Biochar Manual for Small Farms in BC

Digital copy (PDF) available at: https://sites.google.com/site/fcfcbiocharmanual

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Authors & Acknowledgements

This manual was written and produced by Jessica Dennis, a UBC student in the Faculty of Land and Food Systems, and is the culmination of an undergraduate research internship. Dave McCandless initiated the production and application of biochar at Fraser Common Farm Cooperative (FCFC), which provided the foundation for the biochar field research. Dave was an essential contributor to the research for the duration of the project. Dr. Hannah Wittman and Dr. Mark Johnson developed the research questions and secured a grant from the Pacific Institute for Climate Solutions enabling the project to go forth and provided invaluable support for the duration of the research internship.

Thank you to all the farmers at FCFC, especially David Catzel for your ideas and help in the field. Thank you to Heather Pritchard, Farm Folk/City Folk and the Community Farms Network for your support.

Forward

This manual is geared towards small farmers and gardeners interested in learning about making biochar and/or using biochar as a soil amendment. The information provided in the manual has been gathered from academic sources, from the work of farmers and small biochar producers, and from fieldwork carried out by the authors at Fraser Common Farm in Aldergrove, BC.

The goal of this manual is not to convince others that biochar should be used. The goal is to provide background knowldege to those interested in biochar and provide information on how to make, apply and guage the success of biochar on a particular farm or site.

Biochar has potential. However there are still many unknowns and further research is required before widespread implementation can safely be recommended.   It is through community participation in the research process that the potential of biochar may be best realised. We hope that this manual is able to help engage the local agricultural community. The manual will begin by describing the potential benefits of biochar used as a soil amendment in terms of both crop yield/soil quality and for soil carbon sequestration. It will then explore small-scale methods of producing biochar, sourcing biochar in BC, characteristics of biochar, application rates and methods, establishing biochar trials, health and safety concerns, economic sustainability and carbon credits.

Disclaimer

The use of biochar may pose health and safety risks. The authors are not responsible for any loss, injury or damage caused as a result of the production, application or use of biochar or charcoal. We recommend that safety and health standards are carefully researched and followed. If you have any uncertainties, we recommend that expert knowledge be sought to ensure that standards are met.
Please review the following statement from the Canadian Biochar Initiative: "Applicable federal and provincial legislation applies to all aspects of biochar, including environmental, air pollution, waste management, hazardous goods, transportation and waste transport, nutrient management, Canadian Food Inspection Agency (CFIA), and other applicable legislation. A Material Safety Data Sheet (MSDS) is available from a manufacturer of biochar."
A sample MSDS for Charcoal, Wood Powder can be downloaded here and viewed as a PDF: www.sciencelab.com/msds.php?msdsId=9923389

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Introduction

What is Biochar?

Biochar is charcoal produced from biomass for use as a soil amendment. It can be produced from biomass sources such as wood, crop residues, and manure, as well as from organic waste streams such as paper mill sludge. The biomass used to produce biochar is termed the feedstock. It is produced through pyrolysis, which is the process of heating biomass at a high temperature in the absence of oxygen. Biochar is characterised by high carbon content, a stable chemical structure resistant to decay, high porosity, and a high specific surface area. Specific surface area is a measure of the total surface area per unit mass. Biochar's potential for climate change mitigation, improved soil quality, and food security has recently brought biochar to the forefront of many research and policy agendas around the world.

Five major potential benefits of biochar:

1. **Improved soil quality, especially on degraded lands**
2. **Increased food production and food security**
3. **Reduction of atmospheric CO_2 through soil C sequestration**
4. **Production of renewable energy from the pyrolysis process**
5. **Redirection of biomass waste streams**


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A Note on the History of Biochar

The term biochar is relatively new, but the use of charcoal in soils is not a new practice and has historically and continues to be used by many cultures around the world. The most commonly cited example is that of the "Terra Preta de Indio" of the Amazon basin. The Terra Preta soils were formed by Indigenous peoples centuries ago and have been found to be highly fertile and richer in carbon compared to neighbouring soils. This fertility is attributed to the charcoal content of the soils that accumulated over time as a result of the society's practices (Solomon et al., 2007).


Major and Glasser

The Terra Preta soil profile shown on the right is dark from the charcoal content compared to its neighbouring soil pictured on the left. Source International Biochar Initiative, Major and Glasser.

Charcoal is Widespread in Soils

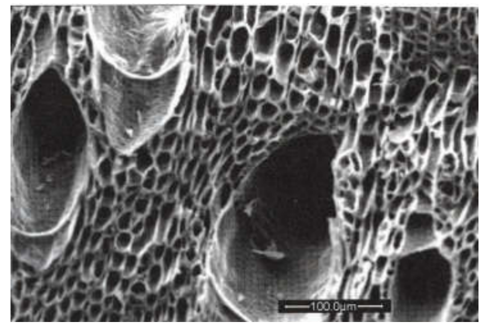
Charcoal is present in many soils around the world, including British Columbia, both from anthropogenic causes such as slash and burn agriculture as well as natural causes such as fire events. For instance, a study in Saskatchewan found that the fertile dark Chernozemic soils, present across Western Canada, contained between 25-65% carbon derived from charcoal (Ponomarenko & Anderson, 2001). Another study using radiocarbon dating found that charcoal present in forest soils in east-central British Columbia contain carbon derived from charcoal ranging from 182 to 9558 years old (Sanborn, Geertsema, Timothy Jull, & Hawkes, 2006).

Regional Research Needed

There has been a dramatic rise in research on biochar, but much of this research has been carried out in arid and tropical regions, with little in temperate regions. The effects of biochar depend on soil type and climate and further regional research is needed in order to fully assess the impacts of biochar on agriculture in British Columbia.

Soil Properties and Processes

Biochar improves soil quality through its effects on varied soil processes. Many of the benefits of biochar derive from its very high surface area and porous structure. Surface area plays an important role in soil chemical reactions and porosity plays an imporant role in physical processes, such as water movement, and creates more area for microbial colonization. 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 fertiliser (Sohi, Lopez-Capel, Krull, & Bol, 2009). Below some of the major soil properties and processes affected are listed. The actual impact of biochar is dependent upon a particular biochar's properties, the soil type, and the climate.



The image on the right is a scanning electron micrograph of wood biochar showing its porous nature. Source: Downie, Crosky & Munroe, 2009

- ***Biochar's surface area can range from 10 – to 400 m^2/gram of biochar***
- ***Fine sand is approximately 0.1 m^2/gram surface area of fine sand***
- ***Clay ranges from 5 m^2/g to 750 m^2/gram depending on clay type***

(Downie, Crosky, & Munroe, 2009)

Beneficial Impacts of Biochar on Soil Properties

Soil Physical Properties:

- Improved water holding capacity and infiltration rate results from increased porosity and pore sized distribution
- Reduction in soil bulk density as a result of biochar's low density, which could improve soil workability and plant growth in heavy soils
- Potential for improved aggregate stability and soil structure

Soil Chemical Properties:

- Increased Cation Exchange Capacity resulting from negative charges on biochar's high surface area
- Liming Effect (increased soil pH) which can make nutrients more available in acidic soils
- Reduced nutrient loss through leaching and associated improved fertilizer efficiency, tied to increased CEC and water retention
- Reduced nitrogen loss through gaseous emissions (methane and nitrous oxide), tied to CEC and the sorption properties of biochar

Soil Biological Properties:

- Increased habitat for micro-organisms in the porous structure of biochar
- Increased abundance of benefical organisms and increased microbial activity

What is CEC?

Cation Exchange Capacity is defined as the total exchangeable cations a soil can adsorb. In other words, CEC is a measure of a soil's ability to hold and release positively charged ions. Many plant nutrients are cations and therefore a high CEC improves a soil's ability to hold nutrients and to release those nutrients, making them available for plant uptake. CEC is generally higher in soils with high specific surface areas. Hence sandy soils have a low CEC and clay soils have higher CEC. (Brady and Weil, 2008)

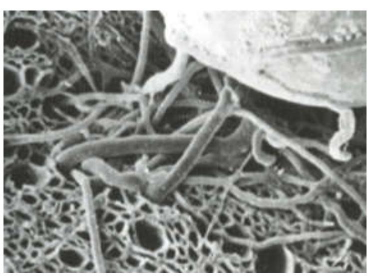
Possible Negative Effects on Soil Properties:

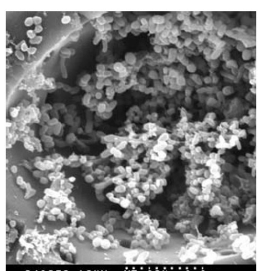
- Fine biochar particles may clog soil pores and decrease water retention
- Biochar may initially be hydrophobic resulting in soil water repellency and decreased infiltration
- Biochar may decrease aggregate stability as it does not contain binding substances like non-charcoal organic matter
- Sorption and accumulation of toxic compounds may occur, eg. pesticides, herbicides, polyaromatic hydrocarbons, heavy metals
- Increased soil alkalinity (raised pH) can lead to nutrients becoming unavailable to plants
- High carbon to nitrogen (C:N) ratio of biochar may result in the immobilization of nitrogen making it unavailable to plants
- Potential for biochar to contain substances that may be harmful to organisms
- Biochar may result in an altered soil microbial community with unclear consequences

Soil Property references: (Lehmann and Joseph, 2009; Pietikainen et al., 2000; Sohi et al, 2009;Verheijen et al., 2010)

Biochar has 3 major interrelated potential benefits to soil quality:

1. ***Improved nutrient retention and availability***
2. ***Improved water retention and water availability***
3. ***Improved soil microbial activity***





The image on the left shows the hyphae of mycorrhizae fungi extending into biochar pores and the one on the right shows microbes inhabiting biochar pores. Source Ogawa, 1994 (left), Yoshizawa, 2005 (right).

The benefits of biochar will likely be more pronounced in sandy soils, which have lower water holding capacities and lower nutrient retention to begin with, compared to loams or clay soils, which tend to have high water holding capacity and lower nutrient retention. The benefits of biochar may also be strongly linked to the liming effect biochar has on acidic soils, and those with neutral to alkaline soils should be cautious of raising their pH too much for this can negatively affect nutrient availability. Biochar is not a replacement for compost and it is unclear at this point how the removal of residues from agricultural soils or slash from forest soils to produce biochar will impact soil nutrient cycling.

There is a large variation in the soil types in BC and within the Fraser Valley. The impact of biochar will be very different in a sandy soil of the Okanagan compared to a clay soil of the Fraser Valley. General trends can provide an idea of what to expect but a site-specific trial is the best way to determine the impact of biochar on a particular farm.

Biochar and Increased Crop Yield

Improved crop yield through improved soil quality is one of the primary benefits that may be obtained through the implementation of biochar in agriculture.

> ***Crop improvements over the control as a result of biochar application has been reported to range from about 10% to more than doubling productivity*** (Verheijenet al., 2010).

Table 1 on the next page describes a selection of biochar trials. The examples in the table were chosen to illustrate biochar's potential to increase crop yields, and these are just a few of the examples available from the academic literature. The examples also illustrate that there is substantial variation in the design and outcome of biochar trials. The outcomes of biochar application are tied to site characteristics, biochar chracteristics and site management. Hence the results of previous research trials may not translate to small-scale agriculture in British Columbia, but certain trends can be drawn from the data to improve our understanding of biochar's impact on crop growth.

Key points from survey of biochar trials:

- **Biochar has been shown to increase crop yields for a variety of crops - grains, legumes, grasses and vegetables.**
  - **Especially when used with fertilizer**
  - **Especially on acidic, degraded, low fertility soils**
- **Biochar used alone may not have a measurable impact on crop yield.**
- **Negative impacts of biochar have been found with very high application rates – there is an upper limit.**
- **Biochar amendments may take more than one growing season to take effect and may last more than one season.**
- **Field trial results are specific to the type of biochar used, the climate, and soil type and will not necessarily translate to a different context.**

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Establishing biochar field trials at Fraser Common Farm in Aldergrove, BC

Table 1: Selected examples of field trial results

Location/ Soil Info	Feed-stock	Trial Details	Application Rates	Results
Quebec, clay loam, reported to be a fertile soil[1]	Wood	Field, soybeans followed by mixed forage, 3 years	3.9t/ha, with dairy manure and synthetic fertilizer	Year one soybean biomass 20% greater in biochar plot. Year two forage biomass 17% greater in biochar plot. Year three forage biomass 4.1% greater in biochar plot and greater animal nutrition value than control.
Australia Alfisol - weathered, moderately leached, acidic[2]	Green waste	Pot trial, radish	10t/ha, 50t/ha and 100t/ha, with and without synthetic N fertilizer addition	No yield difference with application of biochar only over control. Yield increased with increasing biochar application in presence of fertilizer - 266% dry mass increase in 100t/ha with fertilizer treatment.
Australia Alfisol - weathered, moderately leached, acidic[3]	Chicken Manure	Pot trial, radish	0,10, 25, 50t/ha with and without a N fertilizer application of 100kg/ha	Yield increase with increasing rate of biochar only. 42% yield increase at 10 t/ha and 96% increase at 50 t/ha of biochar application. Biochar + fertiliser resulted in highest yield of all treatments.
Brasil, Ferralsol - strongly weathered, acidic soil[4]	Wood	4 year field trial, 1 rice planting followed by 3 sorghum plantings	11t/ha with and without synthetic NPK fertilizer, and with and without compost	Charcoal alone had no impact. Charcoal with NPK fertilizer doubled grain production over fertilizer alone. Charcoal with compost did not improve yield over treatment with just compost. Compost with NPK fertilizer produced greater yield than charcoal with NPK fertilizer.
Italy, Sandy – loam, neutral pH[5]	Wood	Pot trial, perennial ryegrass	0, 10, 30, 60, 100 and 120 t/ha	Grain yield was increased 6-10% from biochar plus fertilizer, corn yield was increased by 24% in treatment with biochar, fertilizer and corn residues
Colombia, Oxisol - acidic and weathered[6]	Wood	Field trial, Maize – soy-bean rotation over 4 years	0, 8 and 20 t/ha (single application in year 1 for the 4 years) with lime and fertilizer	No results year 1. There was an increase in the 8t/ha of 19, 15, 71% and in the 20t/ha plots of 28, 30 and 140% over the control in year 2,3,4 respectively.
Aldergrove, BC, Orthic Humo-Ferric Podzol, sandy texture, neutral pH[7]	Alder wood	Field trial, Detroit red beets	10t/ha biochar only, 10t/ha biochar with compost, 10t/ha biochar and com-post tea, compost only	Beets had uniform germination across treatments, there was no visible difference between treatments with biochar and those without at 8 weeks into growth. Final yield data pending.

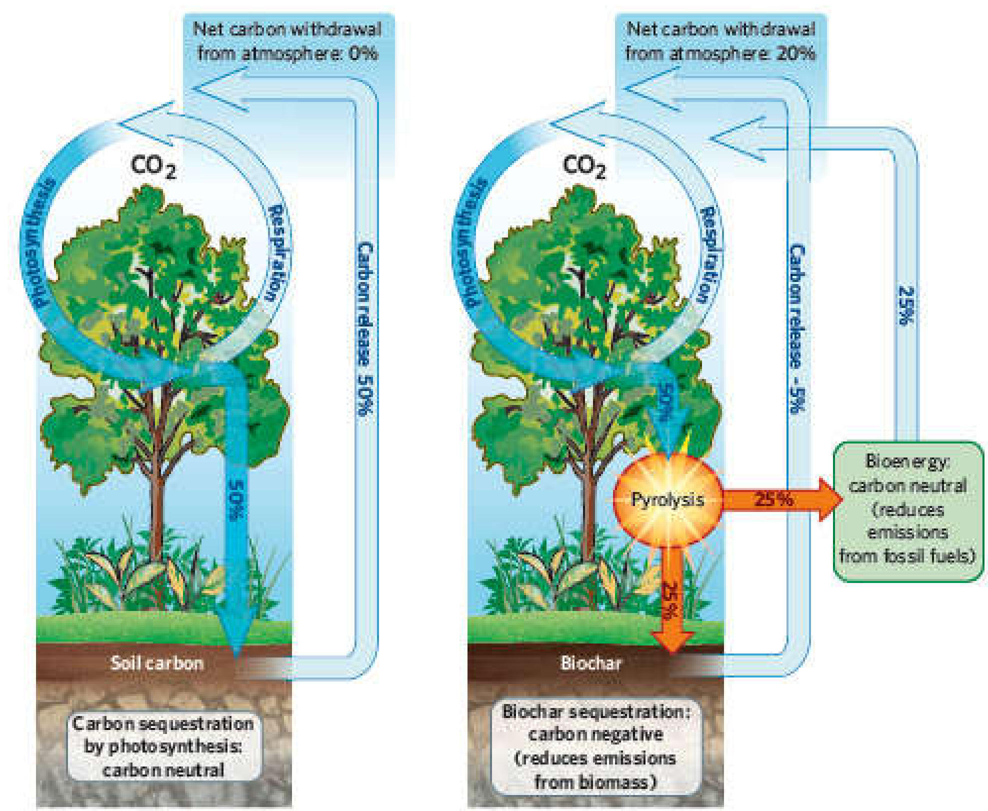
1. (Husk & Major, 2009, 2011)
2. (Chan, et al., 2007)
3. (Chan, et a., 2008)
4. (Steiner et al., 2007)
5. Baronti, et al., 2010)
6. (Major, et al., 2010)
7. Fraser Common Farm Cooperative Trials, authors' research, 2011

Soil C Sequestration & Climate Change Mitigation

Carbon dioxide (CO_2) is a major greenhouse gas contributing to global warming. Photosynthesis by plants removes CO_2 from the atmosphere, but when plants decay, CO_2 is released back into the atmosphere as organic matter decomposes. The pyrolysis of organic matter alters its chemical structure, resulting in an organic form of carbon that is resistant to decay. Once biochar is applied to soil, the carbon is expected to remain in the soil (out of the atmosphere) for centuries to over a thousand years. There are other means of increasing soil carbon in agriculture. The broad term "carbon farming" has recently emerged to describe any practice that acts to sequester soil carbon. No-till/low-till is an example of a method that reduces carbon loss from agricultural soils. Compared to raising soil organic matter levels, biochar has the advantage of adding a carbon source that is resitant to decomosition. Many of the methods of carbon farming reflect the philosophies of permaculture, organic, and/or ecological agricultural systems.

Biochar has the potential to be carbon negative and reduce atmospheric carbon:

- ***Soils store nearly 4x more organic C than the atmosphere***
- ***Annual plant uptake of CO_2 is 8x greater than anthropogenic CO_2 emissions***
- ***Diverting merely 1% of annual net plant uptake of CO_2 into biochar would mitigate nearly 10% of current anthropogenic CO_2 emissions (Gaunt & Cowie, 2009)***



The image above (left) indicates the carbon cycle in which the amount of CO_2 taken up by plants is equal to the amount of CO_2 released back into the atomosphere through plant respiration and normal soil processes. The right side illustrates how biochar reduces the amount of CO_2 released from soil processes, thereby resulting in a net withdrawal of atmospheric carbon. Source: Lehmann, 2007.

Soil C Sequestration & Climate Change Mitigation

Evidence of biochar's ability to sequester soil carbon:

- Carbon dating measuring the age of charcoal derived carbon in the environmment shows that the charcoal can remain in the soil for hundreds of years to thousands of years (Downie et al., 2011; Sanborn et al., 2006; Skjemstad et al., 1998).
- Laboratory incubation studies measuring decompostion rates over short periods of time have been use to estimate that biochar's life span could range from hundreds to thousands of years (Liang et al., 2008; Nguyen and Lehmann, 2009).
- Comparison of the carbon content of charcoal containing soils to nearby non-charcoal-containing soils have demonstrated an accumulation of carbon thought to be a result of charcoal's resistant nature (Solomon et al., 2007).

Mean residence time (MRT) is the length of time biochar derived carbon will remain sequestered in the soil. MRT has been estimated to range from several hundred to several thousand years

Biochar can reduce GHGs in more ways than just soil C storage:

- Use of organic waste to produce biochar decreases emissions from biomass decomposition in landfills
- Bio-oils, gases or heat produced from biochar manufacturing process can reduce fossil fuel emissions
- Potential for reduced emissions of N_2O and CH_4 from agriculture (from soil and compost piles) as a result of biochar's sorptive properties (Clough, 2010; Van Zwieten et al, 2009)

Life Cycle Analysis (LCA)

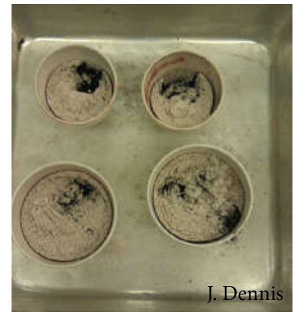
LCA is a technique used to assess the environmental impact of a particular product by assessing all aspects of that product's life cycle from resource extraction, manufacturing, transportation, implementation through to disposal. In order to accurately characterize the greenhouse gas (GHG) reduction potential of a particular biochar project, an accounting of all GHGs released during the biochar production and project implementation must be weighed against the reductions achieved by the project. Life cycle analyses have been carried out and have demonstrated that depending on the design of the biochar project, it has the potential to be carbon negative or be a source of carbon. In one life cycle analysis it was found that if a biomass waste stream was used, the biochar project was carbon negative, but if a crop is grown for the sole purpose of making biochar the system can be a source of carbon emissions (Roberts et al., 2009). Biochar projects have the potential to be carbon negative and a tool for climate change mitigation if well designed.

Biochar Properties

It has been emphasized throughout this manual that the effect of biochar depends on soil type, climate and biochar properties. The temperature of the pyrolysis process and the properties of the original feedstock are the two main factors influencing the properties of biochar.

Biochar is composed of three main components:

1. **Ash** is the inorganic portion and any readily available nutrients in biochar will be in this fraction. This fraction is usually quite small, and alkaline.
2. **Labile carbon** is the portion of the biochar that is susceptible to decomposition by soil microorganisms and the carbon in this portion will be lost in the form of CO_2 from respiration like normal organic matter.
3. **Recalcitrant carbon** is the portion that is highly stable and resistant to decomposition by soil organisms for a very long period of time. It is this portion that is responsible for biochar's ability to sequester carbon in the soil.



Biochar samples being tested for ash content at UBC - white layer of ash can be seen sitting on top, with unashed black biochar below.

The relative proportions of the above three fractions vary with the pyrolysis process and feedstock material. Other important properties that vary are pH, cation exchange capacity (CEC), electrical conductivity (EC), surface area, nutrient content, and porosity.

There are many methods for testing the specific properties of biochar. However they are often costly, require special lab equipment and not practical for small farmers. Knowledge of how temperature and feedstock affect the final product may give small producers a general idea of the properties of the biochar they are producing.

As pyrolysis temperature increases:

- Biochar yield decreases (bio-oil yield increases)
- pH increases
- Electrical conductivity increases
- Ash content increases, labile carbon content decreases and recalcitrant carbon content increases (proportionally)
- Total carbon content increases (carbon becomes concentrated as result of mass loss)
- Total porosity increases, micro-porosity increases, but pore-sized distribution decreases
- Surface area increases until a point at a very high temperature where deformation occurs resulting in a decrease in surface area
- potential CEC increases initially, however may decrease at higher temperatures (>500^{o}C)
- Nutrients may become concentrated, or they may be lost to volatization depending on the temperature at which a particular nutrient volatizes

Biochar Properties

The chemical composition of biochar is directly related to the composition of the original feedstock:

- Wood feedstocks produce high carbon, low ash and low nutrient content biochars
- Green waste produces intermediate carbon content, intermediate ash and nutrient content
- Manure feedstocks produce higher ash content, higher nutrient content and lower carbon content biochars
- Wood biochar has a high surface area and sorptive ability, thought to be a result of its original high lignin content

If lab analysis is desired:

A soil analysis lab, such as Pacific Soil Analysis Inc. in Richmond, can carry out some basic tests. If more advanced testing is desired a lab that does coal analysis could be tried, such as SGS Canada or ALS Global both located within the greater Vancouver area.

Chracterization Standards:

A set of chracterization standards are being developped for manufacturers of biochar and these can be found on the International Biochar Initiatives website. www.biochar-international.org/characterizationstandard

Application Rate & Methods

Field Application rate:

Based on a survey of literature and reports on biochar trials it was found that field applications of biochar range from about 5 t/ha (metric tonnes/hectare) to 40 t/ha, with lower rates of below 20 t/ha being more common. Some case studies found that increased rates of biochar either did not improve results over lower rates, or in some cases resulted in a negative effect on yield. It is recommended that applications rates of 5 - 10 t/ha in field applications be used to begin with.

A field application rate of 5 - 10t/ha is recommended.

1 tonne = 1000kg

1 ha = 10000m²

$10t/ha = 10000kg/10000m^2 = 1kg/m^2$

$5t/ha = 5000kg/10000m^2 = 500g/m^2$

1ha = 2.47 acres

$10t/ha \approx 4t/a \approx 0.2\ lbs/ft^2$

$5t/ha \approx 2t/a \approx 0.1\ lbs/ft^2$

Application frequency:

The effects of biochar may not be apparent in the first growing season after application, and it is recommended that observations be made over multiple seasons before deciding to apply more biochar. The accumulation of charcoal in the highly fertile Terra Preta soils is thought to have occurred over a long period of time and the natural accumulation of charcoal in soils also occurs over centuries. Hence, multiple small applications of biochar over time may be more effective than a single very large application. Research on biochar is relatively new and there is no recommended application frequency.

Application method:

Biochar can be a challenge to apply to the soil because of its dry and dusty consistency. The loss of biochar to the atmosphere must be avoided as it contributes to air pollution and is a health hazard. Spreaders have been tried for application, however, in field trials in Quebec it was estimated that 30% of the total biochar was lost to the atmosphere using a lime spreader (Husk and Major, 2009). Machinery used for row application of fertilizers could be experimented with. For smaller areas application by hand is effective, but precautions still need to be taken to avoid wind loss. It is recommended that biochar be moistened before being applied. The challenge is getting the biochar to a consistency that can still be spread easily but isn't too dusty. It is recommended that farmers experiment with different methods and levels of moisture in the biochar to find one that best suits their spreading methods.

Biochar should be turned into the topsoil. Topdressing is not recommended as it leads to risk of wind loss, plus the interaction of biochar with the soil is conducive to the beneficial properties of biochar being realised. The process of turning in the biochar also presents a risk of wind loss and again whether working by hand or with a tiller, it is recommended that the biochar and soil be moist before incorporating.

Photo showing biochar being applied by hand at FCFC. The biochar was moistened before application, then re-moistened after aplication and then turned into the top 15cm of soil by hand using a shovel.

'Charging' biochar with compost or compost tea

Instead of using water to moisten the biochar another option is either mixing the biochar in with compost or soaking it in compost tea before applying it to the soil. This process is termed charging or activating the biochar, and has two major benefits. It moistens the biochar, which lessens the dust hazard when applying to the soil, and secondly it may accentuate the beneficial properties of biochar. Compost tea and compost are high in microorganisms, and when a biochar is soaked in the tea or mixed with compost it allows for the highly porous biochar to become inoculated with microorganisms. In turn, when the biochar is added to the soil, beneficial organisms are also being added, increasing the benefits of the biochar. Biochar should be soaked in the tea once the tea has been made and then applied to the soil right away. Biochar can be mixed in with finished compost before application, or it can be mixed in with unfinished compost and left during the composting process. Compost is rich in nutrients and with biochar's high surface area and sorptive capacity it may adsorb nutrients and decrease nutrient loss through volatization or leaching during the composting process. Plus any adsorbed nutrients will then be added to the soil along with the biochar.

Methods of Small-Scale Biochar Production

Pyrolysis is a thermochemical conversion process in which biomass is heated in the absence, or near absence, of oxygen at temperatures in the range of 350 – 800 °C. Pyrolysis is a broad term encompassing various technologies ranging from very simple to extremely complex. Pyrolysis produces biochar, bio-oils, and gases in varying amounts depending on the process. The design of a pyrolysis reactor depends foremost on the desired end product and on the resources and technology available (Garcia-Perez, Lewis, & Kruger, 2010). The following section describes two low-tech methods of pyrolysis that can be employed on small farms for the production of biochar.

Fraser Common Farm Coop Kiln Design – Single Barrel Retort
(based on design described by Kelpie Wilson, link to site on next page)
The design of the kiln retort at FCFC consists of a single 55 gallon steel drum held horizontally over the ground on a metal stand. A perforated steel pipe routes from a hole in the top-back of the drum along the bottom of the drum and releases the gases that fuel the fire. There is space under the drum where an initial wood fire can be built in order to initiate the pyrolysis process. Cinder blocks are used to surround the whole drum to minimize heat loss.

Materials and Cost:

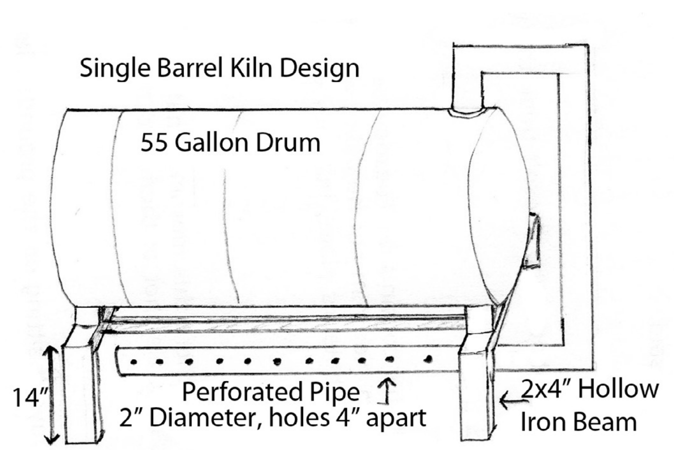
55 gallon steel drum (with lid and clamp)– $40
Gasket + cement for drum lid - $25
Scrap of Sheet metal for base - $0
Cinder blocks (72 x 3.00e) - $216
Rebar for cinder block top (6 pieces) - $17
Steel Pipe for gases (approx. 2 inch diameter) - $40
Metal for stand (2x4 hollow steel, approx. 16 feet) - $80
3 hours of welding labour - $180

Kiln Materials Cost: $418
Kiln Cost with welding labour: $598

Steps for building a single barrel retort kiln:

1. Build a stand (iron or steel)
   - it must withstand the weight of the loaded barrel and high temperatures (500-800C),
   - ensure sufficient room to build and access fire under barrel (bottom of barrel 14-16” off ground).

2. If fire brick is desired underneath barrel to build the fire on, place it on ground under the stand. For a less expensive option use a piece of scrap sheet metal.



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3. Drill holes 4 inches apart in portion of pipe that will be under barrel

4. Cut hole in the top rear of the barrel and attach pipe using flange, bolts and stove cement to create seal.

5. Build kiln walls with cinder blocks. Top can be made by threading rebar through 1/2 depth cinder blocks
   - alternatively reclaimed bricks or stones could be used
   - leave a hole at base of back wall to allow air flow and fire wood to fire

Kiln Photographs

Images of steel beam kiln stand holding barrel, rebar threaded through cinder blocks to create a top, front view of kiln where barrel will be loaded and then sealed with clamping lid, and rear view of kiln with finished wall with a hole to allow air flow and fuel to the fire.

Note: the above materials and steps are just a suggestion and can be altered to meet your needs and supplies once the basic design concept is understood

It is estimated that the heating temperature of this kiln design is somewhere between 500ºC-700ºC range and the efficiency is about 25% (the mass of biochar produced is 25% of the original air dried wood weight).

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Kelpie Wilson

Further Design Resources:

Online instructions for design by Kelpie Wilson:
www.greenyourhead.com/2010/01/backyard-biochar-kiln-instructions.html
Video by Kelpie Wilson
www.youtube.com/watch?v=ahIX54facp0&feature=player_embedded#at=63
Photo-Stream by Kelpie Wilson
www.flickr.com/photos/81339495@N00/3472078219/in/photostream
Same design but with two barrels side by side for increased production from Twin Oaks Forge
www.twinoaksforge.com/BLADSMITHING/MAKING%20CHARCOAL.htm
Similar idea with a more complex design and ability to divert gases:
seachar.org/wordpress/archives/422

Pyrolysis involves very high temperatures, potentially high pressures within the barrel, and the potential release of toxic gases. Safety must be a priority when designing a pyrolysis unit. If you are unsure about the safety of your design be sure to contact someone with experience or engineering expertise to inspect your design.

Methods of Small Scale Biochar Production

Steps for Making Biochar in your single barrel retort kiln

1. Completely air dry the feedstock (wood in this case)
2. Load the drum with dried feedstock
3. If using wood, chop to about kindling size
4. Build a wood fire under the drum
5. Replace cinder blocks around the drum, but leave a hole at bottom for air flow to the fire
6. Feed fire with wood until gases start burning and are enough to sustain fire
7. Dampen fire with a spray bottle and/or shut air hole if fire is too hot and needs to be controlled
8. Takes approximately 4.5 hours for charring process to be completed
9. Let cool overnight
10. Remove lid and unload biochar (shovel out)
11. Store biochar in sealed container

Grinding Biochar:
To apply biochar to the soil it will need to be ground or crushed in some manner. At FCFC an old cement mixer is used to grind the biochar. A few rocks are added to the cement mixer along with the biochar and some water to keep dust down. The mixer is covered to prevent dust and turned on. The ground biochar is then screened using a 4mm screen - large chunks are reground. Note that biochar dust is an air pollutant, hazardous to inhale and an explosion hazard. Ensure that the grinding method chosen is not releasing dust into the air.

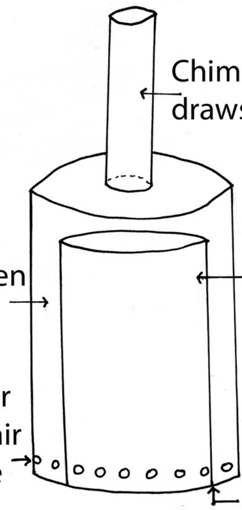
An possible alternate method is to chip wood before pyrolysis if you have access to a chipper or wood chip waste. However the small wood size will burn faster and it is not known if wood chips work well in the FCFC kiln design.

At Fraser Common Farm only wood has been tried in the kiln, but other feedstocks could be experimented with such as crop residues, nut shells, prunings from trees or berries, invasive plants such as black berries, etc.

Methods of Small Scale Biochar Production

Double barrel retort design

The double barrel design consists of a smaller barrel filled with the feedstock placed inside a larger barrel. The inner barrel creates an environment with minimal oxygen but is not entirely airtight and allows gasses to escape from the bottom into the space between the two barrels. The outer barrel has air holes around the bottom and a chimney on top to create an up-draft. The space between the two barrels is loaded with kindling and set on fire, and a lid with a chimney is placed on top. Oxygen will flow from the holes in the bottom of the outer barrel towards the chimney and the fire will move downwards burning the kindling. The gases that are released from the inner barrel will burn and further fuel the pyrolysis process as well as limit air pollution.



J. Dennis

Double Barrel Design Resources:

Basic two-barrel design by Folke Günther: http://www.holon.se/folke/carbon/simplechar/simplechar.shtml (this design doesn't have a lid with chimney but one could be added)

Video of Perter Hirst of New England Biochar: www.youtube.com/watch?v=RXMUmby8PpU&feature=player_embedded

Video by Dale Hendricks: http://www.youtube.com/watch?v=SaixJyg5D0c&feature=related

Video from Bodgers Hovel Australia using similar concept but with a brick outer wall and barrels inside: http://www.youtube.com/watch?v=HpXalctrL6A

Design using same concept but a more complex structure from Carbon Zero: www.biochar.info/biochar.CarbonZero-Experimental-Biochar-Kiln.cfml

There are many other small-scale designs that can be found online. When choosing a design some key considerations are the efficiency of biochar production (% conversion), prevention of emissions, ease of use, safety, durability, labour and materials cost. Though some designs may appear simple and low cost, be sure to consider the environmental impacts when weighing the options. If not done properly the production of biochar could release harmful gases such as methane and carbon monoxide. In order for biochar to aid in the mitigation of GHGs the production of biochar must not itself be contributing to air pollution.

Pyrolysis involves very high temperatures, potentially high pressures within the barrel, and the potential release of toxic gases. Safety must be a priority when designing a pyrolysis unit and if you are unsure about the safety of your design be sure to contact someone with experience or engineering expertise to inspect your design.

Sourcing Biochar Off-Farm

There are barriers to making biochar on a farm, such as the time and labour required, start-up cost and the availability of feedstock. Making biochar on site is not practical for all farmers and purchasing from a supplier may make more sense in some cases. Many start-up businesses specializing in biochar production and pyrolysis technology are emerging in British Columbia. Biochar availability is currently limited but will likely increase in the near future.

Local Biochar Suppliers:

Diacarbon, based in Burnaby - http://www.diacarbon.com
Alterna Biocarbon, based in Prince George - http://www.alternaenergy.ca

Suppliers outside of BC:

Vermont Biochar - http://vermontbiochar.com/biochar/
New England Biochar - http://newenglandbiochar.org/Products.html
Carbon Char - http://www.carbonchar.com/
Biocharm - http://www.biocharm.com/
Real Montana Charcoal - http://realmontanacharcoal.net/default.aspx

Mobile pyrolysis

Transporting large amounts of biomass is costly, relies on fossil fuels, and results in the emissions of GHGs. An alternative to transporting the biomass is creating mobile pyrolysis units that can process the biomass on site or nearby. The biochar is a much smaller volume and mass for transporting than the original biomass. Plus ideally the biomass being processed would then be applied within the same area, reducing the need for transportation. Diacarbon in Vancouver is currently developing a mobile pyrolysis unit for use within the region. A mobile pyrolysis unit may prove beneficial to farms or industry with large amounts of biomass who cannot process it on their own, as well as for providing biochar to those farms who do not have sufficient on site biomass or time to produce biochar.

Farm scale mobile pyrolysis unit from Agritherm.

Sales of pyrolysis machines

An option for future consideration is purchasing or building a pyrolysis machine for shared regional production. If a farm or a region has large amounts of biomass it may make economic sense to purchase a small to medium size pyrolysis unit from a manufacturer. More advanced pyrolysis technology allows for more efficient production of biochar, for more accurate control over pyrolysis process parameters, may be more environmentally sound, less labour intensive than home made production units, and safer.

Companies specializing in pyrolysis technology:

Agritherm, Ontario - http://www.agri-therm.com/index.htm
Advanced BioRefinery Inc., Ontario - www.advbiorefineryinc.ca/technology
Biochar Solutions, Colorado - http://www.biocharsolutions.com/index.html
New England Biochar, Massachusetts - http://www.newenglandbiochar.org/

Using Biochar in Potting Mix - Replacing Peat:

Peat is a limited resource mined from bogs around the world. Peat mining has a negative effect on the ecosystems from which the peat is mined as well as negative impact on global climate change. Many small scale farmers use potting mix in which peat is a primary component. Peat based potting mixes are not sustainable and recently coir (coconut fibre) has become a popular replacement for peat. Unfortunately there is no local supply of coir in BC. Biochar's low density, high water holding capacity and nutrient holding capacity make it a potential replacement for peat in potting mix, in addition biochar would then be transferered into fields through transplanting. Fraser Common Farm has been experimenting with biochar potting mixes and has had some success and found some barriers. The potting mixes tried have consisted of different proportions of biochar, compost and worm castings. Research is ongoing to produce a biochar based potting mix.

Left shows: the biochar potting mix trials at FCFC just after seeding. Middle: very poor lettuce germination that occurred in a potting mix of 50% biochar, 25% compost and 25% worm castings. Right: shows celeriac that germinated and grew normally in a typical potting mix (peat, perlite, compost) but with a small amount of biochar (< 10%) added in. All photos by J.Dennis.

What has been learned so far from potting mix trials at FCFC:

- 50% and 33% biochar in potting mix resulted in poor lettuce germination in a controlled and replicated greenhouse trial
- High pH was likely a cause of poor lettuce germination in 50% biochar mix; pH was 8.1
- Alkaline tolerant brassicas germinated in the 33% biochar mix
- A 25% potting mix was found to have a pH of 6.9, a suitable pH for plant growth
- A rate of less than 25% biochar may have potential
- Lab analysis at UBC found that a minimum of 10% biochar in a mix is needed to achieve a similar water holding capacity as a peat based mix (Hilbert & Johnson, 2011)
- 50% biochar resulted in surface crusting - an undesirable texture for potting mix
- The growth of celeriac and brassica starts demonstrated that biochar has the potential to be a successful ingredient in potting mix
- Further trials need to be carried out using different potting mix ingredients and rates of biochar before any recommendations can be made on the use of biochar in potting mix

Establishing Biochar Trials

If you are interested in using biochar at your farm or in your garden it is highly recommended that trials be carried out at your location with the biochar you will be using. Again the results of using biochar are dependent on soil type, climate and biochar properties. The results will also be influenced by the management practices specific to each farm. The results may be tied to type of fertilizer, compost and/or soil amendments used with the biochar, the application rate chosen, water management, crop choice, and/or method of incorporation.

Step 1: Germination and worm avoidance tests

- These measure are taken to ensure that the biochar you have made is not harmful to organisms and does not contain substances or properties that inhibit germination
- See resource 1 below for detailed instructions

Step 2: Bench (pot) Trials

- Mix biochar that you will be using with the soil to which you will be applying the biochar
- Add the same proportions of biochar, compost and other amendments you plan on using in the field
- Direct seed or transplant into pots containing biochar-soil mix and observe growth
- Make sure to have control pots (without biochar) to make comparisons

Taking regular field observations is important. Above: monitoring growth in beet trials at FCFC.

Step 3: If bench trials are successful, establish a small field trial

- Establish a field trial that fits in with your farm management system
- Ideally establish in a manner in which observations can be made over multiple growing seasons
- Multiple treatments can be used in the same trial. For example the treatments in the FCF trials were control, biochar only, compost only, compost and biochar, biochar soaked with compost tea
- Try to pick an area that has uniform soil, light, water, etc.
- Replication and randomization is ideal (concept explained in resources 1 & 2)
- Soil testing before and after is recommended

Resources with detailed instructions for establishing field trials:

1. A detailed biochar trials guide has been produced by Julie Major of the International Biochar Initiative and explains in detail how to design the biochar tests and trials. The "Guide to Conducting Biochar Trials" is publically available at:
www.biochar-international.org/extension

2. For further information on designing research trials on small farms there are three publically available guides from the Organic Agriculture Centre of Canada:
http://www.organicagcentre.ca/ResearchDatabase/res_welcome.asp

Health and Safety

Producing and working with biochar poses occupational health and safety concerns and measures should be taken in order to ensure health and safety standards are met. There are not yet standards specific to biochar, however those standards related to charcoal have been adapted to biochar production and handling.

Health and Safety issues can be divided into three main categories:

1. On-site pyrolysis operation health and safety concerns:

fire, explosion, sealed unit at very high heat, release of toxic gases (ex. carbon monoxide)

Precautions:

- Build pyrolysis unit in an open area with lots of air circulation ideally away from any structures
- Ensure that gasses can escape from the kiln to avoid pressure build up, the gasses need to be burned or condensed as they are toxic
- Keep a fire extinguisher and water source close by
- Do not open kiln until it has fully cooled (leave overnight)– it could ignite when exposed to oxygen

2. Biochar soil application health and safety concerns:

very dry, dusty and small particle sizes could lead to inhalation of particulate matter which can damage respiratory system and cause other health problems, toxic organic substances (carcinogens) may be present in some biochars

Precautions:

- A face mask should be worn if there is any chance of inhaling biochar dust
- Do not spread on a windy day, release biochar as close to ground as possible to avoid drift
- Thoroughly mix biochar into soil, avoid topdressing
- Try mixing biochar in with compost prior to application
- Wet biochar down with water (or try a compost tea) prior to using
- If tilling area with biochar ensure soil is moist to prevent excessive dust
- Wear gloves to avoid potential skin irritation

A respirator is effective in preventing the inhalation of particulate matter and can be purchased at a store carrying safety equipment.

3. Storage and transportation health and safety concerns:

potential for spontaneous ignition of biochar or explosion caused by dust particles

Precautions:

- Let fresh charcoal be 'cured' by exposing to open air for 24 hours, this may help reduce chances of ignition
- Store as lump charcoal, grind just before use (dust is more prone to ignition)
- Store and transport in sealed containers or a covered pile
- Store outside, away from buildings, in a cool, dry well-ventilated spot

If you purchase biochar from a manufacturer they must supply a Material Safety Data Sheet (MSDS). An example for biochar can be found in the following document **www.dynamotive.com/assets/resources/PDF/PIB-BioChar.pdf** produced by Dynamotive (pages 19-21).
The health and safety information provided on this page is from the following references, which are publicly available online, and can be consulted for more details: (Collison et al., 2009; Sohi et al, 2009;Verheijen et al., 2010).

Economic Sustainability

Biochar certainly holds value in its potential to mitigate climate change, improve soil quality and contribute to food security. However in order for biochar to be implemented it must be economically sustainable for farmers. Currently the investment and labour costs of the biochar project at Fraser Common Farm outweigh the economic returns. The project is still in the development stages and as with many investments it may take more than one season before any economic returns are seen.

Three primary costs of small-scale biochar production and application:

- Kiln materials and maintenance costs
- Labour time of collecting, drying, storing, chopping feedstock
- Labour time in making, storing, applying biochar

Four main potential economic returns on investment in biochar for farmers:

- Increased yield
- Reduced reliance on external amendments for fertility - reduced expenditures
- Energy Capture through making use of the bio-oil, the gases, or heat produced from the pyrolysis process for on farm purposes, eg. heating a greenhouse (but requires higher technology, with an associated cost)
- Carbon credits

What are Carbon Credits? and Will they benefit small-farmers in BC?

Carbon credits often come up in economic discussions of biochar implementation. It seems that to make the use of biochar in agriculture profitable, the reduction of GHGs achieved may need to be given an economic value, and currently the dominant strategy for doing so is through carbon markets and carbon credits.

Carbon Offset: is a reduction made in greenhouse gases in one location to balance (offset) GHGs being produced elsewhere. Carbon offsets are measured in metric tonnes of carbon dioxide-equivalent (CO_2e) and can include six primary greenhouse gases (CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6)

Carbon Credit: refers to the reduction of one metric tonne of carbon dioxide or its equivalent in other greenhouse gases and has a monetary value attached to it. Carbon credits can be sold by those with carbon offset projects and bought by those producing GHGs on what is termed carbon markets. The value of a carbon credit is determined by market forces and as such fluctuates. At the time of writting carbon credits vary from $5 - $25 depending on the market.

In British Columbia, the *Greenhouse Gas Reduction (Cap and Trade) Act* was introduced in 2008 and as a result a cap and trade system is scheduled to come into effect in BC in 2012. The cap and trade system will allow for the trading of carbon offset credits amongst sectors, including agriculture. A crown corporation, Pacific Carbon Trust, has been established to administer carbon offsets in BC. Soil carbon sequestration is a potential carbon offset project in agriculture and can be achieved through any project or management strategy that resutls in the sequestration of carbon in the soil for a long period of time. Therefore biochar projects have the potential to be an eligible carbon offset project in the agriculture sector. There is a rigorous application process to have an offset project validated on regulated markets which are controlled by the government. Voluntary markets exist and may have less rigorous application processes that are better suited to small-farm projects.
For information on BC carbon credits visit the PCT site at www.pacificcarbontrust.com, the Western Climate Initiative at www.westernclimateinitiative.org, visit the BC Ministry of Environment site at www.env.gov.bc.ca/cas/mitigation/cap_trade.html, or the BC Ministry of Agriculture's Climate Action site here www.agf.gov.bc.ca/resmgmt/ClimateActionPlan/index.htm.

Challenges to establishing soil C sequestration offset projects:

- Measurement of soil carbon can be difficult to accurately quantify (spatial and temporal variation).
- Cost of measuring and monitoring soil carbon may be expensive.
- For a biochar project it would need to be demonstrated that the production/collection of feedstock, manufacturing and application of biochar did not produce more GHGs than the biochar sequestered.
- Carbon sequestration must be permanent (defined as 100 years), having land management implications
- Administration costs of validating and monitoring a project may be high.
- Due to biochar's variability, it has been suggested that for an offset project, biochar should be analysed to determine the recalcitrant carbon content (analysis cost).
- Ownership of the offset credit may be an issue if the biochar is being purchased offsite for use in an offset project.
- There is currently a lack of clear protocol and standards.

Will small farms benefit from carbon credits?

- Price fluctuations in carbon markets cannot guarantee a stable return.
- The amount of carbon that can be sequestered is directly tied to the amount of land available - the costs of establishing a biochar offset project may outweigh the potential returns for small farms.
- Pooling of small projects is permitted and hence farm networks may be able to reduce administrative costs of offset projects through pooling.
- Leased land may be a barrier to the permanancy requirement.
- Offset projects must meet an additionality criteria, therefore C sequestration though practices that have long been practiced in small scale organic/ecological agriculture my not be applicable (ex. low till, cover cropping, mulching, hedgerows, woodlots).
- Voluntary (not government regulated) markets usually have less rigorous standards and may be more suitable for small-farm offset projects

Source: carbonfarming.wordpress.com

- ***Carbon credits are estimated to range from \$5 to \$25/t CO_2e***
- ***If soil organic matter in the top 10cm of soil is raised by 1% it equates to approximately 23.5 tonnes of CO_2e/acre***
- ***A 10 acre farm would receive \$117.50 to \$587.50 in carbon credit payments (Carbon Coalition Against Global Warming, 2010)***

Recommended Resources

Books:

Bates, Albert. (2010). The Biochar Solution: Carbon Farming and Climate Change. New Society Publishers, Gabriola Island, BC. (Available at the Vancouver Public Library)

Bruges, James. (2010). The Biochar Debate: Charcoal's Potential to Reverse Climate Change and Build Soil Fertility. Chelsea Green, White River Junction, VT. (Available at the Vancouver Public Library)

Lehmann, J. and S. Joseph, Eds. (2009). Biochar For Environmnetal Management: Science and Technology. London; Sterling, VA, Earthscan. (ebook access with purchase of IBI membership, or can buy from amazon)

Taylor, Paul. (2010). The Biochar Revolution: Transforming Agriculture & Environment. Global Publishing Group. (avalable for purchase on amazaon)

Free Online Reports: (click below, or search for documents to find the link to a PDF)

Three review papers on biochar focused on agricultural use:

Sohi, S., Lopez-Capel, E., Krull, E., & Bol, R. (2009). Biochar, climate change and soil: A review to guide future research. CSIRO Land and Water Science Report 05/09.

Verheijen, F., Jeffrey, S., Bastos, A. C., van der Velde, M., & Diafas, I. (2010). Biochar Application to Soils A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. Italy: European Commission, Joint Research Centre, Institute for Environment and Sustainability.

Granatstein, D., Kruger, C. E., Collins, H., Galinato, S., Garcia-Perez, M., & Yoder, J. (2009). Use of biochar from the pyrolysis of waste organic material as a soil amendment: Final project report. Wenatchee: Center for Sustaining Agriculture and Natural Resources, Washington State University.

Review of Pyrolysis Technology

Garcia-Perez, M., Lewis, T., & Kruger, C. E. (2010). Methods for producing biochar and advanced biofuels in washington state. Part 1: Literature review of pyrolysis reactors. First Project Report., Pullman, WA: Washington State University.

Social Perspective and Critical Analysis of Biochar

Leach, M., Fairhead, J., Fraser, J. and Lehner, E. (2010) Biocharred Pathways to Sustainability? Triple Wins, Livelihoods and the Politics of Technological Promise, STEPS Working Paper 41, Brighton: STEPS Centre

Economic Perspecitve based out of Washington

Galianato, S., J.K. Yoderb, D. Granastein. (2010). Economic Value of Biochar in Crop Production and Carbon Sequestration. Working Paper Series: 2010-3. Pullman, WA: Washington State University.

Websites:

International Biochar Initiative - www.biochar-international.org

This website is the most extensive resource out there. It has regular news updates, access to manuals and standards being produced by the IBI, links to biochar projects and websites across the world, and a very long bibliograhy of academis biochar litterature.

Canadian Biochar Inititave - www.biochar.ca

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