Northeast Sustainable Agriculture Research & Education

Farmer Grant Final Report

December 10, 2010

Project Title: **FNE09-673** ***The Effect of Biochar Applications on Soil Fertility and Crop Production on a Small Vegetable Farm in the Northeast US***

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1. Goals of the project

The main goal of this project is to learn how "biochar" affects the growth of different crops, and its impact on soil fertility under conditions likely to be found in the northeast US. Biochar is a fine-grained charcoal high in organic carbon and largely resistant to decomposition. It is produced from pyrolysis of plant and other biomass wastes. A small farm located in the Maine coastal community of Surry is the site where randomized, replicated research plots with varying amounts of biochar were planted over a two-year period, with different, representative types of vegetables – soybeans, carrots and corn. In order to accurately assess the importance of biochar on crop productivity and soil quality, detailed records on crop yields were kept, and soil tests were undertaken before and after the experiment.

In addition to the above goals, the characteristics of the three types of biochar utilized were also analyzed in the first year. Plant yield were recorded for both crop seasons and for each amount of char utilized, and finally soil characteristics were also studied at each stage of the project.

2. Farm Profile

Organic vegetables, berries and flowers are grown on Morgan Bay Farm by one full-time farmer, one half-time farmer and one apprentice. Produce is sold in a farm stand located on the property as well as at a local co-op and through a school lunch program. School children visit the farm each fall to harvest vegetables for an "all local organic lunch" prepared at the school. In 2008 the farm operated a small CSA. Approximately 2 acres are under cultivation. The farm has been in operation for over five years. The test plots for this project are located on ground that grew a variety of vegetables previous to 2009 and are on a southeast facing slope. The project has the potential to affect the sustainability of this farm by increasing the long-term fertility of the soil, enhancing soil nutrition and plant growth, improving the pH of acid soils, and increasing yields while decreasing the cost and time necessary to otherwise amend the soil more frequently as with compost.

3. Project Activities

This report summarizes the results over two seasons of the biochar field trial project. The biochar field test plot soil is a poorly drained clay-loam that had previously grown corn and other mixed vegetables (see soil test profiles below). 24 test plots, 6'x10' in size, were established, for a total growing area of 1440 sq ft. Eight of the 24 test plots are the controls; the other 16 have varying types and amounts of biochar. The plots chosen for the various treatments were randomly selected, and 4 replications were established for each treatment and crop. The biochar was applied to the test plots the first week in June of the first year, at a rate of 1.5lb/sq.ft (32 tons/acre). and 0.5lb/sq.ft.

(11 tons/acre). Each biochar plot was further subdivided in the first year, into thirds, which received equal amounts of three different types of char: a low temperature char 400 degrees C+/- made from hardwood (80%) shavings and sawdust (labeled 'Bruce's char'), a medium temperature char (500C+/-) made from hardwood pallet pieces charred and run through a chipper (labeled 'George's char') and high temperature char obtained from Chip Energy, a product made from hardwood fuel pellets and obtained from an industrial pyrolysis furnace located in Illinois (See Table 3).

It was not possible to track yields according to types of char utilized during the second season of the Project since tending of the soil and preparing beds for the second season mixed all three types of char. Yields were kept for both seasons of the project according to the total amounts of char applied in the first year.

A soil test of the entire plot was taken in the beginning, and for each of the separate test plots at the end of the 2009 growing season, and also at the end of the 2010 growing season. The soil tests were performed by the University of Maine Soil Testing laboratory. A summary and a comparison from year to year of the results of these soil tests can be found in Table 2. Based on the initial soil test, the following fertility inputs for all test plots were applied at the beginning of the 2009 season: fishmeal – 40lb/1500sq ft, bonemeal – 40lb/1500 sq ft, Azomite 20lb/1500 sq ft.
Sweet corn ('Delectable' variety) and soybeans ('Envy' variety) seeds obtained from Johnny's Selected Seeds were planted on June 10, 2009. For the second season (2010), corn was again planted but this time in what had been the soybean plots, and carrots (Nantes variety) were planted where the corn grew in 2009. No additional fertilization was used for the 2010 season, based on an overall soil test taken in the spring of 2010.

4. Results

At the end of the 2009 growing season randomly selected samples of each of the crops were harvested and various plant yield measures for each treatment plot and subplot were obtained. A total of twelve soybean and six corn plants were randomly selected from each treated plot, with plants being drawn from the approximate center of each of the third subplot divisions that contained the various types of biochar. A total of 16 soybean plants and 8 corn plants were harvested from the control plots. Overall in 2009 fresh weight yields for 108 soybean and 56 corn plants were obtained. In the second year, all the marketable crop was weighed from each of the test plots. Excluded from the weights were undersized carrots (less than 0.5 inches top diameter), and stalks without ears of corn. Careful attention was paid to equalize spacing between all the plants in both years, in each of the test plots.

Overall, the biochar additions did not increase yields in the first year, and seem to have instead resulted in the reduction in crop yields (see Table 1). The second year the results suggest a favorable effect from biochar. Plots receiving 0.5 lbs/sq.ft of biochar had a higher average weight of carrots harvested than plots with no biochar – a 25.8% difference. The application of 1.5lbs/sq.ft to the test plots planted with carrots yielded 18.0% difference as compared to no char. With corn there was a 6.2% difference between the no char plots and those with 0.5lbs/sq.ft of biochar, while the corn plant average weight difference was more substantial at 9.0%.in those plots that had received 1.5lbs/sq.ft of biochar. See Table 1 below.

Table 1 – Plant Yield Measures & Yields (2009 - 2010)

2009 **Measures**	**Yield**		
	No-char plots	**0.5 lbs of char plots**	**1.5 lbs of char plots**
Soybeans Av. fresh weight per plant (lb) / *N* of plants	**0.188** / **16**	**0.153** / **44**	**0.170** / **48**
Av. number of soybean pods/plant	**44.1**	**40.5**	**42.9**
Corn Av. fresh weight per plant (lb) / *N* of plants	**1.58** / **8**	**1.43** / **24**	**1.55** / **24**
2010			
Carrots Av. fresh weight per plant (lb) / *N* of plants*	**0.089** / **1268**	**0.112** / **1113**	**0.105** / **1209**
Corn Av. fresh weight per plant (lb) / *N* of plants	**1.45** / **51**	**1.54** / **49**	**1.58** / **50**

Note: As described on page 3, crop plants were sampled in 2009 and weighed in aggregate for each of the four test plots per condition. In 2010, total biomass was initially measured per plot, then divided by number of plants. In neither year were plants weighed individually. Hence, taking into account also the small number of plots for each condition, we lack sufficient number of data points for calculating the variances as required for statistical testing.

Comparing the corn crop from year to the next in table 1, the average weight yields showed improvement, with 7.7 percent higher average weights in those plots receiving 0.5 lbs/sq.ft. of biochar, and 1.9 percent higher average weights in those plots that received 1.5lbs/sq.ft

5. Soil Characteristics

A profile of soil conditions was obtained from the University of Maine Soils Laboratory at the beginning of the Project, and at the end of both growing seasons. These results are provided in Table 2 below. Soil from plots containing biochar had some improvements in soil characteristics, particularly in the second year -- soil pH, organic matter, phosphorus, percent saturation of calcium, magnesium, and potassium were all increased. In addition CEC (cation exchange capacity) was also clearly improved in 2009 over readings that were taken in the no char plots, but declined in 2010.

Table 2 – Comparing Changes in Soil Characteristics from 2009 to 2010

Soil indicators	**Measured results** 10/04/09						
	Beginning (pre-fertilization)	**No char**		**0.5 lbs of char**		**1.5 lbs of char**	
		2009	**2010**	**2009**	**2010**	**2009**	**2010**
Soil PH	5.4	6.1	5.6	6.0	6.0	6.1	6.1
% Organic matter	8.7	8.6	9.2	9.4	10.9	8.4	10.0
Phosphorus	5.8	20.5	16.1	22.6	20.4	24.2	26.1
% saturation potassium	6.8	3.5	1.8	4.7	3.1	4.7	3.1
Calcium	36.1	63.8	70.1	62.1	82.3	65.5	82.9
Magnesium	12.8	10.2	12.1	11.2	14.7	10.6	14.0
CEC	8.4	14.1	8.1	14.7	9.7	15.0	9.7
Acidity	44.3	22.4	16.0	22.6	na	19.3	na

*** Soil test results provided by the University of Maine Soil testing Service, Orono, Maine**

6. Biochar Comparisons

The three types of char that were used for the Project were compared. (SeeTable 3) According to McLaughlin et al (see Table 3 footnote below) adsorption capacity is believed to contribute the bulk of the moisture retention and most of the capacity of a biochar to buffer soluble organic compounds. These characteristics may help stimulate microbial populations in the soil by stabilizing the minimum moisture and carbon source levels in the soil and elevating microbial survival rates during times of drought and shortages of other soluble carbon sources. Adsorption capacity is a crucial property of biochar created at the time of manufacture and is unlikely to improve over time. It is measured by "challenging" the char with a known substance, usually an organic vapor, and measuring the extent of uptake of the challenge gas under controlled conditions; in this case the weight percent uptake of R134a (1,1,1,2 tetra-fluoro-ethane – the refrigerant used in automobile air conditioners) was~~is~~ utilized. This analysis provides a means of comparing relative adsorption capacities among different chars.

Char #1, which had the smallest particle size, had higher adsorption qualities and the harvest results suggests that it became more active and more quickly assimilated in the soil. Char # 1 and #3 provided the best overall yield in comparison with the char # 2 and no char plots. Char # 3 had more ash content as a result of the higher temperature used for its production. It also tended to be more active in changing soil conditions (see PH and potassium soil readings obtained), and in affecting yields. Char # 2 contained partially charred particles which other researchers have also shown can inhibit performance. Additional performance and yield from the different chars was provided in the Interim Report submitted to SARE in February of 2010. These comparisons of the different chars supports the theory that the smaller particle size of biochar pulls N from the soil in more quickly in the first year, with less being available for plant growth.

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Table 3

Characteristics of Three Biochars Utilized

	Biochar # 1 Bruce's char	Biochar #2 George's char	Biochar #3 Chip Energy char
Characteristics	Low (400C) temperature,multi-purpose, backyard energy & char production process	Moderate (500C) temperature, double barrel, backyard production process	High temperature,byproduct of industrial energy production project
Feedstock	70 – 80% hardwood shavings & sawdust	Hardwood pallets charred & chipped	Commercial hardwood pellets
Adsorption Capacity	1.50%	1.30%	2.18%
Adsorption Capacity of various commercial lump cooking charcoals			
	High	moderate	low
Comparisons	5 - 8% (ex. Montana & Cowboy charcoal)	1.5 – 2.0% (ex. Average commercial charcoal)	1.0 - 2.0% (ex. Low cost charcoal with fuel starting additives)

*. These measurements were provided by Hugh McLaughlin based on the methodology described in the paper **"All Biochars are Not Created Equal, and How to Tell Them Apart"** by Hugh McLaughlin, PhD, PE, Paul S. Anderson, PhD, Frank E. Shields and Thomas B. Reed, PhD, August/2009

7. Farm & Site Conditions

2009 was an unusual growing season even for a region known for high climate variability. Within a week of the planting date a total of 8 inches of rain fell. From June 19 – 21st, another 4.5 inches fell. The recorded long term average monthly rainfall for June in this part of Maine is 9.56 inches of rain. In 2009 a total of 22.3 inches was recorded for the month. In July, the following month, some precipitation fell 22 out of 31 days. As a result corn seed germination was spotty, weeds were prolific and difficult to manage, and plants were setback significantly during the initial growing period. Overall, these conditions reduced germination, and lowered our yields. The 2010 growing season was more “normal” and yields were less variable and more consistent among the plots having similar amounts of biochar amendments.

8. Cooperators/Outreach

The Maine Organic Farmers and Gardeners Association (MOFGA) helped develop this Project and reviewed and advised on the analyses of results. Jean English, editor of MOFGA’s newspaper, and Eric Sideman, MOFGA’s technical advisor, have reviewed and provided helpful comment on Project reports and progress. Biochar was applied to a small display garden at MOFGA’s Common Ground Education Center in Unity in 2009, and signage informed those attending the MOFGA Common Ground Country Fair about this Project. The Maine Cooperative Extension service assisted with establishing the research plots.

The Project principals made several presentations on biochar and this Project including an hour long workshop at the MOFGA’s Common Ground Fair on September 23, 2009. In addition, George Hoche, one of the biochar suppliers for the Project, helped assemble and display a biochar production retort at the Fair.

Project coordinators, Ron Poitras and Sue Straubing, also presented at the Northeast Biochar Symposium at the University of Massachusetts on November 2009. Finally, Ron Poitras presented a summary of the project and reported on biochar utilization on farms at the ACRES USA Convention in St Paul Minnesota on December 6, 2009.

9. Assessment

The implications from these field trials are:

- In soils that already have a high organic matter content, such as the soils at the Morgan Bay Farm, biochar showed modest crop yield improvements in the second year. (see Table 1).
- Our research suggests that biochar applied to cold climate soils may take longer to work, and where soils already have a high organic matter content, the yield improvements are not as dramatic as have been found in other areas where soils are poorer.
- Accumulating research results from this Project and elsewhere suggests that Biochar performs best in soils that are inefficient in retaining nutrients, where CEC is low and rainfall seasonally high. Morgan Bay soils already had fairly high CEC readings.
- Size of biochar particles, and how it is produced, affect performance when first applied. Some evidence in the literature indicates that multiple smaller applications spread over time may work best.
- Adsorption capacity of biochar is an important factor in determining how biochar will perform. Low adsorption chars will benefit from a period of soaking and inoculating with fertilizers before being placing in the soil. There are significant soluble organics that likely will leach from the chars the first season and that can inhibit plant growth initially.

- Biochar # 1 (“Bruce’s char”) and biochar # 3 consistently performed better than char # 2. Pieces of torrified wood appeared among the charcoal in Char #2 -- a sign of insufficient charring – which has been shown to have an inhibiting factor to performance.
- The evidence suggests that a short-term nutrient deficiency existed particularly in the first year for the high nitrogen demanding corn plants as a result of char possibly competing with the plants for available nitrogen. One remedy for this would have been to ‘charge’ the biochar with water and nutrients (particularly N) before incorporating into the soil.
- The biochar additions did not seem to increase yields in the first year. In the second year those plots receiving biochar had a higher yield overall than those plots that received no biochar.
- Soil quality improved with the addition of biochar. Soil from plots containing biochar had improvements, particularly in the second year -- soil pH, organic matter, phosphorus, percent saturation of calcium, magnesium, and potassium were all increased. In addition CEC (cation exchange capacity) was also clearly improved in 2009 over readings that were taken in the no char plots, but declined in 2010.

10. Summary

Overall, adding biochar did not lead to increases in yield in the first year. The results from the second year of the project however suggest overall increases in crop yield from the addition of biochar. Plots receiving 0.5 lbs/sq.ft of biochar had a higher average weight of carrots harvested than plots with no biochar – a 25.8% difference. The application of 1.5lbs/sq.ft yielded 18.0% difference as compared to no char. With corn there was a 6.2% difference between the no char plots and those with 0.5lbs/sq.ft of biochar, while the corn plant average weight difference was more substantial at 9.0% in those plots that had received 1.5lbs/sq.ft of biochar.

The first year results are not inconsistent with other biochar trials that have been conducted in soil and temperature climates similar to ours. In comparing our results with those obtained by the Blue Leaf organization with its test plots in Quebec[1], a somewhat similar climate region, we note some similarities.

Our research, as well as a literature review of similar studies, suggests that biochar performs best in soils that have productivity constraints, and those that are inefficient in retaining nutrients. The Maine soil where we conducted our study already had a high percent of organic matter already present, with consequent good nutrient retention but was primarily constrained by low pH, nitrogen, phosphorus and insufficient calcium (see

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[1] * Blue Leaf is a Canadian social purpose organization with interest in biochar as a climate mitigation measure as well as for use for enhancing commercial agriculture. In 2008 a biochar field trial was initiated on a commercial farm in the Eastern Townships’ region of Quebec, which is within the St Lawrence River basin. A cellulose based (hardwood tree wastes) ‘fast pyrolisis’ (high temperature) biochar obtained from the DynaMotive Energy Corporation was used. The application rate was approximately 0.10 lb/sq ft. and applied as small 1mm size particles. This trial saw a modest overall increase in the yield of soybean plant biomass (6%) but recorded an 8% decline in seed weight per plant, and 25% fewer seeds per plant than in plants from the control plot. A mid-year report for 2009 indicated better result from the biochar addition – a 16% increase in total plant biomass for the biochar plot, as measured against the control plot. http://www.blue-leaf.ca/main-en/files/BlueLeaf_Biochar_Field_Trial_2009_Mid-season_Report.pdf

Table 4). According to biochar researcher Christoph Steiner "…the "char effect" is less pronounced in soils rich in soil organic carbon …" (Biochar@yahoo.com [biochar] Re:Latitude / Soil metabolism and Char Response. August 26, 2009). According to Steiner, again, biochar's effectiveness may vary with latitude – yield benefits decrease in cooler climates, at least in the first year or two. Organic matter decomposes very quickly in the tropics, on the order of 100% per year, while in Alaska probably on the order of 3 – 5 % per year. In Maine it is probably about 15 - 20%, depending on site conditions.

The first year appears to be important in allowing N build-up to occur in the biochar. Repeated applications of smaller amounts of char, and pre-innoculating the char with nutrients, would likely avoid low N plant availability to plants in the first year. Like ramial chips, another source of recalcitrant carbon added to the soil, biochar pulls N from the soil in the first year, with less being available for plant growth. It is important that trials in temperate climate zones run for more than one year -- char alters as it settles in, soil communities develop, conditions change and yields improve over time.

It is clear that yield improvements can be realized with the addition of biochar to growing areas, particularly where there are nutrient deficiencies. Soil amended with biochar behaves in many ways like soils with high organic matter – storing nutrients and providing a refuge for soil biology. However the cost of obtaining biochar, or the labor involved in making it, may present significant barriers to its more widespread use on small farms in the Northeast. If biochar production can be combined with some other function, such as heating a greenhouse, or using readily available wood lot slash and/or field residues as fuel for making biochar then the economics of biochar use may become more favorable.