NRCS CIG Final Report and Practice Guidelines

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1. Executive Summary

The primary purpose of this project was to see if we could combine two farm waste streams: woody debris and animal manure, in order to make valuable composts and organic fertilizers for use on the farm. We worked with eight farms and a large crew of volunteers and advisors to carry out multiple projects and experiments, making and using biochar, over the two and half year grant period. The project was developed and implemented by the Umpqua Biochar Education Team. UBET is a learning and sharing network of dedicated volunteers.

Abundant debris is available from forested land and woodlots on farms and ranches in our region. Customarily, the debris is burned to ashes in the open air, reducing the fuel load danger, but producing considerable smoke pollution. A more valuable and environmentally favorable alternative is to use woody debris to produce biochar as an additive to improve soils in farms, gardens, pastures and forests. We designed and manufactured biochar kilns for this purpose, with the help of Umpqua Community College and others. Over the course of the project we made more than 70 cubic yards of biochar on farms and in the forest.

We recorded production parameters for many of our biochar burn sessions. Our results indicate an average labor input of 4.4 person hours per cubic yard of biochar produced. Most farmers can produce a cubic yard of biochar for about $100. Better processes for sorting, drying and covering feedstock may greatly improve the process efficiency. Dry feedstock is especially important to the efficiency of the process both on a material input basis and on a labor time basis.

Not only did we develop a cleaner method for disposing of waste woody debris, we also used the resulting biochar to help control nutrient loss through better manure management. Because we had a variety of producers using different systems for composting and manure management, we experimented with many different processes. We found that the most efficient process is to use biochar directly in the barn where it can capture nitrogen from urine and manure as it is generated. In one cattle barn, we found that adding biochar in the barn increased the nitrogen content of the manure compost from .82% to 1.27%. We also found that biochar could almost completely eliminate ammonia odors in a goat barn.

We further tested some of the compost products in a variety of pot trials and field trials. While some of these experiments have shown conclusively that biochar compost produces plant growth improvements, many of our results are still preliminary, and we identified areas where more work needs to be done.

We have also successfully shared our work through an ambitious program of workshops, presentations, and on-farm demonstrations. We created a website for sharing pictures, stories and results. Other sharing projects include a tool library and contributions to the Pacific Northwest Biochar Atlas.

We surveyed our entire set of practices and collected the ones that we felt most confident about sharing into a set of Practice Guidelines, included in the Appendix. We hope that these documents will benefit others as they investigate biochar for their own uses.

Jim Long – founder of UBET

In Memoriam, 1935-2016

"He surveyed the area, saw where he could contribute, and did so."

2. Introduction

This report is the final deliverable for the NRCS CIG project titled: **On-farm production and use of biochar for composting with manure**.

In Douglas, Josephine and Jackson Counties, we worked with farmers to develop simple methods for using woody debris to make biochar, and compost it with animal manure. The goal of the project was to help farmers transform two problem waste streams, woody debris and animal manure, into high quality compost that will improve farm soils.

This is a new way to approach these waste materials and turn them into beneficial resources. The methods we developed for converting woody waste to biochar may require slightly more time to execute than simple open burning disposal, but we hoped to demonstrate that the return on investment of time is positive for the farmer, as measured by better results in manure management tasks, reduced odor and flies in animal enclosures, and better quality compost.

Ultimately, the application of high quality biochar compost will help improve farm soils and improve pasture and crop production. We also experimented with using biochar directly in barns for odor control and manure management.

We involved a large pool of volunteers to design kilns and systems for making, post-treating and composting biochar. We conducted pot trials and field trials using the resulting biochar composts, and we documented our work and shared it through on-farm workshops, public events, guideline documents and a website blog. Below is a summary list of our accomplishments:

- Educated the public about the potential for mitigating climate change by using biochar production as a drawdown vector for removing carbon from the atmosphere by converting biomass to recalcitrant charcoal for soil.
- Provided open source biochar kiln designs to instructors and students at Umpqua Community College. Students were presented with challenging projects valuable for learning welding, drawing and design skills.
- Demonstrated biochar production using inexpensive, clean, nearly smoke-free pyrolysis processes as a much cleaner alternative to smoky burn piles currently used to dispose of waste wood and brush.
- Helped reduce forest fuel loads for better fire protection.
- Demonstrated the use of biochar to better manage odors, flies and leachate from livestock barns, enclosures and feeding areas.
- Improved composting processes and compost quality, with cascading benefits as biochar and biochar-enhanced compost were used to enrich soils.
- Taught farmers and volunteers simple tests for monitoring compost processes and quality.
- Conducted workshops for landowners and invited guests to teach techniques for making biochar and using it in compost.
- Conducted pot trials and field trials on biochar compost amendments.
- Produced an economic analysis of biochar production and use on each farm to help producers make decisions about appropriate biochar use.

- Produced practice guideline documents on how to make biochar using simple, clean techniques and how to utilize, monitor and assess the value of biochar in manure management, composting, and soil improvement.

This Conservation Innovation Grant was extensive in both geographic scale and in the number of people and resources involved. We interacted with about a dozen farms, choosing eight for full participation in the grant. We worked with dozens of volunteers and students, involved several researchers from USDA-ARS, and received help from biochar experts. Likewise, our activities were similarly varied and extensive. We designed and fabricated kilns, produced biochar in the field, cleaned barns, built compost piles, implemented pot trials and field trials, and shared our work. Below is a list of people, resources and activities that were part of this project:

<table>
<tr>
<td>

- People
  - Volunteers
  - Farmers
  - UCC Students & Teachers
  - OSU Researchers
  - Biochar Experts
- Farms
  - Animals
  - Compost
  - Woody waste
  - Pasture
- Technology
  - Kiln design
  - Kiln logistics

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- Science
  - Pot trials
  - Compost experiments
  - Field trials – four farms
- Economics
  - Tracking labor & machinery inputs
  - Quantifying benefits
- Extension
  - Workshops
  - Expos
  - Practice Guidelines

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This report includes a discussion of the methods we used and the results we achieved. It also includes two sets of documents intended for further dissemination: case studies of each farm describing methods and results in detail; and a set of practice guidelines that give instructions for making, understanding, and using biochar. These documents are found in the Appendix.

3. Background: Why Make and Use Biochar?

3.1. The Problem

Forest and livestock operations can have both adverse and beneficial impacts on soil quality, air quality, water quality, soil health, animal health, and human health. Forest fuel load reduction, forest health treatments and logging operations produce abundant debris on forestlands in Josephine, Jackson and Douglas counties. Additional woody material is generated from the removal of woody weeds that are invading pastureland. Customarily, the debris is burned to ashes in the open air, producing considerable smoke pollution, but reducing the fuel load danger.

A more valuable and environmentally favorable alternative to incineration is to use woody debris to produce biochar as an additive to enrich farm soils, manage odors of manure and improve composting operations and compost quality. Biochar is increasingly recognized as a tool in managing livestock operations. For example, studies have shown that biochar can be used to minimize fly populations and reduce odors and leachate from accumulations of manure. Biochar blended with manure compost helps control odors, adsorb nutrients, and "charge" otherwise sterile charcoal before it is applied to farmland.

Similar to activated carbon, biochar helps soils hold moisture into dry seasons, retain nutrients through wet winters, build soil structure, and support soil biota. Biochar can also absorb odors, adsorb some heavy metals and other toxics, and filter water. Abundant research literature shows that biochar is a valuable tool for manure management in barns and compost piles. It speeds the compost process, reduces odors and produces higher quality compost with a higher content of humic substances, and it produces beneficial results in plant growth tests.

Where possible, biochar may be produced commercially in large-scale, controllable, centralized facilities where the energy generated can be utilized. However, much of the biomass found on farms and ranches in Oregon can be considered as "stranded" biomass; it is not economical to chip and transport these small amounts of material from remote landscapes to a central industrial facility. While it is possible to fabricate small-scale units that can make biochar and use the energy on farms and ranches, the capital costs for acquiring them are high, and the supply of biomass available on a farm or the need for heat energy may not justify the installation of such equipment. This CIG project demonstrates ways to make biochar with small-scale, simple units on farms and ranches that include forests and livestock operations whose management would benefit from the application of biochar to manage manure, control odors, and treat run-off water.

The market for traditional uses of forest biomass (co-generation of heat and electricity) has been stagnant due to the low price of renewable energy. This lack of demand for biomass generated electricity places additional urgency on commercializing other products, such as biochar. Biochar presents an emerging market opportunity that, if successfully adopted, could provide additional outlets for woody biomass from forest and agricultural operations. Successful adoption of farm-scale biochar production would provide several important benefits including increased value to private landowners and increase revenue generation in distressed rural communities. Additionally, farm-scale adoption of biochar represents a carbon neutral source of renewable materials and renewable energy; helping the region's forests and rural communities contribute to a low-carbon economy.

3.2. What is Biochar?

Biochar is a modern technology that is based on a range of traditional agricultural practices that return carbon to soil in the form of long-lasting charcoal. Charcoal performs many important functions in soil, enhancing water holding capacity, retaining nutrients, improving soil tilth, and increasing soil humus content, resulting in increased plant growth and vigor. Some of the most fertile soils in the world, including the midwestern Mollisols, contain large amounts (up to 50% of the total soil carbon) of charcoal from past grassland fires.

Biochar is produced by baking biomass without the oxygen that would cause it to burn completely to ash. Baking wood and other plant materials releases a flammable gas that yields energy. That is the basic biochar-making process, but the end product is not a single, well-defined substance. Depending on the feedstock and processing conditions (time and temperature), different biochars can have very different properties. The International Biochar Initiative, an organization formed by leading biochar scientists, has issued Biochar Standards for reporting characteristics of biochar, and guidelines for selecting biochar materials for specific uses. See the IBI Biochar Classification tool at: [http://www.biochar-international.org/classification_tool.](http://www.biochar-international.org/classification_tool)

Fused carbon rings form the microstructure of biochar; while at coarser scales a highly porous carbon matrix structure emerges that has robust ion-exchange properties. This structure supports soil fungal and bacterial life while holding water and nutrients. Plant roots are attracted to biochar, and with proper nutrient support, plants of all kinds seem to thrive in biochar. Because it is not easily degraded by chemical or microbial action, biochar holds great promise for restoring a source of long-lasting carbon in depleted agricultural soils, while at the same time, it provides a method for drawing down carbon from the atmosphere.

3.3. How Can Biochar Boost Soil Carbon?

Soil carbon comes in many forms. There are two main pools of carbon: organic and inorganic. Organic forms can be further divided into "recalcitrant" or resistant to decay, like humus, and "labile," where the carbon is in easily degraded compounds such as oils, sugars and alcohols which are available food sources for microbes. The organic carbon pool also includes both the living and the dead decomposing bodies of bacteria, fungi, insects, worms and all other organic material found in soil such as plant debris and manure. Inorganic carbon consists of carbonate ions, which are typically found as salts like calcium carbonate and dolomite minerals, mostly in the form of rocks and sand.

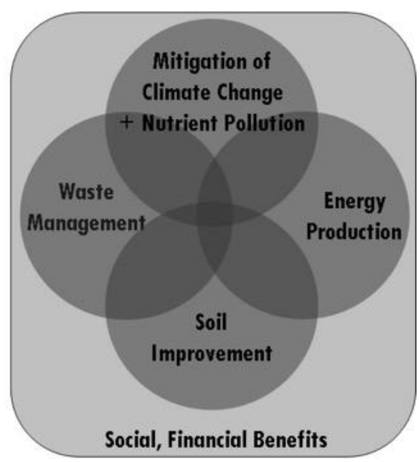
Soil building is the product of a self-reinforcing, positive feedback loop. But soil decline is also a self-reinforcing loop that can result in catastrophic soil loss if it is unchecked. Agriculture tends to deplete soil carbon by reducing the amount of natural organic inputs found in native ecosystems. However, modern, chemically-based agriculture depletes soil carbon drastically. Nitrogen fertilizers combined with tillage accelerate microbial respiration, burning up soil carbon faster than it is replaced. Due to the loss of organic carbon reservoirs, many soils have become nearly lifeless substrates that must be continually fed with irrigation water, mineral nutrients and pesticides to produce a crop. Although productive in the short term, this practice is not sustainable. Soil scientist Rattan Lal estimated in 2010 that "Most agricultural soils have lost 25% to 75% of their original soil organic carbon (SOC) pool."

Is it possible that biochar can substitute for some of this missing soil carbon? Some of the most productive and resilient soils in the world contain significant quantities of "natural" biochar. Nature makes megatons of biochar in the process of naturally occurring wildfires in forests. Prairie fires can also generate a lot of biochar. Tall grasses burn quick and hot, however, close to the ground where the roots start, air is excluded so the base of the grasses will pyrolyze and not burn. This kind of natural charcoal is present in some of the most valuable agricultural soils in the world: the carbon-rich Chernozems of the Russian steppe and the Mollisols of the US Midwestern prairie states. Recently, scientists (Mao et al. 2012) have looked more closely at the Mollisols, and found that they contain charcoal that is "structurally comparable to char in the Terra Preta soils and much more abundant than previously thought (40–50% of organic C)."

Traditionally, farmers had various methods of adding charcoal to soil through field burning methods and scattering of wood ashes that had a high content of char. Today, a modern biochar industry is forming that proposes to generate a charcoal residue useful for agriculture as a co-product from various bioenergy technologies. Biochar is also generated in fields and forests from crop waste and forest slash where it can be used on site with minimal processing.

3.4. Multiple Benefits of Biochar Systems

The multiple benefits of biochar can be divided into four, interrelated categories: waste management, energy generation, soil improvement and climate change mitigation. There are many different technologies for producing biochar and many different and widely varying biomass feedstocks that can be used. Hence, there are multitudes of different possible biochar systems. Inevitably, not all biochar systems will be able to achieve all four objectives listed in the diagram below.



Multiple benefits of biochar. (From Lehman & Joseph, 2009.)

In most cases, biochar systems will show the greatest benefits if waste feedstocks are used. Waste materials that have a disposal cost are usually the most economically viable to use. However, some feedstocks are more challenging to pyrolyze than others. The challenges may come from the physicochemical nature of the feedstocks themselves (for example, wood species and moisture content) or from the difficulty and logistics of collecting and transporting the feedstocks. For instance, wet feedstocks like sewage sludge require drying, and a waste like forest residues is distributed across the landscape and must be collected. Depending on the pyrolysis temperature, pressure, and feedstock moisture content, production of biochar can release heat, combustible gases and condensates. Electricity generation and process heat from pyrolysis are most economically produced in large scale industrial facilities that may be a long distance away from the biomass feedstock sources. Accordingly, many existing biochar production systems do not utilize the energy generated by pyrolysis.

The methods developed in our CIG project are intended to cover three of the main biochar objectives: climate mitigation through carbon sequestration; soil improvement; and waste management. Furthermore, the waste management aspect of this project is multi-faceted: not only did we develop a cleaner method for disposing of waste woody debris, we also used the resulting biochar to help control nutrient pollution through better manure management.

3.5. The Value of Biochar for Landowners

Farmers, ranchers and forest landowners are concerned about maintaining and improving the quality of soil, water and air. Biochar made from fuel load reduction debris offers a tool to improve all of these, at a cost that is affordable.

As a soil amendment, biochar has many positive impacts:

- Biochar helps soils hold moisture into dry seasons (Basso et al 2012). Many researchers have found similar results in a variety of soil and biochar combinations and have shown that the effect of biochar on water holding capacity in coarse textured soil increases linearly with biochar application rate (Briggs et al 2012).
- Biochar has been shown to prevent leaching of nitrogen into groundwater in diverse cropping systems (Ventura et al 2013, Eldridge et al 2010). As a result, producers can avoid nitrogen pollution problems and may be able to use less fertilizer.
- Biochar helps to support healthy populations of beneficial soil microbes that are needed for optimally productive soil (Lehmann et al 2011, Pereira et al 2012).
- Biochar is useful in livestock operations for managing odors of manure and flies (Toth et al. 2016, DuPonte et al. 2012).
- Biochar can also improve composting operations and compost quality (Ma et al 2013).

3.6. How biochar works in soil and compost

If you look at a list of things biochar is supposed to do in soil, you'll find it is very similar to claims for what compost can do. Both biochar and compost are said to provide these benefits, taken from various claims made by biochar and compost manufacturers:

- Improves tilth and reduces soil bulk density
- Increases soil water holding capacity
- Becomes more stable by combining with clay minerals
- Increases cation exchange capacity (CEC - the ability to hold onto and transfer nutrient cations: ammonium, calcium, magnesium, and potassium)
- Improves fertilizer utilization, by reducing leaching from the root zone
- Retains minerals in plant available form
- Supports soil microbial life and biodiversity
- Helps plants resist diseases and pathogens
- Helps plants grow better in high salt situations
- Adds humus carbon to the soil carbon pool, reducing the atmospheric carbon pool

If compost really can do all these things, why do we need biochar? The answer is twofold:

First, unlike biochar, compost is quickly broken down by microbial action in soil over months to decades, depending mostly on climate and weather. Biochar lasts at least one order of magnitude longer in most soils. Second, biochar has important synergistic effects when added to compost. Biochar is proving to make faster, more nutrient rich, more biologically diverse and more humified, stable compost. Some of these effects are explained below.

Biochar keeps compost moist and aerated, promoting increased biological activity.

The composting process is governed by various physical parameters that are subject to alteration by the addition of biochar materials as bulking agents. Some of the parameters that most affect compost are: aeration, moisture content, temperature, bulk density, pH, electron buffering and the sorptive capacity of bulking agents. Biochar pores hold air. Water is also held in biochar pores and in the spaces between particles. Moisture is the vehicle for bringing dissolved organic carbon, nitrogen and other plant nutritive compounds into contact with biochar surfaces where they can be captured. Biochar's stable carbon matrix accepts electrons from decomposing organic compounds buffering electric charges that might otherwise impair microbial activity and be responsible for the production of greenhouse gases like methane and hydrogen sulfides. Biochar promotes microbial activity in compost. Steiner et al (2011) tested 5% and 20% additions of pine chip biochar to poultry litter compost, and found that the addition of 20% biochar caused microbial respiration (measured as CO_2 emissions) to peak earlier and at a higher level than either the 5% or 0% biochar treatments.

Biochar increases nitrogen retention

Numerous studies have shown that biochar is effective at retaining nitrogen in soils (Steiner et al. 2008, Clough et al. 2013). Several studies have also shown that biochar enhances nitrogen retention in compost, reducing emissions of ammonia. Ammonium (NH_4^+) is the aqueous ion of ammonia. Ammonium is generated by microbial processes and nutrient cascades that convert nitrogen from organic forms found mainly in proteins and nucleic acids into mineral forms (ammonium, nitrate and nitrite) that can intermittently be converted by nitrifying and denitrifying microbes to gaseous emissions that include volatile ammonia gas (NH_3), nitrogen gas (N_2), nitrous oxide (N_2O) and other reactive nitrogen gases (amines and indoles). At neutral pH, the aqueous ammonium (NH_4^+) and the gaseous ammonia (NH_3) are in equilibrium. Higher pH forces more of the aqueous ammonium into the gas phase that can escape to the atmosphere. Several studies have confirmed that biochar in compost could increase total nitrogen retention by as much as 65% (Steiner et al. 2010, Chen et al. 2010, Huang & Xue 2014). The ammonia retention ability of biochar can also improve with composting. Adding 9% bamboo charcoal to sewage sludge compost, Hua et al. (2009) tested sorption of ammonia on biochar during composting and found that while ammonia retention was correlated with saturation of binding sites in fresh bamboo biochar, this did not hold for composted bamboo biochar. They found that biochar increased its ability to retain ammonia during the composting process. During composting the biochar is subjected to an accelerated aging process. That means that biochar surfaces get oxidized and enriched by carboxylic (acid) functional groups. The latter more than doubled at the end of the composting period, improving the capacity to exchange cations like ammonia.

Biochar improves compost maturity and humic content

Several studies have looked at effects of biochar on the timing and results of compost maturation and found that adding biochar to compost reduced the amount of dissolved organic carbon (labile carbon) in mature compost while increasing the fraction of stable humic materials (stable carbon). Following the addition of 2% biochar to compost, Jindo et al (2012) recorded a 10% increase in carbon captured by humic substance extraction and a 30% decrease of water-soluble, easily degradable carbon. They also found an increase of fungal species diversity in the mature biochar compost as compared to the control and proposed that these fungi were responsible for the increased humification. Another study by Zhang et al (2014) found that sewage sludge composted with wood biochar had up to 30% more humic substances than the control.

Biochar compost improves plant growth

Several researchers have experimented with various combinations of compost and biochar added as separate amendments (Fischer & Glaser 2012, Liu et al. 2012). These studies found improved plant growth response when biochar was added to soil along with compost. A 2013 study in Germany looked instead at biochar composted together with other materials (Shulz et al. 2013). They tested six different amounts of biochar in the compost, from 0 to 50% by weight, and also three different application rates of each compost type. Using oats in greenhouse pots on two different substrates (sandy soil and loamy soil), they discovered that plant growth was increased as the amount of biochar in the compost increased. They also found that plant growth increased with increasing application rates of each type of biochar compost. They confirmed the synergistic effect of biochar and compost on plant growth, but were not able to determine exactly what each of the components, biochar and compost, contributed to the effect. New work has begun to identify organic coatings on biochar surfaces as the source of nutrients and plant growth stimulation. These coatings occur during the composting process through microbial action (Hagemann et al. 2017).

4.0 Review of Methods

4.1. Roles of Participants

This project has been carried out by farmers and by a group of volunteers, the Umpqua Biochar Education Team, as directed by Kelpie Wilson of Wilson Biochar Associates. UBET is a committee of the South Umpqua Community Partnership, an organization dedicated to restoration ecology and sustainable stewardship in the South Umpqua River basin. SURCP engages in collaborative restoration projects with many partners. SURCP provided administrative support for this grant. The UBET committee was formed to work on various biochar demonstration projects with a focus on outreach and education.

UBET would like to dedicate this work to our founder, the late Jim Long. Jim Long was a Professor of Adult and Continuing Education at Washington State University, Pullman, for 27 years. After his retirement, he moved to Douglas County, Oregon, where he was involved in more than two dozen community groups. He was to serve as co-director and evaluator of this UBET CIG project. We have sorely missed having his participation in this project. We hope that he would be proud of our work, and his example continues to inspire us.

Through their community contacts, UBET members helped to recruit participating farmers. UBET members helped to design and test biochar kilns and scheduled and helped with biochar kiln demonstration workshops and composting workshops. UBET members also conducted biochar compost experiments and biochar field trials. Some UBET members were also participating farmers.

Participating farmers had different levels of engagement in the project. Some farmers conducted field trials, while others did not. Some farmers used outside sources of biochar while others made their own biochar. Some farmers used biochar in barns while others used biochar only in compost piles. The details of farmer participation are given in the findings.

Wilson Biochar Associates is a biochar consultancy owned by Kelpie Wilson. She directed the project, organizing all the participants and sub-projects. UBET members served the function of project evaluators, reviewing and commenting on results and protocols. Don Morrison was the primary UBET member responsible for reviewing the work.

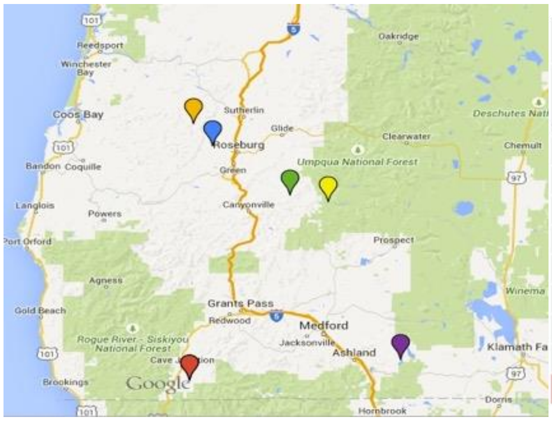
The project benefitted immensely from the expertise and help of our advisors and supporters. We are especially grateful to Kristin Trippe and Claire Phillips of the USDA ARS Forage Seed and Cereal Research Unit at Oregon State University in Corvallis for reviewing our experimental data and performing some statistical analysis for us. Agricultural consultant Frank Shields of Gabilan Lab in Watsonville, California gave us both advice and a reduced fee for biochar analysis. Shannon Andrews of the OSU Central Analytical Lab helped us organize and interpret test results. Steve Renquist of OSU Extension in Roseburg answered our questions about pasture management and field trials. Ian Fisher and Duane Thompson of UCC Welding program were part of our design team and they and their students fabricated many different prototype biochar kiln designs. Brian and Kim Vicklund of Vicklund & Son also contributed fabrication expertise to our kiln design process. Grant Scheve of Oregon Biochar Solutions donated several cubic yards of biochar to help us complete some experiments when we ran out of our own supply.

4.2. Farm Assessments

The first phase of the project was a series of visits to the eight participating farmers. We also visited several other farms that ended up not participating fully in the work, mostly due to time constraints on the part of farmers. Each assessment included a list of farm resources and constraints such as the availability of farm machinery to move feedstocks and water for quenching biochar. The assessments also collected information on farm soils, production outputs and the goals of the farmer for participating in the project. Below is a checklist of information that we gathered from each farmer as part of our assessment. We used this information to design a biochar implementation plan for each farm. We also tallied farm resources including acreage and livestock numbers, and made a location map. We visited 12 farms, originally, but only 8 stayed with the project for long enough to produce measurable results documented in this report. However, most of the farms we contacted received some advice and information about biochar, and some of those farms also produced and used biochar.

Farm Resource Checklist

- Invasive Brush
    - species
    - control activities
- Hazardous Fuels
    - locations
    - amount
    - annual removal
- Woodlot
    - dead tree harvest for firewood
    - coppice
    - woodlot regeneration
- Manure Areas
    - barns
    - feeding areas
    - corrals
    - compost piles
- Irrigation
    - type
    - deficit
    - available for biochar quenching
- Composting
    - current practice
    - amount produced
    - testing
    - goals
- Biochar Production
    - safe burn areas
    - labor available
    - desired production amount
- Biochar Compost Application
    - pasture
    - crops
    - forest
    - erosion control
- Remediation
    - native plant establishment
    - riparian
    - gully erosion
- Equipment
    - feedstock handling
    - composting
    - biochar application
    - monitoring and testing
- Monitoring
    - soil tests
    - compost tests
    - water quality - runoff
    - animal health



Farm Livestock and Acreage						
cows	pigs	sheep & goats	fowl	horses	pasture acres	woodlot acres
250					200	
600		325			1150	120
	12	37	100		35	3
		47			35	43
	60	60	200		30	250
			18		1	
		17	73		6	6
		3	36	17		
850	72	489	427	17	1457	422

4.3. Kiln Design and Fabrication

The standard practice for disposal of logging slash, brush and crop waste on farms is open pile burning. This is undesirable for several reasons, perhaps most important, for the generation of polluting smoke. However, it also represents a waste of resources as carbon that could be added to soils ends up in the atmosphere as carbon dioxide.

Theory of Flame Carbonization

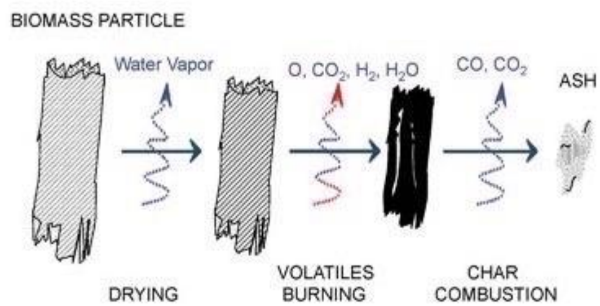
The practice of turning these biomass wastes to biochar for soil enhancement is a desirable alternative, but only if this practice is cleaner than the standard practice of open pile burning. For this result, it is necessary to use tools and methods that will not produce smoke. Traditional charcoal making methods, however, are very polluting as they rely on smoldering combustion. For this reason, this project placed a strong emphasis on designing clean burning techniques for making biochar. The primary technique we used is termed ***Flame Carbonization***.

Flame Carbonization differs from traditional low-tech charcoal-making methods that use dirt covered pits and mounds. The dirt covering serves to reduce the air available for combustion, producing a charcoal residue. This form of smoldering combustion produces no flames, but lots of smoke. The resulting charcoal is high in condensed volatiles – good as fuel, but not so good as biochar for application to soil.

In contrast, the Flame Carbonization method uses the flame itself as a way to reduce air and preserve the char from combustion. This seems counter-intuitive, but when a full understanding of biomass combustion is provided, it makes sense.

Biomass burns in two stages: a gasification stage that burns volatile gasses in a flame, and a char combustion stage that burns solid carbon without visible flames. Charcoal can only burn slowly as its surfaces are exposed to air. The oxygen slowly attacks and consumes the char, oxidizing it layer by layer. However, if the combustion process is interrupted before the char combustion stage, the char can be preserved. Flame carbonization is essentially the same as gasification. It works by gasifying the wood and then burning the gas in a flame.

Traditional charcoal making uses dirt covered mounds to exclude air. Volatile gasses are released as highly polluting, unburned smoke.



Stages of biomass combustion. To make charcoal in an open fire, simply stop the process before it turns to ash.

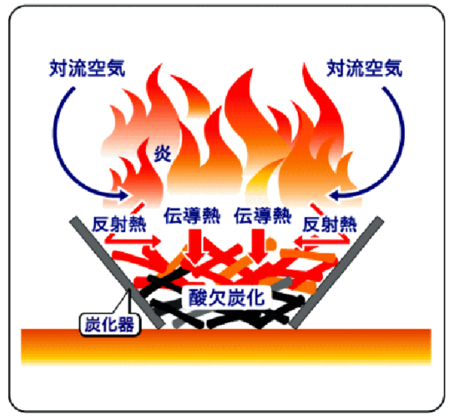
When heat is applied to wood, the moisture and volatiles are released. The volatiles can burn, producing a flame. The flame continues to transfer heat to the remaining wood by radiation, continuing the process. When all the volatiles are gone, char remains. Char burns more slowly, in a different mode (notice that charcoal in a barbeque grill just glows, without a flame), and this gives us an opportunity to quench the material with water or dirt and save the char.

Several different versions of the Flame Carbonizer method can be used to convert woody debris to biochar. These methods are clean and safe. They are clean because they work by always keeping a flame on top of the fire. The flame burns the smoke so that there is only a very small amount of emissions. These methods are safe because they require water or another means to quench the fire at the end in order to save the char, resulting in complete extinguishment of the fire.

Basic Methods

The first method, called the ***Rick Burn*** (also sometimes called a Conservation Burn), is illustrated by the Jack Daniels method for making charcoal. The Jack Daniels distillery makes clean charcoal for filtering whiskey. They stack 2"x2" maple boards in a rick and light it on fire. The flame engulfs the rick, and burns up all the smoke that is created. As the outside portion of each stick burns away, it heats the inner portion, which chars. As soon as each stick is charred, it loses structural integrity, and the whole pile collapses at once into a pile of glowing coals. It is then quenched with water and the char is recovered for use.

Jack Daniels charcoal rick.



Japanese cone kiln diagram shows how the flame on top excludes air from hot char layers below.

The second method, called a ***Flame Cap Kiln***, is illustrated by the Japanese cone kiln. This device, available only in Japan, is a steel cone that excludes air from the bottom of a small pile of wood. The pile is lit on the top. Once it burns to coals, more wood is added, until the cone fills with char and it is quenched with water. As long as a flame is kept on top, it will burn only the new wood, and not the char. Older layers of char are protected from oxygen by the newer layers of char. A Flame Cap Kiln can be almost any shape. It can be a cone, pyramid, cylinder or box made of steel or brick, or it can be as simple as a pit dug in the ground.

Rick Burn or Conservation Burn Method – Details of Operation

The Rick Burn method, based on the Jack Daniels rick, has three main characteristics:

- it is a loosely stacked burn pile of dry material
- all the material in a given pile is roughly the same thickness
- it is lit on the top

In Sonoma County, California, the Sonoma Biochar Initiative has worked with vineyards to convert grape prunings to biochar with Conservation Burns using the Rick Burn Method. The group provides ongoing training opportunities to help more producers take advantage of this cost-effective biochar production method. Advantages of the Conservation Burn include:

- No special equipment required
- Greatly reduced smoke emissions as compared to conventional burning
- Reasonable char production for little extra effort when piles must burn anyway

Disadvantages of the Conservation Burn as compared to other methods:

- Char production is less than methods using a container
- Quenching can be time-consuming
- Char is difficult to gather up and remove if not used on site

The Conservation Burn method is best suited for materials that are regular in size, small in diameter and very dry, like the grape prunings. However, a material like straw will not work well with this method because it packs too closely. Forest slash is often too large or variable in size and also too wet to work well in a Conservation Burn. Since most of our material in this project was forest slash, we developed several different kilns specifically for use with forest slash. However, often farms have orchard prunings or woody weeds like blackberries or other brush that need to be removed. These are the materials that will work most efficiently in a Conservation Burn.

Air flow in a Conservation Burn or Rick Burn is by concurrent axial flow. Air enters the bottom and sides of the pile and sweeps gasses upwards where air is available on the top to burn them. Concurrent flow means that the volatile gasses and the air flow move in the same direction. This can produce a long, shooting flame at times that can be difficult to control. Furthermore, when the flame shoots up very high, it cools at the tip and you may see black soot falling away from the flame tip. This black soot is carbon and other chemicals that have condensed when they encounter cool air. This is the black carbon particulate matter that is causing so much havoc with our climate. The primary sources of black carbon particulates are fires and diesel exhaust. When conducting a Rick Burn, it is best to avoid creating a long shooting flame.

This very loose pile of small diameter brush burns fast and hot. As it burns down, it requires tending to move the loose pieces back into the fire. This sort of material can produce a large amount of biochar in a short time. These two piles produced a cubic yard of biochar.




Conservation Burn of vineyard prunings conducted by Sonoma Biochar Initiative. Piles are built with similar sized material, covered to keep dry, and lit on the top once winter rains have started. Photos: Raymond Baltar/Sonoma Biochar Initiative




Once the pile collapses, it is time to tend and consolidate it. Quenching uses a combination of water and spreading to cool the char. If the char is not spread out, residual heat can evaporate all the water and re-ignite the char. Photos: Raymond Baltar/Sonoma Biochar Initiative.

Flame Cap Kiln – Details of Operation

The Flame Cap Kiln method uses a container to exclude air from the bottom of a pile of burning biomass. This method starts by building a rick pile in the container, lighting it on top, and letting it burn until coals are formed. However, it then switches to a second stage of layering new material on top of the coals until the container is full. As each new layer bursts into flame, the heat transfers by radiation into the partly charred material underneath which continues to char, releasing gasses for the flame. The flame also consumes all the air that might otherwise reach the char underneath. The combination of flame on top and container on the bottom preserves the char until it can be quenched and saved. A Flame Cap Kiln must be continually tended, adding new fuel before the top layer turns to ash. When the kiln is full of hot char, and the flames are gone, it's time to put it out.

Air flow in a Flame Cap Kiln is by countercurrent flow. As the gas rises and burns, the flames will pull air in from the sides and from above. A complex and shifting vortex pattern will form that balances rising convection currents with pressure drop where the flame consumes oxygen. This vortex pattern can also become quite chaotic and unstable, so it's helpful to add things like a wind screen. Another difference that can be observed between the two methods is the location of the flame. In the Rick Burn, the flame starts on the top of the pile and gradually moves down. In a Flame Cap Kiln, the flame moves up in the container as new material is added.

Flame Cap Kiln: Counter-current flow	**Rick Burn: Concurrent axial flow**
	
• Gas flows upward while air flows downward • Counter-current flow is established as burning fuel draws air downward • Flames stay low and close to fuel • Smoke burns in the hot zone	• Air flow and fuel flow (gas) move in the same direction • No external limits on air entrainment • High flame velocity • Flame cools at the top, producing soot

Flame Cap Kiln Design

This project developed and manufactured Flame Cap Kilns specifically designed for use in processing forest slash. We experimented with several designs, with descriptions and illustrations of different design variations given in the table below. One of the kilns was designed for the purpose of working off road on forested slopes typical of conditions in our Oregon woodlands. It has a solid bottom to prevent air leaks and it is only 24 inches in height, for easier loading of heavy forest slash. For this reason, we called it the Oregon Kiln.

We also developed several other styles of Flame Cap Kilns, including a kiln called the Ring of Fire kiln, which is a simple cylinder made of one or two layers of sheet steel. The Ring of Fire kiln is lightweight and easy to transport, but as it has no bottom, it needs to be used on a flat surface so it can be sealed with dirt. The double wall Ring of Fire is the most efficient kiln that we designed. It holds in heat better, and the taller walls both reflect heat and protect the flame from wind. The second layer of steel also helps protect the operator from radiant heat, which can be intense.

Kiln	**Picture**
Oregon Kiln – Forestry Dimensions: • 5'x5' top base • 4'x4' bottom base • 24" sides • 14 gauge steel	
Oregon Kiln – Backyard Dimensions: • 4'x4' top base • 3'x3' bottom base • 24" sides • 14 gauge steel	
Oregon Kiln – Farm • 5'x5' top base • 4'x4' bottom base • 24" sides • Fork pockets on bottom • ¼" plate steel	

Oregon Kiln with windscreen	
Oregon Kiln with dry quench lid	
Ring of Fire – original	
Double-walled Ring of Fire with sections and two-piece quenching lid	

Oregon Kiln for Forestry – complete description

- 5’ top base, 4’ bottom base, 2’ high
- Sized for feedstock - Logs 4 to 5 feet long and up to 6” diameter
- Less than 200 lbs – can be skidded by 2 people or lifted by 4 people
- Ergonomic for loading feedstock - Only 2 feet high
- 14 gauge steel
- Durability estimated at hundreds of uses
- Angle iron reinforced rims to resist warping
- Corner brackets and lift points for moving with hoists and loaders
- 1.5” drain with plug for draining quench water
- Sheet steel lid can be used for dry quenching
- Wind screen can be used if needed

Design Details

Certain design details are important to the operation of the Oregon Kiln. The pluggable drain allows the kiln to be flooded for quenching and subsequently drained so that the char can be unloaded. Corner brackets with eyebolts provide lifting points so the kilns can be loaded in and out of trucks and trailers. Four solid handles on the sides enable four people to easily lift and carry the kilns for off-road placement. In the newest version, we have added 2” angle iron to the rim to prevent warpage. Regarding durability, we expect these kilns, despite being relatively lightweight, to last for hundreds of burns.

Oregon Kiln Design details

	
Lift point and angle iron rim	Drain and handle

Operations

- Ergonomics: The low profile of the Oregon Kiln is designed for ergonomic loading of the kiln. Loading requires workers to lift feedstock from a pile near the ground, carry it to the kiln, and dump it in. We wished to avoid the need to lift material above shoulder height in order to throw it into a kiln. To produce a cubic yard of biochar in this kiln requires moving on the order of 5 cubic yards of feedstock (about one cord of wood) that could weigh more than 2 tons.

- Transport: The Oregon Kiln was designed for efficient transport to a work site. The kilns are stackable. They will fit in the back of a standard full-size pickup, or they can be loaded onto a trailer. We set up a trailer with a jib crane to make loading easier with a small crew. The crane also helps with the more difficult job of stacking kilns.
- Siting: Because it has a solid bottom, the Oregon Kiln can be used on uneven ground and on mild slopes.
- Wet Quenching: This kiln can be flood quenched with less than 50 gallons of water. Once enough water has been added to cool the char, it can be drained immediately and the char unloaded. Or it can be charged with nutrients and left to soak for a while.
- Dry Quenching: The Oregon Kiln can also be effectively dry quenched using a sheet metal lid sealed with dirt.

The Oregon Forestry Kiln fits in the bed of a standard full size pickup truck. Kilns can be stacked on a flat bed or loaded in a trailer modified with a jib crane using the corner lift points.

Manufacturing

Our kilns were manufactured by the Umpqua Community College (UCC) Welding Program in Roseburg, Oregon and by Vicklund & Son – a structural steel fabrication company in White City, Oregon. While UCC was able to construct kilns for the cost of the materials, the commercial fabricator charged market rates, giving us an idea of what the actual manufacturing costs would be. The most recent version of the kiln made by Vicklund & Son cost $675 when made in a batch of four kilns. Presumably this price could come down with mass production, however the price of steel can change this number.

UCC Welding Program students manufactured kilns for this project. They also produced kiln fabrication drawing sets, found in the Practice Guidelines.

Ring of Fire Kiln – Complete Description

- Dimensions of cylinder - 78” diameter, 44” height
- Three modular sections – 86” x 44”
- Section flanges are 2” wide. Joined with C-clamps.
- 18 gauge steel
- Sized for feedstock - Logs 4 to 5 feet long and up to 6” diameter
- Lightweight modular construction allows easy transport and setup by one person
- Durability estimated at dozens of uses
- Heat shield protects workers from excessing heat while loading
- Heat shield also improves biochar conversion efficiency by holding in more heat
- Outer heat shield made of 12 pieces of corrugated roofing 24” x 44” bolted together
- Heat shield is perched on 4-5 bricks to allow for primary air intake at bottom of Ring.
- Primary air flowing between shield and inner ring is pre-heated – helping with cleaner combustion
- Inner ring is sealed air tight with soil at base
- C-clamps for quick setup and easy unloading
- Sheet steel lid is effective for dry quenching

Ring of Fire Kiln showing kiln assembly; outer ring set up on blocks for air flow; quenching lid sealed with dirt; finished biochar; components disassembled for transport.

Operations

- Ergonomics**:** The heat shield is very advantageous for two reasons: First, it helps to hold in heat for more efficient biochar production, and second, it protects the worker. These kilns put out a lot of heat energy and a cooler working environment helps with worker stamina and safety. The taller walls of the inner ring also reflect heat during the earlier stages of the burn while the feedstock is still low down in the kiln, further improving the charring efficiency of the kiln. One disadvantage of taller walls is the need to lift feedstock above shoulder height to load.
- Transport: The Ring of Fire Kiln is easily transported and set up by one person.

- Siting: This kiln is best used on flat ground with a soft surface. The bottom edge must be sealed with dirt, or air will enter the bottom of the kiln and change the combustion dynamics, resulting in more ash.
- Wet Quenching: It is not practical to quench this kiln with water. Since it has no bottom, it cannot be flood quenched. Simply spraying water on the char while it is in the kiln is not effective because water evaporates from hot char and char retains heat very efficiently. However, if the kiln is opened and the hot char is dumped on the ground, it can be quenched with a combination of water spraying and raking to spread the char into a thin layer so it loses heat.
- Dry Quenching: It is easier to use the dry quenching method with the lid, although it requires an overnight cooling period. Once it has cooled, remove the clamps and the sides come apart, making the char easy to remove.

Manufacturing

Cost for inner ring made from 18-gauge steel was $800 including the two-piece half-circle cap plates for dry quenching. The three sections of the inner cylinder are cut from sheet steel and rolled to a 40” radius to form them. The 2” flanges are bent at 90 degrees. Three clamps are used at each seam for a total of nine clamps.

Kiln Drawings

See the Practice Guidelines for a set of drawings and manufacturing guidelines for constructing both the Oregon Kiln and the Ring of Fire kiln. UCC Welding Program students produced the drawings.

Additional Kiln Designs

The UCC welding program made four additional kilns that had fork pockets for use with tractors. One kiln also had a tilt mechanisms for dumping. We have only just begun to use these kilns, but so far the farmers who have them really appreciate the convenience. This feature was very useful for several reasons. First, all the moving could be done by tractor, avoiding physical work of moving the kilns and allowing the kiln to be placed in remote areas of the farm more accessible to the tractor than a truck. Secondly, where water was not available, kilns full of hot biochar could be picked up and transported closer to the water source for quenching.

UCC Welding program made heavy duty kilns with fork pockets for easy moving with a tractor or fork lift. One kiln has a spout and tilt mechanism for dumping.

Using the kiln with fork pockets at Page Creek Ranch.

4.4. Biochar Production and Logistics

We manufactured a total of 12 biochar kilns with Umpqua Community College. In addition, Wilson Biochar Associates (working with Vicklund & Son) manufactured 16 additional kilns. Some of those kilns were used for the project during organized burn events. The UCC kilns were loaned out to farmers for use at their convenience.

We estimate that we made about 12 cubic yards of biochar during the first six months of the project from September 2015 to March 2016. This was enough to get started with a few composting projects, but we would have liked to have more. However, the very wet winter made biochar production difficult. The following winter season of 2016-2017 was even wetter, limiting our biochar production again, to about 12 cubic yards.

Wet feedstock drastically reduces the yield of biochar and requires much more labor to produce. It was instructive, however, to see that we could make biochar under very unfavorable conditions – even in the rain.

As a consequence of wet winters limiting our biochar production, we received a donation of 4 cubic yards of biochar from Oregon Biochar Solutions in order to complete some of our biochar field trials and barn applications. This biochar is made in a conventional biomass energy boiler. It is similar in many respects to the biochar we made from forest slash in flame cap kilns, with high carbon content, low ash and high surface area. See section 6.2, Biochar Quality Results, for a chart comparing the biochars we used.

Feedstock logistics

We have learned from experience that keeping feedstock dry is a big challenge. Feedstock dryness affects the amount of biochar production. Farmers who wish to make biochar from waste biomass can do so fairly easily, if they have dry feedstock, even if the weather is wet. However, feedstock preparation and storage in a dry location is time-consuming and requires planning. We have found that most of our farmers are very challenged to add this task to an already heavy work load. However, proper timing of operations can make a big difference. For instance, if feedstocks are spread out for drying in the spring and then used for biochar early in the fall before rains set in, you can avoid the work of piling and covering.

Piles must be covered with tarps to keep them dry during winter. Wet feedstock is not efficient to use for biochar.

For those producers that already gather and pile slash and brush for disposal by burning, the extra work to cover piles may not be a big consideration. We helped one producer, Daisy Hill Farm, acquire some used truck tarps for covering feedstock. These are available from a truck tarp repair shop at low cost and they are much longer lasting than plastic tarps.

Kiln temperature, biochar characteristics and yields

Fuel moisture content has an impact on biochar production efficiency and yields. More energy is used to evaporate water, so there is less energy available for thermochemical conversion of biomass into aromatic carbon structures. This will slow the conversion process.

The difference in heat output between dry feedstocks and wet feedstocks is very noticeable to the kiln operator. We measured temperatures inside the kilns with a thermocouple probe and found that temperatures ranged from 300 degrees F to 1600 degrees F, depending on the locations within the kilns and on the feedstock and other conditions. We did not attempt to measure temperatures in a systematic way to try to correlate kiln temperatures with other variables, but we did observe that the hottest areas of the kiln are always near the flames, and that as the char builds up in the kiln, the lower layers cool off to about 300-400 degrees F.

Temperature measurements – Ring of Fire Kiln (shown in degrees Celsius). As the flame front move up during the burn, the finished biochar begins to cool.

Emissions, Heat Output and Safety

When operated properly, a flame cap kiln produces only a small amount of smoke. Normally, operators of the kilns we used will not be exposed to a lot of smoke because smoke should be consumed in the flame. However, under wet conditions or when burning green material such as pine needles with lots of volatile organic compounds, smoke may be generated. Puffs of smoke occur mostly when new material is added to the kiln, however, if feedstock is wet, it can be difficult to keep a strong flame on top of the kiln to burn the smoke. For best results, use dry feedstock, however, we were able to keep a strong flame going on top of the kiln even with somewhat wet feedstocks, if we were careful to add small diameter material at a constant loading rate to keep the flame hot enough to burn the smoke.

The biochar kilns used in this project put out a lot of heat. When feedstocks are very dry and in hot weather, the amount of heat can be difficult to tolerate. In these conditions, operators can adjust the loading rate and add only small amounts of material at a time to reduce the power output of the kiln. Windscreens can also be added to the kilns that will protect workers from radiant heat. The Ring of Fire Kiln with its integral heat shield helps to protect workers from the heat. Smaller kilns have less heat output because power output is proportional to cross-sectional area of the burning surface. For this reason, we do not recommend using kilns that are bigger than our large Oregon Kiln, which is five feet across, and we caution against overloading kilns with too much material, especially in dry conditions. If machinery can be used to load kilns, then it is possible to scale up the kiln size.

It is important for operators to be aware of all safety considerations when working around open flames and to protect themselves from heat and from smoke inhalation. We added a safety discussion and checklist to the Practice Guideline*: Using a Flame Cap Kiln to Make Biochar*.

Large Scale Biochar Production Demonstration Project – Drew Veg Biochar

While most of our biochar production sessions on farms were one-day jobs involving a small crew of workers, we had an opportunity to demonstrate techniques and outcomes of a large biochar job combined with fuels reduction on a Forest Service stewardship contract awarded to SURCP. The 15-acre site was logged during the spring of 2016 and whole trees were yarded to a spur road, cut into four foot lengths and spread out on the road for drying.

In October, 2017, over the course of the three days, with a crew of volunteers, we produced 28 cubic yards of biochar from about 150 cubic yards of feedstock. This was very close to our estimate of 30 cubic yards based on a projected 20% conversion efficiency.

This demonstration project helped us understand some important issues and limitations for doing this kind of work in the woods. The inputs, outputs and logistical considerations we encountered will help farmers who would like to tackle bigger forestry jobs in their woodlots and forest lands. A complete report on the Drew Veg Biochar Project is included in the Appendix, *Field and Farm Reports*.

Drew Veg Biochar Project on the Umpqua National Forest. Covered piles ready to use. Kilns deployed along spur road consumed 150 cubic yards of feedstock over three days and yielded 28 cubic yards of biochar.

Drew Veg Biochar Project. Making biochar is the first step. The next challenge will be to gather it and transport it to nearby farms for use.

Biochar Post -Processing

Another technical issue we addressed is char crushing. Biochar produced in flame cap kilns has a wide range of particle sizes from 3-4 inch chunks to fine grains. The granular sizes are easiest to mix into compost and soil, so it is desirable to break the bigger chunks into smaller sizes. Smaller particles are also more reactive with soil chemistry and biology, so smaller particles are more effective for the applications.

Biochar is somewhat brittle and fairly easy to crush. Dry biochar is much easier to crush than wet biochar because water enters the pores of biochar and strengthens its resistance to crushing. We experimented with different methods for crushing biochar. We tested a hammer mill and found that it worked well when used with very wet biochar, producing a fine biochar slurry. However, slightly damp biochar tends to clog badly and dry biochar makes too much dust. We have also used a leaf vacuum and a lawn roller to crush biochar.

Biochar can be crushed by driving over it with a truck or lawn roller. We tried two sizes of leaf vacuums. The small one worked fairly well, but the big one is much better, with a more effective and durable impeller for chopping char.

Biochar before and after crushing with DR leaf vacuum. Leaf vacuum produces a more consistent particle size than rolling or crushing with vehicle tires.

Production conditions and biochar properties

Biochar quality produced in Flame Cap Kilns can vary according to feedstock species, moisture, and ash content. However, the degree of carbonization and percentage of fixed carbon is usually high. This occurs because of the high temperature at the flame where pyrolysis takes place – about 1250 to 1400 degrees F (680 to 750 degrees C, from: Cornelissen et al. 2016). The process can be characterized as a continuous batch system: while new feedstock is continually added, the biochar is only emptied from the kiln when it is full and the batch is completed. This results in a long residence time in the hot zone of the kiln and hence a fully carbonized biochar is generally produced, however, there can be pieces of less fully charred material due to cold spots on the edges of the kiln.

Given the heterogeneous nature of the feedstocks we used – a mix of species, size classes and moisture levels – we expect that the resulting biochar will have variable qualities. Often we find that larger pieces of material are not completely charred. These can simply be set aside and added to another batch, but any given batch of biochar is like to have some material that is less completely charred because of high moisture levels, or it have more ash due to more burning of the char.

One of the objectives of this project was to give farmers the tools they need to evaluate the quality of biochar and biochar composts for use in production systems. The important biochar characteristics for use in agriculture are mainly the pH and the relative proportions of char, ash, and volatile organic compounds left in the material. Ash content will impact pH. Volatile organics are mostly harmless compounds that will degrade in soil or compost as microbes consume them. However, it is possible that some more harmful compounds like benzene can be present in small amounts. Benzene is a polyaromatic hydrocarbon or PAH. Most biochar does not contain these compounds because they burn off in the fire.

We sent samples of some of our biochars to a lab for proximate analysis, also known as "burn fractions" (ash, char and volatiles), pH, electrical conductivity (EC or salts), moisture content, and some indicators of porosity and specific surface area. Those results are reported in full in the findings.

Biochar lab tests are expensive, and not really necessary to make and use biochar with our methods. To test biochar in the absence of laboratory analysis, you can simply smell it and touch it. If it has a strong smell, be cautious about using it directly in soil. Rub a bit on your skin. If it feels greasy and requires soap or detergent to remove, don't use it directly in soil. This easy field test works well because PAHs only stick on a biochar in considerable amounts if condensates from the vapor phase have been adsorbed during the production process - in that case many other compounds leaving an odor or taste would also stick to biochar surfaces. Flame carbonizing methods usually allow a free path for volatiles to escape, producing a clean, high carbon biochar.

Conditioning Biochar

Some biochar properties are fairly easy to change. For instance, ash content can be changed by rinsing the biochar with water. Water rinsing will also wash away some of the salts, reducing electrical conductivity. We have found that when biochar is composted, the pH drops and it becomes less alkaline. We could get an even greater pH drop by fermenting biochar with molasses and a lactic acid inoculant. Another option is to quench biochar with nutrient solutions such as manure and water or urine. This is likely to add nutrient salts and raise EC.

Goat manure was added to the kiln along with quenching water, making a nutrient-rich biochar "stew."

4.5. Using Biochar for Manure Management

The primary purpose of this project was to see if we could combine two farm waste streams: woody debris and animal manure, in order to make valuable composts and organic fertilizers for use on the farm. Because we had a variety of producers using different systems for composting and/or manure management, we experimented with a lot of different processes. The most efficient process is to use biochar directly in the barn where it can capture nitrogen from urine and manure as it is generated. However, some barns are cleaned daily and it is more convenient to add biochar as barn scrapings are piled for composting.

Farmer participants in this project use several different manure management systems. These can be summarized as:

- Pack barn, where manure and bedding build up over several months until they are cleaned out and piled all at once. Some barns use very little bedding, and others use a lot. Some piles are mixed with wood chips for better composting. Some piles are not mixed with anything else, just piled as pure manure.
- Daily or frequent cleaning where manure is cleaned out and added to a compost pile. There is very little bedding in these systems and no extra carbon is added to the compost piles.
- Some producers had no animals on the farm and they imported manure from elsewhere in order to build hot, thermophilic compost piles from other farm waste materials.

Our goal was to design a protocol for each producer for using biochar in their preferred manure management system to the best effect. To help guide our efforts, we began by investigating how others have approached the problem, with the following findings:

A manure pack in the barn can be managed or unmanaged. An unmanaged pack is simply the accumulation of manure and bedding in the barn that is cleaned out at regular intervals. A manure pack may also be managed to accelerate composting in the barn. Typically this is done by a combination of acidifiers to prevent ammonia volatilization and regular rototilling of the pack to create more aerobic conditions for composting.

There is another, perhaps easier way to degrade manure in the barn that can avoid the work of rototilling. Pioneers in Asia have used a different decomposition pathway to digest manure in barns. This anaerobic pathway is based on lactic acid fermentation, the same process that produces pickles, yogurt and silage. It differs from anaerobic putrefaction by producing organic acids, alcohols, sugars and other beneficial substances rather than ammonia, hydrogen sulfide and harmful, reduced substances (Higa & Parr 1994). The process requires moisture control and degradable carbon and it produces a low pH.

Following a fact-finding mission to Korea in 2008, scientists at the University of Hawaii developed a dry deep litter system for pig barns in Hawaii. The system uses at least 60 cm of high carbon bedding material mixed with charcoal and cinders. It is inoculated once with indigenous micro-organisms (IMO), which include lactic acid bacteria. No tilling or stirring is required. Farmers using the system report healthier animals, almost no odors and no flies. Biochar is an essential part of this self-composting manure pack which can remain in place for up to a decade before cleaning (DuPonte et al. 2012).

The lactic acid inoculant also serves to acidify the biochar and increase its effectiveness in sorbing ammonia. Ammonia tends to volatilize at a pH of around 9, yet many of the biochars we produced had a pH of around 10. We chose to use a commercially available microbial inoculant called EM-1 (Effective Microorganisms), available from several manufacturers in the US. EM-1 includes a consortium of species along with the lactobacilli. Some of these are facultative anaerobes, that is, they can survive either with or without the presence of oxygen by altering their metabolism.

Below is a summary of the systems in use on the different farms and how we incorporated biochar into the manure management process. Further details are provided in the Field & Farm Reports in the Appendix.

Daisy Hill Farm

Daisy Hill Farm is in the process of restoring land that was previously a neglected vineyard. After tearing out the old vines and using them for biochar production, the goal was to use biochar compost to help establish a diverse pasture with grasses, legumes and perennial forages. We made one batch of biochar compost using chicken manure and garden waste that reached 150 F within three days. The second year, the chickens were gone and we were out of biochar so we used biochar donated by Oregon Biochar Solutions and fermented it with EM-1 and molasses.

East Fork Ranch

East Fork Ranch has been using biochar in small compost piles composed of mixed cattle and equine manure. The piles are windrows about 8 feet long, 3 feet wide and 2 feet high. They each have about ¼ of a cubic yard of biochar mixed in and are not being turned. The windrows are heating up well. This pile construction differs from past practice which was to use large heaps for composting. Those piles took several years to break down. The new, smaller windrows are composting much faster, with less shrinkage than previous practice. The farmer estimates that the volume of compost he can produce in small piles with biochar is double the amount he produced previously.

Michaels Ranch

Michaels Ranch uses little to no bedding in the winter feed barn. Odors are not a problem because the barn is very open. The purpose of adding biochar to the winter barn is more for improving the compost than for improving the barn environment. Michaels Ranch uses high carbon boiler ash (that qualifies as biochar) as a liming agent on their pastures, so it was not too difficult for them to add some of that material to the barn. The first year, they were not able to add the biochar in the barn, but mixed it in to the piles as the barn was being cleaned. They kept one manure pile as a control, but there was no difference in the temperature measurements of the piles. Neither pile reached thermophilic temperature. However, by September when we checked on them, the piles with biochar had a nice, crumbly, soil-like consistency, while the piles without were still very wet and goopy. The piles without biochar had also shrunk by almost half. The second year, biochar was added to the barn at the beginning of the winter season, and was mixed into the manure by cattle hooves. This material was cleaned and piled in Spring 2017, and it reached thermophilic temperatures, composting nicely.

Morrison-Fontaine Forestry

This farm produces some hay and timber, but they also have a large subsistence vegetable garden and orchard. They make compost from garden waste every year, and import manure for the compost piles. Piles were constructed in 6-foot diameter wire bins in October 2015 using 2 parts biochar; 2 parts fresh, hot, smelly dairy manure; 3 parts goat barn waste. Piles quickly reached 140 F, stayed hot for weeks and finished with abundant worms. We picked out some of the biochar chunks and tested them with a bioassay. Results are discussed in the findings.

These wire compost bins at Morrison-Fontaine Forestry are typical of those used at several of the farms. These piles were carefully layered with manure, biochar and garden waste. They got very hot and composted successfully.

Page Creek Ranch

Page Creek Ranch was not able to make biochar until Fall of 2017. They have been using it in the horse barn for several months and they report that the stable is drier and the horse's hooves are cleaner and less susceptible to disease.

Siskiyou Alpaca

Siskiyou Alpaca made several compost piles in wire bins with manure that is cleaned out of the barn every couple of days. One pile had about 12.5% biochar and one pile had about 3.6% biochar. Two control piles were also made at the same time, and temperature records were kept for all of the piles. We found that the composting process is very sensitive to the rate of added biochar. Temperature records showed that the pile with 12.5% biochar was slightly cooler than the control, while the pile with 3.6% biochar was slightly hotter.

Tierra Buena Worm Farm

Tierra Buena Worm Farm uses rabbit manure that is collected without bedding in a barn where ammonia levels get quite high. We added biochar to the manure pits under the rabbit cages along with EM-1 spray. This was effective in reducing ammonia odors. Tierra Buena also uses biochar in their worm bins. They have tried different methods of adding biochar with food and bedding and all methods seem to improve the conditions in the worm bins. Before adding biochar, the bedding material was compacted and slightly anaerobic. Biochar added some much needed carbon and the worm bins became more productive.

Willow Witt Ranch

Willow Witt Ranch uses a manure pack that builds up over several months between cleanings. Along with some straw bedding, goats drop some of their alfalfa feed onto the floor as they eat. As a result of goats' messy eating habits, a lot of alfalfa is wasted and becomes bedding. Willow Witt recently started a new program of feed control to improve animal health by restricting feed. As a result, the animals don't waste as much. Willow Witt was faced with either having to purchase straw for bedding, or start using biochar. Willow Witt also adds wood chips to compost piles and were hopeful that biochar could reduce the need for producing wood chips, which is a time-consuming farm operation. We tried two methods at Willow Witt. The first year, we took the biochar made on the ranch and packed it into 55 gallon drums along with bokashi (wheat bran inoculated with lactic acid bacteria) and molasses to ferment for several weeks. This effectively lowered the pH of the biochar to less than 6. The biochar was sprinkled once a week on top of the bedding in the barn. This was successful, but the supply of biochar ran out. During the second year, we used biochar donated by Oregon Biochar Solutions, again sprinkled in the barn once a week, but this time the inoculant was added by spraying an EM-1 solution. This combination was very successful in completely eliminating ammonia odors. We have not been able to evaluate the impact of biochar on the compost piles themselves.

4.6. Compost and Fermentation Experiments

We have learned that adding biochar to compost must be done with careful reference to C:N ratios. Biochar affects C:N in at least two ways: it contains degradable carbon, increasing C:N, and it also absorbs N, potentially reducing C:N by making it less available to compost micro-organisms. Despite these effects, when biochar is combined with a concentrated N source like fresh chicken manure without much bedding, it has a positive impact on the composting process and the result is a soil-like material in a short time. However, when biochar is added to compost that already has a lot of hard to degrade carbon like woodchips or sawdust, it can cool the compost. Given our inconsistent results with the first compost piles that we built, we decided to do some small scale experiments to help us better understand how biochar can impact compost C:N. Below are some hypotheses concerning biochar impact on compost:

- C:N of biochar itself could be about 100:1 or greater – it depends on the biochar
- Typically, only about 10-30% of the total C in biochar is available for microbes to consume (measured as volatile matter).
- Biochar influences C:N by absorbing N
- Biochar compost may be slightly cooler simply because biochar holds more water
- Biochar content for good compost ranges from 3%-20% depending on N content of manure and other ingredients

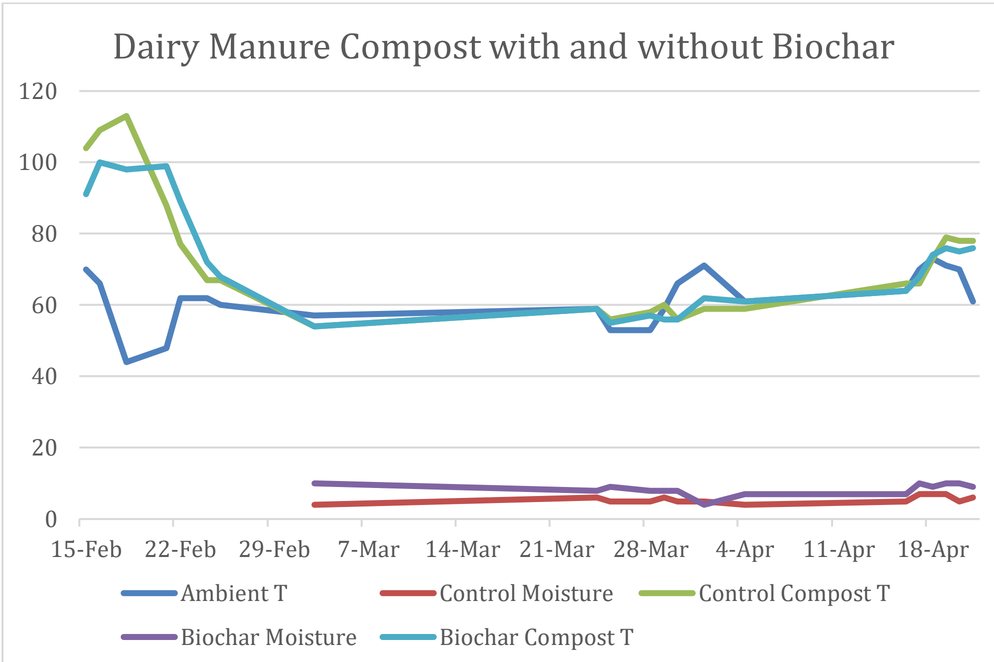
We did several small scale compost experiments to try to find answers to these questions and some additional questions we had about the effect of lactic acid fermentation on biochar pH. There results of these experiments helped to guide the rest of our composting work on the farms. Results of these experiments are reported here:

Washed Dairy Manure Compost

This experiment took place in two side by side cement block enclosures that were 4’x4’ in footprint, filling up to about 2.5’ high with about 1 cy of material. Medium was washed dairy manure that was at least 6 weeks old. Char was added to one pile at about 20% by volume.

The compost without biochar heated up faster to a higher peak than the compost with biochar. The reason most likely is because the char changed the C:N ratio and the cow manure was low nitrogen to start with. Also we noticed that the char caused moisture levels to be slightly higher which could have kept it a bit cooler than the compost without char.

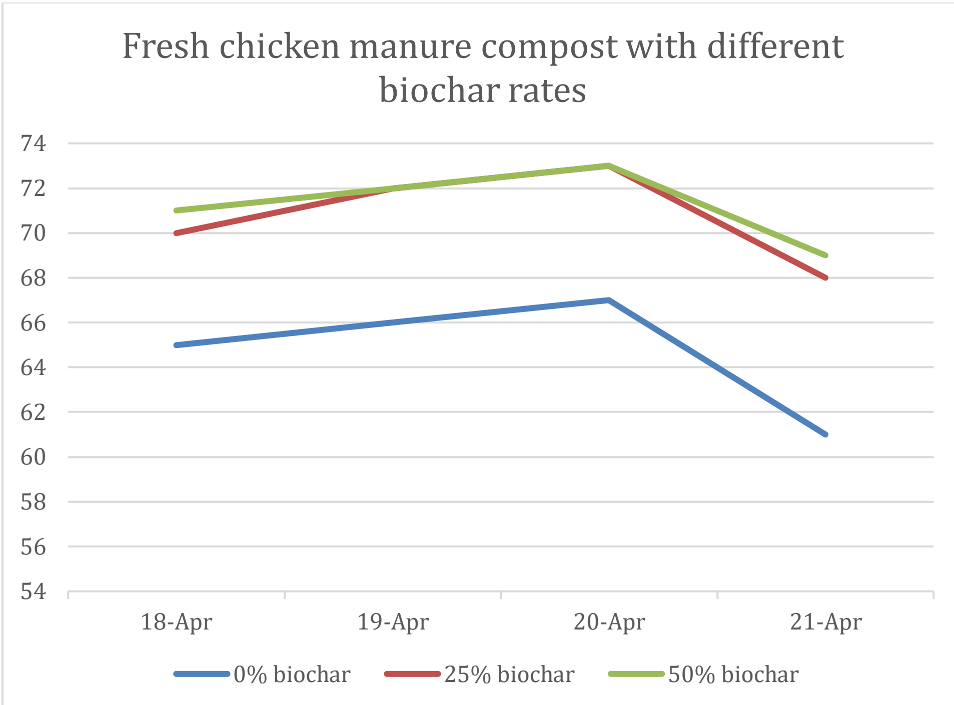
On 3-24, we added 2 cups of molasses and 80 ml of wood vinegar to each pile, mixed in water. Both piles showed a small temperature spike. We added the same mixture to both piles again on 4-16, again observing a small temperature spike in both piles. There was no real difference between the response of the piles to the additions. When we built the piles, we assumed that dairy manure had a C:N of 13:1 but in reality, the dairy manure was probably more like 37:1. Adding biochar made the C:N even higher.



Fresh Chicken Manure Compost

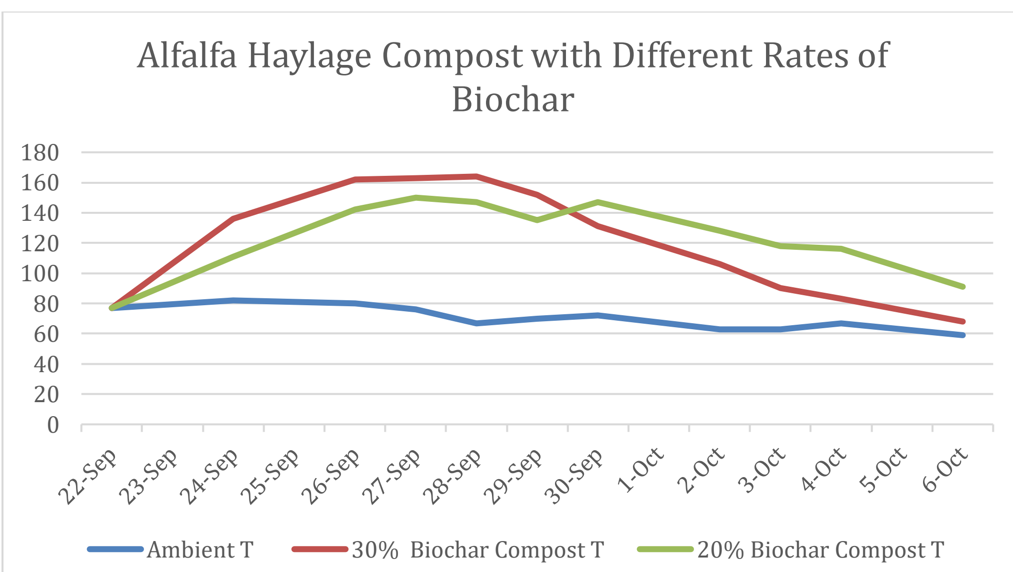
We used fresh chicken manure with very little bedding from a commercial egg laying operation and divided it into 3 piles of 10 gallons each. We mixed in biochar at rates of 50%, 25% and 0%. Despite the small pile size and likely because of the high N content of the manure, the piles did heat noticeably and we were able to measure some temperature differences between them, as shown in the chart below. After 6 weeks of composting we measured the pH of the piles and found clear differences. Piles with more biochar had lower pH than piles with less or none. It was interesting to see that the high pH biochar was able to lower the pH of the compost. We also noticed that the piles with biochar produced a very nice, soil like substrate with no odor after only 6 weeks.

Final pH after biochar addition to fresh chicken manure and 6 weeks composting			
	0% biochar	25% biochar	50% biochar
Final pH	*8.65*	*8.25*	*8*



Alfalfa Haylage Compost with Different Rates of Biochar

Our final compost experiment was aimed at testing two different rates of biochar in an otherwise balanced compost mixture. The base of the compost was an alfalfa silage feed (Chaffhaye) mixed with some finished greenwaste compost and minerals at the rate of 2 cups per cubic feet of compost ingredients (4 parts rock phosphate, 4 parts glacial rock dust, 1 part Azomite).



We made two compost mixtures in fiber sack containers and added 30% biochar by volume to one, and 20% biochar to the other. Temperature measurements were recorded for the first two weeks of composting. A pH measurement was made seven weeks after composting started. The pH of the sack with 30% biochar was 6.4, while the pH of the sack with 20% biochar was 6.0. Both piles heated up quickly, but the one with more biochar heated more quickly to a higher temperature, showing the biochar had a kickstarting effect on the compost.

Fermentation Experiment

We wanted to see if we could lower the pH of biochar using EM-1 inoculant. We prepared a five gallon bucket of coarse biochar and added a cup of EM-1 inoculant with one cup of molasses and just enough water to wet the char. We sealed the bucket and stored it in a warm place for 4 weeks. After the fermentation, we tested the pH of the biochar ferment with litmus paper. It was about 6 as compared to a pH of the untreated biochar of 9. We left beakers of both biochars in water solution in the open air for another 2 weeks and re-tested the pH. The fermented biochar was now pH 7, while the untreated biochar remained at 9. We demonstrated that we could successfully lower the pH of biochar using EM-1 inoculant.

4.7. Biochar Compost Pot Trial and Field Trials

We conducted both pot trials and field trials to help evaluate the results of our biochar composts. One pot trial was conducted with the help of the USDA ARS Forage Seed and Cereal Research Unit at Oregon State University in Corvallis. Researchers there helped us harvest and process the above and below ground plant growth and they conducted laboratory analysis and statistics. The complete report on this pot trial is presented in the Appendix, *Field & Farm Reports*. We used the results of this trial to help guide the field trial at Morrison-Fontaine Forestry, and to advise a local farmer on fertilizer rates for using boiler ash on his pasture.

We developed our own bioassay protocol to conduct additional pot trials. The method is detailed in the practice guideline: *Plant bioassays*. We conducted bioassays of compost that was produced on two farms, Michaels Ranch and Siskiyou Alpaca. The results were used to guide field trials set up on those farms.

We also conducted one other field trial at Daisy Hill Ranch. We did not perform a bioassay before this field trial. Below is summary of the trials we did:

- Daisy Hill Farm pasture establishment – no pot trial. Field trial compared biochar compost against control. Second application was made in October 2017.

- Michaels Ranch pasture – Pot trial compared cow manure compost with and without high carbon boiler ash. Field trial also included boiler ash alone. Second application will be made in April 2018.

- Morrison-Fontaine Farm hay field – Pot trial compared two kinds of boiler ash and one biochar, all with and without lime and fertilizer. Field trial compared biochar compost and combinations of plain biochar, lime, fertilizer.

- Siskiyou Alpaca bokchoy bed – Pot trial and field trial compared alpaca manure compost with and without biochar.

The four field trials were all very different, reflecting different production systems on the farms and different levels of ability to conduct a field trial. We need to emphasize that these are farmer-led field trials. We needed to work within constraints of farmers' resources and sometimes operate on a larger scale than would be most desirable for accuracy, so that farm equipment could be used for application of treatments. The trial at Morrison-Fontaine Farm was set up to high standards and has yielded good experimental data. The other three trials are bit rougher, but two of them will be repeated with new applications of biochar to the same plots. We are hopeful that over time, farmers will begin to see some impacts of the biochar treatments. Results of all of the field trials are discussed in the Findings, and included in the individual farm reports presented in the Appendix.

4.8. Workshops, Demonstrations and Sharing

Sharing our results was a big part of this Conservation Innovation Grant. The project was developed and implemented by the Umpqua Biochar Education Team. UBET is a learning and sharing network of dedicated volunteers. Below we describe the different outreach events, demonstrations, workshops and presentations given over the project period. We also created a website for sharing pictures, stories and results. Other sharing projects include a tool library and contributions to the Pacific Northwest Biochar Atlas.

Public Presentations in Chronological Order

- Organized the UBET Biochar Expo in October 2015 and presented project info to public.
- Conducted two biochar burns in forestry settings that served as training sessions for forestry workers. One was on a USFS forest restoration project near Cave Junction and one was at the Alder Creek Community Forest in Canyonville.
- Biochar burn demonstration at Michaels Ranch.
- Biochar burn demonstration at Tierra Buena Worm Farm
- We held two one-day public workshops in April and May 2016. The April workshop took place at Frog Farm in Cave Junction, starting with a slide presentation in the morning that covered basic information about biochar and composting and as well as information about using biochar in manure management in barns and using biochar in anaerobic fermentation to create fertilizers with beneficial microorganisms (bokashi). About 25 people attended the workshop.
- In May, we held a similar workshop in Roseburg at the Tierra Buena Worm Farm, starting with a presentation in the morning and moving into hands-on demonstrations. We made bokashi and also made a "potluck" compost pile with ingredients provided by participants. We demonstrated how to use the pH and TDS instruments to monitor soil and compost. We had 30 attendees.
- We had an opportunity to present information about our project at the US Biochar Initiative Symposium in Corvallis, Oregon on August 22-24, 2016. Kelpie Wilson presented information about the Conservation Innovation Grant and Don Morrison presented our plan for a large forestry demonstration project on the Umpqua National Forest.

- Biochar Expo at Umpqua Community College in October 2016 – about 50 people attended an all-day workshop that included classroom presentations, displays and demonstrations of biochar technology.
- Kelpie Wilson presented a slideshow and biochar kiln demonstration for the Josephine Soil & Water Conservation District's grower symposium.
- Neal Hadley presented a biochar demonstration for the Lookingglass Garden Club March meeting.
- OSU Extension Tree School at Phoenix School. Don Morrison and Scott McKain made a presentation on biochar.
- OSU Extension Living on Your Land Symposium. Kelpie Wilson presented biochar information and demonstrated a biochar kiln.
- Don Morrison began an outreach program at the elementary school in Glide, and provided biochar for the school garden.
- On April 19, 2017, UBET held a public workshop on biochar composting at Tierra Buena Worm Farm. We made biochar in several kilns and shared experiences and results using biochar in compost and worm bins
- On May 12-13, UBET volunteers presented a biochar activity (demonstrating the way biochar adsorbs water) and demonstrated biochar kilns for 800 middle school students at the Firewise Expo held at the Jackson County Fire District 3 Headquarters.
- November 6 – Kelpie Wilson and Don Morrison presented project information to the Douglas County Forage Group meeting at the home of Troy Michaels.

Biochar composting workshop at Tierra Buena Worm Farm, showing bokashi demonstration and "potluck" compost pile.

Don Morrison and Scott McKain of UBET talk with middle school students about biochar, soil and fire safety.

UBET Website

The UBET website (www.ubetbiochar.blogspot.com) developed for the project has been a good tool for collecting pictures, stories and reports on our work. We also started an email discussion list that has helped with organizing work sessions and events. We have heard that our impact extends beyond the region as people from around the US and other parts of the world are using our site as a resource. We will post the Biochar Practice Guidelines developed through this grant on the UBET website, making them available to a global audience.

Biochar Atlas

Two of our farms, Michaels Ranch and Morrison Fontaine Forest Farm, have been profiled as case studies in the Pacific Northwest Biochar Atlas found at http://www.pnwbiochar.org/. The Biochar Atlas is provided by USDA ARS to share tools, reports and evaluations of biochar benefits.

Tool Library

The biochar kilns manufactured by this project have been used on the participating farms, but they are also available to UBET members and friends on loan. UBET will continue to manage the sharing of these kilns as a "tool library."

5. Quality Assurance

5.1. Sampling Procedures

During the course of the project, we sampled soils, compost, and biochar, and sent materials to various labs for analysis. We used composite sampling techniques for compost and biochar, taking about a cup of material from four to five different locations in a pile and then mixing them in a bucket before transferring the sample to a one gallon ziplok bag.

We followed a composite sampling procedure for all soil samples as well, taking about a dozen core samples in a random pattern from fields where we implemented field trials and combining them into one sample for analysis. We used a soil core sampler in most cases (AMS 401.04 7/8" X 21" Soil Probe w/Handle), but this tool was not adequate for sampling some of the more compacted soils at some of the farms. For those soils, we used an axe to cut 4” deep slices of soil.

Initially, we were not aware of the need to refrigerate soil and compost samples before submission to a lab, and some of our soil and compost samples were stored for weeks and even months at room temperature. This may have had some significant impacts on the test results.

5.2. Testing Procedures

Biochar production:

- We used a wood moisture meter (Extech MO50 Compact Pin Moisture Meter) to measure samples of wood feedstock to determine moisture levels.
- We used a thermocouple (Omega HH806AU Multi-logger Thermometer) with a 24” Type K handle probe to measure kiln temperatures.

Compost:

- We measured compost temperature using the REOTEMP Backyard Compost Thermometer - 20" Stem (Fahrenheit) for small compost piles, and the REOTEMP Heavy Duty Compost Thermometer - Dual Scale C & F (36 Inch Stem) for large compost piles. We also used the Omega Multi-logger to measure compost pile temperatures.
- We measured compost pile moisture levels using the REOTEMP Garden and Compost Moisture Meter (17 Inch Stem).

We used two different procedures to make pH measurements:

- More accurate procedure was to make a 2:1 solution of distilled water mixed with the sample in a glass beaker and set on a stir plate for 30 minutes. After a 30 minute rest period, we used the pH probe (Oakton pH 5+ Handheld Meter, pH/ATC Probe with +/-0.01 pH accuracy) in the liquid solution to measure pH.
- We performed 2-point calibration with pH 7 and pH 10 buffers before each lab session.
- For quick measurements, we made the same 2:1 solution in a jar and shook the jar for about a minute, then let it rest for ten minutes and used Hydrion pH paper in the solution (Hydrion Ph paper with Dispenser and Color Chart - Full range Insta Chek ph- 0-13).

Barns:

- In some of the barns, we used litmus paper to measure ammonia: Hydrion Ammonia Meter Test Paper Roll, 0 to 100ppm Range
- Mostly we relied on the human olfactory sensor provided on the front of our faces to determine whether biochar had an impact on ammonia in barns.

5.3. Lab Testing

We used several different soil labs to test soil, compost, and manure: A&L Western Laboratories, AgSource Laboratories, and Oregon State University Central Analytical Laboratory. We used different laboratories for soil analysis for different farms in order to be consistent with past soil tests from those labs. However, we sent most of our compost and manure samples to OSU because they could do tests such as enzyme analysis that were not available at other labs. Most of our biochar tests were done by Gabilan Labs and chemist Frank Shields, who has been one of the pioneers of biochar testing. We also sent three biochar samples to A&L Labs for nutrient and metals analysis.

5.4 Pot Trials

Our first pot trial was conducted in a greenhouse at Morrison-Fontaine Forest Farm. At the end of the growth phase, we transported the pots to the USDA-ARS lab in Corvallis, where researchers analyzed the results and allowed us to participate in the lab procedures. We conducted our bioassay pot trials at Wilson Biochar Associates shop in a horticultural growth chamber using T-5 lighting, heat mats and a temperature-controlled exhaust fan. Results were weighed using the MyWeigh Balance 601 scale, accurate to .01 grams.

5.5. Field Trials

Treatment design:
We used the International Biochar Initiative *Guide to Conducting Biochar Field Trials* (Major, 2009) as our primary reference for designing and implementing field trials. However, we consciously deviated from some procedures in order to accommodate farmers' needs. As a result, only one of our field trials (Morrison-Fontaine Forest Farm) can be considered to be a valid field trial. The others fall into the category of field demonstrations.

Application methods:
For the smaller field trial plots, we used five-gallon buckets to apply the biochar compost and other treatments. At Michaels Ranch with 12-foot by 100-foot strip plots, a manure spreader was used. We measured application rates by setting out three 18" square sheets of paper on each plot strip on the left edge, right edge and center of the strip, to catch a sample of the material as applied by the manure spreader. We then weighed each sample and calculated the application rate in tons per acre for each plot.

Biomass harvesting:
We used several methods to harvest biomass for our field trials. At Michaels Ranch, we used a hula hoop as our sample square and harvested pasture growth with shears. At Morrison-Fontaine we used a lawn mower with grass catcher to harvest all the pasture growth on each 10x10 foot plot. We dried each of these harvests in a barn loft in the hot, dry summer weather for several weeks before weighing. At Siskiyou Alpaca, we harvested bokchoy by snipping with shears and weighed the fresh weight of the produce. At Daisy Hill, we did not do any biomass harvest.

6. Findings and Results

This section of the report includes our findings and results compiled for the different categories below:

1. Biochar production results
2. Analysis of biochar test results
3. Manure management practice results
4. Compost analysis test results
5. A summary of pot trial and field trial results
6. A summary of economic data

Additional results are presented in the Appendix as a series of stand-alone documents:

- Field & Farm reports summarizing work on our biochar forestry project and on eight farms with details of field trials
- Five Practice Guidelines to help others make and use biochar on farms. Practice Guidelines include:
    1. Practice Guideline: Using a flame cap kiln
    2. Practice Guideline: Kiln construction drawings
    3. Practice Guideline: How to use biochar in barns
    4. Practice Guideline: How to use biochar in compost
    5. Practice Guideline: Plant bioassays

6.1. Biochar Production Results

One of the questions we set out to answer with this project was whether or not farms could make their own biochar in an economical manner. We provided kilns and expertise to farmers, but the farmers had to provide dry feedstock, properly sized for use, and labor to make biochar. This was often a challenge, depending on the nature of the farm and farm production systems. For the farms that were already engaged in forestry or vegetation management, biochar production became a routine part of farm chores, adding a manageable amount of additional work, accompanied by additional benefits. For other farms, not much engaged in forestry work, biochar production could be too much additional work to take on.

Farms that incorporated biochar production into existing forest management tasks were East Fork Farm, Morrison-Fontaine Forestry, Page Creek Ranch and Willow Witt Ranch. All of these farms were already actively engaged in forest management. Daisy Hill Farm had an existing pile of vineyard removal material that needed to be burned for disposal, so making biochar instead was not a great deal more labor. Tierra Buena and Siskiyou Alpaca did not have their own source of woody debris, but found plenty of slash to use on neighboring properties. Both of these producers are making vermicompost (the alpaca manure windrows are full of worms) and need relatively small amounts of biochar. The biochar production effort needed to produce several cubic yards per year is not that great.

The table below shows farm resources and biochar production over the grant period. In some cases, an outside source of biochar was used, either high carbon boiler ash (40% carbon) or biochar donated by Oregon Biochar Solutions. Farmers produced about 41 cubic yards of biochar in total. Commercially produced biochar from Oregon Biochar Solutions sells at a current retail price of $250/cy. Total value of the biochar we produced is $10,250.

Farm	Forest Acreage	Woody Waste Acreage (vineyard or orchard removal)	Biochar produced (cubic yards)	Outside source of biochar used (cubic yards)
East Fork Farm	120		6	
Daisy Hill Farm	1	4 (vineyard)	2	2 – OBS biochar
Michaels Ranch	120	30 (prune orchard)	2	42 – boiler ash
Morrison-Fontaine	80		11	
Page Creek Ranch	20		6	
Siskiyou Alpaca	0		2	
Tierra Buena Worm Farm	0		4	
Willow Witt Ranch	250		8	2 – OBS biochar
Total Biochar Produced			***41 cubic yards***	

Michaels Ranch is the largest farm in our project. Because they had a readily available, free source of high carbon boiler ash, it made sense to use that material instead of spending the time to make biochar. However, we missed an opportunity to make biochar from 30 acres of prune orchard that were removed and burned during Spring 2017. It would have been a large undertaking to process that much material into biochar using the small kilns and manual labor that we had. There are many large opportunities like this on farms and forests in our region that require an industrial approach to producing biochar. We provide a further discussion of such opportunities and how our project informs new approaches, in the conclusions section to this report.

6.2. Biochar Quality Results

Biochar testing is expensive ($200/sample for a full analysis), so we did not try to test all of the different biochar batches that we made. We picked nine samples to test, mostly samples of biochar we used in biochar field trials. The table below gives values for several different biochar characteristics. We included some results for the commercial biochar from Oregon Biochar Solutions for comparison.

Biochar Tests											
Biochar Sample	Notes on sample origins	Date	pH	EC (mmhos /cm)	ash %	Volatile Matter %	Fixed Carbon %	Neutralizing value (% CaCO3)	Water Holding Capacity (ml water per 100 g dry char)	Butane Activity (g/100g dry ash free char)	Dry Bulk Density (lb/cu ft)
1. Boiler Ash 1	Tipton Ranch	4/4/16	7.2	0.562	40.9	16.5	42.6	14.6	68.5		44
2. Boiler Ash 2	Michaels Ranch	4/4/16	8.4	1.485	57.8	13.4	28.8	25.2	73.3		48
3. Morrison madrone	wet quenched	4/4/16	8.1	1.672	10.2	13.5	76.3	5.6	81.3		23
4. Morrison mixed conifer	wet quenched	2/21/18	9.2	0.61	8.6	20.4	71	6.2	107.9	7	11.7
5. Morrison mixed conifer	dry quenched	2/21/18	9.5	0.82	30.3	17.4	52.3	1.6	113.2	7.5	10
6. Morrison mixed conifer	composted (dry quenched)	2/21/18	9	1.9	14.1	0.26	85.6	14.9	124	2.8	12.5
7. Siskiyou Alpaca oak	wet quenched	2/21/18	10.1	0.55	5.4	21.5	73.1	7.4	90.1	7.1	10.1
8. Siskiyou Alpaca oak	composted	2/21/18	8.5	0.19	1.8	14.8	83.4	2.4	102.7	2.7	9.5
9. Daisy Hill grape vines	wet quenched	2/21/18	10.1	0.49	10.4	9.7	79.9	6.4	119.2	5.9	10.5
10. Oregon Biochar Solutions	commerical biochar	2/14/18	10.5	1.212	8.7			11.1		10.2	4.9

The characteristics that have the most immediate impact on application to soil and compost are the pH and the ash content of biochar. Macro and micro-nutrients in the ash can also have a considerable impact on soil fertility, especially for high ash content samples like boiler ash. To learn more about nutrient content, we sent the two boiler ash samples and one biochar sample to a soil lab for analysis:

LAB NO: 20677 DATE: 01/13/2016

ORGANIC FERTILIZER REPORT

PAGE: 1

SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	REPORT OF ANALYSIS IN PERCENT									REPORT OF ANALYSIS IN PARTS PER MILLION					
A-1	0.47	0.63	1.44	1.310	1.578	0.040	0.890	5.540	0.150	11490	15600	3072	67	299	60.0

SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	POUNDS OF NUTRIENTS / TON														
A-1	9.4	12.6	28.9	26.2	31.6	0.8	17.8	110.8	3.0	23.0	31.2	6.1	0.1	0.6	0.1

☐ Reported on an as-received basis Moisture =

☒ Reported on a dry basis Moisture = 52.71%

Organic Matter = 45.48 %
CaCO3 Equivalent = 16.52 %

LAB NO: 20678 DATE: 01/13/2016

ORGANIC FERTILIZER REPORT

PAGE: 2

SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	REPORT OF ANALYSIS IN PERCENT									REPORT OF ANALYSIS IN PARTS PER MILLION					
A-2	0.48	0.78	1.79	2.380	2.867	0.290	0.940	7.260	1.130	11910	17510	3397	102	690	130.0

SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	POUNDS OF NUTRIENTS / TON														
A-2	9.6	15.6	35.7	47.6	57.3	5.8	18.8	145.2	22.6	23.8	35.0	6.8	0.2	1.4	0.3

☐ Reported on an as-received basis Moisture =

☒ Reported on a dry basis Moisture = 59.72%

Organic Matter = 53.47 %
CaCO3 Equivalent = 23.46 %

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SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	REPORT OF ANALYSIS IN PERCENT									REPORT OF ANALYSIS IN PARTS PER MILLION					
A-3	0.66	0.12	0.27	0.810	0.976	0.020	0.240	2.140	0.080	1793	1394	772	15	102	19.0

SAMPLE ID	Nitrogen N	Phosphorus P	Phosphate P_2O_5	Potassium K	Potash K_2O	Sulfur S	Magnesium Mg	Calcium Ca	Sodium Na	Iron Fe	Aluminum Al	Manganese Mn	Copper Cu	Zinc Zn	B
	POUNDS OF NUTRIENTS / TON														
A-3	13.2	2.4	5.5	16.2	19.5	0.4	4.8	42.8	1.6	3.6	2.8	1.5	< 0.1	0.2	<0.1

☐ Reported on an as-received basis Moisture =

☒ Reported on a dry basis Moisture = 65.38%

Organic Matter = 91.55 %
CaCO3 Equivalent = 6.69 %

In these fertilizer analysis reports, A-1 and A-2 are boiler ash, and A-3 is biochar made at Morrison-Fontaine Forestry from madrone. It is easy to see that both boiler ash materials contain more P, K, calcium and an important micronutrient, boron. This difference is discussed in the report, *Pot trial to determine application rates of urea with biochar or boiler ash in an acidic pasture soil*, found in the Appendix, *Field & Farm Reports*. These are the materials that we used in the pot trial.

Other important biochar characteristics include bulk density and the ratio of charred carbon to volatile carbon. Bulk density increases greatly when ash content is high, because mineral ash weighs more than char. The content of volatile carbon that is not completely charred will also increase bulk density, because it fills in the pore spaces of biochar. Also, the type of biomass makes a difference. Sample #3 was made from madrone, a dense hardwood. At 23 pounds per cubic foot, the madrone biochar is about twice the bulk density of the other biochars we made, mostly from mixed conifers. The lightest biochar used in the project was the commercial product from Oregon Biochar Solutions. This biochar also had a low ash content. Most of our applications to compost were made on the basis of volume ratios, so this needs to be kept in mind when comparing results using different biochar materials, along with the ash content.

Proximate analysis can indicate how much of a biochar sample is fully charred. This involves slowly heating biochar to drive off any remaining volatiles, and then weighing the carbon that is left. The final step in this process is to burn up all the carbon and weigh the remaining ash. When you subtract the ash from the de-volatilized carbon, you will get the percentage of fixed carbon. The biochars we made generally had high contents of fully charred carbon. This is due to our high temperature flame carbonizing process that drives off most of the volatiles and fully chars most of the material.

Gabilan Labs, where most of our biochars were characterized, measures the water holding capacity of biochar, reporting the amount of water that 100 grams of char can hold. This tells us something about the amount of porosity and surface area in the material that holds onto water by surface tension, both within particles, and between particles of biochar.

Porosity and surface area are very difficult and expensive to measure accurately. However there are some indicators that can help us compare materials. Specific surface area is a measure of the capacity of biochar to adsorb substances to the pore surfaces. Activated carbon is an industrially produced material used in filtration. High surface area and other surface properties help activated carbon grab onto and hold many substances to filter them out of drinking water and for other applications. Activated carbon can have a specific surface area of between 500 and 2000 square meters per gram. All this surface area is packed into the tiny pores that are folded into a gram of activated carbon. There are several techniques used to measure or estimate surface area. One method uses butane activity, or the amount of butane that can be held by 100 grams of dry char. A correlation can be made between the butane number and the specific surface area. For instance, a butane number of 10g/100g char corresponds to about 450 square meters of surface area per gram of char. By this measure, we can see that the commercial biochar from OBS has a very high surface area. The biochar we produced had butane numbers ranging from 5.9 to 7.5, so they also have fairly high surface area.

Two of the biochars that we tested were picked out of compost piles, and they had interesting properties as compared with the un-composted samples. For instance, if you compare sample numbers 5 and 6, and also numbers 7 and 8, these are the same biochar before and after composting. The composting process reduced the active surface area by more than half, most likely by filling attachment sites with organic compounds so they are no longer “sticky” or available to bind to new substances. At the same time, composting reduced the content of ash and volatile matter in the biochar, and the amount of salts (decreased EC). We do not know exactly why all these changes occurred.

6.3. Manure Management Practice Results

The other main goal of this project was to see if we could use biochar to make a positive difference in the way farms handle manure management. We wanted to not only make an improved manure compost with more retained nutrients, but also improve barn environments and animal health.

It is up to farmers to determine whether the methods we developed (as discussed in section 4.5) are worthwhile. As we closed the project, we interviewed all of the farmers to find out what they think of the practices that they tried, and whether or not they will make permanent changes in the way that they handle manure. All of the farms that have livestock are likely to continue biochar manure management:

- East Fork Ranch is using biochar in compost piles after manure is cleaned from the barn, and they are happy with the positive impact on the compost process, which is much faster and more productive than before.

- Michaels Ranch has seen definite improvements in the composting process and the nutrient content of manure compost since using biochar in the winter feed barn. The total nitrogen content of the piled manure increased from .82% to 1.27% (see Compost Analysis Results, below). Even though there are no definitive results from their field trial yet, they would like to continue the practice at least for a while to see if there are positive results.

- Page Creek Ranch has only been using biochar in their horse barn for a few months, but already they see results. The stable is drier and the horse's hooves are cleaner and less susceptible to disease. They will definitely continue the practice.

- Siskiyou Alpaca sees value in adding biochar to manure compost piles, but they are not likely to begin adding it in the barn, mostly due to time constraints.

- Tierra Buena Worm Farm has found that biochar is an easy way to add much needed carbon to worm beds. Before using biochar, the worm beds were compacted and anaerobic in places. Now the beds are much healthier, more aerated and more productive. It is possible that biochar can also reduce the amount of fecal coliform contamination in worm castings.

- Willow Witt Ranch is happy with the result of using biochar and EM-1 in their goat barn. They have completely eliminated ammonia odor in the barn, and that is worth a lot. They have not had a problem with coccidiosis in the kids since beginning the practice, which may or may not be a result of the biochar. They are also beginning to use biochar in the outdoor goat pens to help control muck, and will start using it in the chicken yard as well. They have not being doing the practice long enough to start seeing results in their compost piles, but they look forward to seeing what the impact is.

6.4. Compost Analysis Results

We have learned a great deal about the behavior of biochar in composting and manure management, but a great many unknowns remain. One thing that was a bit surprising that we have learned is how much biochar can change the apparent C:N ratio of a compost pile of aged manure, and most surprisingly that this can happen with as little as 3.6% biochar by volume. On the other hand, very fresh chicken manure with no other carbon source like bedding, can be combined with as much as 50% biochar and reach a higher temperature than chicken manure with less biochar. These results have lead us to the conclusion that biochar is best used in the barn as part of bedding, or even as a substitute for other bedding, where it can absorb urine directly and capture the nitrogen. Adding biochar in the barn guarantees a hot compost. Adding it to aged manure could result in a cooler pile.

However, even if adding biochar to compost results in a slightly cooler pile than compost without biochar, we still think it is beneficial to add biochar. As long as the pile still reaches a proper thermophilic temperature, there is no harm to the composting and the result may still be a superior compost. It will certainly be beneficial to the biochar that is composted. After going through the composting process, the biochar will be charged with nutrients and microbes and be ready to impart benefits to soil as a slow-release fertilizer and a source of beneficial microorganisms.

Biochar clearly has an impact on the composting process, but how much impact does it have on the resulting compost product? We sent some of our finished compost for lab analysis. There are many different measure of compost quality. The US Composting Council recommends testing compost for the following: pH, salts, NPK, organic matter, moisture, maturity (though bioassay), stability (through CO2 respiration) and pathogens.

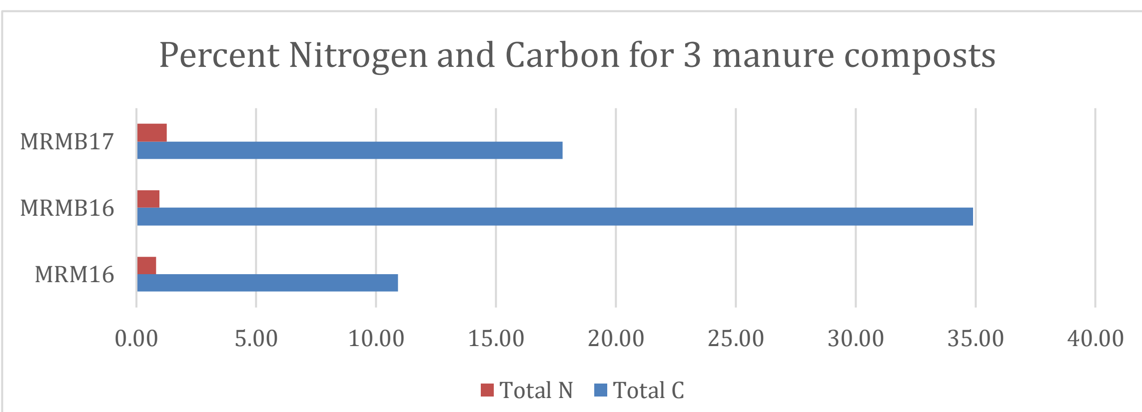
We sent our samples to the OSU Central Analytical Lab because they had the most variety of tests available at a reasonable price. Not knowing which tests would be most meaningful, in addition to standard nutrient profiles, we tried a few different measures of microbial activity to see if we could gain any insight into the impact of biochar on compost microbes. The results of the nutrient profiles and microbial measurements are given in the two tables below.

		Hannah Benchtop Meter		Dry Combustion Direct Measure			Mass loss	KCl extractinon		Total - Dry Ash Procedure				Extractable - Mehlich 3			
Sample Identification		pH	dS/m	ratio	%		%	ppm		ppm				ppm			
Sample ID	CAL ID number	pH	EC	C:N	Total C	Total N	Total Ash	NO3-N	NH4-N	P	K	Ca	Mg	P	K	Ca	Mg
MRM16	217097-1	-		13	10.90	0.82	79	70.0	23.0	1300	2500	4500	9900	340	5000	2600	790
MRMB16	217097-3	-		37	34.90	0.95	50	160.0	6.0	3800	16000	26000	3600	460	11000	8700	1900
MRMB17	218211-1			14	17.78	1.27	39	717.2	16.6	3941	15137	19765	2490				
SAC July	217225-1	6.9	0.312	14	21.00	1.50	60	121.0	22.0	3816	1065	10716	3006	2041	730	6980	2232
SAB 12	217225-2	7.1	0.251	30	41.50	1.40	35	191.0	13.0	2904	591	15390	3054	845	371	6860	1524
SAB 6	217225-3	7.3	0.207	16	23.00	1.40	53	43.0	17.0	4576	1640	13348	5042	2007	1035	6880	2928
MOSOUP	217261-1	8.5	3.560	42	67.30	1.59		803.0	18.9								
DAISY CHAR	217261-2	8.9	0.614	50	55.90	1.12		566.0	16.6								
TBWORM	217261-3	7.6	0.005	9	20.40	2.19		1136.0	55.0								

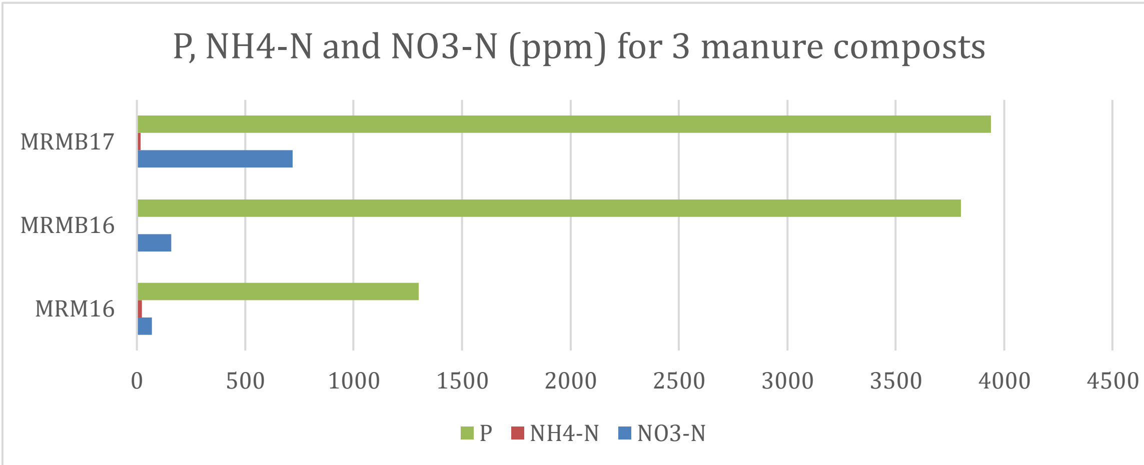
		B-glucosidase activity	CO2 Respiration		Active Carbon
Sample Identification		nmol/g dry soil/hr	ug CO2-C/g dry soil/day	ug CO2/g dry soil/day	mg active C/kg dry soil
Sample ID	CAL ID number				
MRM16	217097-1	51			
MRMB16	217097-3	12			
MRMB17	218211-1	178			
SAC July	217225-1	92	129	473	835
SAB 12	217225-2	33	71	260	960
SAB 6	217225-3	50	97	356	831
MOSOUP	217261-1	8	12	43	612
DAISY CHAR	217261-2	47	5	19	763
TBWORM	217261-3	96	56	205	634

MRM16 , MRMB16 and MRMB17 are the composts from the Michaels Ranch winter feed barn. MRM16 is the 2016 cattle manure without biochar and MRMB16 is the 2016 cattle manure mixed with biochar (high carbon boiler ash) during the barn scraping and piling process. These are the materials that were used in the field trial. The nutrient profile shows that both carbon and minerals are higher in the MRMB16 compost, as would be expected. The high carbon boiler ash contributes not only carbon, but large amounts of minerals, especially calcium and potassium. The unexpected result is that total N is higher in the MRMB16 material, despite the fact that the manure was diluted with the low N content biochar (.48% N) at the rate of about 20% by volume. This shows us that the biochar helped to retain N in the compost. Furthermore, the form of the N changed from ammonia to nitrate, with 160 ppm of nitrate in the MRMB16 as compared to 70 ppm of nitrate in the MRM16.

In 2017, the biochar was added directly to the barn where it was available to capture N as it was generated. The cattle also mixed the material thoroughly. The result was dramatic. Total N content of the compost increased to 1.27% as compared to .82% for the 2016 plain manure and .95% for the 2016 manure with added biochar. Total phosphorus also increased, however this could have been contributed by the biochar, which had a total phosphorus content of 7800 ppm.



The ratio of nitrate to ammonia also changed with the addition of biochar. Compared to the 2016 manure without biochar, the 2017 biochar manure compost had ten times the level of nitrate.



The microbial indicators also show a distinct difference. In this case we only tested for the beta-glucosidase enzyme activity, an indicator of glucose-consuming microbes. The MRMB16 had only about 25% of the level of enzymes in the un-amended manure. But the MRMB17 had the highest level of enzyme activity of any of the composts we tested, corresponding to the temperature measurements we took during the composting process, indicating strong microbial action.

We found a similar result in the Siskiyou Alpaca manure composts. SAC is the control without biochar; SAB 12.5 is the manure with 12.5% biochar; and SAB 3.6 is the pile with 3.6% biochar. In this case, we added tests for CO_2 respiration, another, broader measure of microbial activity. Here we can see that SAC has the highest levels of microbial activity, while the compost with the most biochar has the lowest levels. Again, these microbial indicators correspond to the compost process temperature measurements, however, these results could just be indicating that the composting process is more complete and the materials with low biological activity are more stable.

Active carbon is an indicator of the organic matter that is easily oxidized and readily available as a carbon and energy source for microbes. We had wondered if a lack of easily degradable carbon might have been the reason for cooler compost temperatures with more biochar, but there were not any large differences in this indicator for any of the Siskiyou Alpaca composts, so this was probably not a limiting factor.

While total N in the Siskiyou Alpaca compost was slightly higher in the no biochar pile, it is notable that even the compost with 12.5% biochar, had N levels almost as high, indicating that it probably did retain more N as a proportion of the original manure than the no biochar compost. Again, as in the Michaels Ranch compost, the nitrate to ammonium ratio is higher in the compost with the most biochar.

The last three composts we tested were MOSOUP – the fermented biochar "stew" used in the Morrison Fontaine field trial; DAISY CHAR – a compost pile (biochar, chicken manure and garden waste) used in the Daisy Hill field trial; and, for comparison, TBWORM – worm castings with about 10% biochar made at Tierra Buena Worm Farm.

MOSOUP was made with 9 cubic feet of biochar, 50 pounds of alfalfa pellets, 2 quarts of worm castings and one pint of molasses, mixed with water to cover and fermented for several months. Of the three materials, this one had the least biological activity and the most salts. Like all of these biochar composts and ferments, it had much higher nitrate than ammonium.

The DAISY CHAR material was biochar compost mixed with additional biochar before field application. This material had less nitrogen than the more concentrated MOSOUP. It appeared to be very stable with low respiration, but an intermediate level of beta glucosidase activity. The TBWORM worm casting had the highest level of N of any of the composts we tested: 2.2% with 1135 ppm of nitrate and 55 ppm of ammonium. Soluble salts were the lowest of any of the materials, and biological activity was the among the highest. C:N ratio seems well correlated to the microbial indicators – the lower the ratio, the greater the level of microbial respiration.

Reviewing these results, we have concluded that the most useful indicators of compost quality are the nutrient profile and C:N ratio. The most important aspects to farmers are the ability of biochar to retain more nutrients in compost, and to help the compost reach maturity faster. Since microbial activity indicators will vary with time over the composting process, these are less useful indicators for farmers.

We also found a lot of value in our bioassay results. Our bioassay method is a simple plant germination and growth test conducted in controlled environment. We used cucumber seeds, grown for two weeks, and then harvested and weighed for biomass. Germinations and growth nodes are counted. The protocol is described in detail in the practice guideline: *Plant bioassays.* All treatments were added in 60 ml doses to 275 g of air dry potting soil. Control was potting soil only. Results for three groups of bioassays are given below.

Treatment	Germination (%)	Secondary Leaves (count)	Biomass (grams)
MRM16	96	41	1.96
MRMB16	100	43	2.07
Control	98	38	1.58

Treatment	Germination (%)	Secondary Leaves (count)	Biomass (grams)
SAB 12.5	96	78	2.16
SAC July	100	54	2.12
Control	98	56	1.70

Treatment	Germination (%)	Secondary Leaves (count)	Biomass (grams)
Composted char	100	67	2.04
TB WORM	84	57	1.87
Control	98	41	1.30

The first group compared the Michaels Ranch cattle manure with and without biochar (2016 piles). While both treatments produced a greater growth response than the control, they were not significantly different from each other. We were not able to test the 2017 biochar manure compost, but based on N-content. we would expect to see a significant growth response.

The second group compared only the high biochar treatment at Siskiyou Alpaca with the no biochar compost and a control. Here we see no real difference in germination or biomass growth, but we do see a considerable difference in the number of secondary leaves or growth nodes. We do not know why adding biochar to the compost would have this kind of growth stimulating effect.

In the last group, we tested two very different materials side by side with a control. The composted char was bits of biochar picked out of a finished compost pile (goat manure, garden waste and biochar) produced at Morrison-Fontaine Forestry. We added this biochar only, with no compost, to the potting soil. The result was very interesting. Not only did the composted biochar produce significantly more growth than the control, it also outperformed the worm castings in all categories: germination, secondary leaves and biomass. This is a curious result, because the worm castings were very high in nitrogen. We did not test the composted biochar for nitrogen, but it is very unlikely that it would have more nitrogen than the worm castings, since none of our other composts with biochar had anything close to the amount of nitrogen in the worm castings. Perhaps the nitrogen that the composted biochar does contain is simply more available to plants. It also noteworthy that the worm castings seemed to inhibit germination. This is not so unusual, as worm castings often have strong organic compounds that can inhibit germination (Levinsh 2011).

We found that the plant bioassay was a useful test that was easy to perform and economical, since farmers can do it themselves.

6.5. Field Trial Results

The ultimate test of biochar is to use it in a field trial. However, properly designed field trials can be difficult and expensive to execute and analyze. We did our best to set up four field trials on participating farms, with the knowledge that some of them would lack the statistical power to answer research questions. Instead, some of our field experiments are more accurately termed on-farm demonstrations, designed to demonstrate how biochar can be applied and used in fields.

We needed to work within constraints of farmers' resources and sometimes operate on a larger scale than would be most desirable for accuracy, so that farm equipment could be used for application of treatments. The trial at Morrison-Fontaine Farm was set up to high standards and has yielded good experimental data. The other three trials are bit rougher, but two of them will be repeated with new applications of biochar to the same plots. We are hopeful that over time, farmers will begin to see some impacts of the biochar treatments. In general, since biochar is a soil conditioner that lasts for a long time, and not a fertilizer, we would expect that the effects of biochar would take time to manifest.

Results from the four trials/demonstrations are discussed below. Complete methods and data sets are included in each Farm Report found in the Appendix.

Daisy Hill Farm - Pasture Field Trial

Goals:

1. Establish pasture for pastured poultry by adding lime and fertilizer and seeding with poultry forage mix.
2. Test biochar-compost mix on biochar plots compared to control plots.

Field condition: former vineyard, vines removed 2 years ago. Now mostly weeds, including knapweed, blackberries, some clover and grass. Field size is 120' x140' – 16,800 sf (.39 acre).

Treatments, pasture field trial:

- Control - lime, fertilizer, seed
- BC – biochar+compost, lime, fertilizer, seed

Experimental Design:

- Randomized block design
- Five replicates
- Plot size 20'x40'

Application rates:

- Lime application rate= 1282 lbs/ac
- Sea Mineral application rate= 25.6 lbs/ac
- Fertilizer application rate= 256 lbs/ac
- Total area for experimental plots = 8,000 sf
- Total area for biochar treatment = 4,000 sf
- Char on hand is 14,080 oz (volumetric)
- Compost (with biochar) on hand is 10,240 oz (volumetric)
- Total amendment volume (char + compost) = 24,320 oz
- Biochar/compost application rate: 6 oz/sf
- Seed was spread across the entire .39 acre field using a hand seeder.

Schedule:

- The treatments and seeds were applied in April 2017. Hand seeding produced variable seeding results that would make accurate sampling very difficult.
- During the summer, irrigation was not evenly applied, due to lack of good equipment and lower than expected water pressure.
- Because the plot sizes were so large, there was too much variability within each plot, making accurate sampling for biomass measurements nearly impossible.

Results:

- Because of poor design with plots that were much too large, this field trial was downgraded to a demonstration. However, we feel this demonstration has value. The land is in an agricultural conservation easement and the goal for this field is to establish a diverse pasture. This will become a long term demonstration project. The farmer already added another application of biochar to the plots in Fall 2017, and plans to add more biochar again in the future. One important difference has been observed so far: the biochar plots seem to have more clover than the control plots.

Michaels Ranch – Pasture Field Trial

We established a field trial on a section of pasture with three blocks using four treatments arranged in twelve-foot wide strips that were about 100 feet long to facilitate use of a manure spreader to apply treatments: manure only, biochar only, manure + biochar mix and a control.

Goals: Determine if adding boiler ash (biochar) to cattle manure produces more pasture growth or improves soil conditions over either manure alone or boiler ash alone.

Field Condition: section of pasture in normal use, about 12,000 square feet.

Treatments:

- Boiler ash only
- Manure only
- Boiler ash mixed with manure
- Control

Experimental Design:

- Randomized block design
- Three replicates
- Plot size – 12' wide strips about 100 feet long. No buffer strips

Application Rates:

- Application rates were calculated from manure spreader calibration samples. The Manure+Biochar mix was the most variable across the blocks, most likely because it formed hard clods that did not flow easily through the spreader.
- There was so much variability in application rates between plots within treatments that accuracy was compromised.
- Since the manure spreader tended to spread a greater application volume of fine material than clumpy material, there was also considerable variability in application rates between the treatments, complicating the results.

Schedule:

- September 29, 2016 - test soil in each of 3 blocks and layout block corners
- October 20-27, 2016 – spread amendments with manure spreader
- Plots were grazed until April when they were fenced to exclude sheep
- June 19 - took plant samples – one from near the middle of each plot, and 3 soil samples per plot
- Consolidated soil samples by treatment and sent for analysis.
- July 12 – open fences for grazing

Results: The results of the forage harvest are inconclusive, with too much variability between treatment plots to come to any statistically solid conclusions.

Forage Harvest, grams

Treatment	Block 1	Block 2	Block 3	Average
Manure	352	335	284	323.7
Biochar	364	410	302	358.7
Manure + Biochar	339	289	362	330.0
Control	307	327	387	340.3

Results of soil test results are also inconclusive. We could not afford to test soil from every plot, so we lumped the soil samples by treatment, destroying our ability to do statistical analysis. However, given the variability in application rates, we did not really lose much information. Nevertheless, we can see the impact of the carbon and the ash minerals in the soil test results below. It is also interesting to note that the manure plus biochar treatment seemed to stimulate microbial activity as measured by enzyme analysis.

Sample ID		%			ratio	pH		dS/m	µmol/g soil/day	µg CO_2-C/g soil/day
Cust ID	Lab ID	Moisture	C	N	C:N	pH	BpH	EC	β-glucosidase activity	CO2 Respiration
Biochar	1	0.1	3.89	0.23	16.9	7.20	7.03	0.150	0.14	22.3
Manure	2	0.1	3.24	0.27	12.0	7.08	6.76	0.042	0.41	26.0
Manure+Biochar	3	0.1	2.91	0.25	11.6	6.99	6.77	0.047	1.04	22.3
Control	4	0.1	3.67	0.26	14.1	7.08	6.65	0.036	0.71	22.9

Sample ID		ppm = mg nutrient/kg soil									meq/100g		
Cust ID	Lab ID	NO3-N	P	K	Ca	Mg	Mn	Cu	Zn	B	Ca	Mg	CEC
Biochar	1	4.3	117.7	397	2913	341	115.1	5.2	11.8	2.3	14.6	2.8	18.4
Manure	2	4.7	75.9	256	2310	232	59.2	4.1	4.8	1.2	11.5	1.9	14.1
Manure+Biochar	3	4.5	69.1	285	2335	272	76.7	4.5	4.9	1.3	11.7	2.3	14.7
Control	4	2.6	66.0	234	2235	245	64.8	4.3	4.3	0.9	11.2	2.0	13.8

Morrison-Fontaine Forestry – Pasture Field Trial

Goals: Establish perennial forage plants for wildlife, improve soil fertility by adding lime, fertilizer and seed. Determine impact of biochar. Determine soil and forage improvement costs for 3 to 8 acres of degraded hayfield.

Pasture condition: Hayfield has been mowed in July for most of the last 25 years and grass hay bales removed. Trial block is located in convex slope configuration that is drier and receives less runoff from upslope compared to concave portions of pasture. Convex slopes are mostly occupied by weeds (crab grass, moss, dandelion, plantain, and grasses) with less than 10% perennial grass and clover cover. A soil analysis indicated low levels of N, K and Boron.

Treatments:

- L - Lime
- L16 - Lime + triple 16
- CL16 - Biochar + lime + triple 16
- BL - Biochar Compost + lime
- C - Control

Experimental Design:

- Randomized block design
- Three replicates
- Plot size 3 meter squares with buffer strips

Application rates:

- Lime – two tons per acre
- 16-16-16 -- 267 pounds per acre

- Boron – "If Boron is below 0.7 ppm apply 2-3 lb B/ac and mix thoroughly with other fertilizers"
- Tetraploid annual rye (Italian Ryegrass recommended by Woody Lane but not available this spring), Dutch white clover (Red clover) and Boston Plantain – 1 lb: 1 lb: 1/2 lb (@ 50lb/ac rate = 1.7 lb/1500sf)
- Glacial rock dust ~1cubic foot mixed with the 6 biochar and biochar compost treatment areas.
- Biochar treatment: biochar made in small kilns from fir and pine slash removed from the land. Three x 5 gallon buckets = 2.34 cf/100sf treatment
- Biochar Compost treatment: Biochar/alfalfa soup made with the biochar. Three x 5 gallon buckets = 2.34 cf/100sf treatment

Schedule:

- In spring 2017, slope was tilled with a rototiller along fall line
- Amendments and seeding
- Rolled after seeding with 4-wheeler perpendicular to slope.
- Buffer strips cut after dry standing condition reached in August
- Plots harvested with lawnmower and grass catcher
- Biomass dried for two weeks in barn loft
- Weighed air-dry samples with a hanging scale with 10-gram precision.
- Soil samples were taken and sent to AgSource Lab for soil analysis

Results (statistical analysis by Claire Phillips, USDA ARS):

- We analyzed harvest weight using analysis of variance, evaluating amendment treatments and block as the main effects, and compared individual treatments post-hoc using Tukey's HSD. This analysis showed that adding lime, alone, had only modest impact and was not significantly different from the control.
- However, the BL, CL16, and L16 treatments all had significantly higher harvest weights than the un-amended control, by 407, 390, and 380 grams, respectively (all with p-values ≤ 0.08). They were not significantly different from each other.
- We also asked: of the four individual amendments—lime, T16, biochar, or biochar compost, what were their individual impacts on harvest yields? Since lime and T16 were added both with and without biochars, we parsed out their impact by analyzing a linear mixed-effects model that considered the additive effects of applying lime, T16, biochar, and biochar compost as fixed effects, and block as a random effect. We used the lme routine that is part of the R statistical language. This analysis indicated that the largest individual effects were associated with addition of T16 (which increased yields by 253 grams on average, p=0.07), and biochar compost (which increased yields by 390 grams on average, p=0.01). The incremental impacts of adding lime or charcoal were not significant. This indicates that improving soil fertility, through addition of fertilizer or microbially active biochar-compost was key to increasing harvest yields.

Siskiyou Alpaca – Vegetable Bed Field Trial

Goals: Test the impact of different alpaca manure composts with different amounts of biochar on a crop of bokchoy in raised beds.
Field Condition: old garden site with raised beds.
Treatments:

- SAC July - Composted alpaca manure with no biochar

- SAB 3.6- Composted alpaca manure with 3.6% biochar
- SAB 12.5 - Composted alpaca manure with 12.5% biochar

Experimental Design:

- One block with randomized plots
- No replicates
- One 60-foot bed, 3 feet wide with 2 planted rows, for a total of 120 row feet

Application Rates:

- Application rate was .3 cubic feet compost/square foot
- Seeding rate was 900 seeds per treatment

Schedule:

- Germination counts were done every week for three weeks
- Harvest was done every week for four weeks and weighed fresh and sold at the local Farmers Market

Results: The results of both the germination and harvest were very close between all the plots. With no replicates, it was not possible to do any statistical analysis, but it is interesting nonetheless, that no large differences were observed for any of the treatments.

6.6. Biochar Economics Summary

We did two kinds of economic assessments for this project. The first approach was to gather data from the many biochar production sessions we conducted and to try to reach some conclusions about the time, labor and other inputs required to make biochar using our methods, and biochar production efficiency on a volume basis of feedstock input to biochar output. The other approach was to place the biochar production in the context of each farm and how the biochar would be used there. We tried to assess the costs of making and using biochar in barns and compost as well as the benefits. Both costs and benefits are different for each farm.

Labor Inputs for Making Biochar

We recorded production parameters for each biochar burn session conducted during the 2015-2016 winter burn season. We recorded burn times, labor hours, weather conditions, feedstock conditions (moisture content, species and approximate amounts) and biochar yield. Our results indicate an average labor input of 4.4 person hours per cubic yard of biochar produced. This does not include equipment preparation and transport time. Given that labor will be the largest cost for farmers once they have access to a set of kilns (about $700 - $800 for either a Ring of Fire Kiln or an Oregon Kiln), and given labor values of $20-25/hr, we have shown that most farmers can produce a cubic yard of biochar for about $100. Currently biochar is selling for $150 - $250 a cubic yard or more in Oregon, before shipping. Better processes for sorting, drying and covering feedstock may greatly improve the charring efficiency. Dry feedstock is especially important to the efficiency of the process both on a material input basis and on a labor time basis.

Biochar Feedstock Efficiency

Biochar production efficiency in terms of output per volume of feedstock input is variable depending on feedstock type, size and moisture content. In general, the dryer and smaller the feedstock is, the more biochar can be produced for the same mass or volume of feedstock. Our largest biochar demonstration at the Drew Veg Biochar stewardship contract gave us an opportunity to aggregate many hours of biochar production to arrive at a number for production efficiency. We produced 28 cubic yards of biochar from about 150 cubic yards of feedstock. This corresponds to a 19% conversion efficiency by volume. See Drew Veg Biochar report, in the Appendix.

Biochar Economics at Individual Farms

Our economic assessments of the participating farms are included in each farm report, provided in the Appendix. These are summarized here:

East Fork Farm

Assumptions for Cost Calculations:

- Labor cost - $20/hour
- Total biochar produced over two years – 6 cubic yards
- Total labor invested in making biochar – 20 hours
- Total labor in crushing 6 cy of biochar – 6 hours

Costs per cubic yard:

- Cost per cubic yard = $87

Anticipated Returns from using biochar:

- Biochar appears to accelerate the composting process, which has benefits for getting finished compost faster.
- Biochar also reduces shrinking of compost, resulting in twice the volume of product.
- Biochar compost may improve garden bed and orchard productivity.
- Biochar used in the animal outdoor pens will alleviate wet, mucky areas.
- Making biochar is cleaner than the previous practice of burning brush piles and less smoke is appreciated.
- Carbon sequestration as a way to combat global climate change is a value that is appreciated by the owners of East Fork Farm. They feel that they are helping to do their part.

Daisy Hill Farm

Assumptions for Cost Calculations:

- Labor cost - $20/hour
- Biochar produced – 2 cubic yards
- Total labor invested in making biochar – 10 hours
- Total labor in crushing 2 cy of biochar – 3 hours

Costs per cubic yard:

- $130

Anticipated Returns from using biochar:

- Improved pasture establishment
- Reduced water use

Michaels Ranch

Costs:

- Approximately 2 equipment-man hours to deliver and mix biochar with manure in 2016 (2x$50=$100)
- Approximately 4 equipment-man hours to deliver and spread biochar (2 times) in barn in 2017 (4x$50=$200)
- Total annual cost for making biochar-manure compost is approximately $200

Anticipated Returns from using biochar:

- Improved manure compost quality (more nitrogen)
- Improved manure compost texture for easier spreading
- Reduced odors and flies in barns
- Increased soil carbon
- Improved pasture water holding capacity
- Improved soil nutrient retention
- Raised soil pH
- Reduced soil compaction
- Better establishment of deep-rooted perennial forage

Morrison-Fontaine Forestry

Assumptions for cost calculations:

- Labor cost - $20/hour
- Approximately 4 man-hours/cy of labor to make biochar ($20x4=$80)
- Approximately 1 man-hours/cy to crush biochar ($20x1=$20)

Cost per cubic yard:

- $100

Anticipated Returns from using biochar:

- Improved pasture renovation
- Reduced water use
- Increased production of quality compost
- Increased vegetable and fruit production in the garden

Page Creek Ranch

Assumptions for cost calculations:

- Labor cost - $20/hour
- Approximately 4 man-hours/cy of labor to make biochar ($20x4=$80)
- Approximately 1 man-hours/cy to crush biochar ($20x1=$20)

Cost per cubic yard:

- $100

Anticipated Returns from using biochar:

- Improved barn environment
- Improved manure compost

Siskiyou Alpaca

Assumptions for cost calculations:

- Labor cost - $20/hour
- Approximately 8 man-hours of labor to make 2 cy biochar ($20x8=$160)

- Approximately 1 man-hours of labor to crush 2 cy biochar ($20x1=$20)

Cost per cubic yard:
- $90

Anticipated Returns from using biochar:
- Siskiyou Alpaca is actively marketing its "Paca-Poo" compost. With added biochar, they may increase the price, the market or both.
- Biochar appears to accelerate the composting process, which may have benefits for getting finished compost to customers in a timelier manner.
- Biochar also reduces shrinking of compost, resulting in a greater volume of product.

Tierra Buena Worm Farm

Assumptions for cost calculations:
- Labor cost - $20/hour
- Approximately 4 man-hours/cy of labor to make biochar ($20x4=$80)
- Approximately 1 man-hours/cy to crush biochar ($20x1=$20)

Cost per cubic yard:
- $100

Anticipated Returns from using biochar:
- Add carbon and aeration to worm bin bedding
- More productive vermicompost

Willow Witt Ranch

Assumptions for Cost Calculations:
- Labor cost - $25/hour
- Set up and make one batch of biochar using two kilns (1.5 cubic yards) – 6 hours
- Crush and store biochar in drums (per cubic yard) – 3 hours

Costs per cubic yard:
- Cost per cubic yard = $150

Anticipated Returns from using biochar:
- Willow Witt currently uses woodchips as a carbon source for composting goat barn manure. Biochar may reduce or eliminate the need for chipping wood, which takes a lot of labor.
- Biochar appears to accelerate the composting process, which may have benefits for getting finished compost faster.
- Biochar also reduces shrinking of compost, resulting in a greater volume of product.
- Biochar compost may improve garden bed and pasture productivity.
- Elimination of ammonia and improved animal health and comfort in the goat barn is a benefit.
- Biochar used in the goat, chicken and compost yards will alleviate wet, mucky areas.
- Making biochar is cleaner than the previous practice of burning brush piles and less smoke is appreciated.

The table below summarizes the economic data we collected for each farm. Some farms were already spending significant time on managing brush of forestry slash by gathering it and burning it in piles. Farms that offset the cost of making biochar by avoiding the cost of incineration are indicated in the table. The other farms either had to import feedstock or biochar.

Cost of Producing Biochar on Farms		
Farm	**Biochar cost/cy**	**Burning anyway?**
East Fork Farm	$87	Yes
Daisy Hill Farm	$190	Yes
Michaels Ranch	N/A	No
Morrison-Fontaine	$100	Yes
Page Creek Ranch	$100	Yes
Siskiyou Alpaca	$90	No
Tierra Buena Worm Farm	$100	No
Willow Witt Ranch	$150	Yes

How Much Biochar Do Farmers Need?

The biggest lesson learned regarding biochar production is the importance of feedstock preparation for making biochar. Farmers who wish to make biochar from waste biomass can do so fairly easily, if they have dry feedstock, even if the weather is wet. However, feedstock preparation and storage in a dry location is time-consuming and requires planning. We have found that most of our farmers are challenged to add this task to an already heavy work load.

However, as a result of our compost experiments and the plant growth assay results, we have learned that it is best to add biochar in small amounts to compost. For farmers, this means that the amount of biochar that a farmer needs to make is smaller than we had initially thought. For instance, a farmer with a small herd of 20 goats might only need to make two cubic yards of biochar per year in order to improve the barn environment and make better compost. Two cubic yards of biochar would require one day to make using two kilns and a labor force of 2 people. It would require up to 20 cubic yards of brush or slash to be hauled, cut to size, dried and covered. This is where the biggest labor effort is needed.

6.7. NRCS CSP Conservation Enhancement Activity E384135Z: Biochar Production from Woody Residue.

The results from this biochar Conservation Innovation Grant have been used to inform the development of a new conservation practice enhancement for the NRCS Conservation Stewardship Program. We worked with the NRCS National Forester, Eunice Padley, to develop ***Conservation Enhancement Activity E384135Z: Biochar production from woody residue***, which was first published in October 2106.

This technical report, and the Practice Guidelines for biochar production and use that are included in it, can serve to inform the development of draft specification sheets, implementation requirements and technical notes in support of Enhancement Activity E384135Z.

These Practice Guidelines are based on our more than two years of experience manufacturing and operating biochar kilns designed for biochar production from woody residue, and using the resulting biochar in barns, compost and manure management.

7. Conclusions and Recommendations

7.1. Conclusions

Over the course of the project we estimate that we have made more than 70 cubic yards of biochar on farms and in the forest. Our kiln designs have proven to be robust and effective, although further improvements can surely be made.

In general, participants have been pleased with the results of this comprehensive, two and half-year exploration of methods for making, using and monitoring biochar applications to barns, compost piles and fields. Most of the farmers involved intend to continue the practices that they learned and developed, and will continue to evolve those practices to meet their needs.

Where farmers spend time managing slash piles anyway, the amount of extra work to make biochar can be assessed relative to the benefits. Jerry Sabol of East Fork Ranch estimated that making biochar from slash piles only added about 20% more work than he was already doing to dispose of slash. He said: ***"Making biochar is 20% more work for twice the volume of compost."*** Clearly, that is a good tradeoff.

Use of biochar to reduce odors in animal barns has been a great success. For some of our farmers, the benefits of biochar in the barn environment are enough to justify the cost of producing it. Suzanne Willow of Willow-Witt Ranch said: ***"We were very impressed by the odor reducing power of biochar. It sure has improved our barns. When you dig into the floor, it looks like it's composting really well. Instead of the plate of waste hay and alfalfa and pee and poop, it's nice compost."***

Others will see the primary benefits in an improved compost that they either use on the farm or sell commercially. In the case of Michaels Ranch, adding biochar directly to the barn produced a composted manure that had ten times the nitrate content of plain manure. Used to fertilize pastures on the farm, this material can reduce the amount of money spent on commercial fertilizer. Troy Michaels said: ***"It appears that it is definitely worthwhile and more effective to add the biochar in the floor of the barn and have the animals mix and deposit on it. The increase in nitrate should be really beneficial."***

The pasture field trial we conducted on the Morrison-Fontaine property showed clearly that a biochar compost treatment could give results equal to a conventional fertilizer treatment of Triple 16 fertilizer and lime. Don Morrison said: ***"I am happy to know that I am able to make an effective fertilizer with on-farm inputs that also builds soil carbon."***

We are satisfied that our methods for making biochar are effective and economical, and that the biochar that we produce is of good quality, with low ash content and a high content of fixed carbon. The kilns we designed were economical to manufacture, and served as a good learning project for community college welding students.

Most of the farmers were able to produce biochar at a cost of around $100 a cubic yard. With current biochar prices at around $250 a cubic yard, this is a real savings. However, this figure does not include the cost of a kiln, or of the cutting, drying and storage of biomass feedstock. Time for farm chores is always limited, and if the price of commercial biochar comes down, some farmers may decide it is more economical to purchase it. Some farms may opt for a combination of approaches, using rough, uncrushed biochar in outdoor pens to control muck, and using commercial biochar in other applications where its fine-grained, uniform particle size is most needed to blend with compost or barn bedding.

Our methods for monitoring and testing the effects of biochar for managing manure in barns and compost piles worked well enough to give us answers to some of our questions, although many questions remain for future investigations. Except for the field trial at Morrison-Fontaine Forestry, the field trials we established did not provide definitive results. However, we feel they have value as long-term demonstration projects. Three of the producers are committed to continued annual applications of biochar to the biochar plots. Two of the farms with field trials are included as case studies in the USDA's Oregon Biochar Atlas. This gives us an opportunity to contribute new data as field trial plots change over time.

We surveyed our entire set of practices and collected the ones that we felt most confident about sharing into a set of Practice Guidelines, included in the Appendix. We hope that these documents will benefit others as they investigate biochar for their own uses.

Our outreach work has been very effective, as we continually learn of new farmers and others who want to know more about our work and adopt and adapt our practices for their own use. We have already disseminated our work beyond the project boundaries in several ways through the work of Wilson Biochar Associates.

Wilson Biochar Associates has manufactured and sold kilns to:

- Utah State University – 4 kilns
- Forestry contractors and landscapers – 5 kilns
- Josephine County Community Food Bank – 1 kiln

Wilson Biochar Associates also conducted a workshop and webinar for Utah State University that can be found online here: https://youtu.be/fVbIosrM1Ts

This Conservation Innovation Grant project was mostly about developing new tools and methods for using biochar, a new material with great potential for use in agriculture, that is not yet widely adopted. The project was less concerned with proving the benefits of biochar than with developing methods, but we feel that we have done both and we are excited to share our results with others.

7.2. Recommendations for Next Steps

Scaling Up

The farms we worked with and the projects that we executed were at a small scale relative to the opportunity that exists to better utilize the waste streams that we dealt with. Huge amounts of forestry waste are incinerated every year, producing harmful smoke pollution. Vast amounts of animal manure are poorly managed, losing nitrogen to the atmosphere and polluting groundwater, while animals suffer in odorous barn environments.

We would like to encourage others to take what we have learned in this project and scale it up. Wilson Biochar Associates was asked to do an analysis for the North Dakota State Forestry Service on the feasibility of using low-tech flame carbonizing methods to process large amounts of waste wood from shelterbelt renewal projects in that state. That report is available here: https://www.ag.ndsu.edu/ndfs/documents/sheltbelt-biochar-press-release-ndsu-lores.pdf/view

We identified several methods of scaling up the flame cap kiln, using containers such as dumpsters or scrap water tanks or grain bins. Any heavy steel container could work. The main consideration when scaling up is the increased amount of heat that will be generated and the safety of workers. When scaling up, loading must be done by machinery, both for reasons of worker safety and for production efficiency. The analysis for NDSU concluded that using such scaled up methods could produce biochar for a cost of between $23 and $62 a cubic yard. Some entrepreneurs are already trying out these ideas. Arborist Brandon Baron has used both a modified 10,000 gallon water tank and a shipping container as flame cap kilns for making biochar for his company, the Tree Service, based in Burns, Oregon.

Arborist Brandon Baron makes biochar in a modified 10,000-gallon water tank and a shipping container (Photo: The Tree Service, Burns, Oregon).

Wider Adoption of Flame Carbonization Practices

The NRCS promotes conservation practices through its many programs to benefit farmers in the United States. Our Conservation Innovation Grant has produced information that will help in the implementation of the new Conservation Stewardship Program ***Conservation Enhancement Activity E384135Z: Biochar production from woody residue***.

The participants in this Conservation Innovation Grant: On-Farm Production and Use of Biochar for Composting with Manure, look forward to assisting with the implementation of the new biochar enhancement activity in any way that we can.

8. Appendices

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8.1. Glossary of Terms

Active Carbon – soil carbon that is easily oxidized and readily available as a carbon and energy source for microbes

Absorption - The process by which one substance, such as a solid or liquid, takes up another substance, such as a liquid or gas, by filling pores, voids or spaces in the first substance.

Adsorption - The adhesion in an extremely thin layer of molecules to the surfaces of solid bodies or liquids.

Biochar - A solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment that is suitable for use in soils.

Biochar Physicochemical Properties - Those physical and chemical properties of biochar that affect the uses of biochar in soils and the environment.

Biochar Quality - Biochar quality is assessed according to the purpose of the biochar use. In the case of biochar used for carbon sequestration in soil, biochar quality is determined by the recalcitrance of the carbon in biochar.

Bokashi – A grain or other carbohydrate fermented with lacto-bacteria and other beneficial microorganisms, often made with EM-1 inoculant.

Carbon Drawdown – Sequestration of carbon dioxide in the biosphere through innovative farming, grazing and reforestation practices.

Carbonization - The conversion of an organic substance into carbon or a carbon-containing residue through pyrolysis.

Charcoal - A solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment that is suitable for use as a fuel.

Conservation Burn – A Conservation Burn is another term for a rick burn.

EM-1 – Effective Microorganisms are a consortium of microorganisms that work together in a self-propagating culture. EM-1 is available commercially from several suppliers.

Fixed Carbon - Fixed carbon is another term for recalcitrant carbon.

Flame Cap Kiln - A flame cap kiln is a carbonizer that uses a cap of flame both to transfer heat to the feedstock and to prevent oxidation of the finished biochar.

Flame Carbonization – A process for carbonizing biomass in the presence of an oxidizing flame that relies on stopping the combustion process before the material turns to ash.

Labile Carbon – Carbon that can be more easily degraded by microorganisms than fixed carbon. Labile carbon includes active carbon.

Pyrolysis - The thermochemical decomposition of organic material in an oxygen-limited environment.

Recalcitrant Carbon - In soils, the recalcitrant carbon pool is that fraction of soil organic matter that is resistant to microbial decomposition.

Rick Burn – A method of loosely stacking woody debris and lighting it on top in order to carbonize the material without producing large amounts of smoke.

Sequestered Carbon – In the context of biochar, sequestered carbon is the recalcitrant carbon content of biochar that is added to soil.

Specific Surface Area – In biochar - a measure of the capacity of biochar to adsorb substances to pore surfaces.

8.2. References

Agyarko-Mintah, E., Cowie, A., Van Zwieten, L., Singh, B. P., Smillie, R., Harden, S., & Fornasier, F. (2016). Biochar lowers ammonia emission and improves nitrogen retention in poultry litter composting. Waste Management.

Basso, A. S., Miguez, F. E., Laird, D. A., Horton, R., & Westgate, M. (2012). Assessing potential of biochar for increasing water-holding capacity of sandy soils. GCB Bioenergy.

Bonhotal J, Harrison EZ. (2004). Testing Composts. Cornell Waste Management Institute. Updated 2015. 6 p.

Chen, S., Rotaru, A. E., Shrestha, P. M., Malvankar, N. S., & Liu, F. (2014). Promoting Interspecies Electron Transfer with Biochar

Chen, Y.-X., Huang, X.-D., Han, Z.-Y., Huang, X., Hu, B., Shi, D.-Z., & Wu, W.-X. (2010). Effects of bamboo charcoal and bamboo vinegar on nitrogen conservation and heavy metals immobility during pig manure composting. Chemosphere, 78(9), 1177–1181. doi:10.1016/j.chemosphere.2009.12.029

Clough, T. J., Condron, L. M., Kammann, C., & Müller, C. (2013). A Review of Biochar and Soil Nitrogen Dynamics. Agronomy, 3(2), 275–293. doi:10.3390/agronomy3020275

Cornelissen, Gerard, et al (2016). Emissions and Char Quality of Flame-Curtain "Kon Tiki" Kilns for Farmer-Scale Charcoal/Biochar Production. PloS one 11.5: e0154617. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0154617

Dougherty, B. (2016). Biochar as a cover for dairy manure lagoons: reducing odor and gas emissions while capturing nutrients. Retrieved March 8, 2018, from http://agresearchfoundation.oregonstate.edu/sites/agresearchfoundation.oregonstate.edu/files/kleber_arf_2015-17_final_0.pdf

Downie, A., Crosky, A., & Munroe, P. (2009). Physical properties of biochar. Biochar for environmental management. London: Earthscan, 13-32.

DuPonte, M. W., & Fischer, D. (2012). The Natural Farming Concept: A New Economical Waste Management System for Small Family Swine Farms in Hawai ʻi: Most Frequently Asked Questions on the IDLS Piggery.

EBC (2012). "European Biochar Certificate - Guidelines for a Sustainable Production of Biochar." European Biochar Foundation. Arbaz: European Biochar Foundation (EBC). http://www.european-biochar.org/biochar/media/doc/ebc-guidelines.pdf.

Fischer, D. R. (2010). Inoculated Deep Litter System. USDA-NRCS, 1–10.

Fischer, D., & Glaser, B. (2012). Synergisms between compost and biochar for sustainable soil amelioration. Management of Organic Waste. Sunil, K. & Bharti, A.(Eds.), InTech, 167–198.

Food and Fertilizer Technology Center, Taiwan. Use of bamboo charcoal to remove the bad smell of manure (n.d.).

Fortey, Richard. (1999). Life: A Natural History of the First Four Billion Years of Life on Earth. Knopf. New York.

Glaser, B., Amelung, W. (2003). Pyrogenic carbon in native grassland soils along a climosequence in North America. Global Biogeochem. Cycles 17.

Goldberg, E.D. (1985). Black Carbon in the Environment: Properties and Distribution. John Wiley & Sons Inc, New York.

Hagemann, N., Joseph, S., Schmidt, H. P., Kammann, C. I., Harter, J., Borch, T., ... & McKenna, A. (2017). Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. Nature communications, 8(1), 1089.

Haider, G., Steffens, D., Müller, D., Kammann, C.I. (2016). Standard Extraction Methods May Underestimate Nitrate Stocks Captured by Field-Aged Biochar. J. Environ. Qual. 45.

Hale, Sarah E, Johannes Lehmann, David Rutherford, Andrew R Zimmerman, Robert T Bachmann, Victor Shitumbanuma, Adam O'Toole, Kristina L Sundqvist, Hans Peter H Arp, and Gerard Cornelissen (2012). "Quantifying the Total and Bioavailable Polycyclic Aromatic Hydrocarbons and Dioxins in Biochars." Environmental Science & Technology 46 (5) (March 6): 2830–8. doi:10.1021/es203984k. http://www.ncbi.nlm.nih.gov/pubmed/22321025.

Hawken, P. (2017). Drawdown: The Most Comprehensive Plan Ever Proposed to Roll Back Global Warming. Penguin.

Hayes, M. H. B. (2013). Relationships Between Biochar and Soil Humic Substances. In Functions of Natural Organic Matter in Changing Environment (pp. 959-963). Springer Netherlands.

Higa, T., & Parr, J. F. (1994). Beneficial and effective microorganisms for a sustainable agriculture and environment(Vol. 1). Atami,, Japan: International Nature Farming Research Center.

Hilber, I., Blum, F., Leifeld, J., Schmidt, H. P., & Bucheli, T. D. (2012). Quantitative determination of PAHs in biochar: a prerequisite to ensure its quality and safe application. *Journal of agricultural and food chemistry*, *60*(12), 3042-3050.

Hua, L., Wu, W., Liu, Y., McBride, M. B., & Chen, Y. (2009). Reduction of nitrogen loss and Cu and Zn mobility during sludge composting with bamboo charcoal amendment. Environmental Science and Pollution Research, 16(1), 1–9.

Huang, X. D., & Xue, D. (2014). Effects of bamboo biochar addition on temperature rising, dehydration and nitrogen loss during pig manure composting. The Journal of Applied Ecology, 25(4), 1057–1062.

IBI (2013). "Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil (i.e. IBI Biochar Standards)." http://www.biochar-international.org/characterizationstandard.

Inoue, Y., Mogi, K., & Yoshizawa, S. (2011). Properties of Cinders from Red Pine, Black Locust and Henon Bamboo. Presented at the APBC Kyoto 2011

Jindo, K., Suto, K., Matsumoto, K., García, C., Sonoki, T., & Sánchez-Monedero, M. Á. (2012). Chemical and biochemical characterisation of biochar-blended composts prepared from poultry manure. Bioresource Technology, 110, 396–404. doi:10.1016/j.biortech.2012.01.120

Joseph, S., Graber, E. R., Chia, C., Munroe, P., Donne, S., Thomas, T., ... & Li, L. (2013). Shifting paradigms: development of high-efficiency biochar fertilizers based on nano-structures and soluble components. *Carbon Management*, *4*(3), 323-343.

Joseph, S., Doug, P. O. W., Dawson, K., Mitchell, D. R., Rawal, A., James, H. O. O. K., ... & Ben, P. A. C. E. (2015). Feeding biochar to cows: an innovative solution for improving soil fertility and farm productivity. *Pedosphere*, *25*(5), 666-679.

Kammann, C., Glaser, B., & Schmidt, H. P. (2016). Combining biochar and organic amendments. *Biochar in European soils and agriculture: science and practice*, *1*, 136-60.

Kammann, C. I., Schmidt, H. P., Messerschmidt, N., Linsel, S., Steffens, D., Müller, C., ... & Joseph, S. (2015). Plant growth improvement mediated by nitrate capture in co-composted biochar. *Scientific reports*, *5*, 11080.

Kappler, A., Wuestner, M. L., Ruecker, A., Harter, J., Halama, M., & Behrens, S. (2014). Biochar as an Electron Shuttle between Bacteria and Fe(III) Minerals. Environmental Science & Technology Letters, 1(8), 339–344. doi:10.1021/ez5002209

Keiluweit, M., Nico, P. S., Johnson, M. G., & Kleber, M. (2010). Dynamic molecular structure of plant biomass-derived black carbon (biochar). *Environmental science & technology*, *44*(4), 1247-1253.

Klüpfel, L., Keiluweit, M., Kleber, M., & Sander, M. (2014). Redox properties of plant biomass-derived black carbon (biochar). *Environmental science & technology*, *48*(10), 5601-5611.

Lehmann J., da Silva J.P., Steiner C., Nehls T., Zech W., Glaser B. (2003b) Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil 249:343.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota–a review. Soil Biology and Biochemistry, 43(9), 1812-1836.

Levinsh, G. (2011). Vermicompost treatment differentially affects seed germination, seedling growth and physiological status of vegetable crop species. Plant growth regulation, 65(1), 169-181.

Liu, J., Schulz, H., Brandl, S., Miehtke, H., Huwe, B., & Glaser, B. (2012). Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. Journal of Plant Nutrition and Soil Science, 175(5), 698–707. doi:10.1002/jpln.201100172

Lovley, D. R., Coates, J. D., Blunt-Harris, E. L., Phillips, E. J., & Woodward, J. C. (1996). Humic substances as electron acceptors for microbial respiration. *Nature*, *382*(6590), 445.

Ma, J., Wilson, K., Zhao, Q., Yorgey, G., & Frear, C. (2013). Odor in Commercial Scale Compost: Literature Review and Critical Analysis (No. 13-07-066). Washington State Department of Ecology (pp. 1–74). Washington State Department of Ecology.

Major, J. (2009). A guide to conducting biochar trials. International Biochar Initiative.

Mao, J. D., Johnson, R. L., Lehmann, J., Olk, D. C., Neves, E. G., Thompson, M. L., & Schmidt-Rohr, K. (2012). Abundant and Stable Char Residues in Soils: Implications for Soil Fertility and Carbon Sequestration. Environmental Science & Technology, 46(17), 9571–9576. doi:10.1021/es301107c

Miller, C. A., & Lemieux, P. M. (2007). Emissions from the burning of vegetative debris in air curtain destructors. Journal of the Air \& Waste Management Association, 57(8), 959–967.

Morrison, Don (2016). Planning and Implementation of a Forest Service Stewardship Contract to Produce Biochar from Vegetation Management Using Hand Crews and Simple Kilns. Presented at USBI 2016**.** http://biochar-us.org/presentation/planning-and-implementation-forest-service-stewardship-contract-produce-biochar

Old, S.M. (1969). Microclimate, fire, and plant production in an Illinois prairie. Ecol. Monogr., 355-384.

Page-Dumroese, D. S., Busse, M. D., Archuleta, J. G., McAvoy, D., & Roussel, E. (2017). Methods to reduce forest residue volume after timber harvesting and produce black carbon. *Scientifica*, *2017*.

Prost, K., Borchard, N., Siemens, J., Kautz, T., Séquaris, J. M., Möller, A., & Amelung, W. (2013). Biochar affected by composting with farmyard manure. *Journal of environmental quality*, *42*(1), 164-172.

Puettmann, Maureen (2016). LCA Of Biochar- How Feedstocks and Production Systems Stack Up. Presented at USBI 2016**.** http://biochar-us.org/presentation/lca-biochar-how-feedstocks-and-production-systems-stack

Rattan, L. (2010). Depletion and Restoration of Carbon in the Pedosphere. Pedologist, 19(32), 19–32.

Schmidt, H. P. (2012). Treating liquid manure with biochar. *Ithaka Journal*, *1*, 273-276.

Schmidt, H. P., Pandit, B. H., Martinsen, V., Cornelissen, G., Conte, P., & Kammann, C. I. (2015). Fourfold increase in pumpkin yield in response to low-dosage root zone application of urine-enhanced biochar to a fertile tropical soil. *Agriculture*, *5*(3), 723-741.

Schulz, H., Dunst, G., & Glaser, B. (2013). Positive effects of composted biochar on plant growth and soil fertility. Agronomy for Sustainable Development. doi:10.1007/s13593-013-0150-0

Skjemstad, J.O., Reicosky, D.C., Wilts, A.R., McGowan, J.A. (2002). Charcoal Carbon in U.S. Agricultural Soils. Soil Sci. Soc. Am. J. 66, 1249-1255.

Steiner, C., Das, K. C., Melear, N., & Lakly, D. (2010). Reducing Nitrogen Loss during Poultry Litter Composting Using Biochar. Journal of Environmental Quality, 39, 1–7. doi:10.2134/jeq2009.0337

Steiner, C., Glaser, B., Teixeira, W. G., Lehmann, J., Blum, W. E. H., & Zech, W. (2008). Nitrogen Retention and Plant Uptake on a Highly Weathered Central Amazonian Ferralsol Amended with Compost and Charcoal. Journal of Plant Nutrition and Soil Science, 171, 893–899.

Steiner, C., Melear, N., Harris, K., & Das, K. C. (2011). Biochar as bulking agent for poultry litter composting. Carbon Management, 2(3), 227–230. doi:10.4155/cmt.11.15

Toth, J. D., & Dou, Z. (2016). Use and impact of biochar and charcoal in animal production systems. Agricultural and Environmental Applications of Biochar: Advances and Barriers, (sssaspecpub63), 199-224.

Ventura, M., Sorrenti, G., Panzacchi, P., George, E., & Tonon, G. (2013). Biochar Reduces Short-Term Nitrate Leaching from A Horizon in an Apple Orchard. Journal of Environmental Quality, 42(1), 76-82.

Wilson, Kelpie (2015). Biochar for Forest Restoration in the Western United States. Wilson Biochar Associates White Paper for South Umpqua Rural Community Partnership (SURCP). September 18, 2015 (revised March 15, 2016).

Wilson, Kelpie (2016). On Farm Production and Use of Biochar for Composting with Manure. Presented at Biochar 2016 - The Synergy of Science and Industry: Biochar's Connection to Ecology, Soil, Food, and Energy, August 22nd - 25th, 2016.

Wilson, Kelpie (2017). Converting Shelterbelt Biomass to Biochar: A feasibility analysis by Wilson Biochar Associates for North Dakota Forest Service. North Dakota State

Wilson, Kelpie (2017). Reducing Hazardous Fuels Using Low Cost Biochar Kilns In Four Utah Counties - WBA supplied biochar kilns and educational resources for the project. More info here: http://www.utahbiomassresources.org/biochar/biochar-research-utah/reducing-hazardous-fuels-using-low-cost-biochar-kilns-in-four-utah-counties

Woods End Research Laboratory (2005). Interpreting Waste & Compost Tests. Journal of the Woods End Research Laboratory, Vol 2. No 1.

Zhang, J., Lü, F., Shao, L., & He, P. (2014). The use of biochar-amended composting to improve the humification and degradation of sewage sludge. Bioresource Technology, 1–7. doi:10.1016/j.biortech.2014.02.080

8.3. Final Project Budget

Total Final Project Budget Allocations			
budget category	Match	CIG	Total
Contractual- Project Director, ag consultant	$ 74,200.00	$ 50,000.00	$ 124,200.00
Travel	$ 429.00	$ 5,802.00	$ 6,231.00
Supplies		$ 8,848.00	$ 8,848.00
Testing services (and postage)		$ 2,850.00	$ 2,850.00
Personnel- Volunteer hours, farmers and help	$ 30,985.00		$ 30,985.00
Equipment rental	$ 1,588.00		$ 1,588.00
SURCP indirect (10% of total grant amt)		$ 7,500.00	$ 7,500.00
TOTAL	**$ 107,202.00**	**$ 75,000.00**	**$ 182,202.00**

8.4. List of Outside Reviewers

We would like to thank the following individuals for reviewing the Biochar Practice Guidelines that we produced. We greatly appreciate their comments and suggestions. Responsibility for any mistakes or omissions in the final documents is ours alone.

Max Bennett, OSU Extension Forester, Jackson & Josephine Counties

Manuel Garcia-Perez, Associate Professor, Department of Biological Systems Engineering, Washington State University, Pullman, Washington

Ian Fisher, Associate Professor, Welding Program, Umpqua Community College, Roseburg,

Gloria Flora, Executive Director, Sustainable Obtainable Solutions

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Stephen Renquist, OSU Extension Horticulture Specialist, Douglas County

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8.5 List of EQIP Eligible Producers

Daisy Hill Farm
Meadow Martell
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541-592-2693 (Home)
541-287-0098 (Mobile)
meadowm@frontiernet.net

East Fork Ranch
Jerry and Lisa Sabol
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541-874-3384
2683 Shoestring Rd
Riddle, OR 97469

Michaels Ranch
Troy and Holly Michaels
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541-825-3760 (home)
michaelsranch@frontier.com

Morrison – Fontaine
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Roseburg, OR 97470
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541-530-2421 (cell)
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Page Creek Ranch
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Siskiyou Alpaca
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Tierra Buena Worm Farm
John Livingston
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541-679-7760
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Willow Witt Ranch
Suzanne Willow and Lanita Witt
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