5-2017

Reviewing Biochar Research and Introducing a Possible Classification System

Patricia G. Burns
Southern Illinois University Carbondale, patriciagayburns@yahoo.com

REVIEWING BIOCHAR RESEARCH AND INTRODUCING A POSSIBLE CLASSIFICATION SYSTEM

by

Patricia Gay Burns

B. A. Southern Illinois University, 2015

A Research Paper

Submitted in Partial Fulfillment of the Requirements for the

Master of Science Degree

Department of Geography and Environmental Resources

in the Graduate School

Southern Illinois University Carbondale

May 2017

RESEARCH PAPER APPROVAL

REVIEWING BIOCHAR RESEARCH AND INTRODUCING A POSSIBLE CLASSIFICATION SYSTEM

By

Patricia Gay Burns

A Research Paper Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Science

in the Field of Geography and Environmental Resources

Approved by:

Dr. Leslie A. Duram, Chair

Dr. Julie Weinert

Dr. Paul Henry

Graduate School

Southern Illinois University Carbondale

April 4, 2017

AN ABSTRACT OF THE RESEARCH PAPER OF

PATRICIA GAY BURNS, for the Master of Science degree in GEOGRAPHY AND ENVIRONMENTAL RESOURCES, presented on APRIL 4, 2017, at Southern Illinois University Carbondale.

TITLE: REVIEWING BIOCHAR RESEARCH AND INTRODUCING A POSSIBLE CLASSIFICATION SYSTEM

MAJOR PROFESSOR: Dr. Leslie A. Duram

Biochar is the product of burning biomass, such as hardwood, rice hulls, bamboo, or even chicken litter, in a low- to no-oxygen environment. The result is a black carbon skeletal-like structure of the original biomass.

Research into biochar as a soil amendment has been influenced by the study of anthropogenic dark, richly fertile soils found in the Amazon rainforest where the native forest soil is acidic and low in fertility. Biochar research for amending agricultural soils is relatively new but there are strong indications that this practice can decrease the need for additional fertilizer and water inputs.

Biochar products will vary in physical and chemical properties and therefore behave differently in the soil. A classification system has yet to be adopted to identify different biochar types. Consequently, there is no data base to search for a particular biochar type for a particular soil or climate. This limits the ability to effectively organize studies or to synthesize research results and to clearly communicate to the general public that the results of any one study are not applicable to all biochars.

This paper reviews the importance of soil health and the limitations encountered in biochar research which highlight the need for research design protocols and a classification system. A possible classification system is presented in Chapter 4.

DEDICATION

I dedicate this work to my children, April, William, Julianna, and Thomas, who have cheered me on and been a source of great encouragement, and to my sisters and brother who have always been there for me. I appreciate you all so much!

"Upon this handful of soil our survival depends.
Husband it and it will grow our food, our fuel,
and our shelter and surround
us with beauty.
Abuse it and the soil will collapse and die,
taking humanity with it."

-From Vedas Sanskrit Scripture
1500 BC

ACKNOWLEDGMENT

I would like to thank my advisor, Dr. Leslie A. Duram, for her guidance, patience, and support in this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Global food security is a pressing topic of conversation at all levels of society. In the face of increasing climate extremes crop management systems that are resilient to environmental stresses are of vital importance. Studies indicate that amending poor or depleted soils with biochar can have a positive impact on soil health and crop yield.

Studies of biochar's potential to improve the resilience and fertility of poor soils were initiated by research into the pockets of rich soil found within the Amazonian rain forest which is typically characterized by low fertility soils (Lehmann 2009). Later, much of the research took a different trajectory by isolating the black carbon substance found there that appeared to play a significant role in the soil's fertility in attempts to replicate the phenomenon (Terra Preta Program). The term biochar was eventually adopted for the black carbon material (Lehmann et al 2006).

Literature reviews suggest that the research approach on biochar has been haphazard with no standard protocol for research design or reporting of variables, such as soil characteristics or chemistry, (Biederman and Harpole 2013), and no widely-accepted classification system to differentiate between the varieties of biochar products (Camps-Arbestain et al 2015). This paper examines why a research design protocol and a biochar classification system is needed. Different biochar products behave differently in the soil both in the short term and the long term (Pignatello et al 2015) a classification system for biochar types is imperative to be able to adequately communicate research design and findings (Lehmann et al 2011). Study conclusion statements often just use the term “biochar” as if the study results could be broadly applied to all biochars. Meta-analyses of biochar research are hampered by limitations on methodology reporting as well as the lack of long-term studies. Inclusion of variable information such as soil properties, crop species and cultivars, and biochar types are necessary for a more robust predictability of biochar applications (Jeffery et al 2015).

1.2 Terra Preta Soils

Terra preta is the local term for the highly fertile anthropogenic black soils found in areas of the Amazon. The soil in the Amazon forest is naturally acidic and low in organic matter. The carbon and nutrients are not stored in the soil but in the decomposing vegetative cover (Mann 2002). High temperatures and heavy rainfall contribute to rapid decomposition of organic matter and washing out of nutrients (Glaser and Birk 2012). However, terra preta patches of the highly fertile anthropogenic soils are rich with organic matter and range in size from small household middens to hundreds of acres (Glaser et al 2001).

Terra preta soils are heavily littered with pottery sherds and contain charred materials such as vegetation, human and animal waste, and fish bones (Sombroek et al 2002). Charred organic material contributes to the dark color of the soil as can be seen in Figure 1. The dark soils have been measured to more than two meters deep (Mann 2002) and carbon dating has shown some of these soils to be thousands of years old (Glaser et al 2001). It is believed that these were agricultural grounds for extensive pre-Columbian civilizations located along the Amazon River (Sombroek et al 2002).

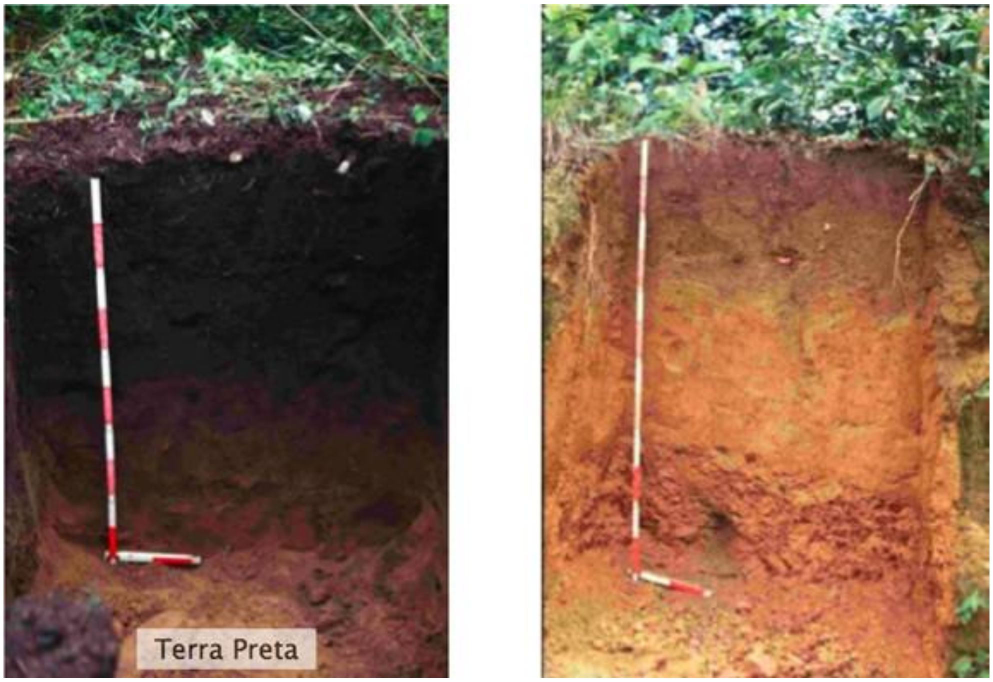

Figure 1. Profiles of terra preta and typical rain forest soil. Source: Glaser et al 2001

The amount of soil organic matter is 50-100% higher in the terra preta soils compared to the surrounding forest soils (Sombroek et al 2002). The pH is less acidic than the surrounding soils and has significantly higher numbers of unique species of bacteria (O'Neill et al 2009).

1.3 Terra Preta Research

While locally well-known, an 1870 paper was the first published description of the "black and very fertile" dark soils found in the Amazon region. The first published chemical description of the terra preta soils appeared in 1903, which credited the soil's carbon particles for its dark color. In 1966 it was suggested that the vast areas of dark soils originated from cultivation practices. There were a few more publications that followed in 1979 and the 1980s. However, it was not until the 1990s that research on the study of terra preta became more intensive (Denevan and Woods 2004).

1.4 Biochar Research Beginnings

The term “biochar” was initially introduced in 1999 to distinguish it from activated carbon made from fossil fuels. “Biochar” as a product for use as a soil amendment was introduced in 2006 (Lehman et al 2006). There are other types of chars such as those that occur naturally, for example from forest fires, and those produced for smokeless heating and cooking, for example charcoal. This paper focuses on biochar as an intentionally made product used for agricultural purposes.

The study of biochar is still relatively young but is a rapidly growing field of research. Johannes Lehmann, a soil scientist at Cornell University and leading biochar researcher, stated there were less than a dozen publications on biochar until 2007 (Averett 2016). According to the International Biochar Initiative (IBI) website there were over 1500 peer-reviewed biochar-related publications in 2015 alone (International Biochar Initiative 2016). A sampling of these 2015 publications include biochar for use as a soil amendment (Fang et al 2015, Iqbal et al 2015), in contaminated water treatment (Essandoh et al 2015, Inyang and Dickenson 2015), as a toxic soil remediation treatment (Puga et al 2015, Herath et al 2015), in lithium-sulfur batteries (Gu et al 2015), and for many other uses.

1.5 Potential Benefits of Biochar as a Soil Amendment

The benefits of amending soil with properly produced and processed biochar include:

- Increased crop yields (Teat el al 2015, Jeffery et al 2015, Biederman and Harpole 2013)

- High porosity providing a large surface area (Yargicoglu and Reddy 2015) for high cation exchange capacity (CEC), important for nutrient availability to crops (Liang et al 2006)
- Improvement of soil water holding capacity (Basso et al 2013)
- Stable microbial habitat, important for resilience of microbial populations (Altieri 1999)
- More diverse microbial populations, important for nutrient bioavailability (O'Neill et al 2015) and immune system functions (Altieri 1999)
- Long-term sequestration of carbon (McBeath et al 2014)
- Reduction of soil density in heavy soils, improving water percolation and root development (Jeffery et al 2015)
- Capture of nutrients in crop soils and riparian buffers reducing the amount of leaching and run-off from agricultural fields into waterways (Yu et al 2014, Sweet 2015)
- Reduction of N_2O emissions from soil (Thomazini et al 2015)
- Potential for helping to control invasive species by adsorbing allelochemicals (Kolb et al 2009)

Biochar has been shown to be effective in binding toxins and heavy metals (Chen et al 2015, Wang et al 2015). Consequently, the efficacy of soil-applied toxic herbicides and pesticides may be impacted by the presence of biochar (Kookana and Graber 2016).

Despite traditional agricultural uses of charred vegetation in various places around the world (Wiedner and Glaser 2015), biochar is not widely known (Lone et al

2015). Conflicting and inconsistent study results for its use as a soil amendment may have impacted public awareness and its utilization.

CHAPTER 2

HEALTHY SOILS

2.1 The Need for Healthy Soils

Healthy soils have stores of organic matter and are full of micro and macro organisms that play a part in the nutrient cycling within the soil (Bowman et al 2016). The organic matter helps to create space in the soil for air and water. It also provides nutrients for plants via the soil microbes. Healthy soil results in reduced crop stress, is full of beneficial microorganisms that out-compete pests, and creates unfriendly environments for the proliferation of pathogens and even some undesirable vegetation (USDA).

The term soil food web is used to describe the relationships in the soil ecosystem (Lowenfels and Lewis 2010a). It consists of all the biotic and abiotic fractions of the soil that are part of the complex paradigm (Kiedrzyńska et al 2015) that distinguishes soil from dirt. The diverse, interconnected, and interdependent parts of the soil food web have been illustrated in Figure 2.

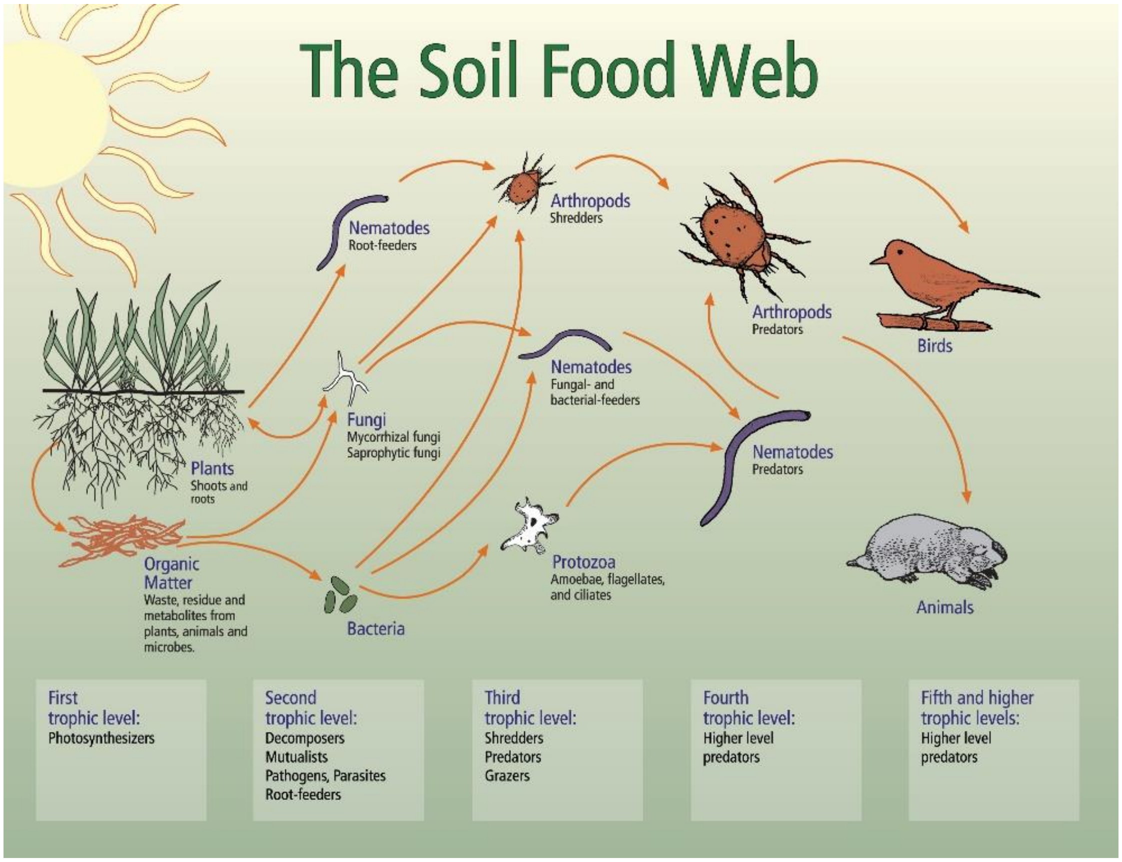

Figure 2. Soil Food Web. Source: USDA Natural Resource Conservation Service (NRCS)

In the United States, conventional agriculture is built on a heavily tilled mono-cropping system that relies on substantial inputs of synthetic fertilizers and pesticides. This model of agriculture greatly expanded after WWII, has severely degraded agricultural soils (Franzluebbers 2010), and dramatically affected soil nutrient cycling (Fox et al 2007). These methods are destructive to the soil food web, the living structures, or ecosystems, of the soil (Pimetel 2005) reducing the soil's resiliency under climatic extremes.

Soil organic matter (SOM) is the decaying material from plants and animals as well as the excrement of soil fauna. The organic matter contributes to soil structure and water holding capacity and serves as a source of nutrients for microbes and other soil life as well as for plants (Alphei et al 1996, USDA). Soil microbes eat SOM that contains bio-unavailable nutrients. They in turn are eaten by predators which releases the nutrients in a bio-available form (Lowenfels and Lewis 2010a). Plant roots release exudates activating specific microbes that provide the plant with the specific nutrient it needs at any particular time (Alphei et al 1996). When SOM is depleted microbial populations dwindle (Altieri 1999).

Bacteria, worms, and other life in the soil create exudates that act like glue, aggregating particles of soil aiding in soil structure (Altieri 1999). Beneficial bacteria and other soil micro-fauna need aerobic conditions to thrive. Many pathogenic microbes will thrive in anaerobic conditions (Lowenfels and Lewis 2010b). Soil compaction, often the result of driving over wet soils, contributes to anaerobic conditions (Barken et al 1987).

When a favorable soil environment is maintained for particular crops then the environment will be unfavorable to many of their pathogens and pests. The management of the diversity and balance of beneficial bacteria and fungi populations is a key to maintaining a favorable soil environment (Ingham 2015).

Creating healthy soil allows growers to utilize the systems that have evolved over time in nature to create healthy plants (Robertson et al 2014, Altieri 1999). Early succession soils have little bacteria and little to no fungi. This is mostly dirt, mostly lifeless. Early succession vegetation will seed in, and through root system interactions, feed what bacteria are there, improving the soil and creating conditions that will support a slightly more diverse vegetation population. This progression of more diverse vegetation feeding more and more diverse bacteria continues with conditions becoming favorable for fungi to develop. Then the balance of fungi to bacteria begins to increase. As the soil continues to evolve, the fungal populations will begin to dominate. Fungal dominant soils are more favorable for small trees, such as fruit trees. When the flora has evolved to old growth forest stage, the fungi have reached an even greater level of dominance (Figure 3) (Ingham 2015).

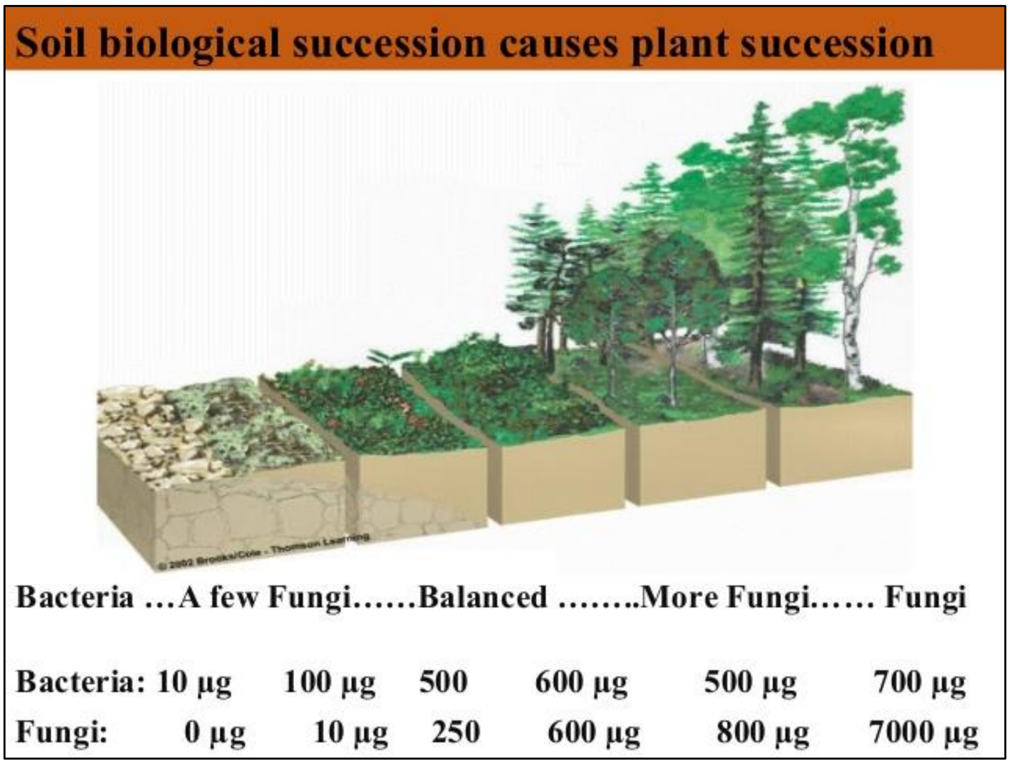

Figure 3. Soil succession showing relationship of bacteria, fungi, and vegetation. Source: Elaine Ingham 2015)

Agricultural soils under conventional cropping management systems have lost much of their organic matter and have been depleted of many beneficial microbes and fungi setting them back to early succession stage soils.

2.2 Biochar as a Tool to Improve Soil Health

As a soil amendment, biochar contributes to the revitalization of soils by providing a stable matrix for bacteria, fungi, water, and air, thus creating a more favorable environment for plant health and resilience.

Biochar has negatively charged surfaces that hold nutrients making them available for the nutrient cycling process. Due to biochar's ability to improve retention of nutrients in bio-available form, it has significant implications for growers who use methods that rely heavily on continual synthetic inputs, and for crop land that has been degraded of structure, organic matter, and a healthy microbiome (Altieri 1999).

Biochar is one tool that can be used by growers as part of a conservation approach to manage their land. Prevention efforts towards nutrient leaching and run-off from agricultural fields into waterways benefit from the application of biochar (Laird et al 2010, Sweet 2015). This type of application may call for raw biochar with high carbon stability.

CHAPTER 3

BIOCHAR RESEARCH LIMITATIONS

3.1 Biochar and Biofuels

As biochar research was expanding, so was research on biofuels. Biochar that was produced as a by-product of biofuel production has often been used in studies of biochar as a soil amendment. This is an inferior biochar for most agricultural purposes due to the processing procedures of the feedstocks that maximize biofuels extraction.

3.2 Biochar Not a Single Product

Feedstock choice and pyrolysis temperatures are the main variables in how a biochar will perform in the soil. Different production and post-production processes result in biochar products that have a variety of chemical and physical properties (Purakayastha et al 2015, Spokas et al 2011) that impact their effects on the soil environment and ultimately on plant health.

Deal et al (2012) tested several kiln-fired and gasified biochars on a strongly acidic soil (pH = 4.7) and found that the gasified biochar with its higher ash content had a beneficial liming effect that improved growth and nutrient availability. However, Rajkovich et al (2012) applied various biochars to a temperate soil of moderate fertility and found that ash content in the biochar did not correlate with growth. In this study feedstock type produced variation in growth at eight times the rate of variation from pyrolysis temperatures. Both were short term laboratory or green house studies.

Kolb et al (2009) found that biochars from manure feedstocks have higher amounts of labile carbon. In a 2015 study with five cellulosic biochars, heating temperature had the greatest effect on pH and specific surface area while feedstock had the greatest influence on water holding capacity (Hale et al 2015).

3.2.1 Feedstock variations. Biochars are products typically made from cellulosic material, although other material or manures may be used as feedstocks. Collectively these feedstocks are referred to as biomass.

The picture below shows biochar produced from wood chips (Figure 4).

Figure 4. Biochar. Source: www.biochar-international.org/regional/ubi

Feedstocks respond differently to the various heating methods (McBeath et al 2014). The resulting biochars will differ in their structure (Figure 5) and function (Lehmann 2007) including: the amount of stable carbon and labile carbon, the amount of volatiles and minerals still attached, and the amount of surface area, porosity (Yargicoglu and Reddy 2015)**,** and electrical conductivity (Rajkovich et al 2012, Deal et al 2011).

Figure 5. Biochar from different feedstocks. Source: biochar.ucdavis.edu

McBeath et al (2014) compared 26 biochars from eleven different feedstocks that included wood, crop residues, manure, organic waste (food), and mill waste (paper). They found that aromatic ring formation increased with increasing temperatures, testing between the ranges of 350° C to 600° C. This had a direct effect on mean residency time in the soil ranging from <260 years to >1400 years. These findings are important both for soil conditioning applications and for carbon sequestration. It is clear there needs to be a classification system to describe the type of biochar used in a study that includes descriptions that address what makes that particular biochar unique in the soil in both the short- and long-term.

3.2.2 Heating variations. In biochar production the biomass feedstock is heated in a process known as pyrolysis. Pyrolysis involves the heating at high temperatures in the presence of little to no oxygen. This process chars rather than combusts the biomass which results in a black carbon product that may physically resemble its feedstock.

There are three main heating processes used for creating biochar: slow pyrolysis at 400-600° C range; fast pyrolysis at 500-550° C range; and gasification at 750-1000° range (Brewer 2010). Several studies have used biochar gasified at 1200° C. Other means of creating biochar are used but research studies tend to stay close to these ranges.

Slow pyrolysis yields the most biochar as a percent of weight and its primary product is biochar. Slow pyrolysis treatment may last anywhere from hours to days. Biochar produced from slow pyrolysis retains more of the original shape of its feedstock and has the most stable carbon structure. Fast pyrolysis treatment is flash heating, lasting only a few seconds, and essentially decimates the feedstock. Its primary product is bio-oil for bio-energy production. Fast pyrolysis produces the smallest particles of biochar. Gasification seeks to maximize extraction of volatile gases and uses a limited amount of oxygen. Gasification produces the most ash and yields the smallest amount of biochar by weight (Brewer 2010).

When the biomass is pyrolyzed much of the hydrogen and oxygen is driven off in vapors. Minerals compounds are reduced to ash. The remaining carbon atoms in the skeletal walls begin to attach to each other forming hexagonal rings (called aromatic rings). As the heat continues to rise the rings form into amorphous crystals and then rumpled sheets (but still in the macro shape of the cellulosic walls). The carbon molecules in the feedstock walls become sponge-like with many pore spaces and a tremendous surface area (see Figure 6) with high electrical conductivity. If the heat continuous to rise the carbon atoms will continue to form more homogenous sheets, like graphite, significantly reducing the surface area and porosity and occupying the available electrons, reducing the product's capacity for electrical activity involved in nutrient exchange (Wilson 2014, Liang et al 2006).

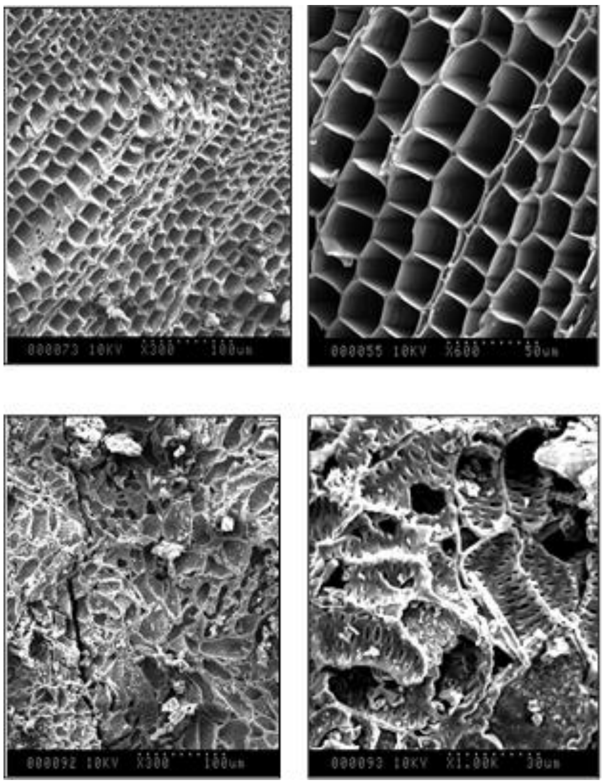

Figure 6. Electron microscopy showing porous nature of biochars. Source: Kernowblack.wordpress.com

The higher the heat, the more volatiles can be squeezed out of the biochar. As the temperatures rise above 600° C the carbon sponge begins to fracture (Pignatello et al 2015) which reduces the beneficial characteristics desired for soil applications.

During pyrolysis some minerals are burned off as ash but some may remain attached (Wilson 2014). Lee et al (2013) found that CEC for peanut hull biochar was optimal at 400° C and that as temperatures increased the CEC value decreased.

Optimal heating temperatures for retaining strong carbon bonds and resisting decay will vary by feedstock. However, some feedstocks will produce more stable biochars. Those made from woody feedstocks have cell walls that are more resistant to degradation from heating than the cell walls of biochar made from grasses or chicken litter (Brewer 2010).

If the desired primary product is for a soil amendment, slow pyrolysis is the preferred processing treatment. Slow pyrolysis produces a greater amount of biochar yield by weight, stronger carbon structural bonds, and therefore greater recalcitrance in the soil, and less ash content (Brewer 2010). Ash has a liming effect and may contribute to an undesired initial increase in soil pH.

3.3 Need for a Classification Scheme and Reporting Protocol

For trial results to be duplicated with a degree of confidence there needs to be a standardized protocol for design and reporting procedures as well as a classification system that will distinguish the type of biochar utilized in the trials (Sesko et al 2015). A reporting protocol might include specific soil characteristics, climate information, and fuller disclosure in conclusion statements of the parameters of the study, such as type of biochar and the length of the study, thus avoiding sweeping conclusion statements that may cause consternation among possible end users. A classification system would allow categorization of study trials that would support searching by biochar type. This would facilitate efforts by researchers to determine how consistently biochar types behaved in similarly designed studies. Individuals who choose to make biochar at home could be better guided by the results of studies if there were distinctions made about biochar type in the reporting of results.

3.4 Biochar not a Replacement for Fertilizer

As traditional practices from around the world included the burning of plant matter and soil to improve fertility (Wiedner and Glaser 2015), early studies on biochar effects on crop yield were designed to test biochar's performance as a fertilizer. However, biochar functions more as a soil conditioner rather than a fertilizer (Lehmann 2009). The inherent fertilizer value of biochar is minimal and temporary. Use of biochar does not eliminate the need for fertilizer (Lehmann 2009). However, biochar may be treated with organic or inorganic fertilizing agents before incorporation into the soil. In a laboratory study of biochar-amended Midwestern soil mixed with manure, dissolved P leaching was reduced by 69% and dissolved N leaching was reduced by 11% compared to the un-amended controls (Laird et al 2010). Fertilizer application rates may be reduced substantially if the potential for leaching has been reduced.

When biochar is incorporated into the soil raw it may temporarily immobilize nitrogen in the soil, reducing availability to plants (Rajkovich et al 2012) and raising soil pH to undesirable levels. This can be avoided by allowing the biochar to oxidize, amending it with nutrients, and inoculating it with beneficial microbes and fungi prior to application. Too many studies continue to test for crop yield improvement in short term studies using raw biochar which frequently obtain poor results, and then make misleading conclusion statements that biochar (as if a single product) was not a beneficial amendment. A classification system, such as is presented in this paper, would clearly communicate that the results were for particular biochar products.

Biochar's value with regard to fertility is similar to that of humus – it provides tremendous surface area (Liang et al 2006) for nutrients, microbes, and fungi to attach, playing an important role in the soil food web. Unlike humus, biochar can have a mean residence time in the soil up to thousands of years.

3.5 Soil Microbial Interactions

Until the last few years the role of micro-organisms on soil fertility and how the soil ecosystem is impacted by the addition of biochar has been absent from the literature. The roles of the various organic and non-organic components in the soil are only just beginning to be understood (Lone et al 2015). As the results of new studies emerge on soil ecosystems, the impacts of biochar additions can be better analyzed (Lehmann et al 2011).

With soil biota playing a crucial role in nutrient cycling, more research is needed on the impacts of biochar on the soil microbiome and on the effects of the microbiome on the aging of biochar in the soil, but these are much more complex processes to quantify and the methods to make these assessments are still being developed (Plaza et al 2015, Lone et al 2015).

3.6 Length of Study Trials

A limitation with many of the study results is the short time frame of the study trials. Most biochar experimental studies span less than one year (Jeffery et al 2015). Since biochar's relationship to the soil changes over time (Pignatello et al 2015) there is a need to observe long-term trends that may build slowly and subtly (Robertson et al 2014). Microbial populations evolve over time in response to changes in the soil and their own activity (Alphei et al 1996). Non-significant or poor first season results may be followed by significant positive results in subsequent seasons without additional biochar application (Liu et al 2014).

In slow pyrolysis, volatile compounds may remain on or recondense onto the surface of the biochar. This may affect certain microbes upon initial application in the soil. Studies indicate though that the volatile compounds degrade over time, possibly by both biological and chemical activity (Anyika et al 2014, Hale et al 2015, Oleszczuk et al 2016), and therefore having only a temporary impact.

3.7 Lab versus Field Studies

Most biochar studies occur in labs or greenhouses. Lab testing is important to tease out information best studied under highly controlled conditions. Horticultural conditions may best be approximated in lab or greenhouse environments. However, the extrapolation potential from lab experiments for field application is limited due to soil chemistry, climate, and microbial variabilities (Jones et al 2012). More field studies are needed to determine best management practices for biochar additions to croplands.

3.8 Biochar Application and Crop Yield

Many of the studies that focused on the relationship between biochar addition and crop yield excluded the important dynamic of soil life in the relationship. When the processes taking place in the living matrix of soil are excluded, results on yield will continue to be inconsistent and impede movement toward a greater understanding of how and under what conditions biochar may be most useful for improving crop yield.

Crop yield results are often conflicting due to variations in any aspect of the biochar-soil-crop-climate system. Figure 7 shows the many biochar variables that may impact crop yield so caution should be exercised when interpreting study results (Jeffery et al 2015). First season yields may vary from subsequent seasons as the amended soil evolves (Liu et al 2014).

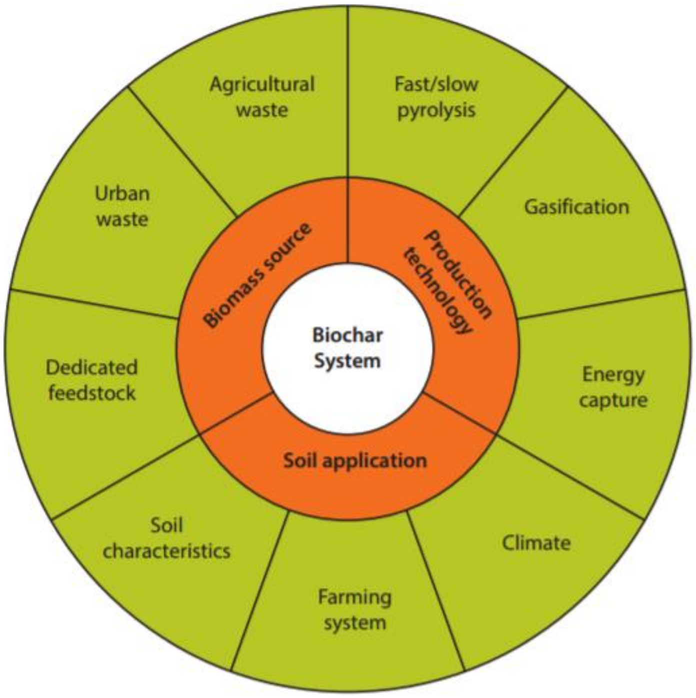

Figure 7. Biochar as a system-defined concept. Source: World Bank Study 2014

A reporting protocol that includes such variable information would make cross-study analyses more relevant.

3.9 Lack of Guidance on Application Rates

There is little data available for guidance on application rates. A meta-analysis indicated that crop yield increased with increasing rates of application up to a point. On average, rates higher that five tons per hectare were associated with increased yields (Jeffery et al 2015).

Lehmann (2009) suggests a one-time large application rate would produce more beneficial effects than small yearly applications. This would be consistent with research that shows biochar ages in the soil creating dynamic relationships with soil bacteria and fungi. Regular soil incorporation of new biochar would disrupt emerging biological structures and repeatedly introduce compounds that can initially inhibit microbial activity (Hale et al 2015).

A study over a five-crop season (Liu et al 2014) demonstrated that significant and consistent increases in soil organic carbon, K availability, and a decrease in N_2O emissions were achieved after a single biochar application.

Some studies attempt to suggest application rates based on inherent fertilizer effects, but since it has sufficiently been demonstrated that biochar is not a replacement for fertilizer, there needs to be a means to determine what would be the optimal rate of application based on product characteristics, such as recalcitrant and labile carbon fractions, as well as its specific end use.

CHAPTER 4

DISCUSSION

4.1 Home Production and Experimentation

Biochar researcher Johannes Lehmann, stated that it is important for farmers to be experimenting to see what works for them in their fields (Averett 2016). Research may soon provide general guidelines for application, but those guidelines will need to be adapted to specific sites.

Biochar is commercially available and being experimented with by local initiatives such as the Sonoma Biochar Initiative in California. An example of experimental farming application in Missouri with a commercially available biochar showed improvement of corn plant health and yield as well as a significant reduction in the amount of fertilizer inputs needed (Yarrow 2016).

Home production, especially for experimentation is a feasible alternative. Homemade kilns do not need to be expensive or difficult to construct. They can be as small as a paint can or constructed of 50-gallon drums (Figure 8).

Figure 8. 55-gallon drum kilns. Source: Katanabuilders.com.

The web site of the Ithaka Institute based in Switzerland provides information on the Kon Tiki kilns which are conical open-source designs developed by Hans-Peter Schmidt. The conical kiln process creates a layer of oxygen-occluding ash on top and creates a vortex of air flow making the process efficient and relatively clean burning (Figures 9 and 10). Conical pits may even be dug into the ground. There are numerous pictures, videos, and websites devoted to various ways individuals can build charcoal/biochar kilns.

Figure 9. Kon Tiki kiln. Source: *www.thebiocharrevolution.com/blog/biochar-production-in-kon-tiki-australia-1*

Figure 10. Kon Tiki kiln with flame curtain. Source: www.thebiocharrevolution.com/blog/biochar-production-in-kon-tiki-australia-1

Made from biomass waste such as logs, trimmings, wood chips, sawdust, corn stover, manure, or from algae grown specifically for biochar production, various feedstocks for biochar production are readily available in the United States. Using landscape waste materials headed for landfills increases the conservation potential for biochar use.

4.2 Sample Classification System

Research protocols and a classification system are needed so that studies can be duplicated with a greater degree of confidence. These measures will help to organize the literature record making searches and future study designs more efficient and relevant. This paper presents a suggestion for a starting point for a biochar classification system (Table 1).

Table 1.

Sample classification system for biochar products

Feedstock	Abbr		Form	Abbr		Oxidized	Abbr		Inoculated	Abbr
Bamboo	**BB**		Chips	**CH**		Yes	**Y**		Nutrient, Bacteria, Fungi	**NBF**
Barley	**BS**		Litter	**LT**		No	**X**		Nutrient Bacteria, No Fungi	**NBO**
Bison Manure	**BM**		Logs	**LG**					Nutrient, No Bacteria, No Fungi	**NOO**
Chicken Litter	**CL**		Manure	**MN**					No Nutrient, Bacteria, Fungi	**OBF**
Corn Stover	**CS**		Sawdust	**SD**					No Nutrient No Bacteria, Fungi	**OOF**
Cow Manure	**CM**		Straw	**SW**					No Nutrient, Bacteria, No Fungi	**OBO**
Hardwood Specified	**HS**		Stover	**ST**					No Nutrient, No Bacteria, No Fungi	**OOO**
Hardwood Unspecified	**HU**		Other	**OT**						
Miscanthus	**MC**									
Oat Straw	**OS**		**Pyrolysis**	**Abbr**					**Wetted**	**W**
Pine Bark	**PB**		Slow	**S**					**Dry**	**D**
Pine Needles	**PN**		Fast	**F**						
Softwood Specified	**SS**		Gasification	**G**						
Softwood Unspecified	**SU**		Other	**OT**						
Switchgrass	**SG**									
Wheat Straw	**WS**									
Other	**OT**									

In this system, a biochar classified as **HU-SD-600S-Y-NBO-W** would be hardwood unspecified in the form of sawdust, heated at 600° C by slow pyrolysis, oxidized, charged with nutrients and bacteria, and wetted before packaging to reduce dust. A simpler version might be to just use **HU-600S-NBO** with the rest of the information on the packaging.

This system is based on soil classification models. The information would not be difficult to discern from the abbreviations and would be useful for gardener, farmer, or researcher. Feedstock and pyrolysis temperature are the two key components in long-term behavior of biochar in the soil. Oxidation and inoculation are two key components in short-term behavior of biochar in the soil. However, if inoculation occurred, then the biochar would most likely have been allowed to oxidize first to reduce inoculant mortality, reducing the classification model to only three components, as in the example: **HU-600S-NBO**.

A classification system would improve research methodology by providing a searchable data base parameter to compare study results and for designing new studies. Favorable results need to be duplicated managing variables as closely as possible to improve predictability of outcomes.

CHAPTER 5

CONCLUSIONS

5.1 Importance of Reliable Data

Access to reliable data is essential for growers and land managers to be able to make appropriate long-term decisions. With a research design protocol for reporting and a biochar classification system there would be less confusion discerning the implications of study results.

Johannes Lehmann and Stephen Joseph edited a comprehensive book in 2015, *Biochar for Environmental Management: Science, Technology, and Implementation* (Lehmann and Joseph 2015)*,* as a review of current literature. This is a wonderful resource for researchers. However, at over 900 pages and with much of the material aimed at the scientific audience it may not be the best tool for disseminating information to the general public. A biochar primer is also needed.

While a biochar may contain some level of nutrients, its agricultural application should not be measured by that parameter. Agricultural biochar needs to be initially charged with a fertilizing agent. Measures for determining subsequent nutrient requirements may need to be developed to reflect biochar nutrient reserves and soil microbial activity. More field research is needed to measure the characteristics of biochar amended soils over multiple growing seasons.

5.2 U.S. Biochar Initiative 2016 Conference

In the first plenary meeting of the August 2016 U.S. Biochar Initiative Conference held in Corvallis, Oregon, various stakeholders were encouraged to ask questions of each other. Industry representatives, scientists, and consumers were in attendance. These questions are distilled from that meeting:

- Researchers asked, ‘What do you want to know?’
- Industry representatives asked, ‘How do we get growers to use biochar?’, ‘How do we organize around the various application purposes?’, ‘How do we define ourselves and biochar for purposes of standardization and regulation?’, and ‘How do we best promote biochar use?’
- Consumers asked, ‘What will this cost me in time and money?’, ‘What will my return be now and later?’ and ‘How do I know what I am buying?’

While there are certainly independent research agendas among the scientific community, this is an industry that is newly evolving and this conference was focused on the synergy of biochar science and industry.

Consumers concerns here were centered around agricultural applications. However, there were other consumers in attendance representing diverse applications such as for sewage or storm water treatment and for toxic soil or water remediation.

5.3 Framing Future Research

Each stakeholder group has their own set of values and goals. Therefore, an important question that needs to be asked is: What are the mission statements of the various stakeholders? From an agricultural perspective, if they are that farmers want to make money today and producers want to make money today, then a different research trajectory will be followed compared to a mission statement that focuses on long-term soil health for long-term food production and security. Long-term goals generally require upfront investment. Investing in long-term soil health does not necessarily mean that one cannot make money today, but the long-term goals become fore-fronted, and a strategy to achieve those goals while staying financially afloat is sought.

It takes a level of community affluence and commitment to implement restoration and remediation programs, but the results of those programs then support the many levels of economy, including those that are quantifiable and those that are not, within the community (Salwasser et al 1998). Ultimately, consumers must be willing to bear the cost (Robertson et al 2014).

As climate extremes threaten agricultural operations, collaboratively working to fore-front soil health becomes even more important in ensuring long-term economic health. All communities are dependent on food security. Food security is dependent on healthy soil. Biochar has the potential to be a significant part of the restoration of soil health highlighting the need for organizing and standardizing research design and reporting.

REFERENCES

Alphei, Jőm, Michael Bonkowski, Stefan Scheu. 1996. "Protozoa, Nematoda and Lumbricidae in the Rhizosphere of Hordelymus europaeus (Poaceae): Faunal Interactions, Response of Microorganisms and Effects on Plant Growth." *Oecologia* 106(1): 111-126.

Altieri, Miguel A. 1999. "The ecological role of biodiversity in agroecosystems." *Agriculture, Ecosystems and Environment* 74: 19-31.

Anyika, Chinedum, Zaiton Abdul Majid, Zahara Ibrahim, Mohamad Pauzi Zakaria, Adibah Yahya. 2014. "The impact of biochars on sorption and biodegradation of polycyclic aromatic hydrocarbons in soils – a review." *Environmental Science And Pollution Research* 22: 3314-3341.

Averett, Nancy. 2016. "Healthy Ground, Healthy Atmosphere." *Environmental Health Perspectives* 124 (2): A30-A35.

Barken, L. R., T. Bøsrresen, A. Njøss. 1987. "Effect of soil compaction by tractor traffic on soil structure, denitrification, and yield of wheat (Triticum aestivum L.)." *Journal of Soil Science* 38(3): 541-552.

Basso, Andres S., Fernando E. Miguez, David A. Laird, Robert Horton, Mark Westgate. 2013. "Assessing potential of biochar for increasing water-holding capacity of sandy soils." *GCB Bioenergy* 5(2):132-143.

Biederman, Lori A. and W. Stanley Harpole. 2013. "Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis." *GCB Bioenergy* 5: 202-214.

Bowman, Maria, Steven Wallander, Lori Lynch. 2016. "An Economic Perspective on Soil Health." USDA website. https://www.ers.usda.gov/amber-waves/2016/september/an-economic-perspective-on-soil-health/.

Brewer, Cathleen. "Biochar Characterization and Engineering." Oral Presentation at Illinois Sustainable Technology Center's 2010 Biochar Symposium. https://www.youtube.com/watch?v=n5AmV42xsnc.

Camps-Arbestain, Marta, James E. Amonette, Balwant Singh, Tao Wang, Hans Peter Schmidt. "A biochar classification system and associated test methods." In *Biochar for Environmental Management: Science, Technology and Implementation*. Editors Johannes Lehmann and Stephen Joseph. London and New York. Earthscan, 2015.

Chen, Tan, Zeyu Zhou, Rong Han, Ruihong Meng, Hongtao Wang, Wenjing Lu. 2015. "Adsorption of cadmium by biochar derived from municipal sewage sludge: Impact factors and adsorption mechanism." *Chemosphere* 134: 286-293

Deal, Christopher, Catherine E. Brewer, Robert C. Brown, Mackay A. E. Okure, Alice Amoding. 2012. “Comparison of kiln-derived and gasifier-derived biochars as soil amendments in the humid tropics.”

Denevan, William M. and William I. Woods. “Discovery and Awareness of Anthropogenic Amazonian Dark Earths (Terra Preta).” Conference presentation. 2004. http://www.eprida.com/eacu/PDF%20Files/BDenevan.pdf.

Essandoh, Matthew, Bidhya Kunwar, Charles U. Pittman, Jr., Dinesh Mohan, Todd Mlsna. 2015. “Sorptive removal of salicylic acid and ibuprofen from aqueous solutions using pine wood fast pyrolysis biochar.” *Chemical Engineering Journal* 265: 219-227.

Fang, Yunying, Balwant Singh, Bhupinder Pal Singh. 2015. “Effect of temperature on biochar priming effects and its stability in soils.” *Soil Biology and Biochemistry* 80: 136-145.

Fox, Jennifer E., Jay Gulledge, Erika Engelhaupt, Matthew E. Burrow, and John A. McLachlan. 2007. “Pesticides reduce symbiotic efficiency of nitrogen-fixing rhizobia and host plants.” *PNAS* 104(24): 10282-10287.

Franzluebbers, Alan J. 2010. “Achieving Soil Organic Carbon Sequestration with Conservation Agricultural Systems in the Southeastern United States.” *Soil Science Society of America Journal* 74(2): 347-357.

Glaser, Bruno and Jago Jonathan Birk. 2012. “State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia.” *Geochimica et Cosmochimica Acta* 82: 39-51.

Glaser, Bruno, Ludwig Haumaier, Georg Guggenberger, Wolfgang Zech. 2001. “The ‘Terra Preta’ phenomenon: A model for sustainable agriculture in the humid tropics.” *Naturwissenschaften* 88: 37-41.

Gu, Xingxing, Yazhou Wang, Chao Lai, Jingxia Qui, Sheng Li, Yanglong Hou, Wayde Martens, Nasir Mahmood, Shanqing Zhang. 2015. “Microporous bamboo biochar for lithium-sulfur batteries.” *Nano Research* 8(1): 129-139.

Hale, Lauren, Madeline Luth, David Crowley. 2015. “Biochar characteristics relate to its utility as an alternative soil inoculum carrier to peat and vermiculite.” *Soil Biology and Biochemistry* 81: 228-235.

Herath, I., P. Kumarathilaka, A. Navaratne, N. Rajakaruna, M. Vithanage. “Immobilization and phytotoxicity reduction of heavy metals in serpentine soil using biochar.” *Journal of Soils and Sediments* 15(1): 126-138.

Ingham, Elaine. 2015. “The Roots of Your Profits.” Lecture presented at Oxford University. https://www.youtube.com/watch?v=x2H60ritjag. Accessed June 2016.

International Biochar Initiative. “State of the Biochar Industry 2015.” Published March 2016.

Inyang, Mandu and Eric Dickenson. 2015. “The potential role of biochar in the removal of organic and microbial contaminants from potable and reuse water: A review.” *Chemosphere* 134: 232-240.

Iqbal, Hamid, Manuel Garcia-Perez, Markus Flury. 2015. “Effect of biochar on leaching of organic carbon, nitrogen, and phosphorus from compost in bioretention systems.” *Science of the total Environment* 521-522: 37-45.

Jeffery, Simon, Diego Abalos, Kurt Spokas, Frank G. A. Verheijen. “Biochar effects on crop yield”. In *Biochar for Environmental Management: Science, Technology, and Implementation*. Editors Johannes Lehmann and Stephen Joseph. London and New York. Earthscan. 2015.

Jones, D. I., J. Rousk, G. Edwards-Jones, T. H. DeLuca, D. V. Murphy. 2012. “Biochar-mediated changes in soil quality and plant growth in a three year field trial.” *Soil Biology & Biochemistry* 45: 113-124.

Kiedrzyńska, E. M. Kiedrzyński, M. Zalewski. 2015. “Sustainable floodplain management for flood prevention and water quality improvement.” *Natural Hazards* 76(2):955-977.

Kolb, Simone E., Kevin J. Fermanich, Mathew E. Dornbush. 2009. “Effect of Charcoal Quantity on Microbial Biomass and Activity in Temperate Soils.” *Soil Science Society of America Journal* 73(4): 1173-1181.

Kookana, R. S. and E. R. Graber. 2016. “Potential Effects of Biochars on the Efficacy of Pesticides.” Reviewed by M. Camps Arbestain (Massey University), S. Sohi (University of Edinburgh), and J. Lehmann (Cornell University). Accessed March 2016. www.biochar-international.org.

Laird, David, Pierce Fleming, Baiqun Wang, Robert Horton, Douglas Karlen. 2010. “Biochar impact on nutrient leaching from a Midwestern agricultural soil.” *Geoderma* 158(3): 436-442.

Lee, James Weifu, Bob Hawkins, Xiaonian Li, Danny M. Day. 2013. “Biochar Fertilizer for Soil Amendment and Carbon Sequestration.” In *Advanced Fuels and Bioproducts.* Editor J. W. Lee. Springer Science+Business Media. New York. 2013.

Lehmann, Johannes. 2007. "Bio-energy in the black." *Frontiers in Ecology and the Environment* 5(7): 381-387.

Lehmann, Johannes. "Terra Preta Nova – Where to from Here?" Chapter 28. In *Amazonian Dark Earths: Wim Sombroek's Vision*. Edited by W. I. Woods, W.G. Teireira, J. Lehmann, C. Steiner, A. WinklerPrins, L. Rebellato. Springer Science. Berlin, 2009.

Lehmann, J., J. Gaunt, M. Rondon. 2006. "Bio-char sequestration in terrestrial ecosystems – a review." *Mitigation and Adaptation Strategies for Global Change* 11: 403-427.

Lehmann, Johannes and Stephen Joseph, editors. *Biochar for Environmental Management: Science, Technology and Implementation.* London and New York. Earthscan, 2015.

Lehmann, Johannes, Matthias C. Rillig, Janice Thies, Caroline A. Masiello, William C. Hockaday, David Crowley. 2011. "Biochar effects on soil biota." *Soil Biology & Biochemistry* 43: 1812-1836.

Liang, B., J. Lehmann, D. Solomon, J. Kinyang, J. Grossman, B. O'Neill, J. O. Skjemstad, J. Thies, F. J. Lutzäo, J. Petersen, E. G. Neves. 2006. "Black Carbon Increases Cation Exchange Capacity in Soils." *Soil Science Society of America Journal* 70(5): 1719-1730.

Liu, Xiaoyu, Yingxin Ye, Yuming Liu, Afeng Zhang, Xuhui Zhang, Lianqing Li, Genxing Pan, Grace Wanjiru Kibue, Jufeng Zheng, Jinwei Zheng. 2014. "Sustainable biochar effects for low carbon crop production: A 5-crop season field experiment on a low fertility soil from Central China." *Agricultural Systems* 129: 22-29.

Lone, Aabid H., Ghulam R. Najar, Mumtaz A. Ganie, Javid A. Sofi, Tahir Ali. 2015. "Biochar for Sustainable Soil Health: A Review of Prospects and Concerns." *Pedosphere* 25(5): 639-653.

Lowenfels, Jeff and Wayne Lewis. *Teaming with Microbes.* Oregon. Timber Press, Inc., 2010a. pp. 19-27.

Lowenfels, Jeff and Wayne Lewis. *Teaming with Microbes.* Oregon. Timber Press, Inc., 2010b. pp. 46.

Mann, Charles C. 2002. "The Real Dirt on Rainforest Fertility." *Science* 297(5583): 920-923.

McBeath, Anna V., Ronald J. Smernik, Evelyn S. Krull, Johannes Lehmann. 2014. "The influence of feedstock and production temperature on biochar carbon chemistry: A solid-state ^{13}C NMR study." *Biomass and Bioenergy* (60): 121-129.

Oleszczuk, Patryk, Marcin Kuśmierz, Paulina Godlewska, Piotr Kraska, Edward Pałys. 2016. “The concentration and changes in freely dissolved polycyclic aromatic hydrocarbons in biochar-amended soil.” *Environmental Pollution* 214: 748-755.

O’Neill, B., J. Grossman, M. T. Tsai, J. E. Gomes, J. Lehmann, J. Peterson, E. Neves, J. E. Thies. 2009. “Bacterial community composition in Brazilian Anthrosols and adjacent soils characterized using culturing and molecular identification.” *Microbial Ecology* 58(1): 23-35.

Pignatello, Joseph J., Minori Uchimiya, Samuel Abiven, and Michael W. I. Schmidt. “Evolution of biochar properties in soil.” In *Biochar for Environmental Management: Science, Technology and Implementation.* Edited by Johannes Lehmann and Stephen Joseph. London and New York. Earthscan, 2015.

Pimetel, David. 2005. “Environmental and economic costs of application of pesticides primarily in the United States.” *Environment, Development and Sustainability* 7:229-242.

Plaza, César, Mark Pawlett, José M. Fernández, Ana Méndez, Gabriel Gascó, Karl Ritz. 2015. “Does biochar interfere with standard methods for determining soil microbial biomass and phenotypic community structure?” *Soil Biology & Biochemistry* 81: 143-146.

Puga, A. P., C. A. Abreu, L. C. A. Melo, L. Beesley. 2015. “Biochar application to a contaminated soil reduces the availability and plant uptake of zinc, lead and cadmium.” *Journal of Environmental Management* 159: 86-93.

Purakayastha, T., S. Kumari, H. Pathak. 2015. “Characterisation, stability, and microbial effects of four biochars produced from crop residues.” *Geoderma* 239-240: 293-303.

Rajkovich, S., A. Enders, K. Hanley, C. Hyland, A. R. Zimmerman, J. Lehmann. 2012. “Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil.” *Biology and Fertility of Soils* 48(3): 271-284.

Robertson, G. Philip, Katherine L. Gross, Stephen K. Hamilton, Douglas A. Landis, Thomas M. Schmidt, Sieglinde S. Snapp, Scott M. Swinton. 2014. “Farming for Ecosystem Services: An Ecological Approach to Production Agriculture.” *BioScience* 64(5): 404-415.

Salwasser, Hal, Steve Morton, Ray Rasker. 1998. “The Role of Wildlands in Sustaining Communities and Economies and Vice Versa.” https://www.fs.fed.us/rm/pubs/rmrs_p004/rmrs_p004_090_095.pdf.

Sesko, Michael, David Shearer, Gregory Stangl. “Commercialization of the biochar industry." In *Biochar for Environmental Management: Science, Technology and Implementation.* Edited by Johannes Lehmann and Stephen Joseph. London and New York. Earthscan. 2015.

Sombroek, Wim, Dirse Kern, Tarcício Rodrigues, Manoel da Silva Cravo, Tony Cunha Jarbas, William Woods, Bruno Glaser. 2002. "Terra Preta and Terra Mulata: pre-Columbian Amazon kitchen middens and agricultural fields, their sustainability and their replication." Oral presentation at 17th WCSS Thailand. Symposium no. 18, Paper no. 1935.

Spokas, Kurt, Jeffery M. Novak, Catherine E. Stewart, Keri B. Cantrell, Minori Uchimiya, Martin G. DuSaire, Kyoung S. Ro. 2011. "Qualitative analysis of volatile organic compounds on biochar." *Chemosphere* 85: 869-882.

Sweet, Audrey. 2015. "Buffers and biochar: influences on surface water quality in agricultural systems." Master's Thesis Southern Illinois University Carbondale. ProQuest.

Teat, A. H. Neufeld, R. Gehl, E. Gonzales. 2015. "Growth and Yield of Miscanthus x giganteus Grown in Fertilized and Biochar-Amended Soils in the Western North Carolina Mountains." *Castanea* 80(1): 45-58.

Thomazini, A., K. Spokas, K. Hall, J. Ippolito, R. Lentz, J. Novak. 2015. "GHG impacts of biochar: Predictability for the same biochar." *Agriculture, Ecosystems and Environment* 207: 183-191.

Terra Preta Program website. "Terra Preta and biochar: are they the same thing?" Accessed November 29, 2016. http://www.terrapretaprogram.org/terrapreta_biochar.aspx.

USDA website. "Soil Biology Primer". https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/.

Van Zwieten, Lukas, Claudia Kammann, Maria Luz Cayuela, Bhupinder Pal Singh, Stephen Joseph, Stephen Kimber, Scott Donne, Tim Clough, Kurt Spokas. "Biochar effects on nitrous oxide and methane emissions from soil." In *Biochar for Environmental Management: Science, Technology and Implementation.* Edited by Johannes Lehmann and Stephen Joseph. London and New York. Earthscan. 2015.

Wang, Hailong and Xiaokai Zhang. 2015. "Biochar for the Remediation of Soils Contaminated with Potentially Toxic Elements." Reviewed by Luke Beesley (The James Hutton Institute) and Johannes Lehmann (Cornell University). Accessed January 22, 2017.www.biochar-international.org.

Wiedner, Katja and Bruno Glaser. “Traditional use of biochar.” In *Biochar for Environmental Management: Science, Technology, and Implementation.* Edited by Johannes Lehmann and Stephen Joseph. London and New York. Earthscan. 2015.

Wilson, Kelpie. 2014. “How biochar works in soil.” *Biochar Journal* Oct 2014. Arbaz, Switzerland. www.biochar-journal.org/en/ct/32. Accessed April 4, 2016.

World Bank Study. “Biochar as a System Defined Concept.” In *Biochar Systems for Smallholders in Developing Countries: Leveraging Current Knowledge and Exploring Future Potential for Climate-Smart Agriculture.* pp. 23. 2014.

Yargicoglu, Erin N. and Krishna R. Reddy. 2015. “Characterization and Surface Analysis of Commercially Available Biochars for Geoenvironmental Applications.” In *IFCEE 2015,* pp. 2637-2646. 2015.

Yarrow, David. 2016. “Down the Wormhole: Customizing Biological Methods for Large-Scale Farming.” *EcoFarmingDaily* at http://ecofarmingdaily.com/wormhole-customizing-biological-methods-large-scale-farming/. Accessed August 2016.

Yu, Y., A. O. Odindo, L. Xue, L. Yang. “Influences of biochar addition on vegetable soil nitrogen balance and pH buffering capacity.” 2nd International Conference on Agricultural and Biological Sciences. 2016. doi: 10.1088/1755-1315/41/1/012029.

VITA

Graduate School

Southern Illinois University

Patricia Gay Burns

patriciagayburns@yahoo.com

Southern Illinois University Carbondale

Bachelor of Arts, Anthropology, May 2015

Research Paper Title:

Reviewing Biochar Research and Introducing a Possible Classification System

Major Professor: Dr. Leslie A. Duram