Biochar Guidebook:

Basics of Biochar and Applications for the Farm

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Introduction to Biochar

Charcoal, referred to as **'biochar'** when applied in agricultural soils, has been shown to improve carbon, nutrient, and water retention in soils, as well as increase biological activity and a plant's ability to absorb nutrients. As a stable form of carbon, charcoal can last in soil for up to 10,000 years. Historical and data modeling suggests that these carbon and biological benefits may continue and even enhance throughout biochar's duration in the soil due to the charcoal's physiochemical structure. Biochar provides a long-term approach to **soil health**, food security, and a way to store carbon in our soils and out of the atmosphere in the age of climate change.

Biochar provides an opportunity to address both soil health and forestry problems in San Juan County. Years of plowing and haying have decreased soil carbon, resulting in lower nutrient and water retention in soils. Simultaneously, a history of fire suppression, combined with dense forest regrowth following clear cut logging in the early 20th century, has resulted in high fire danger and a propensity of low commercially viable timber. Most private landowners may not have the knowledge or expertise to adequately deal with large amounts of biomass materials that result from creating defensive space around homes and buildings for fire protection. Other landowners may just wish to improve the overall health of their forest. Biochar provides an avenue to utilize the excess woody biomass resulting from forest restoration practices, and turn it into a long-term benefit in garden and farm soils. The production of biochar allows the use of **local resources to help manage local issues** that contribute to the resilience of forest and farming ecosystems in the San Juan archipelago.

Excuse me waiter…there's carbon in my soil (or not…)

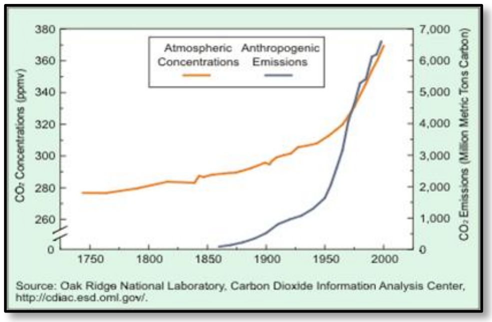
When thinking about improving soil fertility, carbon often takes a backseat to nitrogen, phosphorous and potassium. While these and other minerals are important, carbon is the foundation for healthy soil as it increases the retention of both water *and* these other nutrients, along with improving biological activity and the ability of plant roots to access minerals through adsorption. Further, biochar has a high resistance to decomposition in soil, a quality referred to as *resonance,* which allows it to provide positive benefits over a long period of time[1]

Traditional practices of tilling the soil, whether in fields or gardens, have been used for many decades. Soil stores carbon in the form of humus that has been created by the decomposition process of generations of dead plants. When soil is tilled, carbon bonds with oxygen, converting it into carbon dioxide that rises into the atmosphere. Nearly 1/3 of the carbon dioxide released into the atmosphere since the industrial revolution is due to tillage.[2] Now agriculture is experiencing a carbon crisis, with 50-70% of the world's carbon in farmland soils off-gassed into the atmosphere due to tillage. Finding ways to store carbon in the soil is one of the foundational questions of sustainable agriculture in a changing climate.

As biochar stabilizes and captures carbon in the soil, it increases the benefits of other carbon farming practices such as no-till farming, cover cropping, and rotational grazing. This assists with plant nutrient exchange as well as reduced climate emissions. Annual soil testing, especially tests that examine soil carbon and active biology, provides the best way to get feedback on the effectiveness of your nutrient and carbon practices.

[1]Biochar Carbon Stability Test Method: An assessment of methods to determine biochar carbon stability. A. Budai; A. R. Zimmerman; A.L. Cowie; J.B.W. Webber; B.P. Singh; B. Glaser; C. A. Masiello; D. Andersson; F. Shields; J. Lehmann; M. Camps Arbestain; M. Williams; S. Sohi; S. Joseph\

[2] Growing a Revolution, David Montgomery, pp 54.

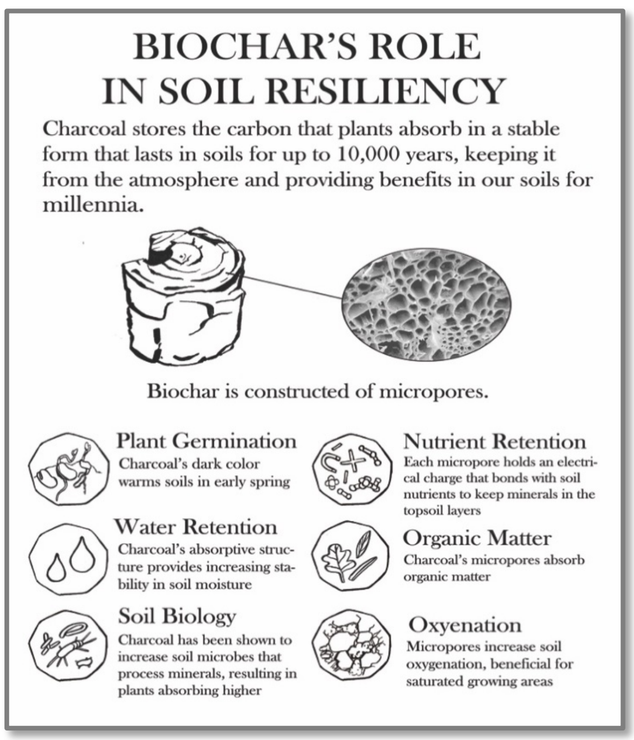


[3]

Understanding Biochar's Benefits

Inside Biochar

The surface area of biochar provides an environment for microbial growth, which is important for the transport and absorption of nutrients. Biochar has significant surface area and complex pore structure (a single gram can have a surface area of over 1,000 square yards).[4] Soil microbes are a critical component of healthy soils, as they digest minerals to make them accessible to roots in a similar way to how intestinal flora digests the food we eat. The most important limiting factor for microbial growth in soils (assuming moisture is adequate) is the amount of available carbon.[5] It cannot be overstated how important carbon and soil biology are to healthy soils and the need to take care of them, just as we would the plants that depend on them.



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[3] https://www.agmrc.org/renewable-energy/climate-change/energy-agriculture-carbon-farming/

[4] www.biochar-us.org; 2018

[5] www.organiclifestyles.tamu.edu; 2018

Beyond increasing soil carbon and biology, biochar has been found to increase nutrient retention and decrease fertility leaching into water systems. The porous nature of biochar captures and stores organic matter, while also having the capacity to absorb 4-6 times it's weight in water. Biochar offers a holistic and multifaceted approach to soil health, providing benefit through a confluence of properties.

Defining Adsorption vs Absorption

Biochar operates on the premise of *adsorption*, using the surface adhesion to transport nutrients on a molecular level to the plant root systems. Roots that can tap into this process also are able to utilize the microbes that live within the structure of biochar, as well as benefit from the moisture retention qualities.

Adsorption is the adhesion or sticking together of molecules of a gas, liquid or dissolved solids, to the surface of a solid, or sometimes a liquid.   It is a surface related event and increases until it reaches equilibrium.

Absorption is the passage of one substance into or through the bulk of another medium. It is a bulk related event and occurs at a uniform rate.

Burning that is Good for the Atmosphere

While fire is often associated with air pollution, effective biochar burns significantly reduce emissions of greenhouse gases from woody biomass into the atmosphere. Burning wood debris off-gases nearly 100% of the carbon contained in the feedstock, and chipping wood material will off-gas the majority of the carbon through the decomposition process, which usually takes between 2-6 years. Burning 100 pounds of brush releases approximately 40 pounds of carbon, which translates to nearly 147 pound of carbon dioxide in the atmosphere.[6] This increase in weight occurs when the released carbon bonds with oxygen, creating carbon dioxide. The process of pyrolysis that is used to convert biomass to charcoal generates carbon-carbon bonds that stabilizes a percentage of the carbon present in the feedstock, allowing the carbon to stay in the biochar rather than be emitted to the air.

Research indicates that the percentage of carbon stabilized in the feedstock changes depending on the material converted into biochar and the method used to produce the charcoal. For example, a field project in Nepal recently demonstrated the following production differences:

- Pit burn: 43% carbon sequestered
- Flame Cap Kilns: 36.8% carbon sequestered
- Steel shield in pit: 56% carbon sequestered

The research project also found that in comparison to traditional open burn piles, Flame Cap Kilns "significantly lower(ed) emissions of CO (carbon monoxide) and NOx (nitrogen oxides)" by consuming these volatile gases in the area of active flame. Flame Cap Kilns illustrated a 650% reduction in carbon monoxide off gassing (54 ± 35 g/kg compared to 351 ± 141 g/kg) and 37,000% decrease in nitrogen oxide (0.4 ± 0.3 g/kg compared to 148 ± 64 g/kg).[7] Therefore, Flame Cap Kilns and pit burns have a significant impact on reducing greenhouse gas emissions in comparison to open burns.

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[6] http://climatechange.cornell.edu/is-it-ok-to-burn-brush/
[7] http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0154617

The Potential of Biochar

There are many uses for biochar, including, but not limited to:

- Soil amendment, conditioner
- Filter medium in water and sewage systems.
- Bedding for animals to control odor and absorb moisture.
- A seed starter medium to replace perlite in potting mix when charged with nutrients.

Role of Charcoal in Natural Ecosystems

Fires that traveled through old growth forests produced between 4-6% charcoal from the total biomass burned. For prairie ecosystems, between 20-40% of the root ball of grasses turns into charcoal with each passing wildfire. As charcoal has a longevity, or resonance, in soil of up to 10,000 years, charcoal levels continued to build each fire season, generating increased fertility over time. Charcoal absorbs water, retains nutrients, and collects organic matter in its pores, enhancing the fertility levels that feed a soil's microbiome.

Historical Use in Agriculture

Humans have used charcoal throughout the world in agricultural production, including Greece, Rome, Japan, Africa, Eastern Europe, and the Americas. Historical use by indigenous villages in the Terra Preta area of the Amazon was first published by Cornell University in 2003, where charcoal dating back between 2,500-4,000 years was found to still have benefits in modern soils such as increased nutrient, water, and carbon retention. Local research in the San Juan Islands has found high charcoal content in the camas gardens of the original Salish people dating back hundreds of years, with increased soil fertility continuing to the present. The implications of this research, which is supported by research through parts of historical charcoal sites in Europe,[8] signifies the long-term impact of biochar additions to agricultural soils for this generation and generations to come.

Research Summary

Thousands of research papers on biochar are coming out annually from universities around the world. A number of meta-analysis papers provide a window into the common findings from this global analysis.

Carbon

While researchers have previously understood that biochar stabilizes the carbon in plant material through increased carbon-carbon bonds, new research indicates that biochar also stabilizes native bioavailable carbon in soil. When biochar is added to soils, carbon off gassing (respiration) decreases by up to 68.8%. Further, higher fire temperatures in the biochar manufacturing process can significantly increase the carbon stabilization properties of biochar.[9] Research indicates that biochar with higher pH (8.1-9) has greater soil carbon stabilization capacity and supports enhanced biological activity compared to biochar with lower pH

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[8] Black carbon and soil properties at historical charcoal production sites in Germany, Borchard, N. et al 2014.
[9] Biochar stimulates the decomposition of simple organic matter and suppresses the decomposition of complex organic matter in a sandy loam soil, Hongguang Cheng, 2017.

values.[10] Deciduous trees, which have a higher pH than conifers, will produce biochar with higher immediate value for the soil. As the vast majority of Pacific Northwest soils are acidic due to the heavy rainfall, high pH biochar can provide a long-term method of increasing soil pH without annual liming. It is important to check your soil pH values through soil testing to make sure you do not transition too far above neutral (7.0).

Biological Activity

Soil biology serves as an intermediary between plants and minerals in the soil, digesting nutrients in a similar fashion to intestinal flora in human digestion. Another meta-analysis paper of 445 academic studies found that soil organic carbon, the food source for soil microbes, was increased on average by 40%, and microbial biomass increased by an average of 18%.[11]

Crop Productivity

Another meta-analysis paper published by Dr. Xiaoyu Liu and his colleagues examined 238 studies of biochar's influence on plant productivity. They found that vegetables increased by an average of 28.6%, and that legume crops, such as peas, beans, and vetch, increased productivity by an average of 30.3%.[12]

Variation on Research

Research also illustrates that results vary significantly depending on soil type, the condition of the soil structure, and the method by which charcoal is produced. A series of meta-analysis papers concluded that higher charcoal production temperatures (above 750-800 F) led to increases in surface area, moisture retention, carbon stabilization, and longevity (*resonance*) in the soil. Lower charcoal production temperatures (below 750-800 F) decreases the resonance in the soil, but increases biochar's ability to retain nutrients and the inherent plant available carbon in the biochar. An integration of biochar made at different temperatures may provide the optimal range of soil enhancements.[13]

Local Research in San Juan County [14,15]

In 2015, University of Washington conducted research on growing beans on ten farms across San Juan County. The research revealed that:

- Biochar increased soil carbon levels between 32-33%.
- Biochar enhanced nutrient retention in the soil: ammonium nitrogen + 45-54%, organic nitrogen + 48-110%, inorganic phosphorus + 29%.

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[10] Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis Shuwei Liu et al, 2016

[11] Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis Shuwei Liu et al, 2016

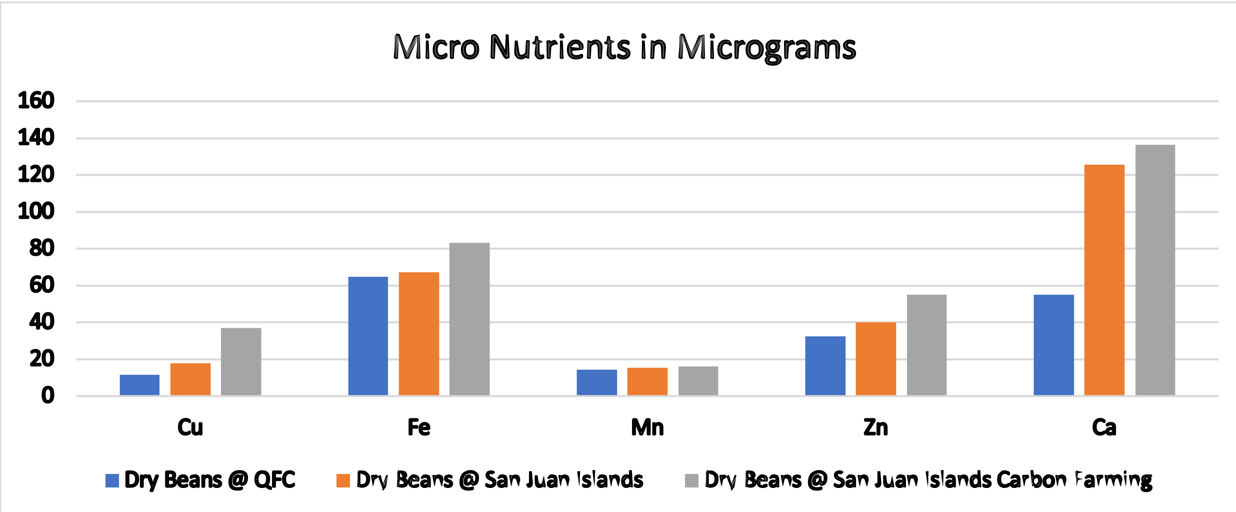
[12] Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data, Xiaoyu Liu 2013

[13] Influence of biochar produced from different pyrolysis temperature on nutrient retention and leaching, Hongguang Cheng et al, 2017

[14] Published in the scientific review journal Agriculture, Ecosystems, & Environment, 2017.

[15] UW PhD candidate Si Gao and the Director of the University of Washington School of Environmental and Forestry Sciences, Dr. Tom DeLuca.

Biochar increased nutrient density of plants, including: copper, iron, calcium, zinc, and manganese. The study compared the average nutrient content of the dry beans grown on conventional farm plots and farm plots where biochar was applied (aka Carbon Farming). The nutrient density of the farmed beans were then compared to beans from a Seattle QFC grocery store.



In 2016, researchers established charcoal plots on an additional six farm sites in San Juan County, which all grew Kuri winter squash. The research revealed that:

- Soil carbon increased by 35%, and biological activity increased by 46-47%.
- Potentially Mineralized Nitrogen increased by 65% with biochar plots in comparison to the control.
- Ammonium nitrogen leaching into subsoil layers was decreased between 13-33%.
- Moisture retention increased 18-20%.

Key trends in this research also showed increased microbial enzyme counts, increased bioavailable phosphorus, and increased crop yield.

Post Processing

Maximizing Surface Area through Pulverizing

Pulverizing charcoal into small pieces and dust creates higher amounts of surface area, which increases the pore space in which nutrients and water can collect. Before pulverizing, charcoal should be wetted down, as the dust can be harmful. There are many ways to pulverize charcoal, but a common farm application involves spreading the charcoal on the ground or pavement and driving over it repeatedly with a tractor or vehicle. Any number of fertilizers or additional soil amendments can be added to the charcoal before it is pulverized in order facilitate the incorporation of the amendments into the biochar. The optimal functional size of biochar ranges from dust to smaller than the diameter of a dime.

Inoculation

It is highly beneficial to inoculate, or "charge", charcoal with fertility before incorporating it into the soil. Without inoculation, biochar may absorb existing nutrients in the soil and generate a short-term nutrient deficiency. Inoculation can be achieved using many different materials, including: compost or compost tea, animal and/or human manure, fish or sea emulsions, etc. Regardless which method is used to inoculate charcoal, the charcoal should never be saturated, as oxygen is key to the functional qualities of biochar.

Inoculation Method 1: Fertilizer Addition

As stated above, nutrients can be added at the beginning of the pulverizing process to help incorporate them into the biochar. Once pulverized, rake the biochar into a windrow (a long narrow strip), and turn the row over with a pitchfork or shovel in order to evenly distribute the nutrients throughout the biochar. It is also helpful to spray the biochar at this point with water, to help the nutrients dissolve and integrate into the infrastructure of the biochar.

Once mixed, place a tarp over the inoculated biochar, or otherwise contain it, as access to sunlight will off-gas various forms of nitrogen that were just added. Wait three days for the fertilizer to incorporate into the biochar before adding it to soil.

San Juan County applied at a rate of .22 pounds of 8-2-4 chicken manure-based fertilizer per square meter. Adding a micronutrient addition will increase the range of nutrient benefits by the biochar. Seaweed is also a recommended addition, as recent research is finding that fermented kelp holds certain fast acting proteins that catalyze the biological activity in the biochar.

Inoculation Method 2: Composting

Incorporating charcoal into your compost can be a way to charge it with minerals and micro-organisms while simultaneously enhancing the microbial population and processes in your compost. If compost is on the dry side, it should be wetted after the charcoal has been added, and allowed to sit for a minimum of two weeks to allow for the establishment of biotic communities and nutrients to inoculate the biochar.

Composters often worry that biochar, as a carbon rich product, will throw off the carbon/nitrogen ratio of a compost pile, which is ideally 25-30 parts C to 1 part N.[16] In reality, most of the carbon in charcoal is not fast acting, and will have a limited influence on the C:N ratio in compost. Biochar can be added to compost at a rate up to 5% of the total compost by volume.

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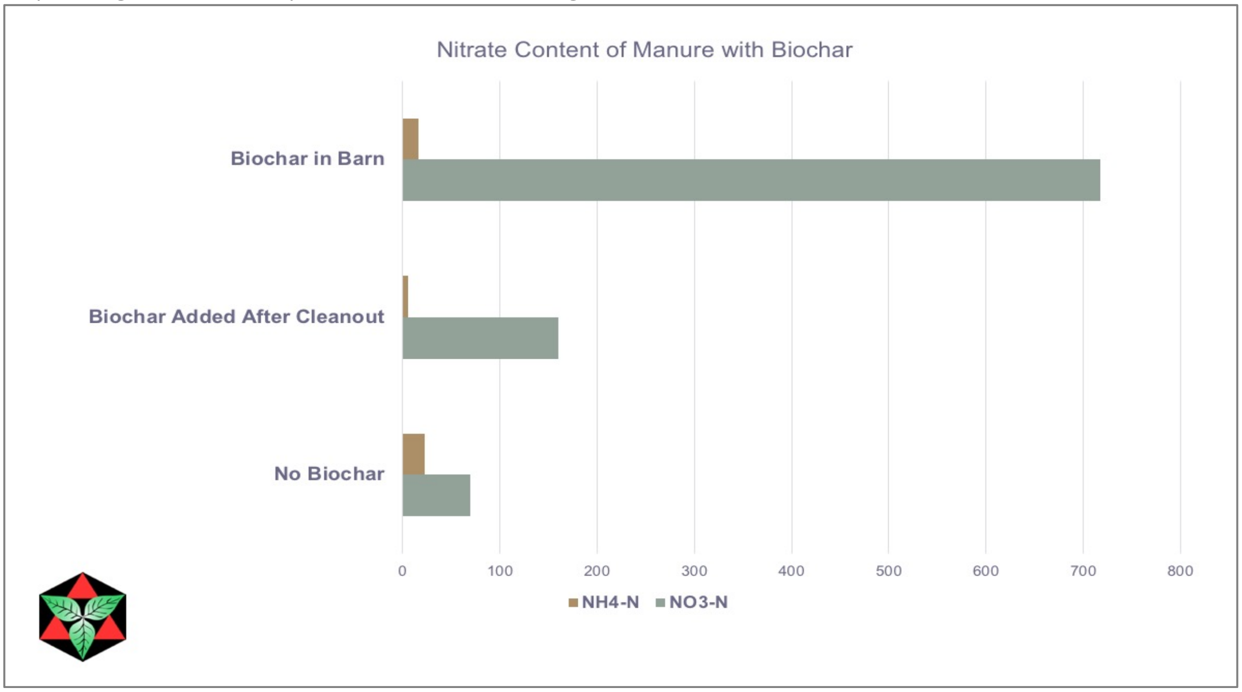
[16] For carbon to nitrogen ratios of common compost materials please refer to the table on this website: http://ucanr.edu/sites/mginyomono/files/170818.pdf

Inoculation Method 3: Using Biochar as Animal Bedding

One of the most promising uses of biochar by farmers is integrating it into animal bedding systems. The biochar absorbs the waste nutrients, reducing ammonia and other odors in barns, stables, and poultry houses, while simultaneously inoculating the biochar with nutrients and active biology. The process of absorption keeps ammonia from volatilizing into the air or leaching through the soil into waterways where it can generate algae blooms. Biochar improves the process of incorporating animal-based nutrients back into crop land by stabilizing the nutrients and creating more opportunities for plant roots to interact with the nutrients. The table below illustrates how nitrate (NO3), which is a more plant available form of nitrogen than ammonium (NH4), is retained in animal manure with the addition of charcoal.

Capturing Barn Fertility with Biochar Bedding



Graphics from Wilson Biochar Associates

Charcoal can be layered each week in sleeping areas or sprinkled throughout the barn at a rate of 5 gallons per 100 square feet. Where manure is thicker, apply as much charcoal as necessary to decrease the smell of ammonia, which indicates the majority of the nitrogen has been absorbed. When ammonium smells return, apply more charcoal.

Application

Various studies have examined application rates, and research is ongoing to determine the best application rates for various forms of agriculture. Given the variability of charcoal quality depending on feedstock and method of production, precise biochar application rates may not be realistic. However, the prevailing charcoal rate of application is 5-10% of the rooting zone by volume. For many soils, this equates to 100 gallons of charcoal per 500 square feet of ground, or one cubic yard of charcoal per 1,000 square feet of ground. For potted plants, use 1 - 2 cups per two gallons of soil.

Biochar produced at temperatures above 750 F are much more stable in the soil, and may only require a one-time application. However, biochar produced at lower temperatures is less stable in the soil and may require re-applications every 2-50 years depending on the wood type and temperature of production. Farmers and researchers find increased value in incorporating higher volumes of charcoal than 5-10% of soil volume, as carbon levels and biological activity appear to increase concurrently in soil.

Methods of Incorporation

Charcoal can be tilled into the soil at a depth between 2-6 inches, or it can be applied to the first several inches of topsoil with a no-till seeder, rake, hoe, or shuffle hoe. Earthworms and roots carry the biochar into the subsoil layers over the first two years after the biochar has been incorporated.

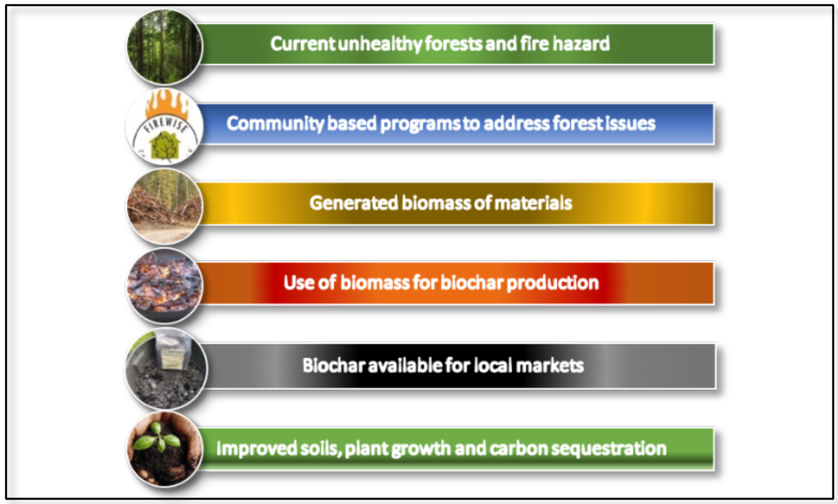
Community Cooperative Model – Forest Health

Solving community issues often requires a multi-pronged approach. Biochar provides an opportunity to turn a problem into a solution by simultaneously reducing fire danger, improving the health of forest and farm soils, increasing food quality, and creating opportunities for community members to work together towards common goals.

In the San Juan Islands, recent efforts by the Firewise Program (and similar forest management programs) have given residents a chance to reduce the fire danger of forests in proximity to their homes and public roads by thinning overstocked stands. Thinning dense forests generates a large amount of woody slash that typically is burned in open piles, returning no benefit and increases the amount of greenhouse gasses released to the atmosphere.

What if neighborhoods and communities worked together along the entire spectrum of forest health and local food resiliency? A coordinated effort of forest restoration and biochar production could result in a system that replenishes soil health, avoids greenhouse gas emissions, and restores the fire resilience of forests.

Example of Community Cooperative Model



Waldron Island provides an example of a community-based effort to reduce fire risk and create a valuable commodity. In 2017 the Waldron Community received funding through the Firewise program to pay for forest restoration along roadsides identified in the 2012 San Juan Fire Assessment as the most critical fire danger points. These particular roads provide the only route for many homeowners in case of a fire. The community was funded to create *fire breaks* along either side of the road by thinning overstocked stands and removing excess woody biomass. The community contributed an equal value to the grant in volunteer labor, which also comprised processing the woody slash into charcoal as a means of disposing of the slash. The slash was converted to charcoal during three community burns over the winter and early spring of 2018.

The Waldron community turning biomass material into biochar.

Waldron Project Numbers:

Estimated amount of biochar created:	25 cubic yards
Number of acres treated:	4
Days to conduct burn:	3
Number kilns used:	3
Personnel:	1-3 for each kiln (all volunteers)

Technical Assistance

The San Juan Islands Conservation District has the ability to help landowners and neighborhoods with forest planning, technical assistance, topic resources, biochar kilns, soil analysis and other conservation minded strategies. The goal of the Conservation District is to work with land managers to address the issues of conservation surrounding soil, water, air, plants, animals, humans and energy (SWAPAHE).

San Juan Island Conservation District (www.sanjuanislandscd.org)
Northwest Natural Resource Group (www.nnrg.org)
Restore Char (www.restorechar.org)
International Biochar Initiative (www.biochar-international.org)
Wilson Biochar Associates (http://greenyourhead.typepad.com/wilson_biochar_associates/)

Learn more about biochar in the world:

Suggested readings:
www.biochar-us.org
The Biochar Journal (www.biochar-journal.org)