Evaluating the agronomic benefits of biochar amended soils in an organic system:

Results from a field study at the UBC Farm, Vancouver.

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Forward

The Centre for Sustainable Food Systems at UBC Farm and Fraser Common Farm Cooperative teamed up to conduct field trials to explore the incorporation of biochar into small scale organic farming systems. Fraser Common Farm Cooperative (FCFC) is a 20 acre cooperative organic farm, established in the early 1970s and located in Aldergrove, British Columbia. Driven by an interest in soil carbon sequestration, Dave McCandless built a small homemade biochar kiln on his farm and has been experimenting with the production and application of biochar at FCFC for the past 4 years.

The UBC Farm is located on the University of British Columbia's Vancouver campus. The farm offers a wide range of interdisciplinary learning, research, and community programs on the site. Through its diverse programs the UBC Farm aims to explore innovative methods of ecological farming and to exemplify new paradigms for sustainable communities. The farm has coarse, sandy soils with nutrient and water retention challenges and was interested in exploring the reported improved nutrient and water retention benefits of biochar, as well as exploring avenues for climate change mitigation on the farm. The biochar trials are one of several research initiatives integrated within the farm's production fields.

The research project was funded by the Organic Sector Development Program (OSDP) and the funding was administered by the Certified Organic Associations of British Columbia (COABC). The biochar for the field trials was donated by Diacarbon Energy Inc., a bioenergy and biochar company based in Burnaby, British Columbia.

Executive Summary

Biochar is charcoal made from waste organic materials via pyrolysis that has the potential to improve crop productivity and sequester carbon when applied as a soil amendment. Increased crop yield is frequently reported from biochar-amended fields primarily in tropical and subtropical regions. The UBC research project investigated the effects of biochar as a soil amendment in an organic system located in a temperate climate. A field trial was undertaken at the UBC Farm in Vancouver, British Columbia to assess the impact of incorporating wood-derived biochar at a rate of 10t/ha into an arable loamy sand on beet yield. Beets were grown in $1m^2$ x $19m^2$ (3.5' x 63') plots that were arranged randomly in blocks with three replicates for each type of the following four treatments: 1) biochar only, 2) compost only, 3) compost and biochar, 4) control (not amended). Total fresh biomass, root mass, shoot mass and number of plants were recorded and analyzed. Pre-and post-trial soil sampling and mid-season foliar sampling were carried out and assessed. The field study also explored the practical side of handling biochar on farm and experience with mechanical spreading is included alongside trial results.

Biochar added at 10t/ha to organically managed loamy sand soil in a temperate climate did not impact beet yield, plant nutrient, or soil nutrient levels positively or negatively over one growing season. A slight increase in soil carbon in the biochar containing plots and a slight decrease in the plots without biochar was observed. A higher density of beets was found in the amended plots and it is hypothesized that biochar may have contributed to soil water retention resulting in higher germination or survival of beet seedlings. A second year of research will be carried out to consider the long term impacts of biochar.

The initial findings from this trial suggest that the addition of biochar to already productive soils may not have the measureable impacts on yield that have been demonstrated in other regions and soils. Despite no clear yield benefits, no negative impacts were found in this trial, which indicates that biochar applications can still be a valuable soil carbon sequestration strategy in these soils. The potential for long-term benefits of biochar remain to be explored through continued research at UBC Farm.

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1. Introduction

Biochar is charred organic matter intended for use as a soil amendment. Biochar is produced by a thermochemical decomposition process called pyrolysis, which consists of heating biomass at a high temperature (≈400 – 800^{0}C) in a limited oxygen environment. Biochar is distinguished from charcoal by its intended use to both improve soil properties and sequester soil carbon (Lehmann and Joseph, 2009). The pyrolysis of biomass results in biochar as well as gas and liquid products in varying proportions depending on the type of organic material and heating temperature (Verheijen et al., 2010). Biochar can be considered as part of a larger picture which includes the generation of renewable energy from biomass and the redirection of organic waste streams, however this report does not further address co-benefits derived from the pyrolysis process.

Figure 1: Biochar made from wood shavings used in the UBC Farm field study.

The term biochar is relatively new and has recently garnered significant interest, but the use of charcoal in soils is not a new practice. The "Terra Preta de Indio" of the Amazon basin were formed from the practices of Indigenous peoples centuries ago and have been found to be highly fertile and richer in carbon compared to neighbouring soils. This sustained fertility and carbon content has been attributed to the accumulation of charcoal in the soil over time (Solomon et al., 2007). Charcoal is present in many soils around the world as a result of both anthropogenic and natural causes. For instance the fertile dark Chernozemic soils, present across Western Canada, have been reported to contain between 25-65% carbon derived from charcoal (Ponomarenko & Anderson, 2001). Radiocarbon dating has shown that forest soils in east-central British Columbia contain carbon derived from charcoal ranging from 182 to 9558 years old (Sanborn, et al, 2006).

Biochar Properties

Biochar is a light weight, highly porous material with high carbon content, a portion of which has a stable chemical structure resistant to decay. Biochar is typically low in available nutrients, though contains some ash content which adds some nutrients, and typically has an alkaline pH (Downie et al., 2009). Though different biochars share these basic characteristics, all biochars have different specific characteristics depending on the properties of the starting organic material (feedstock) and the pyrolysis parameters used for production (Chan & Xu, 2009). For instance a wood derived biochar will contain a higher proportion of carbon than a manure biochar due to starting differences in carbon content. In turn a manure biochar will contain more ash than wood biochar due to higher nutrient content in manure (Novak, et al., 2009; B. Singh, et al., 2010). A review of the literature found that biochar can be made out of a wide diversity of feedstocks including various types of wood, straw and stalks, grasses, nut shells, algae, manure, paper mill waste, and sewer sludge. To be sustainable biochar should be produced from a waste biomass stream and not from the primary production of biomass.

The pyrolysis heating temperature and duration can vary and has an important impact on a biochar's final properties. As production temperature increases the amount of biochar produced decreases (liquid and gases increase), pH increases, porosity and surface area increase up to a certain temperature, carbon content becomes concentrated, proportion of labile carbon content decreases, and proportion of recalcitrant carbon content increases (Gundale & DeLuca, 2006; Keiluweit, et al., 2010; Novak, et al., 2009; Peng, et al., 2011). Labile carbon refers to forms of carbon that are more readily broken down in the soil and recalcitrant refers to forms of carbon resistant to decay. As a result of feedstock and pyrolysis variability, there is a wide variation in the properties of biochars, which in turn contributes to the variability of its impact when used as an agricultural soil amendment. For this reason there has been significant research to characterize the chemical and physical properties of biochars produced from different feedstocks under different pyrolysis conditions, including a local project based out of Langara College Vancouver[1] (Břendová et al., 2012; Novak et al., 2009). The biochar used in the UBC Farm trial was produced from a softwood biochar and at a pyrolysis temperature of approximately 500^0C and further characterization is provided in the materials section.

Soil Benefits and Crop Productivity

Biochar improves soil quality through its effects on key soil processes. Many of the benefits of biochar derive from its highly porous structure and associated high surface area. Charges on the high surface area can increase cation exchange capacity (CEC) thereby increasing a soil's ability to retain and supply nutrients. Increased porosity can increase soil water holding capacity and the small pore spaces with positively charged surfaces can improve soil water retention and in turn reduce nutrient loss through leaching (Lehmann and Joseph, 2009; Verheijen et al., 2010). Charcoal in soils has also been linked to increased soil microbial populations which may increase beneficial soil processes mediated by soil organisms including nutrient availability (Kolb et al., 2009; Lehmann et al., 2011). The majority of biochars add little in terms of available nutrients to the soil and as such can be thought of as a soil conditioner, as opposed to a fertilizer (Sohi, et al, 2009).

Biochar is not intended to replace compost and in fact it is thought that the benefits of biochar will increase by adding biochar in combination with a source of nutrients and microbial life such as compost or a compost tea. This has been shown in previous field trials in which it was found that biochar added with a fertilizer or compost had greater results on crop yield than biochar used alone and in some cases (but not always) than the fertilizer used alone (K. Y. Chan, et al., 2007; K.Y. Chan, et al., 2008; Steiner, et al., 2007; Zwieten, et al., 2010). Some trials have also seen improved crop growth with just biochar while some have found no benefit from adding biochar alone (Chan, et al., 2007; Chan, et a., 2008; Steiner et al., 2007; Baronti, et al., 2010).

A growing number of field and pot trials have assessed the impact of biochar on crop yield. The findings of these trials have been highly variable and have ranged from no difference in yield over the control to doubling crop productivity as a result of biochar addition. In a review of

[1] http://www.langara.bc.ca/departments/chemistry/biochar-project/project-description.html

biochar trials Jeffrey et al. found that amending with biochar produced a small but statistically significant average increase of 10% in crop productivity (2012). There is a high degree of variability between reported yield benefits as a result of the high degree of variability in the trials, which stems from variation in the rate of biochar added, the type of biochar added, the initial soil type and soil management, climate, trial design, duration, and the type of crop grown (Verheijen et al., 2010).

Biochar's benefits will likely be more pronounced in sandy, depleted, and/or low organic matter soils and many of the trials showing pronounced yield impacts have been carried out in depleted, acidic tropical or sub-tropical soils. The initial pH of soils has been identified as an important factor in the impact on yield as biochars are alkaline and can have a liming effect. Many field trials have been carried out in tropical or semi-tropical areas with acidic soils and it has been hypothesized that the improved crop yield seen in these soils may be at least partially attributed to a liming effect (Jeffrey et al., 2011). While there is clear evidence that biochar can have positive impacts on crop yield, there is significant variability and yield benefits are not observed in all cases. It will be useful for future research to identify under what circumstances the adoption of biochar as an agricultural soil management strategy will prove beneficial and economical for farmers.

Soil C Sequestration and Soil GHG Fluxes

In addition to agronomic benefits there is a great interest in the climate change mitigation potential of biochar stemming from its ability to sequester soil carbon over a long time. Under normal circumstances CO_2 is removed from the atmosphere by photosynthesis and added to the soil in the form of organic matter, then as the organic matter decomposes CO_2 is released back into the atmosphere though microbial respiration. The pyrolysis of organic matter results in a form of carbon with an altered chemical structure (aromatic C rings) that is resistant to microbial decomposition, called recalcitrant or fixed carbon. When added to the soil this carbon is not readily decomposed and hence carbon remains in the soil and out of the atmosphere (Lehmann et al., 2006). The biochar used in the UBC Farm trial contained 88.6% carbon and 85% of that carbon is reported to be 'fixed.'

Once biochar is applied to the soil, the carbon is expected to remain sequestered in the soil (out of the atmosphere) for a very long time. Carbon dating studies measuring the age of charcoal derived carbon in the environment (Downie et al., 2011; Sanborn et al., 2006; Skjemstad et al., 1998) and laboratory incubation studies measuring decomposition rates over short periods of time (Liang et al., 2008; Nguyen and Lehmann, 2009), have both demonstrated a potential lifespan in the range of hundreds to thousands of years for charcoal derived carbon in the soil. To highlight the difference between biohcar and compost, it has been estimated that biochar can on average sequester 25-50% of its feedstock's carbon for 100s to 1000s of years, whereas compost or organic residue additions sequester 10-20% of its feedstock's carbon for 5 -10 years (Lehmann et al., 2006). On top of the soil carbon sequestering potential, research has also suggested that biochar can contribute to reduced emissions of N_2O and CH_4 from agriculture (from soil and compost piles) as a result of biochar's sorptive properties and effects on nutrient cycling (Clough, 2010; Van Zwieten et al, 2009).

Many projections have been made regarding biochar's potential to reduce global CO_2 emissions. One such projection is that diverting 1% of annual net plant uptake of CO_2 into biochar would mitigate nearly 10% of current anthropogenic CO_2 emissions (Gaunt & Cowie, 2009). Biochar is one potential strategy amongst many actions that need to be taken concurrently to address climate change impacts globally.

UBC Farm Research Objectives

While there has been significant research on the impact of biochar on soils and crop yield there remain many unknowns. Much of the initial field research has been carried out in tropical and sub-tropical regions which tend to have weathered, nutrient poor, low organic matter and acidic soils, which differ from those of temperate regions such as the Fraser Valley of BC. Few field trials in North America were found and no published accounts of field trials were found in British Columbia. Furthermore many of the trials to date have been in conventional systems and hence are not directly translatable to organic production systems. There is also generally a need for further on farm field research, alongside controlled lab studies, as well as more multi-year studies to observe long term impacts. The trials at UBC Farm aimed to contribute to addressing some of these gaps in research through initiating a multi-year biochar field trial integrated into an operating organic production systems in a temperate region. The research also aimed to explore the more practical aspect of efficiently and safely handling and applying biochar on a small farm.

The overarching goal of the project was to contribute to the understanding of biochar's potential for contributing to sustainable soil management, crop productivity and climate change mitigation in a small-scale organically managed mixed crop farming system located in a temperate climate. The specific study objectives were as follows:

1. To determine the impact of adding a softwood derived biochar at 10t/ha, with and without compost, to a loamy sand soil in a temperate climate on beet yield in an organically managed agroecosystem.
2. To assess the impact of adding 10t/ha of softwood derived biochar on soil properties (pH, CEC, soil carbon, soil organic matter, total nitrogen, extractable nutrients, available N and available P) over one growing season.
3. To experiment with and determine the practicality of handling and mechanically spreading biochar in a small scale agricultural system.
4. To establish biochar experimental plots that can be maintained following the completion of the year 1 study to allow for research on the longer term effects of a soil biochar application on crop yield, soil quality and carbon sequestration.

2. Materials and Methods

Site Characteristics

The field study was carried out at the Centre for Sustainable Food Systems at UBC Farm located on the University of British Columbia campus in Vancouver, Canada. The UBC Farm encompasses 24 hectares of mixed crop and coastal western hemlock forest. The field trials were integrated into the farm's annual crop rotation fields and were managed in accordance with existing management practices used on the farm. The UBC Farm strives to use ecological farming practices and meets the provincial organic standards as set out by the Certified Organic Associations of British Columbia.

The climate at UBC Farm is a coastal temperate climate characterized by moderate temperatures and high average annual rainfall with drought like conditions in July and August requiring irrigation for vegetable crops. The mean annual rainfall is approximately 1,250 mm and the mean annual temperature is 11.5^0C. The total rainfall and mean temperature during the course of the field trial (July – September 2013) was 187.6mm and 17.5^0C respectively (Government of Canada, 2013).

The field trial site is characterized by a low elevation and gentle slope with a south-west aspect. The soil classification is Bose Humo-Ferric Podzols. These soils formed from glacial deposits resulting in a sandy textured soil with high coarse fragment content and are characterized by low water holding capacity and poor nutrient retention without appropriate management, (Luttmerding, 1981). The UBC Farm soils have been improved over many years of management but remain characterized by a high level of coarse fragments and water and nutrient retention challenges. A soil particle size analysis was carried out and the soil texture of the specific field trial area is a loamy sand (76.8% sand, 18.4% silt, and 4.8% clay). A soil chemical analysis was also carried out prior to the application of amendments to characterize the initial field conditions and the findings are displayed in Table 1.

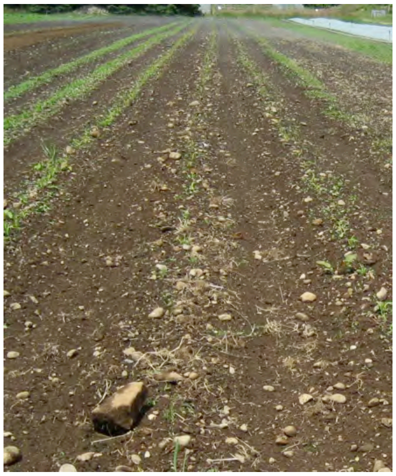

Figure 2 : The field study site is characterized by a stony, coarse textured soil.

Table 1: Field trial site initial soil conditions, the numbers reported below are the mean and standard deviation of 12 composite samples from the trial field.

	pH (H_2O)	**% OM (LOI)**	**CECe Cmo+/ kg**	**Total N %**	**Total C %**	**Available N03N (mg/kg)**	**Available NH4N (mg/kg)**	**Available P (mg/kg)**
Mean	6.10	11.62	16.28	0.30	5.64	13.70	2.53	152.53
S.D.	± 0.20	± 0.66	±1.31	±0.02	±0.41	±3.19	±0.63	±19.52

The crop selected for the field trial was beets (*Beta vulgaris*) and the variety used was Red Ace F1 Hybrid. Beets were selected as the trial crop because they are a commonly grown crop in the region, they were already part of the UBC Farm's crop rotation, they can be direct seeded, and the whole plant is harvested at a single time which facilitates the measuring process. A review of previous biochar field trials revealed that a very diverse range of common agricultural crops have been trialed to date including various grains, grasses, legumes and vegetables. There was not found to be a particular trend with respect to crop selection or a common rationale for crop selection in previous field trials. Hence a crop that was suitable to the region, to the farm crop rotation, and to the trial design was selected.

Pre-Trial Germination Test

A pre-trial germination test was carried out in a greenhouse on site to ensure the biochar obtained for this trial would not have an adverse effect on germination rate or seedling establishment. The germination test followed the procedure recommended by the International Biochar Initiative (Major, 2010). The germination test with three replicates was prepared on May 11, 2013. Soil was obtained from the experimental field, large rocks were removed, and soil was mixed with biochar at a rate of 13.5t/ha, slightly greater than intended rate of 10t/ha for the field trial. Six 50-cell flats were sterilized with a bleach solution and three flats were filled with soil only (controls) and three flats with the biochar-soil mix. Each cell was planted with one seed of *Beta vulgaris* (beet, Red Ace, 97% germination rate, supplied by Johnny's Selected Seeds). The seeds were thoroughly watered in and subsequently watered by an overhead spray system on an automatic timer. Seedlings were counted and observed 7, 11 and 18 days after planting.

Figure 3: Germinated beets in biochar containing mix.

Trial Design and Establishment

A randomized complete block design with three replicates and four treatments was established for a total of 12 experimental plots each 20.5m^2 (1.07m x 19.20m) in size. The four treatments were 1.Control (no amendment), 2. Compost (28.8t/ha dry matter basis), 3. Biochar (10t/ha), and 4. Biochar (10t/ha) + Compost (28.8t/ha dry matter basis). See Figure 4 below for field layout.

Bio. + Comp.	Control	Compost	Biochar	Bio. + Comp.	Biochar
non-experimental crop					
Biochar	Compost	Control	Bio. + Comp.	Compost	Control
Block 1		Block 2		Block 3	

Figure 4: A randomized complete block design was used for the field trial layout as shown above. Three blocks were established along two field length beds and the four treatments were randomly assigned within each block. A non-experimental crop was planted in a bed between the trial beds as a buffer between treatments. A smaller central area of each plot was harvested to reduce any edge effect where the treatment applications met.

Compost and biochar were both spread mechanically using a topdresser, which allowed directed application at the bed width of 3.5 feet, and then were mixed into the topsoil (approximately 15cm deep) using a tiller. Experimentation with the spreader settings and biochar moisture level was carried out to determine ease of handling and spreading.

Beets were seeded at a uniform density in two rows across each plot using a hand pushed seeder. Beets were sown on June 30, 2013 and were hand harvested on three occasions at day 92, 95, and 109 from a central subplot of 13.0m^2 to reduce edge effects. An overhead sprinkler irrigation system was designed to maximize even watering across treatment plots, and all plots were watered on the same days for the same amount of time. Due to study limitations the amount of irrigation water supplied was not tracked and soil moisture was not monitored during the field trial. While efforts were made to supply water equally across treatment areas it is recognized that the overhead irrigation system may have resulted in unequal water supply and is a potential source of error.

Figure 5: L-R, T-B: Biochar spread on the trial plots, biochar being tilled into the topsoil, direct seeding beets, beets germinating in a biochar containing plot, beets growing in trial field, mature beets near harvest date.

Biochar
The biochar was sourced off farm from the local company Diacarbon Energy, Inc. The softwood feedstock consisted of a mix of spruce, fir and pine wood waste obtained locally from BC lumber mills. The biochar was produced using a slow pyrolysis process with an average heating temperature of approximately 500^{0}C, maximum temperature of approximately 575^{0}C, and a heating time of 30-40 minutes in a continuous flow pyrolysis reactor. General parameters and chemical analysis of the biochar were provided by the supplier and are shown in Table 2.

Table 2: Softwood biochar specifications on a dry basis as reported by supplier.

Feedstock	Ash %	Volatiles %	Fixed C %	pH	C %	N %	H %	O %
Spruce, fir, pine	3	12	85	8.2	88.6	0.4	2.8	5.1

A particle size analysis was carried out to characterize the range of particle sizes in the biochar amendment. The particle size analysis was performed using the method described by Baker (2012). A series of stacked dry sieves (75, 106, 425, 707, 1700, 2000, and 6300µm) were used to separate biochar particles based on size. Sieves were shaken by hand for 15 minutes to accelerate the separation process before being put on a mechanical shaker for 3 hours. A large amount of BC (162.77g) was used to minimize any effect on results due to adhesion of fine biochar dust to sieve surfaces.

Compost
A dairy manure and turkey litter compost was obtained from a local supplier and the chemical specifications were provided by the supplier, selected parameters are shown in Table 3. The rate of compost dropped by the spreader was determined to be 2.78kg/s and from this it was calculated that 159.12kg of wet compost was added to each plot (approximately 1/3inch layer over soil). The dry mass of the compost was determined by oven drying subsample at 105^{0}C and the rate of compost application by dry mass was calculated to be 28.8t/ha and the application rate by volume was $90.2m^{3}$/ha.

Table 3: Compost specifications as reported by supplier

Compost Feedstock	C:N	pH	CEC (meq/100g)	Total N (%)	Available ppm			
					P	K	Ca	Mg
Dairy manure, turkey litter	12:1	7.0	28.1	2.21	923	2760	758	2597

Foliage Sampling and Analysis
A composite foliage sample was taken from each of the twelve plots 54 days after seeding and sent to a lab for nutrient content analysis. A leaf blade (no petiole) was taken from a plant at every 5ft along the plot and the most-recently-matured leaf on the beet plant was selected as it provides the most sensitive indicator of the nutritional status of the plant (Hochmuth et al., 2012; Rosen and Eliason, 2005; Spectrum Analytic Inc., 2009)

Pre- and Post-Soil Sampling and Analysis
A soil sample was taken prior to the addition of soil amendments (June 27, 2013) and a second soil sample was taken 125 days later following the completion of crop harvest (October 30,

2013). In both cases a composite sample was taken from each of the 12 plots using a soil probe. Samples were taken at a depth of 15cm (equivalent to depth at which biochar and compost were incorporated). Sample analysis was carried out by the BC Ministry of Environment Analytical Chemistry Lab located in Victoria, BC. The mean of the twelve sample results was calculated as an indicator of the initial soil conditions of the trial field and is shown in Table 1 above. The change in soil parameters between the post harvest sample and pre-treatment sample were calculated and assessed.

Figure 6: Drying soil samples for analysis.

Figure 7: L-R, T-B: Mature beets ready to harvest, harvesting beets, washed beets draining, weighing beet root mass.

Monitoring, Harvesting and Crop Yield Measurements

Visual monitoring was carried out for the duration of the field trial. All treatments regularly weeded mechanically and by hand. The beets were harvested by hand from a central area of 13.0m^2 from each of the twelve plots to reduce any edge effect between treatments. Three separate harvests (92, 95, and 109 days) were done to manage labour time required for hand harvesting and weighing, and for marketing reasons. On each harvest day an equal area of beets was harvested from each of the twelve plots. The number of plants was counted and total fresh biomass was weighed. The foliage was then removed and root mass was weighed, foliage mass was calculated by difference. Beet roots were sorted and anything less than 1.5inches in diameter was culled as it is considered too small to sell by the farm. Culled plants were counted and culls were weighed thereby providing the marketable root biomass by difference as well as cull rates. Treatment effects on crop yield variables were analyzed by analysis of variance (ANOVA) using R, block effect was included, (R Core Team, 2013).

3. Results

Germination Test

The number of germinated seeds, out of the 50 seeds sown per flat was counted and Table 4 shows the number of germinated seeds up to 18 days after planting. The germination rate is shown as a percentage for the final count on day 18. Figure 8 below shows the mean germination rate in the biochar and control flats. The 95% confidence intervals of the biochar treated sample mean completely overlap with the 95% confidence intervals of the control sample mean. There is insufficient evidence to support the hypothesis that the application of biochar has an effect on the germination rate of beet seeds. Visual observations were made and there was no noticeable difference between the seedling growth with and without biochar in terms of size and leaf colour.

Table 4: Number of germinated seeds observed at 7, 11, and 18 days after planting, and germination rate based on day 18 count.

Replicate	7 days		11 days		18 days		Germ. Rate (%)	
	Biochar	Control	Biochar	Control	Biochar	Control	Biochar	Control
1	38	34	43	35	43	35	86	70
2	30	29	35	34	36	33	72	66
3	34	41	43	44	44	47	88	94

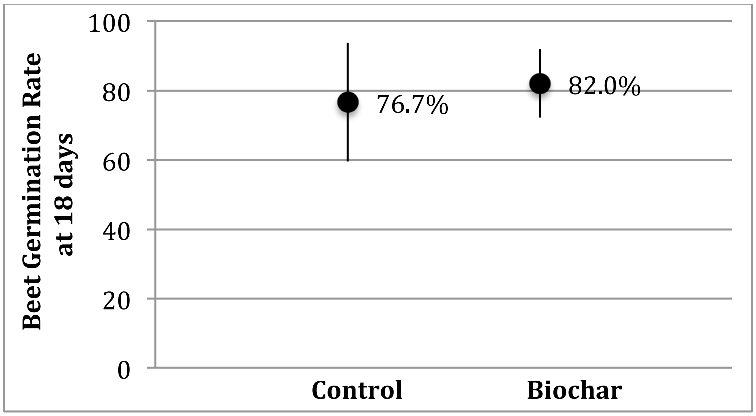

Figure 8: Mean germination rate based on mean number of germinated seeds in 50 cell flats 18 days after planting of *Beta vulgaris*. Bars represent 95% confidence intervals, n = 3 for both biochar treatment and control group.

Biochar Particle Size Analysis

Sand-sized particles (50 - 2000μm) were found to dominate (about 91.4%) in this softwood-derived biochar, with about 8.3% of the mass being coarse fragments (> 2000μm) as shown in Table 5 below.

Table 5: Biochar particle size distribution.

Size class (μm)	Weight (g)	% of biochar weight
>6300	0.510	0.3%
2000 - 6300	12.262	8.0%
1700 - 2000	9.100	5.9%
707 - 1700	56.747	36.9%
425 - 707	34.394	22.4%
106 - 425	37.765	24.5%
75 - 106	2.627	1.7%
<75	0.497	0.3%

Foliage Analysis

The foliar sample was used to assess plant nutrient status during the growing season and to determine if there was any difference in nutrient uptake between the plants in the different treatment areas. Mean values and standard deviation around the mean were calculated from the each treatment (n=3) and are displayed in Table 6 and Table 7 below alongside reported nutrient sufficiency ranges for table beets.

Table 6: Macro-nutrient content of beet leaves at day 54 of growth reported as mean ± standard deviation (n=3)

Treatment	% N	% P	% K	% Ca	% Mg
Control	4.10 ± 0.30	0.37 ± 0.04	4.60 ± 0.68	1.44 ± 0.06	0.85 ± 0.05
Biochar	3.95 ± 0.23	0.44 ± 0.04	4.35 ± 0.21	1.46 ± 0.10	0.84 ± 0.05
Compost	4.13 ± 0.32	0.43 ± 0.06	4.27 ± 0.21	1.43 ± 0.17	0.80 ± 0.02
Compost + Biochar	4.24 ± 0.20	0.43 ± 0.03	4.63 ± 0.77	1.48 ± 0.12	0.83 ± 0.06
Sufficiency Range[1]	**2.6 – 4.0**	**0.2-0.3**	**1.7-4.0**	**1.5-3.0**	**0.3-1.0**

[1] Hochmuth et al., 2012

Table 7: Micro-nutrient content of beet leave at day 54 of growth reported as mean ± standard deviation (n=3).

Treatment	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	B (ppm)
Control	9.33 ± 1.16	93.00 ± 29.55	118.33 ± 19.55	64.33 ± 14.01	73.67 ± 4.51
Biochar	12.00 ± 1.00	99.00 ± 11.36	130.00 ± 16.09	62.67 ± 11.72	73.00 ± 6.24
Compost	11.00 ± 1.00	96.00 ± 20.07	138.00 ± 18.52	68.00 ± 5.29	73.00 ± 1.73
Compost + Biochar	10.33 ± 0.58	96.67 ± 12.10	126.67 ± 10.79	69.67 ± 5.13	70.67 ± 7.77
Sufficiency Range[2]	**5 - 15**	**15 - 30**	**50 - 200**	**70 - 200**	**30 – 80**

[2] Rosen and Eliason, 2005

Soil Analysis

An analysis of change in soil nutrient levels from the pre-trial (taken prior to addition of amendments) to the post-trial values did not reveal any significant effects on extractable or exchangeable nutrients associated with the biochar treatments. The extractable micro and macro nutrients showed both increases and decreases depending on the nutrient. Boron and phosphorus were found to increase across all 12 plots regardless of treatment, whereas calcium, manganese and available nitrogen were found to have decreased across all treatments. The magnitude of the increase or decrease varied substantially between treatment replicate plots and there was not a significant difference in increase or decrease associated with a particular treatment. Potassium and magnesium were found to have increased in the plots in which compost was added and have decreased in the biochar and control plots and is likely just a result of nutrient additions from the compost. Total nitrogen changed very little between pre and post trial in all treatments. The other nutrients varied in magnitude and direction of change (increase or decrease) within replicate treatments.

Mean carbon showed a slight increase in the biochar containing treatments and showed a slight decrease in the control and compost only treatments, however there is significant variance around the means as shown in the overlapping 95% confidence intervals in Figure 9 below. pH increased slightly across all twelve plots and mean change in CEC was variable with a slight increase in the compost and biochar + compost treatments and a slight decrease in the control and biochar only treatments. Figure 9 below illustrates the mean pre- and post-trial pH, CEC, TN and TC values for the four treatments. The large and overlapping 95% confidence intervals are indicative of the variability of the data and lack of significant treatment effect on these variables.

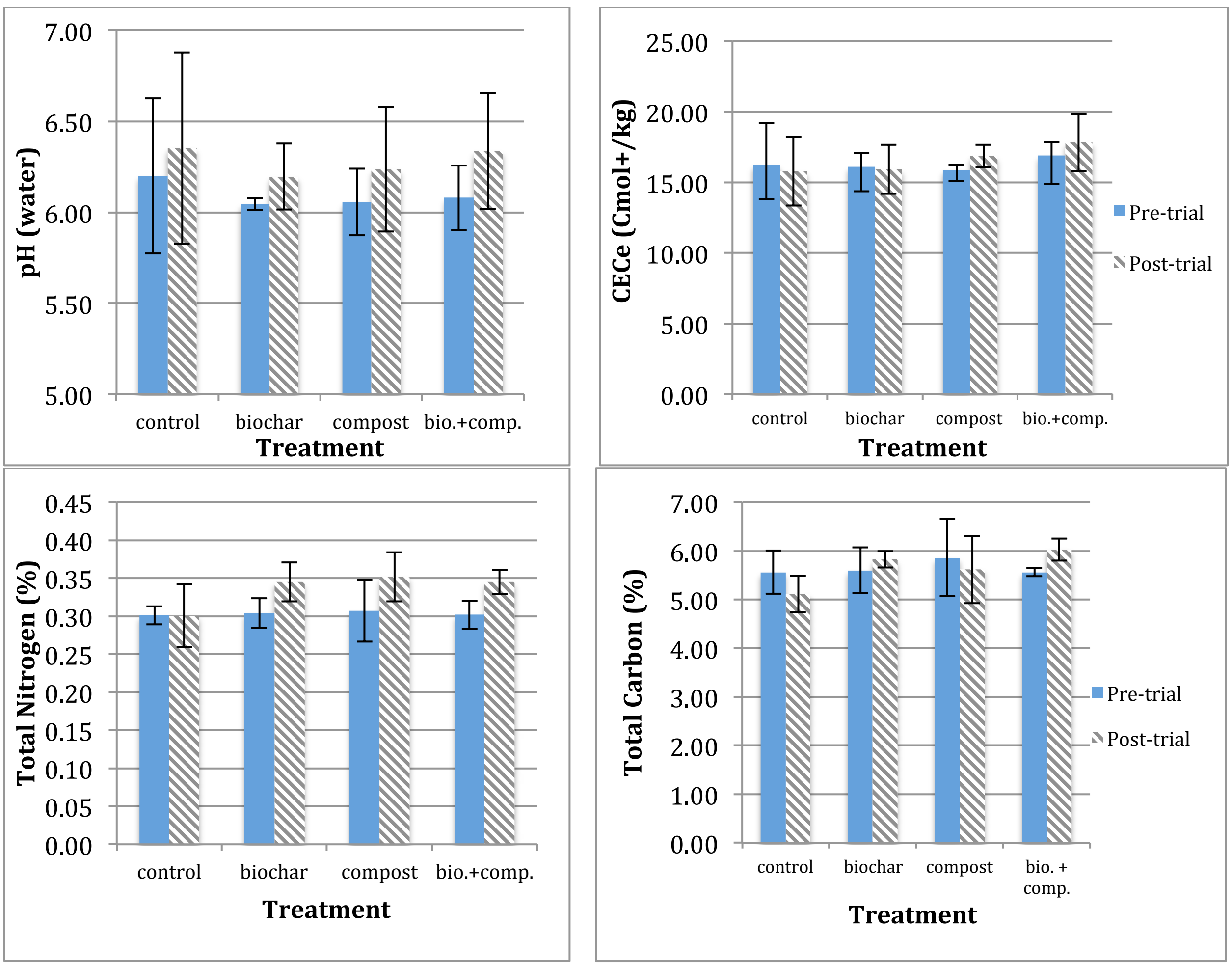

Figure 9: Mean total nitrogen, total carbon, CEC and pH levels in treatment soils before and after trial (n=3). Blue bars indicate the pre-trial value and the grey bars indicate the post trial value of the parameter. Difference between the bars is the change in parameter over the duration of field trial (125 days between sampling). The error bars are the 95% confidence intervals.

Visual Observations

The beets germinated successfully across all treatment plots and the timing of germination was observed to be even across the different treatments. Within 14 days it was observed that the compost only treatments and the biochar + compost treatments had a higher density of beet seedlings and the seedlings appeared larger and more vigorous than those in the biochar only and control plots. This contrast between the higher density in the compost containing plots and the lower density in the control plots remained clear as the plants matured. The rate of growth and density in the biochar only plots appeared slightly greater than that in the control plots during the early stages, however this difference was less pronounced than difference between compost and control and became difficult to differentiate as plants matured. No difference could be observed between the biochar + compost treatment and the compost only treatment. See Figure 11 below. The observation that the density of individual plants was lower in the control plots is reflected in the plant count data shown with the yield data below. Some variability in plant size between the same treatments in different blocks and within plots was observed as the plants matured. This variability likely stems from natural soil variability within a field and/or unevenness in water supplied by overhead irrigation to the field. This observed variability is reflected in the beet yield data.

Beet Yield

Total fresh biomass, root mass, and shoot mass were analyzed using a one-way ANOVA including block effect. No statistically significant differences in total fresh biomass or in total root mass were detected between treatments ($p=0.063$ and $p=0.093$ respectively). The treatment effect on total fresh biomass is close to significant, but as illustrated in Figure 10 below, the difference in total biomass was a result of the compost addition rather than the biochar treatment. Total marketable root mass (roots >1.5in) and biomass/plant was also analyzed and no significant treatment effect was found. See Figure 10 for the total fresh biomass results displayed as yield (fresh biomass t/ha).

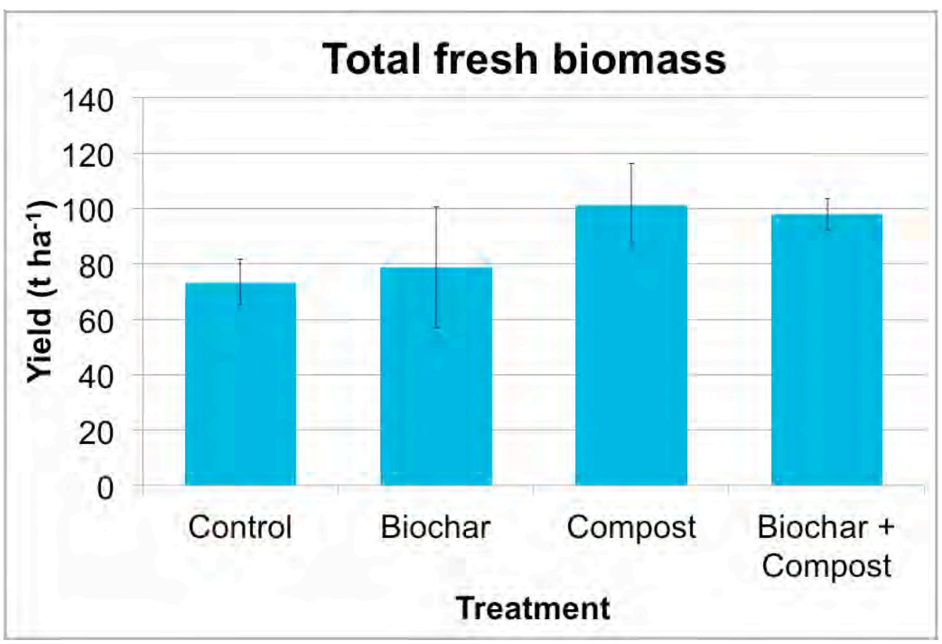

Figure 10: Total fresh biomass of beets with different treatments. Vertical bars show 95% confidence intervals. No significant treatment effect on total yield was found ($p = 0.063$).

Control

Biochar Only

Compost Only

Biochar and Compost

Figure 11: Photos illustrating the differences observed between plant density and rate of plant growth in the control compared to the different treatments. All photos taken from same height 20 days after seeding.

A treatment effect was detected with respect to shoot biomass (p=0.0491) however the post ANOVA follow up analysis (TukeyHSD) did not reveal a treatment effect at a significance of $p < 0.05$. The most significant effect was found between the compost treatment compared to the control ($p = 0.078$) and the biochar + compost treatment compared to control ($p = 0.11$) which indicates that treatment effect on shoot biomass stems from the compost application rather than the biochar. See the box plot in Figure 12 below for an illustration of the shoot biomass results.

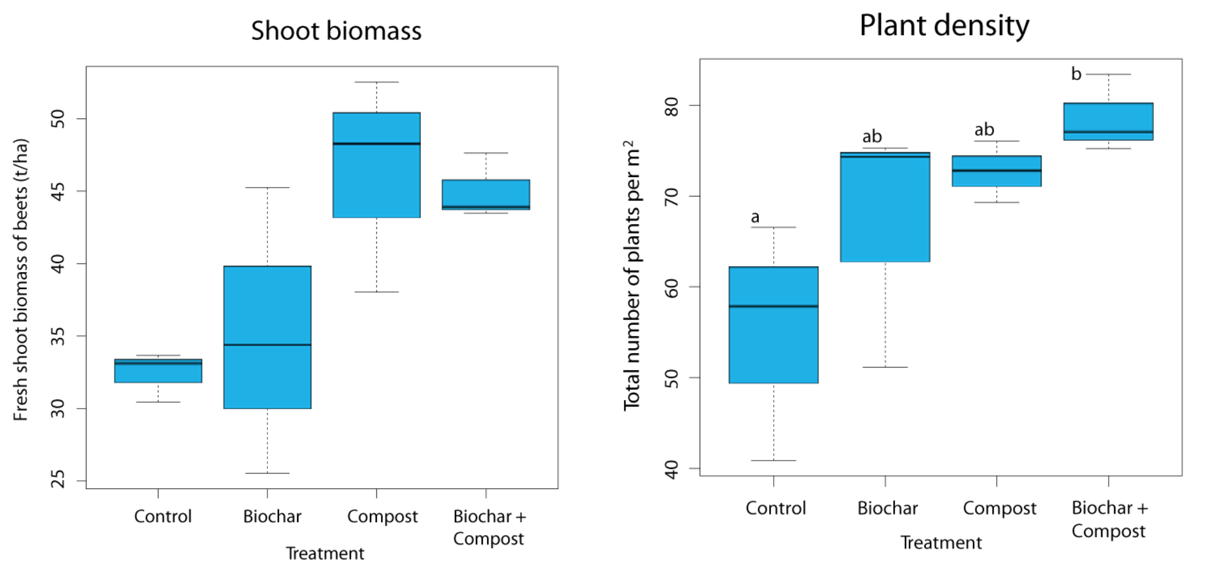

Figure 12: ***Left*** – box plot of the fresh shoot yield in t/ha for the four treatments; ***Right*** – box plot of plant density, different letters identify which treatment effects are statistically different from one another ($p < 0.05$). The box represents the upper (75%) and lower quartile (25%) of the data termed the interquartile range, the horizontal line inside the box is the median of the data, and the ends of the whiskers show the highest and lowest data points.

The total number of plants harvested from each treatment area was counted and total plant density was derived from the number of plants/area. Significant difference in plant density was detected between treatments (p=0.021). The post hoc TukeyHSD test revealed that the plant density was significantly higher in the biochar + compost treatment compared to the control (p=0.017). The differences in mean plant density between the other treatments was not found to be statistically significant ($p < 0.05$) in the post hoc analysis. See Figure 12 above for a box plot illustrating plant density results.

The number of marketable plants was calculated by subtracting the cull plant count (roots < 1.5in) from the total plant count. A significant treatment effect was found on the marketable number of plants (p=0.034) and the post hoc TukeyHSD test found that the compost only and the compost + biochar treatments had a significantly greater number of marketable plants than the control (p=0.049 and p=0.040 respectively).

The number of culled plants (root < 1.5 inches) and the mass of the culled roots was recorded and used to calculate the cull rate of the treatment areas. The cull rates, both number of culled plants/area and the mass of culled roots/area revealed no significant difference between the treatments. See table 8 below for a summary of the results and statistical analysis.

Table 8: Summary of mean beet yield findings and p-values calculated using a one-way ANOVA including the block effect, n=3. Post hoc TukeyHSD test used when ANOVA P-value was < 0.05 to identify which treatments were significantly different from one another.

Treatment/ Variable	Control Mean	Biochar Mean	Compost Mean	B+C Mean	P-Value ANOVA	P-Value Tukey HSD
Total biomass t/ha	73.39	78.83	101.18	97.93	0.0628	N/A
Total root biomass t/ha	40.98	43.76	54.88	52.91	0.0933	N/A
Marketable root biomass t/ha	37.63	40.18	51.20	48.72	0.135	N/A
Total shoot biomass t/ha	32.41	35.07	46.29	45.02	***0.0491***	Control to Compost 0.0783 Control to B+C 0.110
Total number of plants	719	873	949	1025	***0.0208***	Control to B+C ***0.0172***
Total plant density #/m^2	55.11	66.95	72.75	78.60		
Marketable number of plants	430	545	603	636	***0.0337***	Control to Compost ***0.0499*** Control to B+C ***0.040***
Cull rate by #	0.38	0.37	0.37	0.40	0.981	N/A
Cull rate by Kg	0.09	0.08	0.07	0.08	0.823	N/A

4. Discussion

Handling and Applying Biochar on a Small-Scale Farm

The biochar application rates of previous trials were reviewed in order to determine an appropriate application rate for this trial. The application rates used to date vary widely from under 5t/ha to over 100t/ha. As mentioned in the introduction there has been a high degree of variability in crop yield results and different application rates used in trials is one of many sources of variability in reported results of biochar applications to date. A review of the literature suggests that a rate in the range of 5t/ha – 20t/ha is suitable for agricultural crops, though the ideal rate would differ depending on many factors such as initial soil quality and crop being grown for instance.

The International Biochar Initiative (IBI) is non-profit organization connecting a diversity of sectors involved with biochar and have developed several resources and standards for the use of biochar in soil which can be accessed on their website[2]. In a biocar fact sheet the IBI reports rates of 2 – 22t/ha being used in field trials and recommends a lower applications rate of 2 - 5 t/ha for agricultural uses (Major, n.d.). Based on the background research on application rates a rate of 10t/ha was chosen for the field trials at UBC Farm. There is not yet a consensus on best practices with respect to application rate and frequency of application to date.

[2] IBI Guidelines for Practitioners and Factsheets: www.biochar-international.org/publications/IBI
IBI Biochar Standards and Certification Program: http://www.biochar-international.org/characterizationstandard

While there is significant amounts of scientific research on biochar there is less information available on the practical aspects of handling and applying biochar on farm, though as mentioned the IBI has a many useful resources available for practitioners[1]. Biochar is a very light weight, porous material that can be quite dusty and as a result can be a challenge to work with. The particle size distribution will vary from biochar to biochar but ranges from a fine dust to coarse fragments. The particle size analysis carried out on the biochar used in the UBC Farm trial found that the dominant particle sizes were in the range of sand-sized particles (0.05mm – 2mm) and overall particle size ranged from less than 0.075mm to greater than 6.3mm. Because of its physical properties, biochar can become easily airborne and windblown when it is being transported, spread or incorporated which is problematic. Windblown biochar during spreading can result in a significant loss and inefficient use, the inhalation of the fine airborne biochar particles can have a negative impact on respiratory health, and the airborne dust from the biochar may contribute to air pollution.

Some initial experimentation was done spreading biochar by hand at Fraser Common Farm Co-op, but this method is only appropriate for a very small scale. Another practice Fraser Common Farm has been experimenting with is the addition of biochar to their potting mix, which has the potential to reduce peat use, and the biochar is then progressively transferred to the fields in small amounts during transplanting.

Figure 13: Spreading biochar by hand at Fraser Common Farm Cooperative.

Figure 14: Brassica seedlings growing in a biochar containing potting mix at Fraser Common Farm Co-op.

The UBC Farm experimented with two types of spreaders for applying biochar. The first spreader tested was a 'Small Tow Drop Spreader' which is a very small plastic spreader that can be pulled behind a small tractor and drops over a 3.5' width. It has holes in the bottom and a wheel driven steel agitator above the holes. This spreader did not work for biochar. It dropped the biochar at an extremely low rate that was inefficient. It is either that the holes are too small for the biochar particle sizes or that the wheel driven agitator rod

Figure 15: Small tow drop spreader was tested and found to be ineffective for spreading biochar at UBC Farm.

is just not effective enough at moving the really light weight biochar down and out the holes – or a combination of both these issues. The use of this spreader for biochar is not recommended.

The second spreader used was a ground drive topdresser that was pulled behind a tractor. The spreader has a capacity of 27 cubic feet or with extended side walls a capacity of 2 cubic yards. The belt speed is adjustable and there is a removable beater the speed of which is also adjustable. There is an adjustable gate at the rear of the box that can be moved up and down to alter the rates at which material comes out. There is also an adjustable wing kit which allows you to control the spreading width.

Figure 16: Ground drive topdresser successfully used for spreading biochar at UBC Farm.

We began with spreading dry biochar using the belt without the beater and with the side wings adjusted to only spread over the 3.5' beds. The belt drops the biochar from about 2 feet above the ground. We worked with two batches of biochar, one of which turned out to be dustier. We chose a calm day with little wind and found that spreading the first batch of dry biochar with the drop spreader produced minimal visible windblown dust. We found this method to be very easy and efficient resulting in a uniform layer of biochar on the soil and the rate of biochar was easily adjustable by changing the rate of the belt and the height of the back gate. The dry biochar was relatively easy to handle, though we were careful to disturb it as little as possible while working with it and wore respirator masks to avoid any inhalation. The second batch of biochar spread in the same way produced visible windblown dust. Therefore particle size of the biochar being spread is a key consideration in choosing a method of spreading. The first batch of dry biochar dropped from the conveyor belt mechanism, without a beater, was an effective method for spreading biochar at a controlled width of 3.5'. However as the second batch was dusty when spreading dry, and biochars will have variable particle sizes, it is recommended that biochar be moistened prior to spreading to avoid potential dust and drift.

We then tested spreading wet biochar with the same spreader and the same settings. We first saturated the biochar by submerging and soaking bags of it in water then let it drain for a couple hours before working with it. Wet biochar was easier and quicker to handle and transfer into the spreader without concern over dust. The wet biochar ended up being sticky and we faced the problem of the biochar caking on the spreader belt and clumping at the spreader gate. We added the beater implement to the drop spreader, which is what is used for compost to break up clumps and get an even spread (the beater throws off the back rather than dropping the substance off the back). The wet biochar with the beater implement on the spreader worked quite well, clumps were broken up, the wet biochar being thrown off the back did not produce any dust, and we were able to control for an appropriate amount and an even spread of biochar. The beater also enables the ability to spreader at a greater width and would be suitable for field applications. While we did not directly test mixing biochar and compost and then spreading, it is expected that this method would work really well as the compost would moisten the biochar and reduce dust. The wet biochar spread using the beater still produced no visible dust and based on this experience it is thought that a larger compost spreader would also work for spreading biochar if it was sufficiently wet or mixed with compost. Biochar was then tilled into the soil without any problems. See Figure 17 below for images of spreading biochar with the topdresser.

Biochar in the back of the spreader.

Dry biochar was best spread using just the conveyor belt and wet biochar was best spread using the beater which is attached here.

Dry biochar being spread over 3.5'width bed.

Dry biochar being spread over 3.5'width bed

Dry biochar being picked up by wind. UBC Farm experimented with spreading two different biochar batches and one was found to be dustier and challenging to spread dry.

Biochar was submerged and soaked in water and then spreading the wet biochar was trialed.

Very wet biochar was found to be sticky and clumped when it was spread using the conveyor melt mechanism.

With the addition of the beater of the spreader biochar clumps were broken up and the wet biochar was successfully spread wihout any dust problems.

Figure 17: Spreading dry and wet biochar using a ground driven topdresser at UBC Farm.

The mechanical spreading of biochar with the small topdresser was successful at UBC Farm and enabled both a directed spread over a bed with as well as a wider spread when using the beater implement. We highly recommend moistening the biochar when applying it. Different types of spreaders will take some experimenting with to determine the best biochar moisture level or biochar to compost ratio to avoid caking and clumping while also avoiding airborne dust. It is highly recommended that masks or ventilators be worn at all times when working with dry biochar.

Crop Yield

No significant effect on beet yield was found as a result of the addition of 10t/ha of biochar with and without compost to a loamy sand soil. While there is a predominance of positive results reported from previous biochar studies, there are also other studies that have found neutral results on crop yield (Granatstein, 2009; Van Zwieten, 2009). Research to date clearly demonstrates that biochar has the potential to increase crop yield (Bierdman and Harpole, 2013; Jeffrey, et al. 2012), however the neutral findings from this trial further supports the importance of recognizing the variability in biochar applications and their outcomes. Positive impacts on crop yield may not be occur in all agroecosystems.

There are previous studies that have found neutral effects on yield in year one and positive effects in following years. For instance a field trial using a wood biochar found no increase in corn yield in year one but increase in yield in biochar amended areas in years 2-4 (Major et al., 2010). Therefore final conclusions from the UBC Farm trial cannot yet be made and a year two of research is planned. It also worthwhile to note that while biochar did not have a significant positive effect on beet yield in this trial, it was not found to have a negative impact either and in fact there have been very few reported trials with negative yield impacts (Bierdman and Harpole, 2013; Jeffrey, et al. 2012). In situations where there are no clear yield benefits, biochar applications may still be a valuable soil carbon sequestration tool.

Soil and Foliage Analysis

Biochar's potential for beneficial impacts on crop yield stem from its potential benefits to soil properties and processes. As previously mentioned it is primarily the physical structure of biochar, its high porosity and associated high surface area, that result in soil fertility benefits rather than the direct addition of nutrients. It has been shown that biochar applications can increase nutrient retention and availability. Previous studies have found that biochar applications can result in increased levels of total, extractable and/or exchangeable soil nutrients and certain studies have found increased levels of certain foliar nutrients as a result of biochar amendments (Bierdman and Harpole, 2013). Studies have also found increased soil CEC and pH levels as a result of biochar applications, both of which are mechanisms through which biochar is thought to contribute to nutrient availability (Nelson et al., 2011; Peng et al., 2011; Singh et al., 2010). However similar to the yield findings there has been variability in the findings to date on the impact of biochar on soil properties and nutrient availability (Bierdman and Harpole, 2013).

The foliar results and the soil test results from the UBC field trial did not reveal any significant effects on plant nutrient uptake or in soil nutrient levels associated with the biochar treatments. The foliar analysis showed that all nutrient levels in all treatment areas where either within or greater than the sufficiency ranges for table beets. The fact that sufficient nutrient levels were available in the un-amended control areas suggests that beet growth in this soil was not faced by nutrient limitations to begin with. In line with the foliage analysis, the before and after soil samples did not reveal any significant trends in changes in soil nutrient levels (total, extractable, or exchangeable) as a result of the biochar treatments three months following application.

The before and after trial CEC levels were analyzed and there was not found to be an effect on CEC as a result of the biochar treatments three months following application. While an increased CEC has been observed in other sandy soils, Silber et al. suggests that improved soil fertility as a result of increased CEC will likely only occur in sandy and low organic matter soils (2010). The trial soils were a loamy sand but they were also quite high in organic matter which may be why an increase in CEC was not observed. There is also a possibility that the benefits to soil CEC may occur over a longer time frame than three months. The chemistry of biochar has been shown to change in the soil over time, a process referred to as ageing, and one of the changes reported is an increase in positive surfaces charges which would increase CEC as a result, (Cheng and Lehmann, 2009).

Another important soil parameter considered was pH. Biochars are predominantly alkaline and have consistently been shown to have a liming effect when added to acidic soils. pH impacts nutrient availability and it is thought that the liming effect of biochar in acidic soils is an important mechanism by which improved crop yield occurs in these soils (Bierdman and Harpole, 2013; Jeffrey et al., 2011). The biochar used in the UBC Farm trial had a pH of 8.2 and the soil had a pH of 6.10. All four treatments showed a slight increase in pH (0.13 to 0.18), however the increase could not be attributed to the biochar treatment as it was observed across all treatments including the control. There is concern that adding alkaline biochar to soil with already near neutral or alkaline pHs could have a negative impact. This study found that the addition of a biochar of pH 8.2 to a very slightly acidic soil (pH = 6.10) had no significant change on soil pH three months following application.

The soils at UBC Farm have been managed using organic practices for over a decade and employ many soil building practices such as compost applications and cover cropping. An analysis of the initial soil quality reveals that the trial site was characterized by an already productive soil. The starting nutrient levels were within appropriate ranges for crop growth (Brady and Weil, 2008; Marx et al, 1999). The soil was characterized by a high initial organic matter level of 11.62% which provides similar benefits to biochar in terms of increasing soil surface area and surface charges, increased CEC, increased microbial activity, improved nutrient cycling and improved soil water retention (Brady and Weil, 2008). As mentioned above the initial soil pH of 6.10 was already at an appropriate level for vegetable crops. The findings from this trial suggest that benefits to agricultural soils and improved crop yield derived from biochar may not be observed when applied to an already productive soil characterized by an appropriate pH for crop growth, high soil organic matter, and adequate initial levels of nutrients. A recent study assessing the application of biochar to corn production in a temperate climate (Wales) over 3 years, corroborates the findings from the UBC Farm Trials. The study from Wales concluded that “the application of biochar to high productivity agricultural systems may not yield the benefits seen in other regions where severe soil problems occur; however, importantly no negative aspects were apparent in this trial,” (Jones et al., 2012).

Total soil carbon was measured before and after the addition of biochar. Biochar is a carbon rich material and is expected to increase the amount of soil carbon and the length of time carbon remains sequestered. Soil analysis carried out in previous studies have found a clear link between biochar additions and increased total soil carbon (Bierdman and Harpole, 2013). The results from this trial showed a slight increase in mean soil carbon in the biochar only treatment over the control and a slight increase in mean carbon in the biochar + compost treatment over the compost. The effect may not have been as pronounced in this study as a result of a lower biochar application rate than other trials or as a result of field variability and only taking one measure of soil carbon for each plot. Year two soil testing will reveal if there is a more pronounced difference in soil carbon levels over a longer period of time.

Plant Density and Soil Water Retention

An interesting observation was made with respect to beet plant density. The beets were direct seeded at uniform density across all treatments yet the results showed a significantly higher plant density in the biochar + compost and the compost treatments. The average density in the biochar only treatment was slightly higher than the density in the control plots however this difference was not statistically significant. These differences in plant density were visually observed shortly after germination during the seedling stage. Since this difference was observed at the seedling stage and since there were not found to be differences in soil nutrient levels between treatments it is thought that the higher plant density in the treatment areas compared to the control may have been a result of increased water retention during the seed germination and/or seedling establishment phase. Previous research indicates that biochar application to soils can improve soil water holding capacity and retention and this may be a factor in both yield improvement and plant nutrient availability (Downie et al., 2009; Johnson et al., 2012). Further research is needed to assess the potential water retention benefits to crop growth at the UBC Farm before any conclusions can be made.

Study Limitations and Future Research

This study was limited in the variables measured and hence was unable to assess the full impact of biochar on the agroecosystem. Yield, plant nutrient status, and soil properties were measured, however other key variables that have been found to be impacted by biochar applications that were not measured include soil water capacity and retention, soil green house gas fluxes, and soil microbial dynamics.

The timeframe of the study is also a limitation and these are only initial results. It is important to note that the initial and post soil tests were only taken three months apart and were taken at different times of the year. The different conditions at the time of sampling could affect results and it is possible that three months was not a significant amount of time for the biochar to have had an impact on soil properties and processes. As mentioned previously some studies have reported a greater impact on yield in subsequent years and biochar may beneficially change over time once exposed to the soil environment. The UBC Farm will be carrying out another year of data collection to observe longer term effects of biochar and if possible will integrate a wider diversity of indicators such as soil water measurements to better assess the impacts of the biochar addition.

5. Conclusion

Biochar addition to an already productive soil was not found to significantly improve soil properties, plant nutrient status or increase yield with or without compost over one growing season. Nor was it found to negatively impact soil properties, plant nutrient status or crop yield. The findings from this trial further support the importance of recognizing the variability in biochar applications and their outcomes. Positive impacts on crop yield may not occur in all agroecosystems and this trial suggests that the addition of biochar to already productive soils may not have the measureable impacts on yield that have been demonstrated in other regions and soils. Improved crop yield is not the only benefit of biochar and as no negative effects on crop yield were observed biochar may still prove to be a beneficial practice to increase soil carbon sequestration in such cases. Biochar applications can have a positive impact on soil water capacity and retention. This potential needs to be further explored at the UBC Farm.

The variable impacts of biochar applications is already widely recognized and it is recommend that future research aim to better characterize the conditions under which biochar applications prove beneficial and those where it may not be a useful practice for a farmer to adopt. It is also recommended that further research be carried out and resources developed on the practical aspects of handling biochar and incorporating it into various farm management systems, as well as the on-farm economics of biochar as a soil management strategy.

Despite the current growing body of research on biochar, there is a high level of variability in field trial outcomes, there remains a lack of long term studies on the yield and overall ecological impacts of anthropogenic additions of biochar to the environment, a lack of regional and system specific research, and a lack of consensus on the exact mechanisms by which biochar impacts soil processes, carbon cycling, and crop yield (Bierdman and Harpole, 2013). While the research to date justifies the excitement over biochar's potential agronomic and climate change mitigation benefits the identified gaps in knowledge also justify continued field research and a precautionary approach towards the adoption of biochar on any scale.

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