen-enriched biochar on soil organic carbon and nitrogen using the Century model. In M., Oelbermann (Ed.) *Sustainable Agroecosystems in Climate Change Mitigation*, pp. 249-268. Wageningen Academic Publishers, NL.

Dil, M. 2011. *The effects of nitrogen-enriched biochar on maize (Zea mays) productivity and soil organic carbon.* MES Thesis, School of Environment, Resources and Sustainability, University of Waterloo, Waterloo, ON, Canada, pp. 135.

Jiang, R.W., Galo, M. & Oelbermann, M. 2021. Biochar as an agricultural amendment: impact on soil and plant properties under elevated temperature and carbon dioxide. *Canadian Journal of Soil Science* (under revision).

Jiang, R.W. 2019. *The effect of biochar amendment on the health, greenhouse gas emission, and climate change resilience of soil in a temperate agroecosystem.* MSc Thesis, Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON, Canada, pp. 150.

Lehmann, J. & Joseph, S., eds. 2015. *Biochar for environmental management: Science and technology*. 2nd edition. *London, UK, Routledge.*

Mechler, M. 2018. *The effect of biochar on soil health and greenhouse gas emissions in a conventional temperate agricultural system.* Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON, Canada, pp. 155.

Mechler, M.A.A., Jiang, R.W., Silverthorn, T.K. & Oelbermann, M. 2018. Impact of biochar on soil characteristics and temporal greenhouse gas emissions: A field study from southern Canada. *Biomass and Bioenergy*, 118: 154–162. https://doi.org/10.1016/j.biombioe.2018.08.019