NRCS CIG Final Report and Practice Guidelines

**Agreement Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure  
**Project Director:** Kelpie Wilson  
**Contact Information:** 541-592-3083, kelpiew@gmail.com  
**Period Covered by Report:** Sep 2015-Mar 2018  
**Project End Date:** March 2018  
**State(s):** Oregon  
**State Component CIG: Yes/No** Yes

Final Report Submitted by:

Kelpie Wilson  
Wilson Biochar Associates  
PO Box 1444  
Cave Junction, OR 97523  
541-218-9890  
kelpiew@gmail.com  
WilsonBiochar.com
# Table of Contents

1. Executive Summary

2. Introduction

3. Background: Why Make and Use Biochar?
   3.1. The Problem
   3.2. What Is Biochar?
   3.3. How can Biochar Boost Soil Carbon?
   3.4. Multiple benefits of biochar systems
   3.5. The value of biochar for landowners
   3.6. How biochar works in soil and compost

4. Review of Methods
   4.1. Roles of Participants
   4.2. Farm Assessments
   4.3. Kiln Design and Fabrication
   4.4. Biochar Production and Logistics
   4.5. Using Biochar for Manure Management
   4.6. Compost and Fermentation Experiments
   4.7. Biochar Compost Pot Trials and Field Trials
   4.8. Workshops, demonstrations and sharing

5. Quality Assurance
   5.1. Sampling Procedures
   5.2. Testing Procedures
   5.3. Lab Testing
   5.4. Field Trials

6. Findings and Results
   6.1. Biochar Quality Results
   6.2. Manure Management Practice Results
   6.3. Compost Analysis Results
   6.4. Field Trial Results
   6.5. Biochar Economics Summary

7. Conclusions and Recommendations
   7.1. Conclusions
   7.2. Recommendations for Scaling Up

8. Appendix
   8.1. Glossary of Terms
   8.2. References
   8.3. Final Project Budget
   8.4. List of Outside Reviewers
8.5. List of EQIP Eligible Producers
8.6. Farm Reports
  8.6.2. Pot trial to determine application rates of urea with biochar or boiler ash in an acidic pasture soil
  8.6.3. Daisy Hill
  8.6.4. East Fork Ranch
  8.6.5. Michaels Ranch
  8.6.6. Morrison-Fontaine Forestry
  8.6.7. Page Creek Ranch
  8.6.8. Siskiyou Alpaca
  8.6.9. Tierra Buena Worm Farm
  8.6.10. Willow Witt Ranch
8.7. Practice Guideline Documents
  8.7.1. Using a Flame Cap Kiln
  8.7.2. Kiln Construction Drawings
  8.7.3. How to Use Biochar in Barns
  8.7.4. How to Use Biochar in Compost
  8.7.5. Plant Bioassays
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>
<thead>
<tr>
<th>People</th>
<th>Farms</th>
<th>Science</th>
<th>Economics</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteers</td>
<td>Animals</td>
<td>Pot trials</td>
<td>Tracking labor &amp;</td>
<td>Workshops</td>
</tr>
<tr>
<td>Farmers</td>
<td>Compost</td>
<td></td>
<td>machinery inputs</td>
<td>Expos</td>
</tr>
<tr>
<td>UCC Students &amp;</td>
<td>Woody waste</td>
<td></td>
<td></td>
<td>Practice Guidelines</td>
</tr>
<tr>
<td>Teachers</td>
<td>Pasture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSU Researchers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biochar Experts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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.

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$_2$O) 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

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

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

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.

<table>
<thead>
<tr>
<th>Kiln</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oregon Kiln – Forestry</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Dimensions:</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>5’x5’ top base</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>4’x4’ bottom base</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>24” sides</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>14 gauge steel</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>

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
<table>
<thead>
<tr>
<th>Oregon Kiln with windscreen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oregon Kiln with dry quench lid</td>
</tr>
<tr>
<td>Ring of Fire – original</td>
</tr>
<tr>
<td>Double-walled Ring of Fire with sections and two-piece quenching lid</td>
</tr>
</tbody>
</table>
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.

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 excessive 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
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.
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.

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.
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*.
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.
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 likely 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.

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:

Goat manure was added to the kiln along with quenching water, making a nutrient-rich biochar “stew.”
• 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.
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 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 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 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              |
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.
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 M050 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 Hydrid pH paper in the solution (Hydron 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.
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.

<table>
<thead>
<tr>
<th>Biochar Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar Sample</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>1. Boiler Ash 1</td>
</tr>
<tr>
<td>2. Boiler Ash 2</td>
</tr>
<tr>
<td>3. Morrison madrone</td>
</tr>
<tr>
<td>4. Morrison mixed conifer</td>
</tr>
<tr>
<td>5. Morrison mixed conifer</td>
</tr>
<tr>
<td>6. Morrison mixed conifer</td>
</tr>
<tr>
<td>7. Siskiyou Alpaca oak</td>
</tr>
<tr>
<td>8. Siskiyou Alpaca oak</td>
</tr>
<tr>
<td>9. Daisy Hill grape vines</td>
</tr>
<tr>
<td>10. Oregon Biochar Solutions</td>
</tr>
</tbody>
</table>

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:

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.

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Hannah Bencktop Meter</th>
<th>Dry Combustion Direct Measure</th>
<th>Mass Loss %</th>
<th>KCl extraction</th>
<th>Total - Dry Ash Procedure</th>
<th>Extractable - Mehlich 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample ID</td>
<td>pH</td>
<td>dS/m</td>
<td>ratio</td>
<td>%</td>
<td>%</td>
<td>ppm</td>
</tr>
<tr>
<td>CAL ID number</td>
<td>pH</td>
<td>EC</td>
<td>C:N</td>
<td>Total C</td>
<td>Total N</td>
<td>Total Ash</td>
</tr>
<tr>
<td>MRM16 217097-1</td>
<td>-</td>
<td>13</td>
<td>10.90</td>
<td>0.82</td>
<td>79</td>
<td>70.0</td>
</tr>
<tr>
<td>MRM16 217097-3</td>
<td>-</td>
<td>37</td>
<td>34.90</td>
<td>0.95</td>
<td>50</td>
<td>160.0</td>
</tr>
<tr>
<td>MRM17 218211-1</td>
<td>-</td>
<td>14</td>
<td>17.78</td>
<td>1.27</td>
<td>59</td>
<td>177.2</td>
</tr>
<tr>
<td>SAC July 217225-1</td>
<td>6.9</td>
<td>0.312</td>
<td>14</td>
<td>21.00</td>
<td>1.50</td>
<td>60</td>
</tr>
<tr>
<td>SAC 12 217225-2</td>
<td>7.1</td>
<td>0.251</td>
<td>30</td>
<td>41.50</td>
<td>1.40</td>
<td>35</td>
</tr>
<tr>
<td>SAC 6 217225-3</td>
<td>7.3</td>
<td>0.207</td>
<td>16</td>
<td>23.00</td>
<td>1.40</td>
<td>53</td>
</tr>
<tr>
<td>MOSOUP 217261-1</td>
<td>8.5</td>
<td>3.560</td>
<td>42</td>
<td>67.30</td>
<td>1.59</td>
<td>803.0</td>
</tr>
<tr>
<td>DAISY CHAR 217261-2</td>
<td>8.9</td>
<td>0.614</td>
<td>50</td>
<td>55.90</td>
<td>1.12</td>
<td>566.0</td>
</tr>
<tr>
<td>TBWORM 217261-3</td>
<td>7.6</td>
<td>0.005</td>
<td>9</td>
<td>20.40</td>
<td>2.19</td>
<td>1136.0</td>
</tr>
</tbody>
</table>
On phosphorus content of 7800 ppm. Increased, however this could have been contributed by the biochar, which had a total manure and .95% for the 2016 manure with added biochar. Total phosphorus also was generated. The cattle also mixed the material thoroughly. The result was dramatic. In 2017, the biochar was added directly to the barn where it was available to capture N as it is captured. MRM

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>CAL ID number</th>
<th>B-glucosidase activity</th>
<th>CO2 Respiration</th>
<th>Active Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRM16</td>
<td>217097-1</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRMB16</td>
<td>217097-3</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRMB17</td>
<td>218211-1</td>
<td>178</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAC July</td>
<td>217225-1</td>
<td>92</td>
<td>129</td>
<td>473</td>
</tr>
<tr>
<td>SAC 12</td>
<td>217225-2</td>
<td>33</td>
<td>71</td>
<td>260</td>
</tr>
<tr>
<td>SAC 6</td>
<td>217225-3</td>
<td>50</td>
<td>97</td>
<td>356</td>
</tr>
<tr>
<td>MOSOUP</td>
<td>217261-1</td>
<td>8</td>
<td>12</td>
<td>43</td>
</tr>
<tr>
<td>DAISY CHAR</td>
<td>217261-2</td>
<td>47</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>TBWORM</td>
<td>217261-3</td>
<td>96</td>
<td>56</td>
<td>205</td>
</tr>
</tbody>
</table>

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 CO₂ 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRM16</td>
<td>96</td>
<td>41</td>
<td>1.96</td>
</tr>
<tr>
<td>MRM216</td>
<td>100</td>
<td>43</td>
<td>2.07</td>
</tr>
<tr>
<td>Control</td>
<td>98</td>
<td>38</td>
<td>1.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAB 12.5</td>
<td>96</td>
<td>78</td>
<td>2.16</td>
</tr>
<tr>
<td>SAC July</td>
<td>100</td>
<td>54</td>
<td>2.12</td>
</tr>
<tr>
<td>Control</td>
<td>98</td>
<td>56</td>
<td>1.70</td>
</tr>
</tbody>
</table>
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,

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composted char</td>
<td>100</td>
<td>67</td>
<td>2.04</td>
</tr>
<tr>
<td>TB WORM</td>
<td>84</td>
<td>57</td>
<td>1.87</td>
</tr>
<tr>
<td>Control</td>
<td>98</td>
<td>41</td>
<td>1.30</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>352</td>
<td>335</td>
<td>284</td>
<td>323.7</td>
</tr>
<tr>
<td>Biochar</td>
<td>364</td>
<td>410</td>
<td>302</td>
<td>358.7</td>
</tr>
<tr>
<td>Manure + Biochar</td>
<td>339</td>
<td>289</td>
<td>362</td>
<td>330.0</td>
</tr>
<tr>
<td>Control</td>
<td>307</td>
<td>327</td>
<td>387</td>
<td>340.3</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>%</th>
<th>C</th>
<th>N</th>
<th>C:N</th>
<th>pH</th>
<th>BpH</th>
<th>EC</th>
<th>β-glucosidase activity</th>
<th>CO2 Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar</td>
<td>0.1</td>
<td>3.89</td>
<td>0.23</td>
<td>16.9</td>
<td>7.20</td>
<td>7.03</td>
<td>0.150</td>
<td>0.14</td>
<td>22.3</td>
</tr>
<tr>
<td>Manure</td>
<td>0.1</td>
<td>3.24</td>
<td>0.27</td>
<td>12.0</td>
<td>7.08</td>
<td>6.76</td>
<td>0.042</td>
<td>0.41</td>
<td>26.0</td>
</tr>
<tr>
<td>Manure+Biochar</td>
<td>0.1</td>
<td>2.91</td>
<td>0.25</td>
<td>11.6</td>
<td>6.99</td>
<td>6.77</td>
<td>0.047</td>
<td>1.04</td>
<td>22.3</td>
</tr>
<tr>
<td>Control</td>
<td>0.1</td>
<td>3.67</td>
<td>0.26</td>
<td>14.1</td>
<td>7.08</td>
<td>6.65</td>
<td>0.036</td>
<td>0.71</td>
<td>22.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>ppm = mg nutrient/kg soil</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cust ID Lab ID</td>
<td>NO3-N</td>
<td>P</td>
</tr>
<tr>
<td>Biochar</td>
<td>4.3</td>
<td>117.7</td>
</tr>
<tr>
<td>Manure</td>
<td>4.7</td>
<td>75.9</td>
</tr>
<tr>
<td>Manure+Biochar</td>
<td>4.5</td>
<td>69.1</td>
</tr>
<tr>
<td>Control</td>
<td>2.6</td>
<td>66.0</td>
</tr>
</tbody>
</table>

**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: 1/2 lb (@ 50lb/ac rate = 1.7 lb/1500sf)
- Glacial rock dust ~1 cubic 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

<table>
<thead>
<tr>
<th>Farm</th>
<th>Biochar cost/cy</th>
<th>Burning anyway?</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Fork Farm</td>
<td>$87</td>
<td>Yes</td>
</tr>
<tr>
<td>Daisy Hill Farm</td>
<td>$190</td>
<td>Yes</td>
</tr>
<tr>
<td>Michaels Ranch</td>
<td>N/A</td>
<td>No</td>
</tr>
<tr>
<td>Morrison-Fontaine</td>
<td>$100</td>
<td>Yes</td>
</tr>
<tr>
<td>Page Creek Ranch</td>
<td>$100</td>
<td>Yes</td>
</tr>
<tr>
<td>Siskiyou Alpaca</td>
<td>$90</td>
<td>No</td>
</tr>
<tr>
<td>Tierra Buena Worm Farm</td>
<td>$100</td>
<td>No</td>
</tr>
<tr>
<td>Willow Witt Ranch</td>
<td>$150</td>
<td>Yes</td>
</tr>
</tbody>
</table>

#### 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

Appendix Table of Contents
8.1. Glossary of Terms
8.2. References
8.3 Final Project Budget
8.4. List of Outside Reviewers
8.5. List of EQIP Eligible Producers
8.6. Field and Farm Reports
  2. Pot trial to determine application rates of urea with biochar or boiler ash in an acidic pasture soil
  3. Daisy Hill Farm
  4. East Fork Ranch
  5. Michaels Ranch
  6. Morrison-Fontaine Forestry
  7. Page Creek Ranch
  8. Siskiyou Alpaca
  9. Tierra Buena Worm Farm
  10. Willow Witt Ranch
8.7. Practice Guideline Documents
  1. Using a Flame Cap Kiln
  2. Kiln Construction Drawings
  3. How to Use Biochar in Barns
  4. How to Use Biochar in Compost
  5. Plant Bioassays

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


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


8.3. Final Project Budget

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

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
Mark Fuchs, Washington State Department of Ecology
Claire Phillips, Researcher, USDA ARS Forage Seed and Cereal Research Unit at Oregon State University, Corvallis
Stephen Renquist, OSU Extension Horticulture Specialist, Douglas County
Frank Shields, Agriculture Consultant, Watsonville, California
Kristin Trippe, Director, USDA ARS Forage Seed and Cereal Research Unit at Oregon State University, Corvallis

8.5 List of EQIP Eligible Producers

Daisy Hill Farm
Meadow Martell
1000 Daisy Hill Rd
Cave Junction 97523
541-592-2693 (Home)
541-287-0098 (Mobile)
meadowm@frontiernet.net
East Fork Ranch
Jerry and Lisa Sabol
jerlis@ymail.com
541-874-3384
2683 Shoestring Rd
Riddle, OR 97469

Michaels Ranch
Troy and Holly Michaels
1085 Michaels Ranch Ln Days Creek, OR 97429
541-863-2035 (cell)
541-825-3760 (home)
michaelsranch@frontier.com

Morrison – Fontaine
Donald B. Morrison and Barbara L Fontaine
7701 Buckhorn Rd
Roseburg, OR 97470
541-440-9685 (home)
541-530-2420 (cell)
541-530-2421 (cell)
dmorrison200@gmail.com

Page Creek Ranch
Art and Jude Vawter
405 Page Creek Road
Cave Junction, OR 97523
541 301-9990
art_at_pagecreek@yahoo.com
http://www.akhal-teke.com/

Siskiyou Alpaca
John Gardiner and Christine Perala Gardiner
(541) 415-2613
john.l.gardiner@gmail.com
PO Box 2451, Cave Junction, Oregon 97523

Tierra Buena Worm Farm
John Livingston
16909 North Bank Rd
Roseburg, OR 97470
541-679-7760
js3andd@outlook.com

Willow Witt Ranch
Suzanne Willow and Lanita Witt
658 Shale City Rd, Ashland, OR 97520
541-890-1998
suzanne@willowwittranch.com
http://willowwittranch.com
A Report on the Drew Veg Biochar Stewardship Contract

16-SA-11061500-019
Awarded to South Umpqua Rural Community Partnership (SURCP)

Start Date: 06/23/2016
End Date: 12/31/2017

Purpose of the Project

- Can we turn our forestry burn piles into biochar?
- Can we add carbon to soils, where it belongs as we remove it from the atmosphere?
- Can we make this restoration activity pay for itself?

These are the questions that UBET (Umpqua Biochar Education Team, a committee of SURCP) wanted to answer with the Drew Veg Biochar Project.

Drew Veg Biochar is the name of a vegetation management and fuel reduction project on the Umpqua National Forest, near the town of Drew, Oregon. The US Forest Service conducts many such projects on National Forests every year for the purpose of reducing fire hazard by removing dense stands of younger trees, mostly in plantations and areas that were previously logged. Some of the wood may be big enough to sell to sawmills, but much of it must be piled and burned onsite. This burning produces large amounts of smoke, and the numerous piles burn holes in the forest duff, sterilizing the soil.

Our alternative approach would yard whole trees out of the forest and process them into biochar on the landings and roadsides. Our objective was to make biochar, a valuable forest product, out of waste fuels. We would avoid smoke produced by standard pile burning practices, and we would avoid burning forest soils by incinerating the waste in place.
This purpose of this project was to demonstrate feasibility of this alternative approach to slash disposal. The work involved the following steps:

1. Cut the trees
2. Yard whole trees to spur roads on both sides of the unit
3. Cut to 4 foot lengths to fit in the biochar kilns
4. Spread out on the spur roads to dry
5. Pile as needed
6. Cover with plastic
7. Load into biochar kilns to make biochar and/or manage pile burning to produce biochar
8. Quench with water or dry snuff as appropriate
9. Transport char to local farms for use as soil amendment

**Project Status Summary**

As of November 28, 2017, steps 1 through 8 have been completed. The remaining biochar will be transported to a local farm as soon as weather permits in the spring.

**Project Accomplishments**

In 2016, South Umpqua Rural Community Partnership completed the first phase of a stewardship contract on a 15-acre unit on the Umpqua National Forest called Drew Veg Biochar. This first phase involved working with a local contractor to thin approximately 800 trees per acre and forward the material to roads for processing into biochar. By June 2016, all the slash had been spread out on approximately ¼ mile of spur road to dry. It was also cut to 4-foot lengths for processing in the Oregon Kiln, a 5-foot wide Flame Cap Kiln manufactured by the Umpqua Biochar Education Team (UBET) and the Umpqua Community College Welding Department.

In September 2016, UBET members visited the site to assess our next steps. With no money remaining in the budget for the biochar production phase, all the work would be done by volunteers. We estimated it would take a crew of six professional forest workers about two weeks to do the job. In assessing our resources, we realized that we did not have enough volunteer labor to finish the job in a timely manner, and started to look at alternatives for getting the job done. Fall rains also arrived very early, precluding any further work being done on the project in 2016.

Using the resources available, we decided on a hybrid approach that would use both kilns and the Conservation Burn method to process material into biochar. The Conservation Burn method involved hiring a contractor to go back and pile about two thirds of the material into piles about ten feet in diameter and 5 feet tall. The Conservation Burn method consists of three steps:

- Pile material loosely so air can flow through it
- Light it on the top so that the flame burns all of the smoke generated
- When it has burned down to coals, quench with water and spread thin with rakes to cool

In spring 2017, SURCP/UBET put out a call to members and supporters asking for funds to complete the piling work. We raised $2,861 in donations from 15 individuals. We paid $1,300 to Rocky Top Ranch to use a mini-excavator to loosely pile the material into 28 piles along one spur road, and a series of 8 windrows along the other spur road. The work was completed in June 2017, and it took about one and a half days.
We measured dimensions of all of the completed piles, and used a pile calculator (https://depts.washington.edu/nwfire/piles/) to estimate volumes and mass of the material. We made a guess for the pile packing factors and made additional estimates of the conversion efficiency of biomass into biochar using either kilns or Conservation Burn Piles.

<table>
<thead>
<tr>
<th>Pile Group</th>
<th>Gross Vol, cf</th>
<th>Adjusted Vol, cf</th>
<th>Adjusted vol, cy</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 piles</td>
<td>8983</td>
<td>6662</td>
<td>246</td>
</tr>
<tr>
<td>8 windrows</td>
<td>7715</td>
<td>4082</td>
<td>150</td>
</tr>
</tbody>
</table>

We estimated biochar production efficiency for the kilns at 20%, predicting a production volume of 30 cubic yards from the 8 windrows. Estimating production efficiency of the Conservation Burn Piles at 10%, we projected a production volume of 24.6 cubic yards.

In September 2017, UBET volunteers covered all the piles with plastic provided by the US Forest Service, and made plans for a three-day biochar work session scheduled to begin on October 16. We put out a call for volunteers and pre-registered 25 volunteers.

Beginning on October 16, we arrived at the site and began making biochar from the windrow piles. We completed those piles and cleaned up and left the site on the afternoon of October 18. Twenty one volunteers signed in at the site over the three days, however, most people came for only one or two days, with a core group of six who stayed for the entire time. We also had a crew of about ten FS fire personnel with engines and water tanks who provided support for the entire three days.

Our kiln resources consisted of (3) four foot Oregon Kilns, (8) five foot Oregon Kilns, (1) six foot diameter Ring of Fire Kiln, and (1) five foot diameter Cone Kiln (see pictures in Appendix).

The method for using the kilns to make biochar uses the following procedure:

- Place kilns near piles of feedstock.
- Load the kiln till it is full, and in the case of the Oregon Kilns, for another foot above the top edge.
- Light evenly across the top with propane torch.
- Once the initial charge has burned down to glowing coals, add additional material in layers.
- When the kiln is full, quench with water or dry quench with a lid.
- After water quenching, the Oregon Kilns were dragged with a tractor to the central landing where they were dumped in a pile.
- A tractor was used to scoop the biochar from the pile and load into tote bags at a bagging station.
- The bagging station was designed by UBET member Gregory Flick and consisted of an A-frame stand with rods to hold the bags up by the handles.

The Forest Service fire engines provided the water. Forest Service also provided two folding water tanks on the site that had been filled the week before with 3000 gallons of water. We found that it took about 50 gallons of water to quench one Oregon Kiln. The Ring of Fire Kiln and the Cone Kiln were dry quenched using a lid sealed with dirt. We ended up using most of the 3000 gallons of water over the three days. Given that our total production was 28 cubic yards, this averages to about 100 gallons of water per cubic yard of biochar produced.
Over the course of the three days, we processed 13 kiln batches on Monday, 14 batches on Tuesday, and 3 batches on Wednesday. Each batch took approximately 4-5 hours from lighting to quenching. We could have run some of the kilns longer and filled them more completely with biochar, but we were required to stop loading early on all three days (2pm) because of warm, dry conditions.

The result of our three day session was an estimated 28 cubic yards of biochar. We measured the biochar in the kilns before they were dumped and loaded into bags. This was very close to our estimate of 30 cy for this amount of feedstock. We had estimated 150 cy of feedstock in the kiln windrow piles and a 20% conversion efficiency to arrive at the 30 cy number. Some differences: in addition to the kiln windrows, we ended up burning most of two piles (an additional 18 cy or so) that were slated for the Conservation Burn method. If these estimates are accurate, our actual conversion rate of wood feedstock into biochar was about 17% by volume.

We had promised biochar in payment to some of our volunteer workers, and we distributed about 3 cy of biochar to three different workers, leaving about 25 cy on the site.

Due to low relative humidity levels, we were not able to conduct Conservation Burns on the remaining 26 piles during the October session.

The pile burning was rescheduled for November 8. A smaller group of six UBET volunteers and a smaller FS fire crew with one engine showed up for the day. With only 250 gallons of water to work with, we chose to experiment with six piles and burn the remainder of the piles using the standard methods, in order to complete the contract in a timely manner.

The Conservation Burn experiment was not a great success. We found that the mix of small brush and large diameter logs (some up to 8”) makes it very difficult to preserve the char. We have tried this technique with more uniformly sized material, and it works much better, especially when all of the material is less than 3” in diameter. Burning mixed sizes like this results in most of the smaller material burning to ash, while the larger material does not char completely, although these top-lit burns are much cleaner, producing very little smoke.

The other problem with this method is that it requires a large amount of water to quench the char, and/or a lot of labor to spread it thin. We were not able to completely quench the 6 piles that we worked with, as we ran out of water. However, rain was moving in later that day, and we need to return to the site and see how much char was preserved. We estimate that we may have produced about 3 or 4 cubic yards of char from the 6 piles.

As an experiment, we surrounded one pile with sheet metal to compare its rate of burn to the adjacent pile. Both piles were lit at the same time. While this pile seemed to burn hotter during the initial part of the burn, towards the end as the pile collapsed, the steel ended up choking off the air supply and prevented the wood from charring. This kind of experiment is how we learn.

We also intentionally lit one pile at the bottom to compare it with the adjacent top lit piles. The comparison between the bottom lit pile and top lit piles was dramatic. The bottom lit pile smoked so badly that the flames could not adequately burn off the volatile gasses. The net result was a plume of very thick, acrid, unhealthy smoke from the bottom lit pile, while the top lit piles burned cleanly without smoke as the cap of flame burned the smoke.
Problems Encountered

- Wet weather in October 2016 and green wood prevented making charcoal on site in 2016.
- Dry weather in October 2017 forced us to make some changes in our plan to burn two batches a day in our kiln session.
- Because of low humidity levels, we had to stop burning at 2pm, so some of the kilns were not completely filled before quenching.
- We also had to delay our pile burning session until November.
- Pile burning was not as productive as we had hoped.
- We learned that it takes a lot of water and labor to adequately quench the open burn piles.

Conclusions and Recommendations

One of our objectives was to determine labor and equipment needs for this kind of project so that economic returns can be calculated. Given that we did not have ideal conditions, we would hesitate to draw conclusions from the actual numbers from this project, however, we have learned a great deal about better ways to accomplish this kind of project that would be more economic, given proper equipment and appropriately skilled labor. Here are some of our conclusions:

We need better methods of sorting feedstock into size classes. It is much more efficient to separate material into three inches and under and three inches to 6 inches. Process these materials in separate kilns or piles so you can avoid burning up small material while waiting for large material to char.

It was hard to determine the actual labor inputs, but the main work is in loading the kilns. Loading depends a lot on how difficult it is to extract material from a pile. Sometimes this takes considerable effort as branches grab on to each other. Some people worked together with one person extracting the material from the pile while the other person loaded it in the kiln. Generally it seemed that one person per kiln allowed the work to be done without exhausting the worker.

We need to find ways to mechanize the loading process. If we are going to mechanize the process, larger kilns can be used, however, machinery will need to be hardened against the heat. Workers also need to take care around even the smaller kilns, as they generate considerable heat. One of our best kilns was the Ring of Fire Kiln because it had an additional heat shield that not only protected workers, but it also prevented heat loss and improved the charring efficiency of the kiln.

Acknowledgements

It took the efforts of many volunteers to complete this project. Below is a list of volunteers and contributors whom we wish to thank:

UBET Members:
Scott McKain  Gani Ruthellen  Kelpie Wilson
Don Morrison  Dennis Morgan  David Marszalec
Barbara Long  MA Hansen  Jerry Sabol
Gregory Flick  Neal Hadley  Mike Burke
OJ Romo  Stanley Petrowski
### Donors who contributed money to the Project:

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emma Shook</td>
<td>Ian Graham</td>
<td>Byron Biochar (Don Coyne,</td>
</tr>
<tr>
<td>Don Morrison</td>
<td>Rita Prothero</td>
<td>Australia)</td>
</tr>
<tr>
<td>Dave Maize</td>
<td>Barbara Long</td>
<td>Blue Sky Enterprises (Michael</td>
</tr>
<tr>
<td>Singing Falls (Stan</td>
<td>Benjamin Discoe</td>
<td>Wittman)</td>
</tr>
<tr>
<td>Petrowski)</td>
<td>Claire Phillips</td>
<td>Gloria Flora</td>
</tr>
<tr>
<td>Ben Todd</td>
<td>Doranne Long</td>
<td>Michael McCue</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Volunteers who came and worked on site doing biochar production:

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galen Treesong-Stevens</td>
<td>Bruce Gardiner</td>
<td>Scott McKain</td>
</tr>
<tr>
<td>Max Hewes</td>
<td>Thida Win</td>
<td>Jerry Sabol</td>
</tr>
<tr>
<td>Julie Norman</td>
<td>Michael Burns</td>
<td>David Marszalec</td>
</tr>
<tr>
<td>Bonnie Way</td>
<td>Mike Hanchin</td>
<td>Neal Hadley</td>
</tr>
<tr>
<td>Robin Way</td>
<td>Kelpie Wilson</td>
<td>Mike Burke</td>
</tr>
<tr>
<td>Bruce Gordon</td>
<td>Don Morrison</td>
<td>Dennis Morgan</td>
</tr>
<tr>
<td>Kylie Meyer</td>
<td>Gregory Flick</td>
<td>Doranne Long</td>
</tr>
<tr>
<td>Alan Baumann</td>
<td>Barbara Long</td>
<td></td>
</tr>
</tbody>
</table>

### Special Thanks to Avram and Garlicana for the use of the farm tractor.

### Special Thanks to the US Forest Service

We would also like to thank Donna Owens, Tiller District Ranger on the Umpqua NF for supporting the development and execution of this project. We thank her and the US Forest Service for providing engine support and a fire crew to back up our efforts during the biochar production sessions.

---

Pictures
Figure 1. Map of project site and site condition after the fuels treatment.
Figure 2. Initially the slash was spread on the spur road. UBET members decided to hire the forestry contractor to pile the material so we could cover it with plastic and keep it dry throughout the winter.
Figure 3. Kiln transport to the site by truck and trailer. Onsite we used a tractor and ATV to move kilns.
Figure 4. Biochar production along the roadside by volunteers with Forest Service engine support.
Figure 5. The Ring of Fire Kiln has greater capacity than the Oregon Kiln. Its integrated heat shield protects workers from the heat.
Figure 6. Adequate quenching water is essential to the process when using wet quenching.
Figure 7. Consolidating and packaging the biochar for transport to local farms is a key part of the production process.
Figure 8. We made an estimated 28 cubic yards of biochar over the three day session.
Figure 9. The UBET crew returned in November to finish burning the last 26 piles. We tried an experiment with roofing steel to see if we could improve heat retention and increase efficiency.
Figure 10. The experiment with roofing steel was not successful. The steel ending up choking off air at the end, cooling the pile. Keeping a strong flame on top is key because the flame provides the heat for charring. The pile without steel produced more char.
Figure 11. We top-lit most of the piles, but as an experiment, we lit this one pile on the bottom. The difference is dramatic. Always keep flame on top to burn up the smoke.
Figure 12. Open burn piles can make a lot of char, but without lots of water, it is hard to quench and save it.
Pot trial to determine application rates of urea with biochar or boiler ash in an acidic pasture soil
Don Morrison\textsuperscript{a}, Kelpie Wilson\textsuperscript{b}, Claire Phillips\textsuperscript{c}, Kristin Trippe\textsuperscript{c}, Viola Manning\textsuperscript{c}

\textsuperscript{a}Umpqua Biochar Education Team (project of South Umpqua Rural Community Partnership), \textsuperscript{b}Wilson Biochar Associates (wilsonbiochar.com), \textsuperscript{c}USDA-ARS National Forage Seed Production Research Center, Corvallis, OR 97331, USA.

\textbf{ABSTRACT}

As part of a NRCS Conservation Innovation Grant (On-Farm Biochar Production and Use with Manure Composting), we undertook a pot trial to help answer questions about application rates for nitrogen and three kinds of carbonized materials (biochar and high carbon boiler ash) on an acidic pasture soil in Western Oregon. We compared biochar made in a flame cap kiln with boiler ash from two different sawmills that burn wood waste for energy. These boiler ash materials are currently being used by ranchers as a pasture amendment and lime substitute. We found increases in plant growth that were correlated to the amendments’ liming abilities. These results suggest that soil acidity is a primary growth-limiting factor, and therefore a successful strategy for establishing application rates of carbonized material is to base it on liming effect. However, the study also showed that carbonized materials can outperform lime, increasing plant growth more than expected based on pH alone. Nitrogen fertilization enhanced both plant growth and microbial activity when applied with boiler ash.

\textbf{INTRODUCTION}

Some ranchers in Douglas County, Oregon, have been using high carbon ash (40%-50% C) as a lime substitute to amend highly leached acidic (sometimes with pH<5) pasture soils. The ash is available at no cost from various types of wood-fired boilers at local sawmills. Our NRCS CIG project was to help farmers make biochar from on-farm resources. We decided to include analysis of this high carbon ash in the project in order to help provide guidance to farmers who wanted to know how much nitrogen to add along with an application of biochar or high carbon ash. We also wanted to know how the biochar we made would compare to the two types of boiler ash being used by ranchers. Biochar has a much higher percentage of carbon than boiler ash, while boiler ash has a higher concentration of metals. Boiler ash could present a risk of heavy metal accumulation if applied at high rates or if applied repeatedly on the same field. Biochar is less likely to present this risk.
METHODS

Treatments
In this experiment, four treatments, both fertilized and unfertilized, were compared against a no amendment control, with five replications. Micronized calcium carbonate was included to compare with the liming contribution of biochar and boiler ash. Two rates of urea-N addition (0 lbs/ac and 100 lbs/ac) were used in all treatments, including the un-amended control soil. Rye grass seeds were planted in pots and thinned to one plant per pot after germination. Plants were grown in a greenhouse for six weeks and then harvested for analysis.

Analysis Methods
Plant biomass was determined by clipping shoots to the root crown and collecting roots by wet sieving through a 1.4 mm sieve to remove soil. Roots and shoots were dried at 45°C for 48 hours. Soil pH and EC were measured in saturated pastes with a 2:1 water to soil ratio. Exchangeable cation concentrations were determined by Mehlich III extraction followed by analysis with an ICP-OES instrument. Results were analyzed using a linear model with liming agent and nitrogen rate nested within liming agent as explanatory variables. Analyses were conducted with the R statistical package (R Development Core Team 2014).

Microbial activity was assessed based on the activity of an extracellular enzyme important to carbon cycling, by monitoring the hydrolytic enzyme β-glucosidase. Microbes produce β-glucosidase, which degrades cellulose into glucose monomers that are used as a microbial energy source. By monitoring the degradation of cellulose, we can assess whether soil amendments differentially impacted microbial decay of soil carbon.

MATERIALS

The soil was analyzed by AgSource Laboratories in Umatilla, OR. We analyzed the three ash/biochar materials at A&L Western Agricultural Labs using standard soil testing methods. The biochar was made from madrone branches using the “Ring of Fire” kiln, pictured below.
Table 1. Soil test results.

<table>
<thead>
<tr>
<th>PERCENT</th>
<th>LBS/acre</th>
<th>MEQ</th>
<th>PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>BpH</td>
<td>Org. Matter</td>
<td>CEC</td>
</tr>
<tr>
<td>Soil</td>
<td>5.1</td>
<td>6.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Table 2. Boiler Ash / Biochar Test Results

<table>
<thead>
<tr>
<th>PERCENT</th>
<th>PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Org. Matter</td>
<td>CaCO3 eq.</td>
</tr>
<tr>
<td>A-1 (boiler ash)</td>
<td>45.5</td>
</tr>
<tr>
<td>A-2 (boiler ash)</td>
<td>53.5</td>
</tr>
<tr>
<td>A-3 (biochar)</td>
<td>91.6</td>
</tr>
</tbody>
</table>

Figure 2. Scott McKain and Don Morrison of UBET make madrone biochar (charcoal) with “Ring of Fire” Flame Cap Kiln.

RESULTS

Plant Growth
Shoot biomass and total plant biomass were both significantly improved with additions of lime, Ash 1, and Ash 2, but not with biochar additions (Figure 3). Nitrogen fertilizer also tended to increase shoot growth, but the difference was only significant within the Ash 1 treatment (p = 0.004). Root growth increased significantly with the Ash 1 and Ash 2 amendments only.

Plant growth generally increased with soil pH (Figure 4).
Microbial Analysis

The complete treatments are shown in Figure 6. While it appears that the biochar (charcoal) treatments had the highest microbial activity, one of the three enzyme assays failed in both the fertilized and the non-fertilized soils. Because that measurement is considered an outlier, we did not have the statistical power to analyze or compare the biochar treatment. Our pairwise comparison (comparing each of the treatments against the control) determined that the microbial community in the Ash1 amended soils had significantly less activity than the control, when no fertilizer was added.

Figure 3. Impact of treatments on root and shoot growth.

Figure 4. Relationship between total plant biomass and soil pH.

Figure 5. Treatments just before harvest.

Figure 6. β-glucosidase enzyme activity
Soil Impacts

All the soil amendments significantly increased soil pH over the un-amended control (Figure 7). In order of liming effect, they ranked Ash 1 > Ash 2 > Biochar. The mineral lime addition was closest in effect to Ash 1, but lower by an average pH of 0.31. Urea addition had no significant effect on soil pH.

The only amendment that significantly impacted soil moisture content was biochar, which increased gravimetric water content by an average of 68% (p< 0.001) over the un-amended control (Figure 8). Nitrogen addition did not significantly impact water content, but there was a suggestive decrease in soil water (p = 0.075) within the biochar treatment, which may be due to the larger plant biomass and increased water demand.

The treatments also provided different levels of various plant macro and micro-nutrients. The Ash 1 treatment provided significantly higher levels of phosphorous (Figure 9) and potassium (Figure 10) to the soil, which could help account for the greater plant growth in the Ash 1 treatment.
DISCUSSION

The minimum recommended pH for annual ryegrass is 5.5, below which level decreased seed yields are observed (Hart and Mellbye 2010). Both the un-amended and charcoal-amended soils had pH levels below or near this critical threshold, while the two ash treatments and the lime were above the threshold.

While all three treatments that exceeded pH 5.5 increased plant growth, the ash treatments increased growth more than lime. This suggests the two boiler ashes benefitted growth through additional means above and beyond their liming effect. Increases in K, P, and Mg (not shown) are the suspected cause.

N-fertilization was important for plant growth only in the Ash1 treatment where pH was optimal. N fertilization also enhanced microbial enzyme activity in both the Ash 1 and Ash 2 treatments. This indicates that both plant growth and microbial activity can be improved with N additions in the presence of high-carbon ashes. However, it is worth noting that microbial activity and plant growth were not directly linked; microbial activity was lowest in Ash 1 while plant growth was highest.

CONCLUSIONS

- Based on these results, it appears that while pH was important to growth, the two boiler ashes benefitted growth through additional means above and beyond their liming effect, likely due to increases in plant-available P and K.

- The results of this experiment showed that the addition of urea at 100 lb/ac has a clear benefit when applied with Ash 1, and this rate of N addition can be recommended to the rancher.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

---

**Farm Report: Daisy Hill Farm**

**Farm Info**
Meadow Martell  
1000 Daisy Hill Rd, Cave Junction 97523

**Management Activities and Goals**
Daisy Hill Farm is 7 acres, 4 acres of which are under an Agricultural Conservation Easement. These acres were formerly a vineyard. Soils in the former vineyard are compacted and unproductive. The old vines have been pulled from one half-acre portion of the vineyard and this field will be managed for pasture.

**Biochar Production and Analysis**
Daisy Hill Farm has abundant legacy piles of brush and waste lumber feedstock suitable for biochar. We used about half the material to make two cubic yards of biochar in March 2016. We intended to make more biochar during the winter of 2017, but never found the opportunity to do so during this extremely wet winter. Piles remain covered and ready to burn as soon as conditions permit. Biochar from the 2016 session was sent to a lab for analysis, with results reported below:

**Biochar Analysis Results**
P pH 10.1  
Ash content: 10.4%  
Volatile Matter: 9.7%  
Fixed Carbon: 79.9%  
Dry Bulk Density: 10.5 lbs/cf

**Manure and Compost**
During the summer of 2016 we made one pile of compost with biochar, garden waste, and manure from chickens and alpacas. Compost temperature was monitored and reached 152 degrees F. The compost pile was then mixed with the remaining biochar for use in the field trial.

**Compost Description**
- Bin diameter – 3.5’
- Fill height – 2.33’
- Total volume – 22.4 cf

**Compost Ingredients:**
- ½ bale straw
- 52 gal old, undecomposed compost
- 37 gal of chicken poo and litter
- 18 gal 2-week old grass clippings
- 10 gal alpaca poo and bedding
- 10 gal urine soaked biochar
- 7 gal food waste
- 7 gal beer grain mash
- 2 gal biochar mixed in with beer mash
- 5 gal forest duff litter

Following the composting and before application to the field trial, the contents of the compost bin were mixed with 110 gallons of crushed biochar, for a total of 190 gallons of material. This was sent for analysis with results reported below:

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Hannah Benchtop</th>
<th>Dry Combustion</th>
<th>KCl extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample ID</strong></td>
<td><strong>CAL ID number</strong></td>
<td><strong>pH</strong></td>
<td><strong>dS/m</strong></td>
</tr>
<tr>
<td>DAISY CHAR</td>
<td>217261-2</td>
<td>8.9</td>
<td>0.614</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>B-glucosidase activity</th>
<th>CO2 Respiration</th>
<th>Active Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample ID</strong></td>
<td><strong>CAL ID number</strong></td>
<td><strong>nmol/g dry soil/hr</strong></td>
<td><strong>umol/g dry soil/day</strong></td>
</tr>
<tr>
<td>DAISY CHAR</td>
<td>217261-2</td>
<td>47</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Field Trial**
A field trial was established in April 2017 on 8000 square feet of the pasture with two treatments: biochar compost mixture and control. The entire field was limed, fertilized with triple 16 and sea minerals, and seeded with a forage mix.

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

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

**Treatments:**
- Control - lime, Triple 16 fertilizer, sea minerals, seed
- BC – lime, Triple 16 fertilizer, sea minerals, seed, and biochar compost mixture

**Seed:**
- Hancock poultry mix, 25 lb. Ryegrass, fescue, clover, millet, radish, buckwheat, peas, turnip
- Creeping fescue, 10 lbs
- White clover, 2 lbs
- Crimson clover, 2 lbs
Experimental Design:

- Randomized block design
- Five replicates
- Plot size 20'x40’. No buffer strips

Plot Map:

![Plot Map]

Initial Soil Analysis

Soil samples were taken in August 2016 and sent for analysis:

<table>
<thead>
<tr>
<th>Farm</th>
<th>Field</th>
<th>Date</th>
<th>Lab</th>
<th>OM%</th>
<th>ENR(lb/ac)</th>
<th>Nitraten (ppm)</th>
<th>K (ppm)</th>
<th>Mg (ppm)</th>
<th>Ca (ppm)</th>
<th>soil pH</th>
<th>CEC</th>
<th>K (meq/100g)</th>
<th>Mg (meq/100g)</th>
<th>Ca (meq/100g)</th>
<th>H (meq/100g)</th>
<th>Na (meq/100g)</th>
<th>% cation saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy Hill Farm</td>
<td>Old vineyard field</td>
<td>Aug-17</td>
<td>A&amp;L</td>
<td>4.5</td>
<td>120</td>
<td>21</td>
<td>13</td>
<td>140</td>
<td>384</td>
<td>699</td>
<td>6.1</td>
<td>6.4</td>
<td>8.2</td>
<td>4.4</td>
<td>38.6</td>
<td>42.6</td>
<td>24</td>
</tr>
</tbody>
</table>

Schedule:

- April 3, 2017 - Spread fertilizer, sea minerals, and lime on whole field
- April 4 - Rototilled entire field and spread biochar-compost mixture on biochar treatment plots
- April 5 - Applied seed to entire field using Earthway hand seeder
- April 10 - Spread 10 bales of straw over entire field
- May - Set up irrigation for pasture – four moveable Rainbird impact sprinklers
- June – Aug - Irrigated pasture once a week as needed
- Fall 2017 – visual inspection of pasture using drone with camera

Application rates:

- Total area of field for fertilizer and seeding = 16,800 sf
- Total area for biochar treatment = 4,000 sf
- Lime application rate= 1282 lbs/ac
- Sea Mineral application rate = 25.6 lbs/ac
- Triple 16 fertilizer application rate = 256 lbs/ac
- Biochar/compost application rate: 6 oz(volume)/sf
- 39 pounds of mixed seed was applied across the entire .39 acre field using a hand seeder.

Results:
We were not able to produce any statistically valid experimental results from this field trial for several reasons. Because the plot sizes were so large, there was too much variability within each plot, making accurate sampling for biomass measurements difficult. Also the procedure used for hand seeding produced variable seeding rates across the field. Finally, during the summer, irrigation was not evenly applied, due to lack of good equipment and lower than expected water pressure.

![Field trial plots](image)

In August, we flew the field with a drone to capture an aerial view of

One important difference has been observed in the field: the biochar plots seem to have more clover than the control plots.

![Field trial plots](image)

Left: Control plots with no biochar have more grasses.
Right: Biochar plots show a greater concentration of clover.
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.

**Biochar Return on Investment Analysis**

Cost and benefits from making and using biochar include the following:

**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

**Next Steps**
- In Fall 2017 we received a donation of two cubic yards of biochar from Oregon Biochar Solutions. We fermented this biochar with a solution of EM1 and nutrients and applied it to the biochar treatment plots along with 50 pounds of dryland pasture mix.
- Daisy Hill Farm plans to make more biochar in spring 2018.
- Daisy Hill Farm will continue to monitor the field trial plots.
- Irrigation will be delayed in summer 2018 and the field plots will be visually monitored to see if the biochar plots are any different.
Pictures

Figure 1. Biochar production session.

Figure 2. Feedstock was mainly grape vines.
Figure 3. About two cubic yards of biochar was produced.

Figure 4. Compost ingredients.
Figure 5. Grasses, clover and knapweed on field before tilling.

Figure 6. Pulling up as many blackberries as we can before tilling. Lime and fertilizer were spread before tilling.
Figure 7. Mixing the biochar compost with additional biochar.

Figure 8. Applying biochar compost mixture by hand.
Figure 9. Hand-seeding the plots.

Figure 10. We were not able to roll the field after seeding, so we applied straw to hold moisture for germination.
Figure 11. Seeds sprouting - picture taken on April 21, 15 days after seeding.

Figure 12. By June the new growth was well established on all of the plots.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

**Farm Report: East Fork Farm**

**Farm Info**  
Jerry and Lisa Sabol  
2683 Shoestring Rd, Riddle, OR 97469

**Management Activities and Goals**  
Jerry and Lisa Sabol manage their 225 acre farm for grazing, woodlot and garden vegetables. They breed purebred Irish Dexter Cattle for sale, with about 10 cow-calf pairs. They have a small flock of chickens and several donkeys and mules that help protect the other livestock from predators. A high tunnel greenhouse grows vegetables year round and a one-acre garden grows summer vegetables. A diverse orchard with fruit trees, blueberries and grapes has been established and new plantings are added every year.

More than half the acreage is forested in mixed conifer and white oak. They have done light touch logging and thinning to restore oak woodland habitat with help from BLM and US Fish and Wildlife Service. Other conservation projects on the land include riparian fencing, addition of root wads for stream revetments and installation of four 3000-gallon tanks to store barn roof runoff to reduce nutrient leaching and to store water for summer use. They have planted many native trees in areas where blackberry was removed.

The pasture was compacted by previous management as it was over-grazed. The Sabols have reduced the stocking rate on the pasture and have sprayed compost tea to help build up soil carbon. They do regular soil testing and can see that their efforts have raised soil carbon in the pasture. Management goals include reducing the amount of time spent managing manure and compost, and improving soils in the garden and orchard. The biggest challenge they have, however, is finding good organic fertilizers for the non-irrigated pasture. There is not enough manure compost to use directly on the pasture. Currently they use compost tea and liquid fish spray, but more fertility is needed.

**Biochar Production**  
Jerry Sabol prefers to make biochar by himself, using a single five foot kiln, when he has the time. This is similar to his method for tackling the multiple burn piles on his property in the past. The difference now is that he takes a bit more time to use the kilns. Because his property is large, it made sense to transport kilns to the piles rather than move all of the feedstock to a central burn area. Jerry began using his tractor to move the kilns and also to dump them when they were full. His methods inspired our kiln design with fork pockets to make it easier to use a tractor to pick up and move kilns. Jerry got the new tractor kiln in December 2017 and he thinks it is an improvement, however, he found that the 1” drain hole in the bottom of the kiln gets plugged too easily so the kiln does not drain. He will modify the kiln and put in a larger drain. Previously, Jerry had to share a kiln with other farmers and only had it part of the time. Now that Jerry has a kiln on his property, he anticipates making more biochar during convenient times.
Jerry has kept a data log of his biochar burns. The information is summarized here:

- Two burns in spring 2016 produced about 3 cubic yards using a total of 7 hours of labor.
- No biochar was produced in Winter 2016-17 because of wet weather.
- Three burns during Winter 2017-18 produced about 3 cubic yards of biochar using a total of 13.5 hours of labor.

The difference in productivity is primarily a result of different feedstocks and variable moisture content. His feedstocks have included: pine, fir and elm branches, old lumber, willow, blackberry canes and wood from pallets.

**Biochar Crushing**

So far, Jerry has been chopping up biochar with a shovel. This method produces a mix of fines and larger particle sizes up to an inch across. This size distribution works ok in compost, but shovel chopping is time consuming.

**Manure and Compost**

Jerry has been using the biochar in small compost piles composed of mixed cattle and equine manure. Some of the char was used in urine collection buckets first, so it was charged with urine before adding to compost. 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. He added bokashi (wheat bran inoculated with lactic acid bacteria) to one of the piles. He is not turning the piles at all.

This pile construction differs from his past practice which was to use large heaps for composting. He reports that those piles took several years to break down. Jerry uses a compost thermometer to check the pile temperatures and reports that the new, smaller windrows with biochar are heating up, but not getting as hot as the big piles did. However, the piles with biochar are composting much faster, with less shrinkage that his previous practice. The pile with bokashi added is doing especially well. He estimates that the volume of compost he can produce in small piles with biochar is double the amount he produced previously.

This makes sense because 1) biochar does not break down and retains its original volume; and 2) during a long composting period in large piles, more of the carbon would have been lost to the atmosphere as CO₂ from the microbial oxidation. Studies have shown that biochar added to compost not only retains nitrogen and other nutrients, but it also retains dissolved organic carbon.

**Barns and Pens**

The Sabols do not want to change their current practice of daily barn cleaning because it is an effective method of interrupting pest and parasite cycles in the barn and protecting animal health. However they do have outdoor pen areas that could benefit from biochar to control winter muck. As they accumulate more biochar, some of it will go toward that use.

**Biochar Application to Soil**

Some biochar was mixed with urine and applied to orchard trees. Some plain biochar was used in the summer garden on tomatoes last year, with no discernable differences to previous year’s production. Starting in 2018, they will use the biochar compost in the summer garden.
Addressing pasture fertility with biochar is a bigger task, and one approach would be to add biochar to animal feed. As the cattle and other animals graze, they would deposit small amounts of biochar mixed with manure directly onto the pasture. The ranch has a good population of dung beetles that feed on the manure and carry it into the soil profile. This is an excellent method of applying biochar to pasture that has been used and documented by researchers in Australia.

**Biochar Return on Investment Analysis**

Reviewing Jerry Sabol’s biochar production records, and his impressions of the benefits received, we estimated the return on investment:

**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.

**Farmer Satisfaction**

Jerry Sabol is pleased with the impact of biochar on his manure compost. He anticipates positive results from using biochar compost in the garden and orchard, but that still needs to be demonstrated. Since he was already spending a significant amount of time managing fuels and brush by burning them in piles, he is pleased to be able to produce biochar with only a little extra effort. He said, “*I am spending about 20% more time managing brush and fuels and getting twice the amount of compost.*”

**Next Steps**

Now that East Fork Farm has a kiln on site, Jerry Sabol anticipates that he will be able to produce a lot more char, as he will be able to more easily take advantage of good weather conditions during the burn season. He would like to experiment more with bokashi as a compost accelerator and soil inoculant. He would also like to try some biochar feeding experiments both to benefit animal health and as a way to apply biochar to the pasture.
Photos

Figure 1. East Fork Farm

Figure 2. Oak savannah restoration at East Fork Farm has produced a lot of small diameter pine and fir slash, distributed around the property.
Figure 3. Some of the livestock at East Fork Farm. Water tanks store runoff water from the barn roof, protecting water quality.

Figure 4. Outdoor pen that could benefit from biochar.
Figure 5. Large compost heaps take a long time to break down into good compost.

Figure 6. New compost windrows with biochar are smaller and they compost faster.
Figure 7. Using the tractor to dump a biochar kiln.

Figure 8. Dumping onto a layer of old roofing.
Figure 9. Quenching while dumping.

Figure 10. Finished char. Early efforts resulted in some un-cooked char. More experience leads to better results.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

**Farm Report: Michaels Ranch**

**Farm Info**
Troy and Holly Michaels  
1085 Michaels Ranch Ln Days Creek, OR 97429

**Management Activities and Goals**
Michaels Ranch produces Emerald Hills Beef on the 756-acre Ranch property and some additional leased acreage. Beef is grass-finished. They also produce lamb. Stock includes 200 beef cow/calf pairs, 200 yearlings and 325 ewes on 450 acres of grazing land. About 120 acres of forest needs occasional management for fuels reduction. Blackberry invasion is managed with herbicides. Pasture fertility is a constant concern. Soils are low pH (between 5.2 and 6.0) and somewhat low in potassium. Several years ago, Michaels Ranch began using high carbon boiler ash as a liming agent and to supply potassium. Fields that received boiler ash applications seemed to green up better in the spring than untreated fields. Boiler ash is an economical alternative to lime, which is very expensive in Oregon.

Troy Michaels is currently applying 200 lbs/ac of NPKS fertilizer (10-20-18-10) on his pastures. He also uses manure from the winter barn where 150 calves are fed every year. The barn is scraped and manure is piled until it can be applied with a manure spreader in different sections of the pasture for fertilizing and increasing soil carbon. He is able to cover about 15-20 acres each year with barn manure. His manure spreader applies about 2 tons per acre. The winter barn produces two piles of about 30 cubic yards each. No bedding is used in the barn, so the barn scrapings are almost 100% manure. These piles shrink as the manure breaks down, however, there is not enough aeration to produce thermophilic compost.

**Biochar Production**
One biochar production session during February 2016 produced about one cubic yard of biochar. While Michaels Ranch does have woody debris and brush that could be used as biochar feedstock, they do not currently spend much time managing their woodlands, so adding biochar production would be a major new time commitment for them. As a result, all of the biochar used in this project has come from high carbon boiler ash (about 40% carbon and 60% ash) that is delivered free by a local sawmill. According to the International Biochar Initiative’s biochar standards for carbon content, this high carbon ash could qualify as a biochar material.

**Biochar Analysis**
We sent samples of the biochar (high carbon ash) to both a soil lab and a biochar lab for analysis. The soil analysis gave us extractable nutrients, and the biochar lab analysis gave us more accurate carbon and ash fractions, also distinguishing fixed carbon from degradable carbon and providing a surface area measurement based on butane activity. This biochar has a higher percentage of volatile, or degradable carbon than biochar that we have made in the flame cap kilns, and a much higher percentage of ash. Butane activity of this material (dry ash-free basis) indicates a specific surface area of about 500 m²/g, which is quite high, and is similar to our other biochar materials. The high ash content provides both neutralizing value and carbonates, reported as a percentage of lime. Results are given below:
ORGANIC FERTILIZER REPORT

REPORT OF ANALYSIS IN PERCENT

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>Cu</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2</td>
<td>0.48</td>
<td>0.78</td>
<td>1.79</td>
<td>2.380</td>
<td>2.867</td>
<td>0.290</td>
<td>0.940</td>
<td>7.260</td>
<td>1.130</td>
<td>11910</td>
<td>17510</td>
</tr>
</tbody>
</table>

REPORT OF ANALYSIS IN PARTS PER MILLION

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>Cu</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2</td>
<td>9.6</td>
<td>15.6</td>
<td>35.7</td>
<td>47.6</td>
<td>57.3</td>
<td>5.8</td>
<td>18.8</td>
<td>145.2</td>
<td>22.6</td>
<td>23.8</td>
<td>35.0</td>
</tr>
</tbody>
</table>

POUNDS OF NUTRIENTS / TON

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>Cu</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2</td>
<td>9.6</td>
<td>15.6</td>
<td>35.7</td>
<td>47.6</td>
<td>57.3</td>
<td>5.8</td>
<td>18.8</td>
<td>145.2</td>
<td>22.6</td>
<td>23.8</td>
<td>35.0</td>
</tr>
</tbody>
</table>

□ Reported on an as-received basis
☑ Reported on a dry basis

Moisture = 59.72%
Organic Matter = 53.47 %
CaCO3 Equivalent = 23.46 %

Our reports and letters are for the exclusive and confidential use of our clients, and may not be reproduced in whole or in part, nor may any reference be made to the work, the result of the company in any advertising, news release, or other public announcement without obtaining our prior written authorization.

GABILAN LABORATORY

Client: Kalpjo
Date Received: 30 of May 2016
Account No.: 3-Char-Agr.-May
Sample I.D.: A2 Michaels

Biochar (physical properties)

<table>
<thead>
<tr>
<th>Property</th>
<th>as-Received</th>
<th>Dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHs value</td>
<td>8.40</td>
<td>NA units</td>
</tr>
<tr>
<td>Electrical Conductivity (ECE)</td>
<td>1.485</td>
<td>NA mhos/cm</td>
</tr>
<tr>
<td>Moisture</td>
<td>63.4</td>
<td>0.0 percent</td>
</tr>
<tr>
<td>Water Holding Capacity</td>
<td>73.3</td>
<td>73.3 mls water per 100g dry char</td>
</tr>
<tr>
<td>Volatile Fraction (VF) (total)</td>
<td>15.4</td>
<td>42.2 percent</td>
</tr>
<tr>
<td>Fixed Fraction</td>
<td>68.2</td>
<td>68.2 percent of VF</td>
</tr>
<tr>
<td>Non-fixed fraction</td>
<td>31.8</td>
<td>31.8 percent of VF</td>
</tr>
<tr>
<td>Ash (total)</td>
<td>21.2</td>
<td>57.6 percent</td>
</tr>
<tr>
<td>acid soluble ash</td>
<td>39.9</td>
<td>39.9 percent of ash</td>
</tr>
<tr>
<td>acid non-soluble ash</td>
<td>60.1</td>
<td>60.1 percent of ash</td>
</tr>
<tr>
<td>Recalcitrant Carbon (estimated)</td>
<td>3.6</td>
<td>9.8 percent</td>
</tr>
<tr>
<td>Estimated at 95% of fixed carbon dry ash-free basis (DAF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutralizing value</td>
<td>9.2</td>
<td>25.2 % (as CaCO3)</td>
</tr>
<tr>
<td>Carbonate value</td>
<td>4.2</td>
<td>11.43 % (as CaCO3)</td>
</tr>
<tr>
<td>Butane activity</td>
<td>NA</td>
<td>5.0 g/100g dry char</td>
</tr>
<tr>
<td>Density</td>
<td>Dry ash-free</td>
<td>11.8 g/100g DAF char</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>132</td>
<td>48.4 lb/cu ft</td>
</tr>
<tr>
<td>Particle Density (acetone)</td>
<td>NA</td>
<td>1.463 g/cc</td>
</tr>
</tbody>
</table>
Manure Management and Compost

In spring 2016, manure from the winter barn was removed and piled into two piles. We had hoped to apply biochar in one side of the barn so that the cattle could mix it into the manure with their hooves, but time constraints prevented that. Instead, the biochar was mixed into one of the piles during the cleanup. About 6 cubic yards of biochar were added to the pile. This pile was about 30 cubic yards in volume, so we estimate that it had about 20% biochar by volume. Since the biochar is only 40% carbon, we had added about 8% carbon to the pile and 12% wood ash. The second pile had no biochar and served as a control for temperature measurements. Temperatures were monitored for several months, and neither pile exceeded 90 degrees F, which is typical of a manure pile with no added bedding. Even though the biochar did add carbon to the manure, it was not well-mixed into the manure, so there were large pockets of pure manure and pockets of biochar, not mixed in. The material from these two piles was used in the subsequent field trial on Michaels Ranch.

In 2017, biochar was added at the beginning of the winter directly into the barn so that manure and urine would soak into the char and animals would mix it with their hooves. Biochar was added in December 2016 and again in February 2017 after the first cleaning. The dump truck holds about 6 cubic yards and six truckloads were used altogether for 36 cy over the two applications, or 18 cy per application. Looking at the size of the piled barn scrapings (approximately 60 cy), we estimated that the application rate of biochar to manure was about 60% by volume. Again, because of the high ash content, the percentage of carbon added was about 24% by volume.

Manure was removed and piled in two piles in late May. This time, both piles were the same – a mix of biochar and manure. We monitored the pile temperatures sporadically throughout the summer. Temperatures measured in both piles reached 140 degrees F and stayed at above 120 degrees for several months. The material is well-mixed and has a much finer texture than the 2016 mixed manure-ash. It resembles soil, not manure, and has no manure odor.

Compost Testing and Bioassay

Both pot and field trials were done with the manure and manure plus biochar from the 2016 piles. Samples from both 2016 piles and from the 2017 pile were sent for analysis of nutrient content and biological activity. See results below:

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Dry Combustion Direct Measure</th>
<th>Mass Loss</th>
<th>KCl Extraction</th>
<th>Total - Dry Ash Procedure</th>
<th>Extractable - Mehlich 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample ID</td>
<td>C:N</td>
<td>Total C</td>
<td>Total N</td>
<td>Total Ash</td>
</tr>
<tr>
<td>MRBM16</td>
<td>217097-1</td>
<td>13</td>
<td>10.90</td>
<td>0.82</td>
<td>79</td>
</tr>
<tr>
<td>MRBM17</td>
<td>218211-1</td>
<td>14</td>
<td>17.78</td>
<td>1.27</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Sample ID</td>
<td>CAL ID number</td>
<td>B-glucosidase activity, nmol/g dry soil/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRBM16</td>
<td>217097-1</td>
<td>51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRBM16</td>
<td>217097-3</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRBM17</td>
<td>218211-1</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

The MRMB17 manure compost had retained even more N. 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 (.78%).

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 more than three times the enzyme activity of the plain manure, corresponding to the temperature measurements we took during the composting process, indicating strong microbial action.

A pot trial compared the MRM16, MRMB16, and a control. These are the materials that we used in the subsequent field trial. While both manure treatments produced increases in growth indicators over the control, they were not significantly different from each other. The results are given below:
Field Application and Field Trial Establishment
We established a field trial on a section of pasture at Michaels Ranch in fall 2016.

**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:**
- Biochar only
- Manure only
- Biochar mixed with manure
- Control

**Experimental Design:**
- Randomized block design
- Three replicates
- Plot size – 12’ wide strips about 100 feet long. No buffer strips

**Plot Map:**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRMB16</td>
<td>96</td>
<td>41</td>
<td>1.96</td>
</tr>
<tr>
<td>MRM16</td>
<td>100</td>
<td>43</td>
<td>2.07</td>
</tr>
<tr>
<td>Control</td>
<td>98</td>
<td>38</td>
<td>1.58</td>
</tr>
</tbody>
</table>
Initial soil analysis:

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>CAL ID number</th>
<th>pH</th>
<th>pH</th>
<th>uS/cm</th>
<th>dS/m</th>
<th>ratio</th>
<th>%</th>
<th>ppm</th>
<th>nmol/g dry</th>
<th>nmol/g C/hr</th>
<th>umol/g dry soil/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR W2</td>
<td>217097-4</td>
<td>6.3</td>
<td>6.6</td>
<td>117</td>
<td>0.127</td>
<td>11</td>
<td>2.60</td>
<td>0.24</td>
<td>8.8</td>
<td>153</td>
<td>5874</td>
</tr>
<tr>
<td>MR W1</td>
<td>217097-5</td>
<td>6.4</td>
<td>6.7</td>
<td>130</td>
<td>0.127</td>
<td>10</td>
<td>2.20</td>
<td>0.22</td>
<td>6.2</td>
<td>141</td>
<td>6388</td>
</tr>
<tr>
<td>MR W3</td>
<td>217097-6</td>
<td>6.4</td>
<td>6.6</td>
<td>130</td>
<td>0.127</td>
<td>11</td>
<td>2.60</td>
<td>0.24</td>
<td>8.7</td>
<td>183</td>
<td>7039</td>
</tr>
</tbody>
</table>

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 (from center of plots) and 3 soil samples per plot
- Consolidated soil samples by treatment and sent for analysis.
- July 12 – opened fences for grazing

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 clumps and fines that did not flow evenly 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.

### Treatment Application Rates - 3 calibrations samples per block on 18" paper squares

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Average, t/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>29.02</td>
<td>131.02</td>
<td>137.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>277.68</td>
<td>119.16</td>
<td>78.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>87.14</td>
<td>88.2</td>
<td>109.23</td>
<td></td>
</tr>
<tr>
<td>Total, g</td>
<td>343.84</td>
<td>338.38</td>
<td>325.89</td>
<td></td>
</tr>
<tr>
<td>lbs/ac</td>
<td>4891.80</td>
<td>4814.10</td>
<td>4636.4</td>
<td></td>
</tr>
<tr>
<td>tons/ac</td>
<td>2.4</td>
<td>2.4</td>
<td>2.3</td>
<td>2.39</td>
</tr>
</tbody>
</table>

| Biochar            | 394.03  | 173.87  | 131.791 |               |
|                    | 82.17   | 174.33  | 174.33  |               |
|                    | 137.46  | 220.89  | 283.17  |               |
| Total, g           | 613.66  | 569.09  | 589.291 |               |
| lbs/ac             | 8730.60 | 8096.50 | 8383.9  |               |
| tons/ac            | 4.4     | 4.0     | 4.2     | 4.20          |

| Manure + Biochar   | 288.98  | 72.49   | 235.06  |               |
|                    | 96.28   | 160.2   | 60.18   |               |
|                    | 157.06  | 66.48   | 201.74  |               |
| Total, g           | 542.32  | 299.17  | 496.98  |               |
| lbs/ac             | 7715.60 | 4256.30 | 7070.5  |               |
| tons/ac            | 3.9     | 2.1     | 3.5     | 3.17          |
**Forage Harvest Results:** The results of the forage harvest are inconclusive, with too much variability between treatment plots to come to any statistically solid conclusions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>352</td>
<td>335</td>
<td>284</td>
<td>323.7</td>
</tr>
<tr>
<td>Biochar</td>
<td>364</td>
<td>410</td>
<td>302</td>
<td>358.7</td>
</tr>
<tr>
<td>Manure + Biochar</td>
<td>339</td>
<td>289</td>
<td>362</td>
<td>330.0</td>
</tr>
<tr>
<td>Control</td>
<td>307</td>
<td>327</td>
<td>387</td>
<td>340.3</td>
</tr>
</tbody>
</table>

**Soil Test Results:** 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, removing 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.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>%</th>
<th>ratio</th>
<th>pH</th>
<th>dS/m</th>
<th>µmol/g soil/day</th>
<th>µg CO₂-C/g soil/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar</td>
<td>0.1</td>
<td>3.89</td>
<td>0.23</td>
<td>16.9</td>
<td>7.20</td>
<td>7.03</td>
</tr>
<tr>
<td>Manure</td>
<td>0.1</td>
<td>3.24</td>
<td>0.27</td>
<td>12.0</td>
<td>7.08</td>
<td>6.76</td>
</tr>
<tr>
<td>Manure+Biochar</td>
<td>0.1</td>
<td>2.91</td>
<td>0.25</td>
<td>11.6</td>
<td>6.99</td>
<td>6.77</td>
</tr>
<tr>
<td>Control</td>
<td>0.1</td>
<td>3.67</td>
<td>0.26</td>
<td>14.1</td>
<td>7.08</td>
<td>6.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>ppm = mg nutrient/kg soil</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar</td>
<td>4.3</td>
<td>117.7</td>
</tr>
<tr>
<td>Manure</td>
<td>4.7</td>
<td>75.9</td>
</tr>
<tr>
<td>Manure+Biochar</td>
<td>4.5</td>
<td>69.1</td>
</tr>
<tr>
<td>Control</td>
<td>2.6</td>
<td>66.0</td>
</tr>
</tbody>
</table>

**Field Trial Discussion**
Given the imprecision of the manure spreader in evenly applying the amendments, it is not possible to draw any statistically valid conclusions from this field trial. As a demonstration project, however, it revealed important logistical issues regarding biochar application methods. It is possible that the biochar manure compost from 2017 will be easier to spread than the other materials, since it is more well-mixed and has produced a more friable material with less clumping.

This demonstration project will return the most value if it can be continued for several more years. Troy Michaels is interested in continuing the practice of adding biochar to the winter barn and making applications to the plots. He is planning another application in the spring of 2018. The second application will modify the original treatments, because there is no longer any plain manure. The plain manure treatments will be left as is, while the manure+biochar and the biochar only treatments are repeated. Over the next several years, these plots can be observed for any differences in spring green up or late season drought tolerance. It is not likely that the Michaels Ranch can continue grazing exclusion to compare forage yields, but we hope that annual soil tests will help Michaels Ranch continue to monitor the results of these test applications of biochar and biochar manure compost.
Biochar Return on Investment Analysis
Since the biochar used at Michaels Ranch is delivered for free, the only costs involved are the costs of applying it to fields or to the barn.

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
- 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

Farmer Satisfaction
Michaels Ranch had been using biochar, as high carbon boiler ash, for several years prior to this project. They used high carbon ash as a lime substitute. Lime spreading costs $90/ac for 1 ton of lime. While the high carbon ash has only about one seventh of the liming value of lime, Troy Michaels noticed that the fields where he had applied boiler ash greened up faster in the spring. This experience has motivated Michaels Ranch to further explore biochar. If the biochar can also increase the value of manure by retaining more nitrogen, that is an additional benefit worth investigating.

Next Steps
- Michaels Ranch will continue the application of biochar in the winter barn.
- In April 2018, Michaels Ranch will spread the 2017 manure-biochar compost on the plots where the 2016 manure-biochar was spread. They will also spread another application of the plain biochar.
- We will use the spreader calibration protocol when spreading the fine-textured manure-biochar compost from 2017, and see if it produces more uniform results.
Photos

Figure 1. Ranch owner Troy Michaels in field that was used for trial.

Figure 2. April 2016 - manure pile without biochar.
Figure 3. April 2016 - Checking temperature of manure pile mixed with biochar.

Figure 4. Field trial plot picture taken in March 2017 before fencing. Sheep were on it all winter. No visible growth differences between plots.
Figure 5. Sheep grazing on field trial plots, March 2017.

Figure 6. Winter barn in 2017 with 36 cubic yards of biochar added.
Figure 7. Manure compost from 2017 winter barn scraping. This pile got hot.

Figure 8. Field trial plots in June 2017. They are not as green as rest of pasture because they were not fertilized with NPK.
Figure 9. Equipment used to harvest samples from field trial plots.

Figure 10. High carbon boiler ash that is delivered to Michaels Ranch from a local sawmill.
Conservation Innovation Grants Number: 69-0436-15-0059
Grantee Name: South Umpqua Rural Community Partnership
Project Title: On-Farm Production and Use of Biochar for Composting with Manure

Farm Report: Morrison-Fontaine Forestry

Farm Info
Donald B. Morrison and Barbara L. Fontaine
7701 Buckhorn Rd, Roseburg, OR 97470

Management Activities and Goals
The 90-acre property is managed for timber, hay, homestead and recreation. Income from timber harvest covers costs for road maintenance, hiking trails, non-commercial harvest and fuel treatments as well as stream habitat improvements. The goal for timber management is to maintain at least 30-50% canopy closure on half of the mature stand acreage. Owners also want to use biochar to help raise soil pH and increase moisture and nutrient retention in hay field soils.

Biochar Production and Analysis
Biochar production began in fall 2015. Approximately 7 pickup truck loads of forest slash were used to make 2 cubic yards of biochar. Kiln used was the simple "ring of fire" kiln made of roofing steel. In fall 2016, about 2 cubic yards of char was made in the Oregon Kiln. An additional 7 cubic yards of biochar was made in 2017 using the Oregon Kiln and a new design for the Ring of Fire Kiln that includes a heat shield.

Analysis results of some of the biochar materials produced are given below. One difference between wet-quenched and dry-quenched biochar is the ash content is higher for the dry quenched material. We also tested some biochar chunks that were picked out of a finished compost pile. The composted biochar has less active surface area as measured by butane activity, most likely because composting has deposited organic material on the biochar surfaces that have filled the active adsorption sites.

<table>
<thead>
<tr>
<th>Biochar Sample</th>
<th>Notes on sample origins</th>
<th>pH</th>
<th>EC (mmhos/cm)</th>
<th>Volatile Matter %</th>
<th>Fixed Carbon %</th>
<th>Neutralizing value (%) CaCO3</th>
<th>Water Holding Capacity (ml water per 100 g dry char)</th>
<th>Butane Activity (g/100g dry ash free char)</th>
<th>Dry Bulk Density (lb/cu ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Morrison madrone</td>
<td>wet quenched</td>
<td>8.1</td>
<td>1.672</td>
<td>10.2</td>
<td>13.5</td>
<td>76.3</td>
<td>5.6</td>
<td>81.3</td>
<td>23</td>
</tr>
<tr>
<td>4. Morrison mixed conifer</td>
<td>wet quenched</td>
<td>9.2</td>
<td>0.61</td>
<td>8.6</td>
<td>20.4</td>
<td>71</td>
<td>6.2</td>
<td>107.9</td>
<td>7</td>
</tr>
<tr>
<td>5. Morrison mixed conifer</td>
<td>dry quenched</td>
<td>9.5</td>
<td>0.82</td>
<td>30.3</td>
<td>17.4</td>
<td>52.3</td>
<td>1.6</td>
<td>113.2</td>
<td>7.5</td>
</tr>
<tr>
<td>6. Morrison mixed conifer</td>
<td>composted (dry quenched)</td>
<td>9</td>
<td>1.9</td>
<td>14.1</td>
<td>0.26</td>
<td>85.6</td>
<td>14.9</td>
<td>124</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Biochar Production Logistics
As a forester, Don Morrison developed a functional and efficient set of logistics for handling and processing logging slash into biochar. He used an ATV and trailer to move logging slash and to move kilns and water tanks to biochar production areas. He and UBET President, Scott McKain, developed the modular Ring of Fire Kiln design with heat shield and innovative quenching lid. As a result of
their successful integration of biochar into ongoing forestry activities. Morrison-Fontaine Forestry made more biochar than any other farm, producing a total of 11 cubic yards over the two-year project. Don Morrison also moved from wet-quenching biochar to a dry-quenching technique. Dry quenched biochar was preferred because it is more brittle and easier to crush than wet biochar.

Biochar Compost
In 2016, biochar was mixed with goat manure, steer manure and hay to make three 3.5 cy compost piles. Temperatures were monitored and reached 140 degrees F. Piles were hot for weeks and never turned, with lots of worms at the end. In 2017, similar compost piles were made again and this compost has been used in the vegetable garden each year. This farm also made a fermented biochar that was incubated in a liquid bath with alfalfa, molasses and worm castings for about 10 weeks in January-April 2017. This material was made for use in the field trial.

Fermented Biochar Recipe
- 1/3 cy of crushed biochar
- 50 lbs alfalfa pellets
- 2 qt worm castings
- 2 c molasses
- water

This biochar “soup” was sent for analysis with results given below:

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>pH</th>
<th>EC</th>
<th>C:N</th>
<th>Total C</th>
<th>Total N</th>
<th>NO3-N</th>
<th>NH4-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSOUP</td>
<td>8.5</td>
<td>3.56</td>
<td>42</td>
<td>67.30</td>
<td>1.59</td>
<td>803.0</td>
<td>18.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>B-glucosidase activity</th>
<th>CO2 Respiration</th>
<th>Active Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSOUP</td>
<td>8</td>
<td>0.2</td>
<td>12</td>
</tr>
</tbody>
</table>

Pot Trials
We conducted an initial pot trial with the help of USDA ARS in Corvallis to learn more about the Morrison Fontaine pasture soil and how it would respond to three different types of biochar with and without fertilizer. Two of the biochar materials were high carbon boiler ash with only about 40-50% carbon. The third material was the Morrison Madrone biochar listed in the biochar analysis results table above. The complete report is included in the Appendix to the Final Report.

In this experiment, four treatments, both fertilized and unfertilized, were compared against a no amendment control, with five replications. Micronized calcium carbonate was included to compare with the liming contribution of biochar and boiler ash. Two rates of urea-N addition (0 lbs/ac and 100 lbs/ac) were used in all treatments, including the un-amended control soil. Rye grass seeds were planted in pots and thinned to one plant per pot after germination. Plants were grown in a greenhouse for six weeks and then harvested for analysis.
Results of the trial showed that the biggest effect from application of biochar was the addition of mineral ash, providing trace minerals and liming capacity. There was also a slight effect of increased soil moisture detected in the Morrison Madrone biochar treatment.

Field Trial
A field trial was established in spring 2017 using four treatments and a control. There were two biochar treatments. One was the fermented biochar described above, with added lime, and the other was plain, uncomposted biochar, with added lime and triple 16 fertilizer.

Goals: Establish perennial forage plants for wildlife, improve soil fertility by adding lime, fertilizer and seed. Improve soil fertility, neutralize acidity, and increase moisture-holding capacity and tilth with biochar and biochar compost additions (plus fertilizer and lime). Determine impact of biochar. Determine soil and forage improvement costs for 3 to 8 acres of degraded hayfield.

Field 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.

Initial Soil Analysis:

December, 2015. AgSource Labs

<table>
<thead>
<tr>
<th>OM%</th>
<th>N</th>
<th>Nitrate N</th>
<th>NH4-N</th>
<th>P (weak B)</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>S</th>
<th>soil pH</th>
<th>buffer index</th>
<th>CEC</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>Na</th>
<th>Mg (meq/100g)</th>
<th>Ca (meq/100g)</th>
<th>Mn</th>
<th>Zn</th>
<th>Fe</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>9</td>
<td>16</td>
<td>36</td>
<td>88</td>
<td>240</td>
<td>1200</td>
<td>19</td>
<td>5.1</td>
<td>6.2</td>
<td>16.7</td>
<td>1.4</td>
<td>11.1</td>
<td>33</td>
<td>0.6</td>
<td>2</td>
<td>6</td>
<td>37.1</td>
<td>1.3</td>
<td>76.5</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

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

Experimental Design:
- Five treatments with three replicates.
- Plot size is 3-meter x 3-meter (approximately 10 ft x 10 ft)
- Blocks are oriented perpendicular to slope gradient of approximately 7%.
Plot Map:

<table>
<thead>
<tr>
<th>Block 1</th>
<th>Lime + 16-16-16</th>
<th>Biochar Compost + lime</th>
<th>Biochar + 16-16-16 + lime</th>
<th>Lime</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 2</td>
<td>Biochar + 16-16-16 + lime</td>
<td>Lime</td>
<td>Control</td>
<td>Lime + 16-16-16</td>
<td>Biochar Compost + lime</td>
</tr>
<tr>
<td>Block 3</td>
<td>Lime + 16-16-16</td>
<td>Biochar + 16-16-16 + lime</td>
<td>Biochar Compost + lime</td>
<td>Lime</td>
<td>Control</td>
</tr>
</tbody>
</table>

Schedule:
- March 2017 – Sprayed Roundup to kill grass
- April 2017 - Slope was tilled with a rototiller along fall line, plots laid out
- Treatments and seed applied
- Plots rolled after seeding with 4-wheeler perpendicular to slope
- Deer fence was erected around the plots
- Summer – No irrigation was used over the summer
- August 30 – Treatments were harvested and dried for several weeks in a barn loft
- September 2017 – took soil samples from each plot and combined by treatment for analysis

Application rates and methods:
- Lime - 2t/ac (110 lb/1200 sf excluding control plots) or approximately 2 x 50# bags/1200 sf of treatment area. Used 1.8 - 50# bags of prilled CaCO3 and applied with a drop spreader.
- 16-16-16 fertilizer - 267 lb/ac (10 oz/100 sf treatment) or ~3.7 lbs/600 sf of treatment area. Spread 10 oz per treatment using a volume sample of appropriate weight.
- Boron 2-3 lb/ac (1.1 oz for 1200 sf: (2.5)(1200)(16)/43560).
- Tetraploid annual rye, 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 ~1cf mixed with the 6 biochar and biochar compost treatment areas (50# bag). Rock dust was unevenly distributed between six treatments with double volume on Block #3 biochar + fertilizer + lime treatment; lower volumes on biochar compost + lime treatments; and with little volume on Block 2 biochar compost + lime treatment
- Biochar Compost application rate: 1/10 cubic yard per 100 square feet treatment area (3 x 5 gallon buckets = 2.34 cf/100sf treatment)
- Biochar application rate: 1/10 cubic yard per 100 square feet treatment area (3 x 5 gallon buckets = 2.34 cf/100sf treatment)

Harvest Results:
Buffer strips were cut after dry standing condition was reached in August using a lawn mower. Then the remaining foliage was cut and collected with mower and grass catcher for each of the 15 treatment areas. Weighed air-dry samples with a hanging scale with 10-gram precision.
Treatment plots with buffer strips mowed before the harvest and weighing of 5 treatments x 3 replicates

Visual observations from earlier in the season suggested a response to both liming and fertilization. This was affirmed by harvest data.

Note: Charcoal label is Biochar. Biochar label is Biochar Compost
Soil Sample Results:
Soil samples were taken and sent to AgSource Lab for soil analysis, and to OSU Lab for microbial and active carbon analysis. Results given below.
Statistics and Field Trial Discussion

We received substantial help in the statistical analysis from Claire Phillips of USDA ARS Forage Seed and Cereal Research Unit at Oregon State University in Corvallis. 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 unamended control, by 407, 390, and 380 grams, respectively (all with p-values ≤ 0.08). They were not significantly different from each other.

```r
> aov1<-aov(Harvest~Treatment+Block, data=Data)
> summary(aov1)

    Df Sum Sq Mean Sq F value Pr(>F)
Treatment  4 414560 103640  4.608  0.0318 *
Block     2  88413  44207  1.966  0.2021
Residuals  8 179920  22490
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 '*' 0.05 '.' 0.1 ' ' 1

> TukeyHSD(aov1)

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = Harvest ~ Trt + Block, data = Data)

$Trt
  diff lwr  upr    p adj
C-BL -390.00000  -813.02469  33.02469  0.0722581
CL16-BL  16.66667  -406.35803  439.69136  0.9999040
L-BL  263.33333  -686.35803  159.69136  0.2871259
L16-BL -10.00000  -433.02469  413.02469  0.9999875
CL16-C  406.66667  -16.35803  829.69136  0.0599865
L-C  126.66667  -296.35803  549.69136  0.8331774
L16-C  380.00000  -43.02469  803.02469  0.0808059
L-CL16 -280.00000  -703.02469  143.02469  0.2417531
L16-CL16 -26.66667  -449.69136  396.35803  0.9993836
L16-L  253.33333  -169.69136  676.35803  0.3174929

$Block
  diff lwr     upr    p adj
B-A  98  173.02072  369.02072  0.5781776
C-A -90  361.02072  181.02072  0.6268645
C-B -188  459.02072  83.02072  0.178008
```

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 microbiologically active biochar-compost, was key to increasing harvest yields.
Biochar Return on Investment Analysis

Cost and benefits from making and using biochar include the following:

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

Next Steps
- The field trial will continue to be monitored for several years and new information about the field trial will be added to the profile on the Oregon Biochar Atlas
Figure 1. Forestry operations yield abundant logging slash for biochar feedstock.

Figure 2. Kilns are easily moved for short distances by dragging with an ATV.
Figure 3. ATV and trailer make it easier to set up biochar production on remote sites.

Figure 4. Don Morrison came to prefer dry quenching biochar over wet quenching. Less need to transport water and easier crushing of dry, brittle biochar are the main reasons.
Figure 5. The modular Ring of Fire Kiln is easy for one person to transport.

Figure 6. Biochar production site at Morrison-Fontaine Forestry.
Figure 7. Successful composting using biochar with fresh manure.
Figure 8. Measuring fertilizer for field trial applications.

Figure 9. Spreading biochar treatments.
Figure 10. Steps to prepare for field trial.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

**Farm Report: Page Creek Ranch**

**Farm Info**  
Art and Jude Vawter  
405 Page Creek Road, Cave Junction, OR 97523

**Management Activities and Goals**  
Page Creek Ranch breeds, raises and trains Akhal-Teke horses for sale. Currently they have about 20 horses, 3 pigs and a flock of 40-50 chickens and guinea hens on the 80-acre property. Most of the property, about 60 acres, is in pasture, with some natural wooded area and significant riparian area along Page Creek. Page Creek was channelized a few decades ago and is still developing natural characteristics. The Vawters have planted many trees in the riparian zone for shade and bank stabilization. Long-term goals include improving pasture and conserving water.

Another goal is to improve the winter barn to make it more practical to feed and clean. They would like to feed all the horses in the barn in winter in order to rest the fields and reduce compaction. They plan to install an aeration system for better compost production. Some compost is used in the garden and orchard, and the rest is spread on fields.

**Biochar Production**  
Abundant wood from past milling operations and existing brush piles provided ample feedstock. Kilns were delivered to Page Creek Ranch in October 2017 and they started making biochar from the old wood piles. Some of the delivered kilns were a heavy duty design with fork pockets for easy transport by a tractor. 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 kilns 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.

In addition to the tractor kilns, the regular forestry kilns were used with a work crew. A Community Fire Plan Grant had paid for much needed fuel reduction thinning in the wooded part of the property the previous spring. This material was piled to dry over the summer. The same grant also paid for a work crew to produce biochar from these piles in November. Altogether about 6 cubic yards of biochar was produced at Page Creek Ranch in fall 2017.

**Biochar Crushing**  
Biochar was not crushed as Page Creek Ranch intends to use the biochar in the horse barn and barnyard where horses’ hooves will crush it.

**Biochar in the Barn and Compost**  
Biochar has been used in the barn for several months. The stable is drier and the horses’ hooves are cleaner and less susceptible to disease. Some of the horses have had problems
with abscesses caused by anaerobic bacteria in the muck. Owners are hopeful that biochar can help with this problem.

As the barn is cleaned and the manure with biochar is piled for composting, the farmers can assess the benefits of biochar to the composting process. If biochar helps to improve the composting process, the Ranch may be able to avoid the cost of installing a compost aeration system.

**Biochar Return on Investment Analysis**

Costs and benefits of making and using biochar on Page Creek Ranch include:

**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 animal health
- Reduced odors and flies in barns and poultry coops
- Improved manure compost quality
- Increased soil carbon
- Improved pasture water holding capacity

**Next Steps**
- Page Creek Ranch is preparing a stable for one of the pregnant mares. They will put down a load of biochar along with wood shavings to improve bedding sanitation.
- They will continue with biochar production as time allows in order to have adequate amounts of biochar for all the barn and barnyard areas.

**Pictures**
Figure 1. Wet barnyard at Page Creek Ranch where biochar will be used.

Figure 2. Tractor kilns were convenient to move to remote parts of the ranch.
Figure 3. Multiple forestry kilns were used with a crew of four workers in the heavily wooded part of the property.

Figure 4. On a busy day with the work crew, rancher Art Vawter loads finished biochar into bags for transport back to the barn.
Figure 5. Using the tractor kilns, biochar can be transported back to the barn in the kiln, saving the step of unloading kilns into separate container for transport.

Figure 6. Biochar ready to be used in the barn.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

---

**Farm Report: Siskiyou Alpaca**

**Farm Info**
John Gardiner and Christine Perala Gardiner  
PO Box 2451, Cave Junction, Oregon 97523

**Management Activities and Goals**
Siskiyou Alpaca manages a herd of 70 alpacas on rented pasture for fiber production and meat. Another income stream is “Paca Poo” composted manure sold to local growers as a premium fertilizer. The farmers wish to add value to this product by incorporating biochar. They would also like to know if biochar can speed or improve the composting or improve compost quality.

**Biochar Production and Analysis**
A stockpile of oak branches was used to make biochar in spring 2016, during one half-day biochar session, producing about two cubic yards. Biochar was subsequently crushed by driving over it with a truck.

**Biochar Analysis Results**
- pH 10.1  
- Ash content: 5.4%  
- Volatile Matter: 21.5%  
- Fixed Carbon: 73.1%  
- Dry Bulk Density: 9.5 lbs/cf

**Manure and Compost**
Alpaca manure is in the form of a small pellet. The animals tend to defecate in only certain areas of the barn, making a pile. These piles are cleaned out within several days and added to a covered windrow for composting. In June 2016, we constructed two compost piles – with and without biochar - in wire bins that held about 1.5 cubic yards of compost. The biochar compost pile had 12.5% biochar by volume. About six weeks later, we constructed two additional piles, one with 3.6% biochar and the other as a control with no biochar. All bins were kept moist by watering with a sprinkler through the summer months. They were uncovered during the winter and received winter rain.

Temperature measurements of both sets of piles showed that the 12.5% biochar pile was a few degrees cooler than the control in the beginning, although both piles reached thermophilic temperatures (128°F and 130°F). The opposite trend was observed for the 3.6% biochar pile and its control. Not only did the 3.6% pile get hotter (134°F vs 122°F), it also reached peak temperature a week earlier. However, these data do not tell the whole story because data collection for the second set of piles did not begin until two weeks after they were constructed.
Piles were composted until April when they were used in a field trial. Observations of the piles during the winter showed that the piles with biochar had fewer worms than the piles without. Generally, the alpaca manure compost has a very high content of red wriggler worms, so the reduced number of worms was notable, although they were still present.

We also noticed that the consistency of the piles was different: even after eight months of composting, both piles without biochar had a slimy, mucky consistency, while both piles with biochar were much more soil-like with crumb structure. The biochar piles also had a lot of weeds and grass growing on top, almost completely covering the piles. The piles without biochar did not have much plant growth on top.
Winter observations on the four compost piles:

<table>
<thead>
<tr>
<th>Date Constructed</th>
<th>Biochar</th>
<th>Temperature on 12/13/16</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/29/16</td>
<td>12.5%</td>
<td>44</td>
<td>Few worms, but very nice and crumbly, looks finished</td>
</tr>
<tr>
<td>6/29/16</td>
<td>0</td>
<td>46</td>
<td>More worms, more slimy, mucky texture, wood fiber not broken down</td>
</tr>
<tr>
<td>8/1/16</td>
<td>3.6%</td>
<td>44</td>
<td>Few worms, more finished looking</td>
</tr>
<tr>
<td>8/1/16</td>
<td>0</td>
<td>44</td>
<td>More worms, more mucky</td>
</tr>
</tbody>
</table>

We also looked at recent manure compost windrows with no biochar:

<table>
<thead>
<tr>
<th>Pile age</th>
<th>Temperature on 12/13/16</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>50 F</td>
<td>Even though pellets broken down, lots of worms</td>
</tr>
<tr>
<td>1 month</td>
<td>76 F</td>
<td>Plenty of worms</td>
</tr>
<tr>
<td>1 week</td>
<td>86 F</td>
<td>Plenty of worms</td>
</tr>
</tbody>
</table>

**Compost Testing and Bioassay**

Three of the compost materials, two piles with biochar and one of the control piles, were sent for analysis with the results given below for nutrient content and biological activity:

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Dry Combustion Direct Measure</th>
<th>Mass loss</th>
<th>KCl extraction</th>
<th>Total - Dry Ash Procedure</th>
<th>Extractable - Mehlich 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ratio</td>
<td>%</td>
<td>%</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>Sample ID</td>
<td>C:N</td>
<td>Total C</td>
<td>Total N</td>
<td>Total Ash</td>
<td>NO3-N</td>
</tr>
<tr>
<td>SAC July</td>
<td>217225-1</td>
<td>14</td>
<td>21.00</td>
<td>1.50</td>
<td>60</td>
</tr>
<tr>
<td>SAC 12.5</td>
<td>217225-2</td>
<td>30</td>
<td>41.50</td>
<td>1.40</td>
<td>35</td>
</tr>
<tr>
<td>SAC 3.6</td>
<td>217225-3</td>
<td>16</td>
<td>23.00</td>
<td>1.40</td>
<td>53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>B-glucosidase activity</th>
<th>CO2 Respiration</th>
<th>Active Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mmol/g dry soil/hr</td>
<td>ug CO2-C/g dry soil/day</td>
<td>mg active C/kg dry soil</td>
</tr>
<tr>
<td>Sample ID</td>
<td>CAL ID number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAC July</td>
<td>217225-1</td>
<td>92</td>
<td>129</td>
</tr>
<tr>
<td>SAC 12</td>
<td>217225-2</td>
<td>33</td>
<td>71</td>
</tr>
<tr>
<td>SAC 6</td>
<td>217225-3</td>
<td>50</td>
<td>97</td>
</tr>
</tbody>
</table>

**Pot Trial**

A pot trial compared the 12.5% biochar compost to the control compost and a control of plain potting soil. Both compost treatments performed better than the control. Biomass yield of the two compost treatments was not significantly different, but the biochar compost had a growth stimulating effect resulting in more secondary leaves than the control compost.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar 12.5%</td>
<td>96</td>
<td>78</td>
<td>2.16</td>
</tr>
<tr>
<td>No Biochar</td>
<td>100</td>
<td>54</td>
<td>2.12</td>
</tr>
<tr>
<td>Control</td>
<td>98</td>
<td>56</td>
<td>1.70</td>
</tr>
</tbody>
</table>
Field Trial

We set up a very simple demonstration to see if biochar composts would have any noticeable effect on a vegetable crop in raised beds. A field trial using bokchoy was established in May 2017 in the vegetable garden.

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:
- W1 - SAC July - Composted alpaca manure with no biochar
- W2 - SAB 12.5 - Composted alpaca manure with 12.5% biochar
- W3 - SAB 3.6 - Composted alpaca manure with 3.6% biochar
- W4 – SAC August - Composted alpaca manure with no 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

Plot Map:

<table>
<thead>
<tr>
<th>W1 – July compost</th>
<th>W2 - 12.5%</th>
<th>W3 - 3.6%</th>
<th>W4 – Aug compost</th>
</tr>
</thead>
</table>

Initial Soil Analysis:

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>CAL ID number</th>
<th>Total ppm</th>
<th>Mehlich ppm</th>
<th>Ratio Total:Mehlich 3 Extractable</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHOYSOIL</td>
<td>217261-4</td>
<td>P 80</td>
<td>K 62</td>
<td>Ca 8911</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>pH</th>
<th>pH</th>
<th>uS/cm</th>
<th>ds/m</th>
<th>ratio</th>
<th>%</th>
<th>ppm</th>
<th>nmol/g dry soil/hr</th>
<th>nmol/g C/hr</th>
<th>umol/g dry soil/day</th>
<th>ug CO2-C/g dry soil/day</th>
<th>ug CO2/g dry soil/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHOYSOIL</td>
<td>5.4</td>
<td>6.5</td>
<td>174</td>
<td>0.174</td>
<td>10</td>
<td>2.50</td>
<td>0.25</td>
<td>169.0</td>
<td>45</td>
<td>1783</td>
<td>1.1</td>
<td>12</td>
</tr>
</tbody>
</table>

Schedule:
- April 2-15, 2017 - rototilled garden area
- April 28 – spread treatments on plots – 15x5gallon buckets (filled to the top) per plot of each treatment – approximately 85 gallons
- April 29-30 – mixed treatments into beds by hand spading and prepared for seeding.
- May 2 – planted bokchoy seed – 2 g of seed per treatment (36 seeds weigh .08g) – approximately 900 seeds per treatment
- May 9 – measured off a 24” section in each bed for counting plant germinations
- May 16 – germination count
• May 23 – germination count
• May 30 – germination count
• June 2 - Harvested all plants that met harvest specifications (at least 6 inches tall)
• Weighed harvested plants from each plot and recorded total weight
• June 9 - Harvest
• June 16 - Harvest
• June 23 - Harvest
• July – took soil samples from each plot (except for W4) and sent for analysis

Application Rates:
• Application rate was .3 cubic feet compost/square foot of garden bed
• Seeding rate was 900 seeds per treatment

Germination Results:

<table>
<thead>
<tr>
<th>Block</th>
<th>10-May</th>
<th>17-May</th>
<th>23-May</th>
<th>Final</th>
<th>Germ. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>60</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>0.49</td>
</tr>
<tr>
<td>W2</td>
<td>68</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>0.56</td>
</tr>
<tr>
<td>W3</td>
<td>43</td>
<td>53</td>
<td>49</td>
<td>49</td>
<td>0.41</td>
</tr>
<tr>
<td>W4</td>
<td>82</td>
<td>93</td>
<td>89</td>
<td>89</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Harvest Results:

<table>
<thead>
<tr>
<th>Block</th>
<th>2-Jun</th>
<th>7-Jun</th>
<th>14-Jun</th>
<th>10-Jul</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>5.75</td>
<td>5</td>
<td>7</td>
<td>16.6</td>
<td>34.35</td>
</tr>
<tr>
<td>W2</td>
<td>1</td>
<td>4.9</td>
<td>6.75</td>
<td>19.6</td>
<td>32.25</td>
</tr>
<tr>
<td>W3</td>
<td>1.25</td>
<td>5.25</td>
<td>5</td>
<td>18.1</td>
<td>29.6</td>
</tr>
<tr>
<td>W4</td>
<td>2.25</td>
<td>3.75</td>
<td>4</td>
<td>17.5</td>
<td>27.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Field Total 123.7</td>
</tr>
</tbody>
</table>

Soil Test Results:

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Lab ID</th>
<th>Moisture</th>
<th>C</th>
<th>N</th>
<th>C:N</th>
<th>pH</th>
<th>BpH</th>
<th>EC</th>
<th>β-glucosidase activity</th>
<th>µg CO₂-C/g soil/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpaca W1 7-17-17 5</td>
<td>0.4</td>
<td>5.53</td>
<td>0.47</td>
<td>11.8</td>
<td>6.85</td>
<td>6.82</td>
<td>0.133</td>
<td>0.84</td>
<td>15.7</td>
<td></td>
</tr>
<tr>
<td>Alpaca W2 7-17-17 6</td>
<td>0.3</td>
<td>5.40</td>
<td>0.36</td>
<td>15.0</td>
<td>7.35</td>
<td>6.99</td>
<td>0.090</td>
<td>0.65</td>
<td>15.7</td>
<td></td>
</tr>
<tr>
<td>Alpaca W3 7-17-17 7</td>
<td>0.3</td>
<td>4.42</td>
<td>0.34</td>
<td>13.0</td>
<td>6.86</td>
<td>6.87</td>
<td>0.107</td>
<td>0.79</td>
<td>18.1</td>
<td></td>
</tr>
</tbody>
</table>
Field Trial Results Discussion
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. We also made the following observations:

Although final germination percentages were not very different between treatments (except for W4), germination was much spottier in W2 and W3 than in W1. We noticed early on that the biochar plots seemed to have less germination overall so we increased the watering, which seemed to bring the germination up in the biochar plots. We think that the biochar chunks on the surface may have been wicking water out of the soil and impacting germination where a biochar chunk was adjacent to a seed. The W-4 plot had the highest germination rate but the lowest overall productivity. That plot had slightly more morning shade than the others, which would support the idea that soil moisture had something to do with variance in germination rates.

Biochar Return on Investment Analysis
Costs and benefits from making and using biochar at Siskiyou Alpaca include the following:

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 seems to improve aeration of compost piles, allowing for taller pile construction. This will help save room in the compost yard.
- Biochar also reduces shrinking of compost, resulting in a greater volume of product.

Next Steps
- Siskiyou Alpaca intends to continue using biochar in the compost windrows.
- They will try for a 5% application rate of biochar.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>ppm = mg nutrient/kg soil</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO3-N</td>
<td>P</td>
</tr>
<tr>
<td>Alpaca W1 7-17-17</td>
<td>5</td>
<td>32.3</td>
</tr>
<tr>
<td>Alpaca W2 7-17-17</td>
<td>6</td>
<td>26.9</td>
</tr>
<tr>
<td>Alpaca W3 7-17-17</td>
<td>7</td>
<td>20.8</td>
</tr>
</tbody>
</table>
• Biochar aeration will allow them to build taller compost windrows, saving space in the compost yard.
• Siskiyou Alpaca will monitor long term productivity in the vegetable beds where the biochar compost treatments were applied.

Pictures

Figure 1. Making biochar from oak branches.

Figure 2. Feedstock was dry and uniform in size, making for efficient biochar production.
Figure 3. Top from L to R: Poo scraped into piles in barn; Paca Poo compost pile; pile construction with biochar; biochar compost under construction; Christine and John Gardiner; finished piles.
Figure 4. Taking sample of compost piles that are 4-5 months old. You can see a lot of shrinkage with less shrinkage of biochar piles.

Figure 5. Four-month-old pile with 3.6% biochar by volume. This pile looks more finished than the control pile, with lots of grass and weeds growing on top.
Figure 6. Alpacas use latrine areas inside the barn, making manure easy to collect.

Figure 7. Bokchoy germinations.
Figure 8. Setting up the treatment plots in the bokchoy bed.

Figure 9. Applying paca-poo compost with different amounts of biochar.
Figure 10. Counting germinations.

Figure 11. Bokchoy harvest was weighed and then sold at a local farmers market.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

**Farm Report: Tierra Buena Worm Farm**

**Farm Info**  
John Livingston  
16909 North Bank Rd, Roseburg, OR 97470

**Management Activities and Goals**  
Tierra Buena Worm Farm is located in a rented warehouse. They have two large worm bins raising compost red worms (Eisenia fetida). For worm bedding and feed, the Farm uses rabbit manure, grass seed cleanings, brewery waste and food waste from other local sources. The Farm sells worms, castings and worm leachate. One goal is to work with the rabbitry to add biochar to the rabbit manure pits to reduce ammonia odors and to provide a more composted substrate for the worms. The farm would like to expand operations to produce commercial quantities of biochar-vermicompost blends, but this will require that the material passes pathogen tests for compost.

**Biochar Production**  
Tierra Buena Worm Farm has covered wood piles and pallets and is a convenient drop-off point for neighbors who can bring woody debris for converting to biochar. About 1.5 cubic yards of biochar was made in 2016 during two sessions and another 1.5 cubic yards was made in 2017. All biochar was crushed and screened with most of the material reduced to a size of 1/2” or less.

**Manure and Compost**  
The rabbitry is in a metal building with rabbit cages elevated over pits that capture manure and urine. A small amount of straw bedding is used, but ammonia emissions are high, requiring active ventilation of the building.

In February 2016, biochar was mixed into one of the manure pits. John Livingston monitored ammonia (using Hydrion pH test strips for ammonia detection) of the pits over a nine-week period, taking measurements about once a week. In addition, the owner of the rabbitry sprayed a lactic acid bacteria inoculant in the entire building once a week. There was a small reduction of measured ammonia emissions in the pit with biochar. Ammonia readings for the biochar pit ranged from 15 to 20 ppm, while the other pits ranged from 20 to 25 ppm. However, it was difficult to make distinct measurements in the open barn as the gaseous ammonia pervades the entire space.

John Livingston also wanted to establish another source of feed for the worms, independent of the rabbitry. He conducted multiple experiments using a bokashi inoculant to pre-compost grass seed screenings, leaves, and food scraps to make them more digestible to worms. Biochar was mixed into the bokashi both before and after the fermentation process.

Different compost and pre-compost materials were offered to worms in small feeding baskets to observe any worm avoidance. So far, the worms have used all the feed, with no avoidance of feed containing biochar or bokashi.
Biochar is also improving the texture of the bedding, keeping it aerated. Previously, the bedding did not have enough carbon and would sometimes get anaerobic on the bottom of the bins. The bedding was also quite compacted and worms were not reproducing well. With biochar, the bedding is less dense, and more baby worms are observed.

The Worm Farm is now harvesting worm castings with added biochar. In order to sell the vermicompost at the farmer’s market in Eugene, they must be certified pathogen free. We sent a sample of the vermicompost for analysis and found that while salmonella was undetectable, fecal coliform bacteria were present at levels above the threshold of 1000 MPN/g, according to NOP Rule 205.105 & 205.203(c). This result would disqualify the vermicompost as a saleable product in that market. Analysis results below:

In 2017, John Livingston began to phase out the use of the rabbit manure and relied more on bags of dog and cat food (acquired for free because they were past expiration date) as worm food. We sent another sample for pathogen analysis in February 2018 and found that the fecal coliforms were reduced to only 3 MPN/g, making the material eligible for certification as a pathogen-free compost. Since the feed was changed from rabbit manure to expired pet food, we cannot draw any conclusions about whether or not the biochar had an impact on fecal coliform numbers. Further testing under more controlled conditions may be warranted. See analysis results, below:
Biochar Return on Investment Analysis
Costs and benefits from making and using biochar at Tierra Buena Worm Farm include the following:

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
- Better worm reproduction and health for more productive vermicomposting
- Tierra Buena Worm Farm should be able to charge a premium for vermicompost with biochar.
- Biochar may be able to reduce the fecal coliform in the vermicompost.

Farmer Satisfaction
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.

Next Steps
- Continue trying new combinations of feed, bedding, and biochar in the worm bins
- Continue producing biochar using waste wood

Pictures
Figure 1. Worm bins in the warehouse.

Figure 2. Additional worm bins ready for expansion.
Figure 3. Manure pits under rabbit cages with buckets to catch some of the urine.

Figure 4. Manure pit with biochar added for odor control.
Figure 5. Making biochar at Tierra Buena Worm Farm.

Figure 6. John Livingston rented a lawn roller to crush biochar.
Figure 7. Char screened into 3 size classes. Left pile is > ½”. Middle pile is between ½” and ¼”. Right hand pile is < ¼”.

Figure 8. Tierra Buena Worm Farm sales booth at a garden show.
**Conservation Innovation Grants Number:** 69-0436-15-0059  
**Grantee Name:** South Umpqua Rural Community Partnership  
**Project Title:** On-Farm Production and Use of Biochar for Composting with Manure

---

**Farm Report: Willow Witt Ranch**

**Farm Info**  
Suzanne Willow and Lanita Witt  
658 Shale City Rd, Ashland, OR 97520

**Management Activities and Goals**  
Willow Witt Ranch produces pastured poultry and eggs, as well as goat milk on 450 acres of high elevation, forested land. Livestock includes about 60 goats, 200 laying hens and 4 guardian dogs. Manure is composted and used in vegetable production and some of it is sold to local gardeners who pick it up by the truckload. Pasture is about 30 acres along the forest edge. Willow Witt Ranch is actively restoring native riparian and wetland areas by livestock exclusion and willow planting. Willow Witt also has a forest management plan for approximately 250 acres of forest in need of hazardous fuel reduction. Recent fuel reduction projects have left several large landing piles of woody debris. Willow Witt Ranch would like to improve composting operations, make better use of woody debris and improve pasture with the goal of increasing the stocking rate of animals.

**Biochar Production**  
Willow Witt Ranch has abundant feedstock suitable for biochar consisting mostly of pine and fir logs and branches with some trash wood and lumber. During two biochar sessions in late 2015 and spring 2016, we made about four cubic yards of biochar. About one cubic yard was made during spring 2017, and three cubic yards were made in fall 2017. During one session, we loaded one kiln with only scrap lumber in order to test the biochar for potential metal contamination from nails and staples. Results found that waste lumber and pallets with nails did not result in excessive levels of zinc or iron in the biochar:

<table>
<thead>
<tr>
<th>Waste lumber w/ nails</th>
<th>Biochar Production Temp (°C)</th>
<th>Dry Sample %</th>
<th>Moisture Content (%)</th>
<th>Volatile Matter (%)</th>
<th>Ash Content (%)</th>
<th>Fixed Carbon (%)</th>
<th>Extractable Zn (mg/kg)</th>
<th>Extractable Fe (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;600</td>
<td>0.3</td>
<td>202.1</td>
<td>10.3</td>
<td>4.1</td>
<td>85.6</td>
<td>11</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>&gt;600</td>
<td>0.4087</td>
<td>333.0</td>
<td>6.9</td>
<td>7.1</td>
<td>85.9</td>
<td>19</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>&gt;600</td>
<td>0.2839</td>
<td>149.6</td>
<td>6.5</td>
<td>6.5</td>
<td>87.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Average               | 228.2                       | 7.9          | 5.9                  | 86.2              | 15.0           | 46.0             |
| SD                    | 94.4                        | 2.1          | 1.6                  | 0.8               |                |                  |

**Biochar Crushing**  
All biochar was crushed to particles of ½ inch or less using a shovel. This was a time consuming operation and one of the next steps will be to see if biochar can be crushed using the farm’s PTO chipper.
Manure and Compost
In order to acidify and condition the biochar, we inoculated about ¾ of cubic yard with bokashi (a blend of lactic acid bacteria, nutrients and wheat bran) and molasses in July. We tested the pH of the char after a month and found that it was reduced from pH 8.5 to pH 5.5. Lowering the pH is important for two reasons: first, it should improve ammonia capture by the biochar in the goat barn. Second, the compost produced on the ranch is already too alkaline leading to problems in the garden beds – see Biochar Application to Soil, below.

After cleaning out the goat barn in October 2016, biochar was added to one ten-foot square section of the barn floor. During the winter, biochar was sprinkled on the bedding approximately once a week. Workers noted that biochar sprinkled on top had the effect of reducing the ammonia smell. During barn cleanout the following June, as we uncovered layers of bedding and manure we sprinkled more biochar (a commercial biochar obtained from Oregon Biochar Solutions) and found that it had an immediate impact on the ammonia. In the past, workers had to wear respirators during cleanout, but found that with the biochar added, respirators were not needed. The barn cleanings were piled for composting.

After the goat barn was cleaned in June 2017, a new protocol was established for the barn using biochar donated by Oregon Biochar Solutions. This biochar has similar carbon content, pH and sorption characteristics to biochar produced on the farm, but it is a nice granular size that is easy to use. It also has low moisture content.

Final Barn Protocol
The barn protocol now in use is simple. Once a week, two 5-gallon buckets of biochar are spread on top of the bedding in the wettest part of the goat barn – a section that is about 12’ x 20’. Then, about a half-gallon of diluted EM-1 inoculant is sprayed over the area. These practices have had very noticeable benefits: there is no longer any detectable ammonia smell (by nose) in the barn, even when digging into the manure pack. The odor is an inoffensive smell of decomposition. A two cubic yard sack of biochar from Oregon Biochar Solutions costs $500. Using 10 gallons a week, it should last for 40 weeks, at a cost of $12.50/week.

Goat and Chicken Yards
Slash pile burning is a regular activity at Willow Witt Ranch, and they continue to use the biochar kilns. They are now starting to use biochar from the kilns in the goat yard. The chunky size of biochar particles is not a problem in the muddy yard, where goats trample on it and crush it, mixing it with soil. When they have produced enough biochar, they will start using it also in the chicken yard. The compost yard is also very mucky in winter and could use some biochar to control the mud. We estimate that the goat yard could use up to 20 cubic yards of biochar, the chicken yard could use up to 10 cubic yards and the compost yard could use 20 cubic yards. Biochar used in these applications does not need to be crushed, as animals and the tractor will do the crushing.

Impact of Biochar on Compost
Goat barn manure is formed into several large piles for composting. The 2017 compost piles contained biochar that was added in the barn, so we compared compost records to the 2016 piles that did not have biochar. There were no strong differences in the temperature records. When the 2017 pile is finished in 2018, the pH should be checked. However, especially with the addition of the EM-1 lactic acid bacteria inoculant, we do not expect to see a dramatic change in pH of the compost.
Biochar Application to Soil

Willow Witt ranch grows market vegetables in beds formed from their compost. They would like to use biochar in the vegetable beds and in the pasture nearest to the goat barn. While soil pH in the pasture is near neutral, soil in the greenhouse vegetable beds is quite alkaline with a measured pH of 7.91. In spring 2016, biochar was added at the rate of 10 cups per 5 gallons of compost into two 2’x2’ sections of a fourteen-foot arugula bed in the greenhouse. Both of the sections with biochar had problems - plants had yellow leaves on emergence and some died. We found that biochar had raised the soil pH in those sections to pH 8.11, which is much too alkaline for arugula.

![Biochar in arugula beds. Left: alkaline biochar applied to alkaline soil reduced germination and growth. Small chunks of biochar visible on soil surface. Right: bed without biochar shows normal growth.](image)

We would not anticipate that the high pH of biochar would be a problem if it was added to the pasture, as the soil pH there is slightly acid. Pasture soil test results are given below:

<table>
<thead>
<tr>
<th>Farm</th>
<th>Field</th>
<th>Date</th>
<th>Lab</th>
<th>O(M) %</th>
<th>P (weak)</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>soil pH</th>
<th>buffer index</th>
<th>CEC</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Witt</td>
<td>pasture near barn</td>
<td>Jun-16</td>
<td>A&amp;L</td>
<td>12.5</td>
<td>13</td>
<td>146</td>
<td>640</td>
<td>3397</td>
<td>6.3</td>
<td>6.6</td>
<td>25</td>
<td>2</td>
<td>20.7</td>
<td>66.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

There was not enough time to complete the composting process for the new piles that have biochar in them, so we do not know if biochar will raise the pH of the compost at all. It will be important to check the compost pH before using it in soil, but we do not expect that biochar will have a big effect on pH of the compost.
Animal Health and Comfort
During spring 2016, biochar was spread around the goat kidding pen to help combat coccidiosis. The problem seemed somewhat less, but other measures with taken with feed and supplements as well. In 2017, there was no problem with coccidiosis. Reduction of ammonia smells in the goat barn has improved the comfort of human workers. It is hard to assess the impact on the animals.

Biochar Return on Investment Analysis
Reviewing records for labor to make biochar, we estimated the cost of production and compared it to the cost of purchased biochar:

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

Savings from making vs purchasing biochar:
- Purchase of 1 cubic yard of biochar would have cost $250
- Total savings = $250 - $150 = $100

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.
- Improved animal health and comfort in the goat barn will be 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.

Farmer Satisfaction
Suzanne Willow and Lanita Witt have expressed their satisfaction with the odor reductions in the barn. They were “really impressed” with the power of the biochar to eliminate ammonia smells. They felt that the expense of making biochar was worthwhile for this reason alone. They also said that since they already spend a fair amount of labor time on burning slash piles, the extra labor to burn material in the kiln and make biochar is not that great. However, they did appreciate that the commercial biochar from Oregon Biochar Solutions was easier to use in the goat barn and did not require the difficult step of crushing. They might consider buying commercial biochar for use in the barn and using the farm produced, chunky uncrushed biochar in the various yards to control muck.
Next Steps

- As the 2017 barn cleanings become finished compost, Willow Witt can begin to observe the effects of biochar on plant growth as the compost is used in garden beds and in the pasture.
- Willow Witt has ongoing forest health problems with some pines succumbing to pine bark beetle. They are planning a logging operation that will produce a large amount of slash that can be used for biochar feedstock. The logging operation can be designed so that the branches and logging slash are cut to size for kilns and staged in an accessible area for biochar production. Advanced planning can reduce the total amount of labor required to process feedstocks and make biochar.
- The biochar crushing step needs to be mechanized and Willow Witt should explore using their PTO chipper to crush biochar for use in the goat barn.
- Willow Witt has found that the EM-1 inoculant spray in the goat barn is beneficial. They can save money by fermenting their own supply of the inoculant in a beer fermenter, using the purchased product as a starter culture. Or they can use waste milk and wash water from the dairy, fermented with lactic acid bacteria.

Photos

*Figure 1. Willow Witt Ranch pasture and barns.*
Figure 2. Electric fencing controls grazing.

Figure 3. First biochar session at Willow Witt Ranch in November 2015.
Figure 4. Feedstock preparation involves transporting slash, cutting to length and splitting.

Figure 5. We start the kiln with smaller diameter brush to build heat.
Figure 6. Once the heat is built up in the kiln, we can add larger material.

Figure 7. We added bokashi and molasses to ferment biochar anaerobically and lower the pH.
Figure 8. Fermented biochar showing a layer of filamentous bacteria culture.

Figure 9. Oregon Biochar Solutions donated a 2-cubic yard tote of biochar for use in the goat barn.
Figure 10. Scattering the Oregon Biochar Solutions biochar on the exposed manure pack helped to immediately reduce ammonia gasses in the air, protecting workers from exposure during barn cleanout in June 2017.

Figure 11. Suzanne Willow digs into the manure pack in February 2018. After months of biochar use, there is no longer any detectable ammonia smell.
Figure 12. Coccidiosis has not been a problem for the goats since biochar has been used in the barn.

Figure 13. A recent pile of biochar produced on the ranch will be used in the goat yard to control muck.
Figure 14. The chicken yard will eventually get some biochar in the wet areas.

Figure 15. New compost piles have biochar.
Figure 16. A new kiln with fork pockets was delivered in February 2018. This will make it easier to produce biochar in remote locations on the 450 acre ranch.

Figure 17. Pine bark beetle infestation will be controlled in a planned logging operation. This will generate lots of feedstock for biochar production.
Practice Guideline: Using a Flame Cap Kiln to Make Biochar

The Flame Cap Kiln method uses a container to exclude air from the bottom and sides of a pile of burning biomass. This guideline covers two types of Flame Cap Kilns:

1. The Oregon Kiln – a steel fire pan with a pyramidal shape
2. The Ring of Fire Kiln – a steel ring with outer heat shield, sealed on the bottom with dirt

These kilns are the designs that we found to be most useful and effective for the forestry situations and feedstocks that we worked with in Oregon. We have made several versions of each type, some designed to break down into sections for easy transport, and some made with heavier steel for moving with a tractor.

There are many other shapes and designs that can work equally well, such as trenches, tubes, cones and simple pits in the ground. Some examples are shown below:

<table>
<thead>
<tr>
<th>Many Types of Containers Can Be Used as Flame Cap Kilns</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://pacificbiochar.com/how-to-make-biochar-with-only-a-match/" alt="The Oregon Kiln" /></td>
</tr>
<tr>
<td><img src="https://warmheartworldwide.org/biochar-oven-specs/" alt="The Ring of Fire Kiln" /></td>
</tr>
</tbody>
</table>

For more examples, see BackyardBiochar.net

This Biochar Practice Guideline was created in 2018 by South Umpqua Rural Community Partnership. Updates available at UBETBiochar.blogspot.com and WilsonBiochar.com. Free to share with attribution.
Flame Cap Kiln Basic 3-Step Method

1. This method starts by building an open pile in the container, lighting it on top, and letting it burn until it collapses and coals begin to form.

2. The operator then switches to a second stage of adding small amounts of new material on top of the coals, one layer at a time, until the container is full.

3. When the kiln is full of hot char, and the flames are gone, it's time to put it out. Either flood it with water, or snuff it with a lid to exclude air.

A Flame Cap Kiln must be continually tended, adding new fuel before the charcoal turns to ash. As each new layer of fuel 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 the closed bottom preserves the char until it can be quenched and saved.

Successful biochar production will consider the following factors:

- **Feedstock moisture:** Ideally, moisture content should be below 25%. Wet wood should be tossed aside and not used until it dries out. You will burn up too much wood to create the heat needed to dry the feedstock. A moisture meter for checking firewood costs about $30.

- **Feedstock size:** ideal size is between 1 and 4 inches thick. If the feedstock is very dry, thicker pieces can be successfully charred.

- **Initial filling of the kiln:** Best practice for lighting is to build an initial rick of medium size material (2” thick is ideal) that is open and loose on the bottom so it can get an air draft as air moves down the sides of the kiln and up from the bottom. The rick should fill the kiln up to about a foot above the kiln rim. On top of the rick of medium size material, place a densely-packed pile of small, very dry brush for kindling. This can be about 12 inches high.

- **Lighting:** Light the kindling and make sure the flame is even across the top. A propane torch is helpful but not necessary if you have dry fuel. Avoid using liquid accelerants.

- **Tending:** Add a new layer of wood when the previous layer begins to show a film of white ash. Try to keep each layer of wood the same diameter so charring is even. Add your biggest material in the middle stages of the burn so it has time to char completely.

- **Finishing:** As the kiln fills with red hot glowing coals, make the last few layers of medium sized material to allow any larger pieces to finish charring. The charring is complete when you no longer see any flames. Don’t worry if bigger pieces are not fully charred. After you quench, just set them aside for the next burn.

- **Quenching – with water:** When all the flames are gone, begin adding water in a gentle spray to the top of the kiln. Take care not to use a strong spray because it can drive air into the kiln and force a cloud of black particulates into the steam. You can wear a face mask during this process to protect your lungs from steam and particulates.

- **Double-check your quenching:** Make sure that there is plenty of water. Too little may evaporate and the char can re-ignite. If you don’t have as much water as you would like, take the time to stir the char in the water until it is all cool. You should be able to put your hand in it. Or dump the wet char on the ground and spread it thin so it loses heat.

- **Quenching – by snuffing:** An air tight lid can work to quench char. Best practice is to use at least some water to help cool the char. A good lid is a thin sheet of steel placed directly on top of the char layer inside the kiln. Seal the edges with dirt or clay. Cool for at least 12 hours.
### Illustrated Guide to Using the Oregon Kiln

<table>
<thead>
<tr>
<th>Steps</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Loading Feedstock</strong></td>
<td>Load dry feedstock loosely in the kiln, up to a foot or so above the kiln edge. Nothing should be more than 3 inches in diameter.</td>
</tr>
<tr>
<td><strong>2. Lighting</strong></td>
<td>Make sure there is dry, kindling size material on the top. Light evenly across the top.</td>
</tr>
<tr>
<td><strong>3. Flame Cap</strong></td>
<td>Keeping a flame cap across the top will burn up most of the smoke.</td>
</tr>
<tr>
<td><strong>4. First Pile</strong></td>
<td>Once the first pile has burned down, start adding more material.</td>
</tr>
<tr>
<td><strong>5. Increasing Size</strong></td>
<td>Now that the kiln is very hot, you can add some bigger material.</td>
</tr>
<tr>
<td><strong>6. Air Cutting</strong></td>
<td>Some pieces may be too close, cutting off air. Pull them apart with a rake.</td>
</tr>
<tr>
<td><strong>7. Quenching</strong></td>
<td>When all the flame is gone and ash starts to form, it is time to quench.</td>
</tr>
<tr>
<td><strong>8. Water Use</strong></td>
<td>Use plenty of water. Too little may result in total evaporation and re-ignition of the char.</td>
</tr>
</tbody>
</table>
Illustrated Guide to Using the Portable Ring of Fire Kiln

Kiln components are lightweight and packable. Set up the inner ring and clamp sections together.

Set up the heat shield. Load the initial charge—loosely packed. Light on top. Note: heat shield on blocks for air flow. Pre-heats combustion air.

Wet quench method uses lots of water. Open up the kiln for final quenching.

Dry quench method—place cap, seal edges with dirt. Check that bottom is sealed too. Let it cool overnight before opening.
CHECKLIST FOR A BIOCHAR BURN – SAFETY FIRST!

Here’s a checklist of things you need to consider when planning a biochar burn:

- Keep a biochar burn log to record your results and promote learning from experience (see included burn log form).
- You need a water source, both for safety and for quenching the char. Secure your water source before you light the kiln.
- Even if you are quenching with a lid or with dirt, always have at least five gallons of water on hand for emergencies.
- Have several shovels and rakes on hand to help control the fire.
- Make sure flammable materials are cleared from around the kiln. Wet the area if it is dry.
- Dry wood. A moisture meter is helpful. It’s not very efficient to use wood that is more than 25% moisture.
- Stage your wood nearby. The kiln will use about ten times its volume in feedstock.
- It is very helpful to sort wood by size ahead of time for efficient layering of similar size material.
- Safety – All helpers should have leather gloves and wear cotton or wool clothing that won’t melt. These piles can put out a lot of heat. Heat exposure for long periods of time is exhausting. Protect yourself and drink plenty of water.
- Burn only during legal burn days and safe conditions. Get a burn permit as required.
- Ignition - You can use a propane weed burner type torch for ignition, but all you need is a match if you have plenty of dry kindling. Light it evenly across the top.
- Make sure the kindling on top is somewhat densely packed so it will sustain a flame and allow the flame to move down to the lower layers. It seems slow to start but pretty soon you’ll find the whole pile is ablaze.
- If you get a lot of smoke, you may be adding too much material at one time. Always keep a strong flame on top of the kiln to burn the smoke.
- Use a wind screen if conditions are breezy. Even if wind is not a factor, a wind screen will help hold in heat for a safer and more efficient biochar burn.
- Stop when you are tired, not when the kiln is full. It’s ok to fill the kiln, but it’s also ok to stop before it is completely full, whether you run out of wood, or just run out of steam.

Tools and Supplies to Have on Hand
- Shovels and rakes
- Water buckets, hoses, nozzles
- Safety equipment: leather gloves, dust masks, eye protection, fire resistant clothing
- Propane torch or matches
- Wrench for installing and removing drain plug
- Chainsaw, hand saw or axe, if needed
## Best Practices for Safe Biochar Operations

<table>
<thead>
<tr>
<th>Wear fire-resistant clothing, and use a heat shield around the kiln.</th>
<th>Keep pets and children away from flames.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shut off and stow propane torches after use.</td>
<td>Protect yourself from smoke.</td>
</tr>
<tr>
<td>Place kilns carefully. Make sure the flame won’t torch overhanging tree limbs.</td>
<td>Have your water source ready to go before you light!</td>
</tr>
</tbody>
</table>
Crushing Biochar

Biochar can be crushed by driving over it with a truck or lawn roller. A small leaf vacuum works fairly well, but a large one is much better, with a more effective and durable impeller for chopping char. You can also use a hammer mill or a roller mill. Be aware that dry char can be very dusty and that wet char can stick and clog machinery. Experiment with moisture levels to find the sweet spot for the equipment that you use for crushing.
## Biochar Burn Log – Record Your Results

<table>
<thead>
<tr>
<th>Date</th>
<th>Ambient Temp</th>
<th>Weather</th>
<th>Location</th>
<th>Feedstock type</th>
<th>Feedstock moisture</th>
<th>estimated amount (cy)</th>
<th>Kilns (type, capacity, number)</th>
<th>Estimated yield (cy)</th>
<th>Start time</th>
<th>Quench time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Biochar Kiln Drawings – Oregon Kiln and Ring of Fire Kiln

1. Oregon Kiln – Forestry Size: 5’ x 4’ x 2’

<table>
<thead>
<tr>
<th>Oregon Kiln - Bill of Materials for (1) 5’x4’x2’ Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>pcs.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Estimated Fabrication Cost – labor and materials (2017 prices) $700

Fabrication Details

• Cut 5’ x 8’ sheet as shown and bend. Then weld on side panels for kiln body.
• Or cut panels separately and weld together.
• Drain hole and handle details shown in photograph

Handle and drain hole details of the Oregon Kiln.

This Biochar Practice Guideline was created in 2018 by South Umpqua Rural Community Partnership. Updates available at UBETBiochar.blogspot.com and WilsonBiochar.com. Free to share with attribution.
2. Ring of Fire Kiln

<table>
<thead>
<tr>
<th>pcs.</th>
<th>Type of Material</th>
<th>Purpose of Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>44” x 78” x 18 ga. sheet metal</td>
<td>Kiln body</td>
</tr>
<tr>
<td>1</td>
<td>77” x 85” 16 ga. sheet metal</td>
<td>Kiln lid</td>
</tr>
<tr>
<td>1</td>
<td>18’ x 1 ½” Flat Bar or similar scrap</td>
<td>Kiln lid reinforcement</td>
</tr>
<tr>
<td>9</td>
<td>1” Drop Forged Light Duty C-Clamp</td>
<td>Kiln body section fasteners</td>
</tr>
<tr>
<td>12</td>
<td>24” x 44” corrugated steel roofing (salvage, free)</td>
<td>Outer heat shield</td>
</tr>
<tr>
<td>36</td>
<td>Stainless steel bolts</td>
<td>To fasten roofing sections</td>
</tr>
<tr>
<td>5</td>
<td>bricks</td>
<td>To rest heat shield on</td>
</tr>
</tbody>
</table>

Estimated Fabrication Cost – labor and materials (2017 prices) $800

Fabrication Details

- Roll sheet metal pieces to 40” radius and bend flanges for kiln body.
- Cut kiln lid sections to give 4” overlap
- Use scrap roofing for outer ring – drill holes and fasten sheets together with bolts

Above left: Use three clamps for each join. Space clamps evenly.
Above right: The kiln lid is in 2 pieces. Place down inside the kiln on top of hot char and make sure that the center sections overlap. Seal the rim with dirt.
On-Farm Biochar Production and Use – Practice Guideline: Kiln Construction Drawings

Ring of Fire Kiln – Kiln Body Sections

Detail A
Scale 1:2

TYP 6 places 91°

86"

44"
Ring of Fire Kiln – Kiln Lid Sections

Note: Two piece lid. Place lid pieces separately on top of kiln with 4” overlap.
Practice Guideline: How to Use Biochar in Barns

Why Use Biochar in Barns?
Biochar can do a great job of reducing ammonia and other odors in barns, stables and poultry houses. There are other benefits too:

- Biochar is very effective at capturing nitrogen (N) that is otherwise lost to ammonia volatilization.
- Ammonia creates unpleasant odors in the barn, and harms the respiratory health of creatures who breathe it.
- As ammonia volatilizes, the nitrogen it contains is lost to the atmosphere. If retained, this N could have fertilized fields.
- As N is lost, phosphorus (P) is concentrated in the manure. When manure is applied at the appropriate rate for N, too much P is added to soil where it can leach into groundwater and contribute to environmental problems.
- Along with odor and ammonia reduction, biochar leads to fewer flies and pathogens, for improved animal health.

Biochar can be added to manure after it is cleaned from barns, but by then, it is often too late to maintain the N:P balance because too much N has already been lost. 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. For even greater impact, biochar can be acidified in order to increase its ability to capture N. See below for some methods to acidify biochar.

How to Use Biochar in Barns
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 other harmful substances. The process requires moisture control and degradable carbon and it produces a low pH.

Scientists at the University of Hawaii developed a dry deep litter system for pig barns in Hawaii that is based on traditional Korean farming practices. The system uses at least 60 cm of high carbon bedding material mixed with charcoal and cinders. It is inoculated once with indigenous microorganisms (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. The lactic acid inoculant also serves to acidify the biochar and increase its effectiveness in absorbing ammonia. Ammonia tends to volatilize at a pH of around 9, yet biochar can have a pH of around 10.

We recommend EM-1 (Effective Microorganisms), a commercially available microbial inoculant that is 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. For more information about EM-1, where to get it and how to use it, see the Resource Links below.

A Protocol for Using Biochar in a Dairy Goat Barn
Willow Witt Ranch has a small herd of dairy goats. The goat barn has 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. We tested two methods of applying biochar to the bedding. Both were effective.

Method #1
- Make biochar and crush to ¼” minus
- To lower pH and inoculate with microbes, prepare 10 gallons of bokashi (wheat bran inoculated with EM-1) and mix with 16 oz. of molasses diluted in two gallons of water.
- Mix bokashi and biochar on a tarp
- Pack mixture into 55 gallon drums to ferment for several weeks
- Sprinkle one 5 gallon bucket of inoculated biochar per 100 sf of barn area, once a week
Method #2
- Make biochar and crush to ¼" minus
- Spread biochar to dry
- Sprinkle one 5 gallon bucket of dry biochar per 100 sf of barn area, once a week
- Use a dust mask while spreading dry biochar
- Make a solution of activated EM-1
- Spray one quart of EM-1 solution per 100 sf on bedding surface, once a week

Biochar Is Also Helpful in the Barnyard
If you have outdoor pens and yards with manure that get wet and mucky, use biochar in those areas to help absorb the odors and moisture. No need to crush biochar to small particle sizes as you would for barn bedding, because the animals will crush it with their hooves and mix it with the muck.

After six months of adding biochar and EM-1 spray in the goat barn, ammonia odor is gone, even when digging into the pack.

Chunky, uncrushed biochar is perfect to add in the barnyard. In this cattle barn, animals have tracked biochar out into the yard where it helps control muck.
Do Your Own Experiments

Every barn is different. Depending on the type and number of animals, the bedding, and other factors, your barn may need more or less biochar to control moisture, odors and pests. Take a look at the resources listed below for more information.

Resources for More Information

General information on biochar in barns:


Making Waste Our Greatest Resource, by Paul Olivier  

Use of Bamboo Charcoal to Remove the Bad Smell of Manure  
Food and Fertilizer Technology Center  
http://www.fftc.agnet.org/library.php?func=view&style=type&id=20110801174821

Biochar: Helping Everything from Soil Fertility to Odor Reduction  
http://ecofarmingdaily.com/biochar-poultry-farming-unexpected-uses-biocarbon/

Ohio Heifer Center recycles manure, saves $800,000 on bedding  
https://www.progressivedairy.com/topics/manure/ohio-heifer-center-recycles-manure-saves-800-000-on-bedding

Information on bokashi, EM-1 and other inoculants:

EM-1 Application Manual – this will tell you how to make activated EM-1 and bokashi  
http://www.7springsfarm.com/content/EM1_APPLICATION_MANUAL.pdf

Natural Farming Hawaii – Odorless Pig Technology  
http://naturalfarminghawaii.net/learn-natural-farming/odorless-pig-technology/

An introduction to Asian Natural Farming  
https://www.echocommunity.org/en/resources/d8397abc-c85f-47a8-96a3-a25c6660e3a5

This Biochar Practice Guideline was created in 2018 by South Umpqua Rural Community Partnership. Updates available at UBETBiochar.blogspot.com and WilsonBiochar.com. Free to share with attribution.
Practice Guideline: How to Use Biochar in Compost

The Composting Process
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, and the absorption capacity of bulking agents. Water is held in biochar pore spaces and voids, and in the spaces between particles. Biochar increases the C:N (carbon to nitrogen) ratio of the compost. Here is a list of different impacts that biochar can have on compost:

- Biochar helps adjust the C:N of high nitrogen ingredients
- Biochar keeps compost moist and aerated
- Compost with biochar may not require turning, or may need less turning
- Biochar increases nitrogen retention
- Biochar improves compost maturity and humus content
- Biochar compost improves plant growth

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: 1) biochar contains at least some degradable carbon; and 2) biochar absorbs N, making it potentially less available to compost micro-organisms. For best results using biochar in compost, it is beneficial to combine biochar directly with a high nitrogen source and then add to compost with other materials that have good C:N ratios.

When planning a compost project on the farm, it may be helpful to do some small scale experiments first to determine the correct ratio of ingredients for achieving a hot compost using biochar. Here are a few helpful things to keep in mind about biochar:

- 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
- It is important to add enough degradable carbon (such as sugars, cellulose or carbohydrates) along with the biochar to help feed microbes
- Biochar may influence the active C:N by absorbing N
- Biochar may influence the active C:N by promoting rapid bacterial metabolism of N
- Biochar content for good compost ranges from 3%-25% depending on N content of manure, amount of degradable carbon, and other ingredients
How to Set Up a Biochar Compost Experiment

Hypothesis
Biochar will impact compost processes (time and temperature) and compost qualities (maturity, nutrient content, humus content).

Treatments
- Set up one compost with biochar and one compost without biochar (a control treatment).
- If you like, you can replicate the experiment with multiple piles of each treatment.
- Pulverize biochar to a size that is mostly ¼” or smaller. Some larger pieces are ok and will help with aeration.
- Apply biochar at between 3% and 25% by volume to the biochar compost.
- Use a compost calculator (see Resources) to estimate C:N ratio of compost ingredients.

Methods
- Choose a compost container – wire bins, open piles, or fiber sacks.
- Construct piles in layers, taking care to add bulk materials and biochar in enough layers to allow natural aeration.
- Water both piles the same.
- Monitor moisture – it should pass the “squeeze test”.
- The Squeeze Test – take a handful of material and squeeze. No water should come out, but when you open your hand, there should be enough moisture to hold the material together so it does not fall apart instantly.

Measurements
- Use the provided data sheet for temperature measurements.
- Daily temperature measurements for first two weeks (or every other day).
- Weekly temperature measurements for next 4 weeks.
- Sample compost after 90 days and send for testing.

Make an experimental compost using wire bins, open piles, or 100 gallon compost sacks. Measure your ingredients and mix by layering.
Lab Tests
Temperature measurements will tell you how the composting process compares with and without biochar, but to know how it compares as a fertilizer, you will want to test the results. You should expect to see an increase in retained nitrogen in the biochar compost. You may also see a difference in the indicators for compost maturity. Below are some tests you can request from most soil labs:
- Nutrient profile
- C:N ratio
- Compost stability test (CO₂ respiration)

Plant Bioassay
- Use a plant bioassay to compare soil with and without biochar compost to see what differences the compost makes in plant growth
- For instructions, see the practice guideline: Plant Bioassays to Evaluate Biochar Compost

Resources

Fiber Compost Sacks
Even though these only hold 100 gallons (half of a cubic yard) we found that they serve well for compost experiments. The outer edges of the sacks will be somewhat cooler, but if the C:N is right, the middle will heat up to thermophilic temperatures for good composting. You may not want to use these as your regular compost container, but they work very well for experimenting with compost ingredients and recipes. Source of fiber compost sacks: https://smartpots.com/compostsak/

Compost Calculators
Several handy calculators and spreadsheets are available online to help you know the C:N of your compost ingredients and the overall C:N of the ingredients mixed together.

- C:N Ratio Compost Mix Calculator
  https://www.klickitatcounty.org/1030/Compost-Mix-Calculator

- Comprehensive Composting Info
  http://compost.css.cornell.edu/science.html

A Useful Biochar Composting Guideline
Technical Note: Conditioning Biochars for application to Soils by James Joyce BE, Principal Technologist, Black is Green Pty.

This Biochar Practice Guideline was created in 2018 by South Umpqua Rural Community Partnership. Updates available at UBETBiochar.blogspot.com and WilsonBiochar.com.
Free to share with attribution.
# Compost Pile Temperature Data Sheet

Instructions: Use one data sheet for each pile. Circle the unit you will use: F or C. Before taking pile temperature, read the thermometer dial in air and record ambient temperature. Insert thermometer as close to the center of the pile as you can. Allow at least 60 seconds for the temperature reading to stabilize. Record the temperature. If possible, take a second measurement at a different location in the pile. Make a note about the weather: clear, cloudy, rain or snow.

<table>
<thead>
<tr>
<th>Units: F or C</th>
<th>Pile Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date/Time</td>
<td>Ambient Temp</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A Wide Variety of Biochar Composts to Compare
We can make a wide variety of compost preparations and fertilizer mixes with biochar and other organic materials including manure, food waste, crop waste, and organic fertilizers such as seed meal, rock dust, liquid fish and kelp meal. We can compost the ingredients in anaerobic compost piles with balanced C:N ratio that promotes thermophilic (heat-loving) organisms, or we can add ingredients to worm bins, or mesophilic (warm) piles that don’t reach thermophilic temperatures. We can also use biochar in anaerobic ferments such as bokashi, or we can simply culture a pile of biochar by adding some nutrients and moisture and allowing native microorganisms to begin consuming nutrients and depositing metabolic products on the surfaces of biochar. These products form organic coatings on the biochar that help determine its benefits to soil fertility (Hagemann et al 2017).

Compost Needs to Mature
All of the above processes take time. During the periods of active metabolism, microbial respiration rates are high and a great variety of unstable or phytotoxic organic compounds are present. These compounds can include ammonia, volatile organic acids, bacterial enzymes, salts and other chemicals that could be toxic to plants, especially seedlings (Woods End Research Laboratory, 2005). This is known as phytotoxicity. Mature compost has broken down these phytotoxic compounds and transformed them into humus, the stable byproduct of microbial metabolism that is beneficial to plant growth. Anaerobic ferments also need to mature before adding to soil because they can acidify soil to the point where it inhibits plant growth.

Compost Can Have Both Nutrients and Toxins
Compost can be tested for nutrient content and availability using soil testing methods. Compost maturity is usually gauged by measuring respiration rate. These tests are done in a lab, yet they will not indicate the presence of phytotoxic compounds. One of the best ways to determine if phytotoxic compounds are present is to perform a plant bioassay.
Plant Bioassay: the Basics
The plant bioassay we use is a two week germination and growth test using cucumber seeds. The basic procedure is to mix the target material with a plain, peat-based potting soil at the desired rate and plant the same number of seeds in each pot. Trays of pots are placed in a controlled environment and grown for two weeks. At the end of the growth period, we count the number of germinations (a strong indicator of phytotoxicity) and the number of secondary leaves. The number of secondary leaves may indicate different levels of growth promoting hormones, nutrients or other constituents in the target amendment. Then we cut, dry and weigh the biomass of each treatment. The biomass weight will tell us something about nutrients available for growth.

The plant bioassay is primarily used for determining whether a compost material is mature enough to use, but it is also useful for comparing the effects of different amendments on plant growth. A complete protocol is outlined below, followed by an Illustrated Guide with additional information.

Plant Bioassay Protocol for Testing Biochar Compost Materials

Materials needed:
- Plain peat-based potting soil with no added nutrients, such as Sunshine Mix #4 with perlite
- A number of 4 inch round plastic pots
- A package of 16 ounce clear plastic drink cups to use as humidity domes
- Greenhouse trays
- Label, tape and indelible markers
- 1000 milliliter beaker
- 100 milliliter beaker
- Clean bins for mixing soil. We use bus trays from a restaurant supply store.
- Mesh bags. We used a nylon net bath scrubber – unfurl it and it is one long mesh tube that can be cut into sections to use as bags to contain the plants for drying.
- Food dehydrator
- Scale accurate to .01 grams
- Controlled growth environment such as greenhouse or growth chamber

Procedure:
1. Determine number of treatments, plus a control using plain potting soil, and label all pots with treatment code and replication number. Use at least 3 replications. Five is better.
2. Determine treatment rate on volume-to-volume basis (usually 20% treatment to 80% soil).
3. Fill one pot with dry soil and tap the pot gently against the table surface to pack lightly. Weigh volume of soil that fills one pot = a.
4. Fill control pots with soil
   a. Multiply weight a times number of replicates (usually 5).
   b. Weigh that amount of soil and place in bin – this will be soil for control pots.
   c. Measure a volume of water equal to half the volume of the 5 control pots and mix with soil to moisten. Let stand for 10 minutes, then fill pots.
5. Mix treatment and fill pots with soil-treatment mix (see example, page 6).
   a. Multiply weight a x 80% x # replicates.
   b. Weigh that amount of dry soil and place in bin.
   c. Multiply volume of one pot by 20% for treatment volume. For example, if pot volume is 300 ml, then 20% of that volume is 60 ml.
   d. Multiply treatment volume by # replicates.
e. Measure the total volume of treatment material into a beaker. Tap to pack lightly. Place total volume of treatment material in bin with dry soil.
f. Mix soil and treatment thoroughly.
g. Measure a volume of water equal to half the volume of the 5 treatment pots and mix with soil to moisten. Let stand for 10 minutes, then fill pots.

6. Mix additional treatments using same method as 5.

7. Plant seeds.
   a. Place 10 cucumber seeds from the same packet evenly spaced on the surface of each pot. Keep seeds away from sides of pot.
   b. Place about ¼ cup of moist, un-amended soil on top of the seeds and press to spread the moist soil evenly across the top of the pot, covering all the seeds with at least 1/8” of soil.
   c. Add about a tablespoon of additional water to each pot to make sure that soil is completely saturated.

8. Prepare plants for growth chamber or greenhouse.
   a. Place a humidity dome (plastic drinking cup) on each pot and secure with tape if needed.
   b. Place pots on trays, randomizing pots within each tray or block.

9. Growth Phase
   a. Determine lighting schedule and set up timers if using artificial light.
   b. If growing in greenhouse, supply heat mats, if needed.
   c. If growing in growth chamber, adjust exhaust fan temperature control as needed.
   d. Grow plants for 14 days. Do not open humidity domes or add any more water.

10. Evaluate results.
    a. Count number of germinations in each pot and record.
    b. Count number of well-formed secondary leaves in each pot and record.
    c. Count number of incipient secondary leaf buds in each pot and record.
    d. Take photographs of trays to record information such as leaf color.
    e. Snip off above ground vegetation at soil level for all of the pots in each treatment (including control) and place in one labeled mesh bag for each treatment.
    f. Place mesh bags of vegetation in drying oven or food dehydrator and dry for 24 hours at 105 degrees F.
    g. Remove dried vegetation from each bag and weigh biomass for that treatment.
    h. Record total biomass for each treatment.

References


<table>
<thead>
<tr>
<th>An Illustrated Guide to Plant Bioassay Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Prepare soil for all treatments</td>
</tr>
<tr>
<td>2. Plant seeds</td>
</tr>
<tr>
<td>3. Top up moisture levels</td>
</tr>
<tr>
<td>4. Cover with humidity dome</td>
</tr>
<tr>
<td>5. Place on trays in growth chamber or</td>
</tr>
<tr>
<td>greenhouse</td>
</tr>
<tr>
<td>6. After two weeks, remove plants from</td>
</tr>
<tr>
<td>growth environment</td>
</tr>
<tr>
<td>7. Count germinations in each pot and</td>
</tr>
<tr>
<td>record</td>
</tr>
<tr>
<td>8. Count number of fully developed</td>
</tr>
<tr>
<td>secondary leaves and record</td>
</tr>
<tr>
<td>9. Count number of incipient secondary buds</td>
</tr>
<tr>
<td>and record</td>
</tr>
<tr>
<td>10. Cut all plants for each treatment at soil</td>
</tr>
<tr>
<td>level and combine</td>
</tr>
<tr>
<td>Step</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>11.</td>
</tr>
<tr>
<td>12.</td>
</tr>
<tr>
<td>13.</td>
</tr>
</tbody>
</table>
SAMPLE GERMINATION AND GROWTH TEST REPORT

Germination and Growth Test Report 12-17-16

Treatments:
DM – Don Morrison’s composted biochar (biochar chunks picked out of compost pile)
JL – John Livingston’s vermicompost (with biochar added to vermicompost bedding)
C – Control (Sunshine #4 potting mix)

Methods:
• 5 replicates of each treatment.
• Base is peat-perlite soil-less medium manufactured by Sunshine.
• Pots are 4” round pots with individual humidity domes.
• Control pots have 330g air-dry potting soil
• Treatment pots have 275g air-dry potting soil mixed with 60ml of amendment
• Each treatment mixed with soil and wet to squeeze test – 600 ml water
• Ten cucumber seeds planted in each pot with two tablespoons of plain soil on top.
• Humidity domes attached
• Treatments randomized on one greenhouse tray and placed in growth chamber for 2 weeks.
• At 2 weeks, remove from growth environment
• Count germination numbers
• Count secondary leaves (for reporting we combined fully developed leaves and leaf buds).
• Cut plants at root level and place in drying oven. After drying, biomass of each treatment is weighed with scale (MyWeigh Balance 601)

Results:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Secondary Leaves &amp; Buds (count)</th>
<th>Biomass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>100</td>
<td>67</td>
<td>2.04</td>
</tr>
<tr>
<td>JL</td>
<td>84</td>
<td>57</td>
<td>1.87</td>
</tr>
<tr>
<td>C</td>
<td>98</td>
<td>41</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Figure 1. Treatments from left to right: DM, JL, C.