Biochar Commercial Agriculture Field Trial in Québec, Canada – Year Three: Effects of Biochar on Forage Plant Biomass Quantity, Quality and Milk Production

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Summary

A commercial scale biochar field trial was established on a farm in Québec, Canada, in May 2008. The initial purpose of this trial was to evaluate biochar handling and application methods using standard farm equipment, followed by preliminary agronomic performance comparisons over several years. It was further intended as an initial evaluation of the agronomic value of biochar in northerly climates on relatively high quality agricultural soils. This trial is not intended, however, as a standard, replicated experiment.

A very fine-grained commercially available biochar manufactured by the fast pyrolysis of hardwood waste was applied to the clay loam soil at an estimated rate of 3.9 t/ha, to a single, 1,000 m^2 plot. Plant, crop and soil data were then compared to an adjacent, unamended control plot over a number of seasons. Soybean was grown in 2008, followed by mixed forage species in 2009 and 2010. In year one – 2008 – soybean plant biomass production was 20% greater in the biochar-amended plot. In year two – 2009 – forage plant biomass production was 17% greater in the biochar-amended plot. In year three – 2010 – forage grown on the biochar-amended plot had both greater fresh biomass (+4.1%) as well as substantially greater animal nutrition value and projected milk production quantities, as indirectly measured by near-infrared (NIR) spectroscopy. Plant nutrient uptake levels were higher with biochar-amended soil.

These results emphasize the need to study the effects of biochar in soil over the long term. They also indicate the influence of biochar, not only on biomass quantity, but on plant nutritional value and milk production, examined here for the first time.

In spite of this not being a standard replicated experiment, the results obtained are nevertheless very promising for the use of biochar in forage crops for dairy production. In particular, the improved plant nutritional values could be critical to positively influencing the economics of biochar use in commercial agriculture. Greater plant nutrient uptake with biochar could also contribute to the abatement of environmental problems related to agricultural nutrients, such as greenhouse gas emissions and the eutrophication of surface waters.

(**Note**: This report is an addendum to a detailed report produced after the second field season in 2009, available at: http://www.blue-leaf.ca/main-en/report_a3.php. Please refer to this report for further details and background information on the trial.)

Study objectives

In the third year of this field trial (2010), objectives included assessing the effect of biochar on:

1. the amount and type of forage biomass produced;
2. the nutritional quality of the forage plants produced, and;
3. the influence of that forage quality on projected milk production.

Brief overview of materials and methods

(For full details of materials and methods see the report issued in 2009.)

Trial establishment

The trial was carried out at Ferme Richard Rouleau, G.P. (N45º32.598, W72º02.237) located in Saint-François-Xavier-de-Brompton, Québec, Canada, in the watershed of the St-François River. The field was leased to, and all field operations were managed by, Ferme Ridelo, G.P. The soil at the experimental location is a clay loam and had previously been managed according to standard agronomic practices, including lime and dairy manure applications. Biochar used in this trial was made and supplied by DynaMotive Energy Systems Corporation[1] (West Lorne, Ontario, Canada). It was manufactured through fast pyrolysis technology to convert hardwood waste biomass into biofuel and biochar, and is commercially available under the name CQuest™. Details on biochar characteristics, field operations and biochar application are found in the 2009 report. The actual application rate is estimated to be 3.9 t/ha, due to significant losses during handling and application.

In early summer 2009 a pasture mixture of ryegrass (*Lolium multiflorum* Lam.), red clover (*Trifolium pratense* L.) and timothy (*Phleum pratense* L.) was broadcast seeded at a rate of 15 lbs/ac (17 kg/ha) and oats (*Avena sativa* L.) were seeded at a rate of 70 lbs/ac (78 kg/ha) using a seed drill. Oats were not re-seeded in 2010.

Crop sampling and analysis

In 2010, forage sampling was done on 4 occasions: before each of the 3 cuts made by the farm operator (11 June, 22 July and 17 Sep) and at one other occasion in late fall (6 Oct). With the exception of the first date, the forage plants were analyzed after collecting above-ground biomass from five 1m^2 quadrats. These quadrats were placed by moving within each plot from a randomly chosen starting point, fixed distances laterally (2 m) and longitudinally (5 m) between quadrat samples (Figure 1).

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Figure 1. Forage sampling, 1m^2 quadrats

Sampled plants were analyzed for three main agronomic performance criteria for forage crops: 1) above-ground plant biomass, 2) plant nutritional quality as forage, and 3) projected milk production.

For plant biomass, both fresh and dry weight yields were examined. Plant population by species was also examined. On 17 September, all plants from a 1 m^2 quadrat of each plot were harvested and separated into their plant species components - clover, ryegrass, oats and others - allowed to dry, and subsequently weighed.

For plant nutritional quality as forage, plants were sent to a forage analysis laboratory (Agri-Analyse Inc., Sherbrooke, Québec, Canada) where analysis was carried out, on the same day as harvest, by near infrared (NIR) spectroscopy. Through NIR analysis, various parameters were examined within five main plant nutrient categories – protein, fat (oils), minerals, starch and fibre. Through this method the NIR results of a homogenous plant mixture are compared to an existing correlation between NIR analyses and wet chemistry nutritional results in order to predict the characteristics of the forage plant sample. Software developed specifically for the dairy industry (R. Shaver *et al.*, University of Wisconsin) was used. The results for plant quantity and quality were then transposed into projected milk production results (Schwab *et al.*, 2003).

Data analysis
Due to the lack of true replication in the design of the experiment, no statistical analyses were performed on the data. However, mean values are presented for all harvest dates combined.

Results

Plant above-ground biomass
The total fresh weight of above-ground biomass harvested was 4.1% higher overall with biochar in this third year of the trial. The moisture content was 0.4% greater and the total dry matter yield was 2.7% greater with biochar (Table 1). (Three of four harvest dates only. Data not available from first harvest date.)

Table 1. Plant Above-ground Biomass

Parameter	Units	Control	with biochar	% Difference
Fresh weight	kg/m^2	1.74	1.81	4.1%
Moisture	%	77.48	77.78	0.4%
Dry matter	%	22.52	22.22	-1.3%
Dry matter yield	kg/m^2	0.3915	0.4020	2.7%

Plant nutritional quality as forage

In all main plant nutrient categories, forage from the biochar amended plot showed total overall superior results for 2010 (Table 2). Protein, fat, starch, total minerals and energy – measured as Total Digestible Nutrients (TDN) – were all greater in the forage plants from the biochar-amended plot. The plant fibre content with biochar is lower; however this is desirable for this forage crop.

Table 2. Plant Nutritional Quality*

Category	Units	Control	with biochar	% Difference
Protein (crude)	%	12.73	13.95	9.6
Fat (oil)	%	2.48	2.61	5.3
Starch	%	4.53	4.67	2.9
Fibre				
Acid Detergent Fibre	%	37.98	36.00	-5.2%
Neutral Detergent Fibre	%	57.11	53.75	-5.9%
Minerals				
Calcium (Ca)	%	0.97	1.06	8.5%
Phosphorus (P)	%	0.23	0.25	9.2%
Potassium (K)	%	0.95	1.01	6.7%
Magnesium (Mg)	%	0.27	0.28	5.1%
Sulfur (S)	%	0.19	0.20	4.4%
Chloride (Cl)	%	1.06	1.20	13.1%
Sodium (Na)	%	0.018	0.016	-11.3%
Total Minerals	%	3.69	4.02	8.8%
Energy				
Total Digestible Nutrients (Weiss)	%	48.38	51.44	6.3

**All results are shown on a % dry matter basis.*

The forage grown in the biochar-amended soil contained more clover and other plants, and less oats and ryegrass than the forage grown in the unamended control plot (Table 3).

Table 3. Plant Population by Species (1 quadrat only)

	With biochar		Control	
Plant	g	%	g	%
Clover	127.8	51%	85.8	35%
Ryegrass	110.2	44%	146.5	60%
Oats	5.0	2%	6.7	3%
Other	5.7	2%	4.9	2%
Total	248.7	100%	243.9	100%

Projected Milk Production from Forage

Three methods of demonstrating milk production from forage plants were calculated from the NIR analysis results (Table 4). All results indicate considerably greater projected milk production from the plants grown in biochar-amended soils, ranging from +16.4% to +43.6%.

Table 4. Projected Milk Production from Forage

Parameter	Units	Control	with biochar	% Difference
Milk/day from forage	kg	4.09	5.87	43.6%
Milk/metric tonne from forage	kg/t	796	927	16.4%
Dry matter yield	t/ha	0.3915	0.4020	2.7%
Milk/hectare from forage	kg/ha	312	373	19.6%

Discussion

Biochar and Biomass Growth

Forage grown on biochar-amended soil in this trial yielded more above-ground fresh biomass (+4.1) than the control plot for the third consecutive year of this field trial. This continues the trend established in the first two years whereby soil amended with biochar – in spite of a low application rate of approximately 3.9 t/ha - contributes to increased biomass production.

Biochar, Nutrient Uptake Efficiency and Plant Nutritional Quality

Forage quality is associated with several criteria. Results of NIR analyses show superior plant nutritional values on biochar plants for dairy production from forage in all key categories – protein, fat, starch, fibre, minerals and energy.

NIR analysis conversion formulae for determining plant protein content are directly related to nitrogen uptake (T. Winslow, Agri-Analyse Inc., 2011). Proteins make up 60-80% of the total plant nitrogen, with soluble protein and a small portion of fibre-bound nitrogen making up the remainder. Crude protein is measured directly by determining the amount of nitrogen in the forage plant and multiplying that value by 6.25, the assumption being that nitrogen constitutes about 16% of protein in the leaf and stem tissue of the forage. From these results it appears that biochar plays a role in improving the nitrogen fertilizer efficiency of the plants. The role of biochar in improving this nitrogen fertilizer uptake efficiency of plants has also been demonstrated elsewhere (e.g. Chan *et al.,* 2007).

The greater presence of clover in forage mixtures grown where biochar had been applied could also be related to the greater available protein content and quality of the forage from this plot. Rondon *et al*. (2007) observed greater symbiotic nitrogen fixation in legumes (beans) when biochar had been applied and attributed the effect to greater boron and molybdenum availability in an acidic tropical soil. Data on the availability of these two nutrients is, however, not available here and we recommend these be examined in future trials.

In addition, the uptake of minerals by plants growing in biochar-amended soil seems to be greater. This points to the potential for improved efficiencies in the use of inorganic and organic fertilizers and subsequent potential cost savings.

Plant fibre refers to the cell-wall constituents of hemicelluloses, cellulose and lignin. The Neutral Detergent Fibre (NDF) values represent the total fibre fraction that make up cell walls. For forage quality, the lower the NDF value, the better (-5.9% with biochar in this case). The Acid Detergent Fibre (ADF) values represent cellulose, lignin and silica (if present). The ADF fraction of forages is moderately indigestible, therefore lower values are better (-5.2% with biochar in this case).

Fat (+5.3%) and starch (+2.9) content are both higher in plants from the biochar-amended plot, contributing to the higher overall plant nutrient energy value. The higher starch content is most likely associated with the lower fibre content.

The energy value of forage, as measured by Total Digestible Nutrients (TDN), is measured here according to the Weiss method. The TDN is the sum of digestible carbohydrate, protein, fat and fibre. Results show 6.3% greater TDN for plants grown in the biochar-amended soil.

In terms of other general factors related to forage quality, a decline in the quality of forage has an impact on the amount of other feedstuffs that the animal is able to consume. A slower ruminal passage time of the forage results in a reduction in intake of not only the forage but also other feeds the animal is consuming. Whenever the quality of forage declines, the amount of concentrates required to be fed increases, if the same dietary energy level is to be maintained (The Cattle Site, 2011). From this we can assume, therefore, that higher forage quality from biochar-amended soils offers the potential for cost savings related to other cattle feed components.

Biochar and Projected Milk Production from Forage Plants
Forage quality is also associated with animal performance, which depends on forage intake, and is measured in this case by milk produced. The three formulae for demonstrating milk production from forage plants in this study all show substantially greater milk production from the biochar forage plants (from +16.4% to +43.6%). Forage digestibility is among the main parameters of dairy production profitability. This factor alone could be critical in positively influencing the economics of biochar use on a wider scale in commercial agriculture.

Biochar, Forage Nutritional Value and Cattle Health
Adequate amounts of all nutrients are not only essential for milk production but also are key ingredients for boosting a cow's immune system. Deficiencies in key nutrients (e.g., specific vitamins and minerals) can reduce disease resistance and leave cows vulnerable to ailments that otherwise would be effectively fought off. In this regard, the higher forage plant mineral uptake shown with biochar could potentially contribute to improved long-term cattle health. Such improved health could, in turn, contribute to better long-term milk production. More in-depth examination is recommended of this aspect.

Biochar and Dairy Milk Quality
While not examined in this study, it is recommended that further investigation be made into the relationship between biochar forage quality and milk quality, in particular as relates to somatic cell counts. We hypothesize from our results that, if improved forage quality leads to improved cattle health, this may in turn lead to improved overall milk quality. More in depth examination is recommended of this aspect.

Biochar, Northerly Climate, Soils and Durability
Results from the third year of this field trial continue to demonstrate the potential for increased agronomic performance with biochar in more northerly latitudes (N45º) and in what are generally considered to be higher quality agricultural soils, in spite of the relatively low application rate used here. It would appear from these third year results that biochar effects in soil continue over longer periods of time. The improvement of beneficial effects of biochar in soil over time was also observed by others (e.g. Major *et al.*, 2010).

Biochar and Environmental Costs
The greater plant nutrient uptake efficiencies from soil shown here also point to the potential for environmental advantages related to the use of biochar in soil, both for water and air. In particular, greater plant nitrogen uptake efficiency demonstrated could contribute to lowering nitrous oxide emissions (a powerful greenhouse gas) from agricultural soils, as well as reducing nitrogen leaching to surface and groundwater, as demonstrated by Singh *et al.* (2010). Also, the greater efficiency of phosphorus uptake demonstrated here (+9.2%) of plants growing in biochar-amended soil could contribute to reducing the presence of this nutrient in hydrological systems (both surface and groundwater), one of the main contributors to the worldwide eutrophication of freshwaters (Schindler and Vallentyne, 2008).

Conclusions

This commercial scale biochar trial, now having completed three years, continues to show increased plant biomass production from biochar-amended soils. Plant nutritional analysis methods also illustrate the potential of biochar to favourably influence the nutritional quality of forage plants - examined here for the first time - in addition to its positive effects on biomass production. In turn, the greater biochar plant nutritional values shown here result in substantially greater projected milk production.

These results are very promising for the use of biochar in forage crops for dairy production. The improved plant nutritional values in particular could be critical to positively influencing the economics of biochar use on a wider scale in commercial agriculture. Based on these results it is anticipated that, under similar conditions, dairy farm producers could expect both greater biomass production, as well as greater milk production, from the use of biochar as a soil amendment. These new findings also illustrate the importance of studying the effects of biochar on plants over a period of years.

Due to the higher plant nutrient uptake, it is further anticipated that the use of biochar as a soil amendment may contribute to attenuating certain environmental problems related to the inefficient use of agricultural nutrients. Amongst these could be lower nitrous oxide greenhouse gas emissions, as well as reduced run-off and leaching of nitrogen and phosphorus to water.

The future acceptance and use of biochar on a large scale depends in large part on its implementation in commercial agriculture. Such adaptation of biochar by commercial farm operators will depend primarily on the economic advantages which biochar may offer. The new preliminary findings in this study point to the possibility of substantial economic advantages for the agricultural use of biochar, in dairy farming in particular.

Based on these results, it is recommended that further, more detailed, investigation be undertaken into the effects of biochar on such agricultural economic factors as plant nutrient values, animal production and animal health.

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