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Preliminary screening of the effect of biochar properties and soil incorporation rate on lettuce growth to guide research and educate the public through extension

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Extension service of the land grant university system is often the first source of public information for emerging soil amendments such as biochar. Biochar is a charcoal product made by heating plant biomass via pyrolysis and is increasingly marketed as an organic soil amendment. As energy-producing pyrolysis industries expand, there is increasing opportunity to utilize locally produced biochar for its potential value in sustainable agriculture. However, the highly variable properties of biochar materials and their effects on plant growth and soil nutrient supply make it difficult to objectively study the effect of this soil amendment and provide guidance to users of locally sourced biochar materials. Therefore, preliminary screening studies are needed to identify potentially beneficial ranges of biochar properties and their effects on soils and plants that can then be rigorously tested in field research. The role of extension in conducting such screening studies is invaluable to providing both guidance to researchers in developing sound study methods, and in educating the public on biochar and the myriad of uncertainties surrounding its use; thereby establishing the need for rigorous research on its properties. In 2014, a simple, yet informative screening trial was performed to identify optimal biochar pyrolysis production temperature, conditioning (that is, degree of crushing) and soil application rate for future field experiments. Lettuce (*Lactuca sativa*, var. Parris Island Cos) chosen for its short growth period and rapid biomass development, was grown in 9-L pots filled with silt loam field soil amended with biochar and/or fertilizer (or none) made from Utah-sourced cherry wood. The pots were uniformly drip irrigated once daily to keep them near field capacity throughout the study period, thereby eliminating any influence of differential soil-plant-water relations. Three biochar products created from the same cherry wood source, but resulting from three different pyrolysis temperatures (375, 475 and 575°C) and either powder ground (P) or masticated (M) texture were applied to soil at three application rates (1, 2 and 3% by weight). Variation in plant dry weight at harvest within and among treatments was high. Lettuce growth with the addition of biochar was decreased as compared to control treatments in all cases, except for biochar produced at the lowest temperature, 375°C. Results indicate that masticated biochar produced at 375°C and applied to soil at the rate of 2% by mass offers the best combination of beneficial response and ease of handling for future field evaluations. This case study's benefit for demonstrating the value of preliminary screening trials to inform both future research and public outreach education is discussed.

Key words: Biochar, soil amendments, pyrolysis, plant growth, high temperatures.

INTRODUCTION

Biochar is a charcoal product created through the pyrolysis process which heats plant biomass in a closed system at high temperatures and under a limited supply of oxygen to produce combustible gases and oils for energy generation and biochemical manufacturing. Biochar may be applied to the soil as a means for soil carbon enrichment and long-term carbon storage, where it can require from 4 to over 100 years to degrade. This property of biochar makes it a desirable amendment because it does not require annual application. The use of soil-applied biochar in agricultural crops has gained interest in recent years because it has been shown to significantly improve soil tilth, nutrient retention and availability to plants, water holding capacity, and soil aggregate stability (Glaser et al., 2002). Biochar has little nutrient value, but biochar properties allow it to retain existing nutrients in the soil. Reported increases in crop yields with biochar amendment may be attributed to an increase in nutrient availability (Khodadad et al., 2011). Biochar application can also stimulate plant resistance to soil borne diseases through promotion of mycorrhizal fungi and soil microbial populations (Steiner et al., 2008).

Despite the literature citing beneficial effects of biochar, these effects have varied among soil types, biochar production practices and application rates. Few studies have evaluated biochar in arid and alkaline soils (Spokas et al, 2012). One study of biochar application in alkaline soils found that biochar had a delayed positive effect on lettuce growth after an initial two to three months of production where growth was stunted. The same study found the initial negative effect was less prevalent for Bermuda grass, especially when subjected to drought stress. Following one month without irrigation, Bermuda grass with a 2 and 4% concentration of biochar in the soil had 50 and 100% recovery, respectively, as compared to an untreated control (Artiola et al., 2012).

While recent reports on the benefits of biochar have stimulated interest among local growers, it is difficult to piece together results from variable studies to produce general recommendations. Also, the cost of biochar varies widely between sources. Growers in the western USA intermountain region need locally-relevant information to help them evaluate whether biochar could be a viable option for their industry. Biochar production and use does extend beyond agriculture, as a part of a larger sustainable system promoting waste management, fossil fuel energy alternatives, and carbon sequestration. Thus, adoption of biochar by commercial growers as a soil improvement technique could promote the growth of green energy technology and job creation. Study findings will be relevant to locations beyond Utah, particularly in the Intermountain West, with similar soils and growing conditions.

The objectives of this study were to 1) screen potential treatment combinations to identify a formational pyrolysis temperature and appropriate soil application rate for producing and utilizing biochar in subsequent vegetable production studies, and 2) generate preliminary scientific data useful in extension public education efforts to illustrate the effect of biochar on vegetable growth.

MATERIALS AND METHODS

The biochar used in this study was made by Western Renewable Technologies (WRT) in Linden, Utah from cherry wood sourced from a cooperating fruit grower within 50 km of the facility. The biochar was separated into thirds and each amount processed at a different temperature: 375, 475 and 575°C for 10, 7, or 4 min, respectively. The pyrolysis machine was manufactured by Biogreen® and operated by WRT. After pyrolysis, half of the biomass produced at each temperature was masticated to 0.6 cm size pieces and half was pulverized to a fine powder. Major (2010) indicates that the ideal biochar particle sizes to improve soil moisture retention have not been determined. Borchard et al. (2012) found in a greenhouse experiment with Italian ryegrass that the influence of biochar particle size on nutrient content in soil and biomass was relatively small. The six biochar products (3 temperatures × 2 particle sizes) were applied to silt loam field soil (pH 7.3) in pots at three different rates: 1, 2 and 3% by mass. Fertilizer (see description below) was uniformly added to all pots resulting in 18 biochar treatments. Two control treatments were included: fertilizer only (no biochar) and soil-only (no biochar or fertilizer) for a total of 20 treatments. Three replicates of each treatment were planted for a total of 60 pots.

Before application, biochar samples were weighed and then soaked in water for two weeks with 0.8 g 4-4-4 organic fertilizer (Jobe's®) per pot. Soaked biochar and fertilizer were mixed into silt loam field soil in a large bin, and transferred to #3 nursery pots (9 liters). Automated irrigation was applied for one minute daily with micro bubblers in each pot.

Lettuce (*Lactuca sativa*, var. Parris Island Cos) was seeded on July 11, 2014 and pots were placed on the gravel covered ground of a Cravo® retractable roof greenhouse. The pots were uniformly drip irrigated once daily to keep them near field capacity throughout the study period, thereby eliminating any influence of differential soil-plant-water relations. Plants were thinned to three plants per pot after three weeks, and harvested 90 days after planting. Average plant weight per pot was recorded and used for data analysis. An average weight for each treatment is shown in Figure 1. The variability of weights between replicate pots is expressed as the standard error.

RESULTS AND DISCUSSION

Lettuce growth in the biochar treatment produced at 375°C and pulverized to a fine powder (375P) was the

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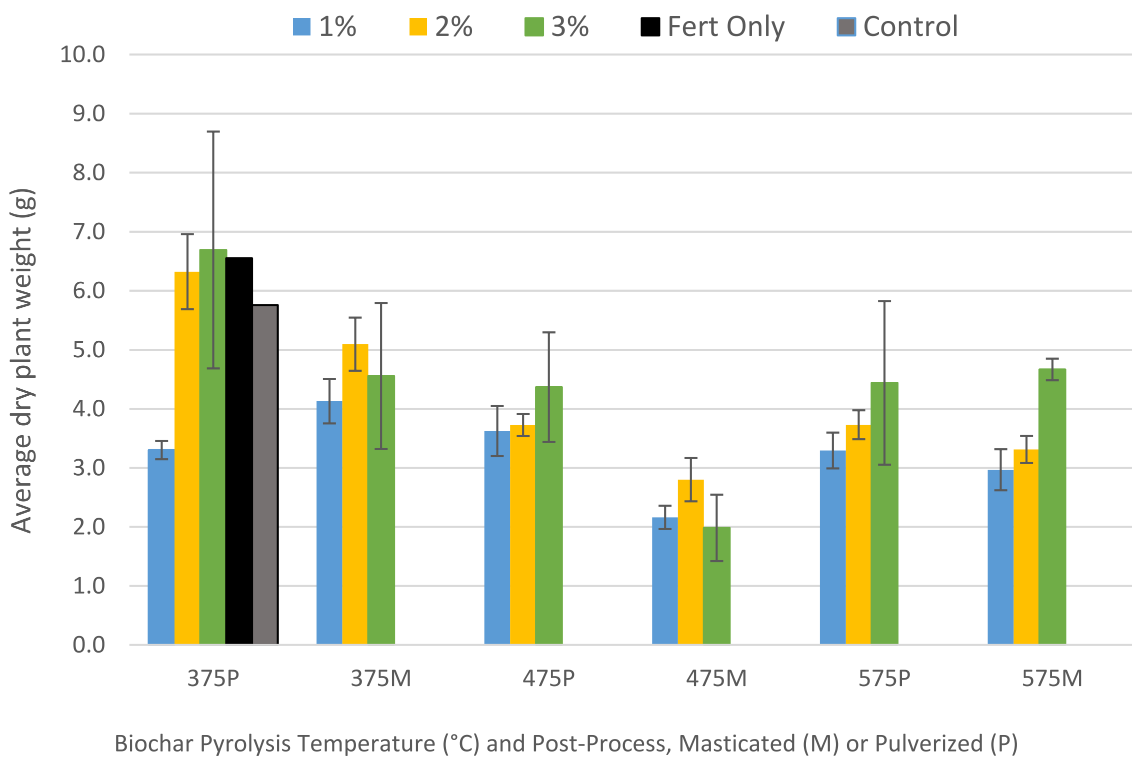

Figure 1. Effect of biochar rate, pyrolysis temperature and particle size on lettuce dry weight per plant. The vertical bars with caps represent standard error (SE).

only treatment to exceed that of the fertilized and unfertilized controls, but only at the 2 and 3% mass-based application rates (Figure 1). Despite its enhancement of plant growth, 375P biochar was difficult to work with due to air drift and hydrophobic properties, making it a much less desirable option for large-scale soil application. The 375°C masticated (375M) biochar, which does not have the drift or hydrophobic properties of 375P biochar, produced lower but statistically similar plant weights to the 375P biochar and performed consistently higher than biochar produced at higher temperatures, regardless of soil application rate. Therefore, the 375M biochar at the 2% mass-based application rate presented the best combination of experimental plant growth effect and ease of handling. Moreover, the biochar formational temperature of 375°C is desirable because of higher biochar yield relative to wood biomass processed and, therefore, higher long-term soil carbon storage potential using this type of biochar.

Greenhouse study

At all temperature treatments, the masticated biochar produced lower plant weights than the pulverized biochar and only one treatment exceeded plant growth above the control. This observation is consistent with a previous study that reported delayed positive response on lettuce growth of two to three months after biochar application (Artiola et al., 2012). Jay et al. (2015) also notes that biochar may have little or no effect on already productive soils, particularly in the first cropping season after application.

Based on the study results, it was determined that the masticated biochar produced at 375°C would be the best choice for future field evaluations and that it should be applied to the soil at a rate of 2% by mass. It was felt that this rate would have the least likelihood of short-term detrimental effects on plant growth and that the masticated biochar had the most convenient handling characteristics for distribution and soil mixing. Studies are currently underway using this result to guide evaluation of biochar in field tomato and melon production settings in Utah.

Value of the study to extension education

The greenhouse study captured an illustrative range of the effect of biochar produced at various formational temperatures and applied to soil at varying rates. The overall range of response and the observed variability within any given treatment are consistent with previous research and provide an effective educational tool in a simple graphical summary.

A hypothetical example of the value of the extension information shown in Figure 1 is as follows: A small, struggling organic vegetable producer is interested in using biochar as a soil amendment to increase soil organic matter, improve soil tilth and water relations, and wants to know what they should be aware of when seeking an appropriate biochar source. The data in Figure 1 would allow an Extension educator to clearly point out that formational temperature is a highly important consideration and one should likely avoid using biochar formed at temperatures above 400°C. Moreover, the data indicate that more (higher application rates) are not always better when it comes to biochar application. In fact, the data in Figure 1 indicate that there is little if there is any statistical distinction between plant growth over the range of application rates.

Based on the data in Figure 1, an extension educator would be able to explain to this hypothetical grower that greater than 50% reduction in plant growth for high formational temperature biochars may occur, and that the additional expense of high application rates may not be justified given the variability of response shown. These are valuable science-based points of discussion for extension clients across a variety of interests and levels of implementation including urban home gardeners, small organic vegetable production operations, or large-scale production horticulture enterprises. From the data presented in Figure 1, an extension bulletin will be prepared to discuss the non-intuitive depressive effect that certain biochars and/or soil application rates may have on crop growth.

This paper clearly outlines the value of preliminary screening studies like the one described herein to determine experimental treatment parameters and generate science-based information from which to educate the public through extension programs.

Conflict of Interests

The authors have not declared any conflict of interests.

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