Open Access Journal of Agriculture Research

ISSN: 2651-9003

Research Article

Murphy B, et al. Open Acc J Agri Res: OAJAR-100016

Concentration Effects of Biochar on Soil Health and Red Leaf Lettuce (*Latuca Sativa*)

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Citation: Murphy B, Torres M, Zhang F, Omaye ST and Ott J (2019) Concentration Effects of Biochar on Soil Health and Red Leaf Lettuce (Latuca Sativa). Open Acc J Agri Res: OAJAR-100016

Received date: 19 June 2019; **Accepted date:** 01 July, 2019; **Published date:** 05 August, 2019

Abstract

Biochar is a porous material with high cation exchange capacity that may increase overall health and fertility of soil; specifically, water and nutrient holding capacity. It is created through pyrolysis of wood or other types of organic matter and is made by thermally degrading biomass in the absence of oxygen. Soil structure is purported to improve with the addition of biochar as an amendment. The purpose of this study was to compare four different concentrations (0%, 2.5%, 5%, and 10%) of biochar in a compost mixture (CM) and standard biochar (PM) on soil moisture, soil temperature, soil pH, and growth of above-ground biomass of red leaf lettuce (*Lactuca sativa)*. The study was done in two trials. Data results from Trials 1 and 2 were combined and analyzed. The trend for germination of lettuce seeds was inversely related to biochar concentration. No concentration-dependent relationship was found related to biomass growth and viticanopy; however, as the biochar concentration increased, the pH of soil decreased and there was a tendency for soil moisture to decrease with increasing biochar concentration. The lack of concentration-dependent effects of biochar the of lettuce growth, is inconsistent with historical observations; ranging from more subjective to limited in defining quantification of concentration effects.

Keywords: Biochar; Feedstock; Fertile soil; Fertilizers

Introduction

Research is ongoing to develop crops that can be cultivated on arid and semi-arid lands in the hope to convert unproductive land to prospective agricultural lands for food and fue [1]. Research for the conversion of unproductive land is useful as we attempt to feed and provide ways for the world growing population on diminishing arable land. Particularly timely research, because there is competition for arable land between crops grown as human sustenance and biofuels, *e.g*., the increased exploitation for biomass energy. This drive towards change in land use has increased food prices in the last decade [2], and led to additional undesirable consequences, such as net increases in emissions of greenhouse gases to the atmosphere [3].

In addition to crop and land development, soil improvement using biochar as an agricultural soil amendment is a prospect that many in agriculture have developed optimism, especially for food crops for human consumption. Biochar has been purported to improve soil health and quality by increasing soil structure due its porosity and low bulk density, which leads to more water and nutrient-holding capacity, as well as a better cation-exchange capacity, all of which help to increase soil health and fertility [4,5].

Further assisting soil improvement, biochar may reduce the phytoavailability of contaminants such as lead, zinc, and cadmium in the soil remaining from anthropogenic activities, increasing the health and fertility of soils [6], and the health of humans who ultimately eat the plant matter grown in contaminated soils. It does this by breaking the source-receptor pathway by which the contaminants enter the plant. Heavy metal contaminants enter plants when they are in the soil solution but the highly negative charge of biochar keeps them from being taken up by the plant [7]. In addition, biochar can be a source of polyromantic hydrocarbons and other human carcinogens.

In addition to soil quality improvement from the addition of biochar as an amendment, current research has focused on the different types of feedstock used to produce biochar it because variations in feedstock, as well as pyrolysis methods, lend to dramatically varying its characteristics [8]. For example, [9] conducted research in a greenhouse where oats were grown in bags. The study compared the growth of oats in two different soils; washed sand and loamy soil, controls with no composted biochar, and mixtures with different levels of composted biochar [10] compared two different biochars using different fertilizer treatments in a field study. Biochar A was produced from corn stalks and biochar B was produced from wood chips, both reaching pyrolysis at 450 degrees C. Both were applied to the soil at a rate of 40 tons per hectare along with Nitrogen fertilizer rates were 0%, 50%, and 100%. Both studies show that plant growth was highly variable and dependent on the source of biochar as well as the nutrient content of various composts.

The objective of this study was to measure the concentration effects of biochar on the growth of lettuce and relationship between soil moisture, soil temperature, soil pH, and growth of above-ground biomass of red leaf lettuce. The study was done in two trials over different times in the growing season.

Materials and Methods

Red leaf lettuce (*Latuca sativa)* was chosen due to the quick time to maturity and the ability to replicate the experiment within a reasonable period. The duration of each trial was determined to be 45 days from planting because red leaf lettuce is a loose-leaf head and common practice is 40-50 days to maturity for a full head and single harvest. Plants were grown in 32” × 32” × 8” raised garden boxes (cedar wood commercially available), to allow for proper drainage with drip irrigation. Electric fencing was erected to protect the seedlings from ground squirrels and other animals. Biological controls were used throughout the experiment, consisting of green lacewings, ladybugs, *Encarsia formosa*, and yellow sticky paper, to protect the lettuce from aphids, white flies, and spider mites.

The study was done in two trials between 04/21/2017 to 06/11/2017 and 10/16/2017 to 12/06/2017, respectively because others have found that biochar improves plant growth in subsequent growing cycles [11]. The greenhouse study was composed of 16 garden boxes, using two different biochar/soil types with four biochar concentrations (0%, 2.5%, 5%, and 10%) for cultivating red leaf lettuce. The maximum value of 10% biochar was selected based on product recommendations not to exceed 10% (w/w) as optimal for growth of plants [12] and concentrations cited in the literature [13-15]. The planting boxes were set up using a randomized complete block design with 15 plants per box and two boxes per treatment, and soil type, for a total sample size of 30 per treatment and soil type. Soil readings for temperature, moisture, and pH were taken daily.

Two sources of biochar were utilized in this study; Genoa, a commercial product provided by Genoa Tree and Landscape Materials (Minden, NV), referred to as Compost Mixture (CM) and Promix (PM) which served as a defined control (certified 97% USDA bio-based product). The biochar from Genoa Tree and Landscape was processed and composted and sold as Compost Mixture. Pinyon-Juniper was the initial feedstock, which was obtained from the U.S. Forest Service. The pyrolysis method they used is unknown. The compost mix from Genoa was delivered in two separate piles; one labeled as 10% biochar concentration and the other a labeled as 0% concentration. However, by observation, the composted soils were not homogenous and the bulk density of its components was drastically different. Therefore, we chose to comprise our concentrations of biochar for each treatment based on a known volume and its corresponding weight. A cubic foot of the CM or PM with and without biochar was weighed. We used this weight to measure out the appropriate amount of cubic feet for each treatment (1 cubic foot of compost mix without biochar weighed 19.3 kg and to obtain a 0% biochar treatment, we multiplied 19.3 kg by the total volume of the box, nine cubic feet). The cubic feet of soil were derived for the 2.5%, 5%, and 10% biochar treatment boxes and weighed out per the above method. We followed the method above for designation of concentrations for the PM boxes as well. Soil for PM was chosen from farm stock commonly being used in greenhouse studies and the contents are controlled for during the manufacturing process and known. The mixture with the PM was sourced from Wakefield Biochar and is certified 97% USDA bio-based product.

The drip irrigation system was set on timers to water once per day for 5-9 minutes, or 279 to 299 mL per row per day. We made this determination by preliminary irrigation trials (Murphy, Torres, Zhang and Omaye*,* unpublished results) and not allowing the soil moisture content to fall below 1.8 on the 10-point scale on the soil moisture meter (Soil Moisture Detector, Gold Queen, at Amazon).Seedlings were planted at 0.5-inch depth and culled at 14 days when it was clear that no additional seedlings were going to germinate. Miracle Grow® fertilizer was prepared according to the ‘outdoor plant’ guidelines of 3.5 g diluted in 946 mL water and applied at an initial rate of 10 mL per site occupied by a plant starting at day 14 and then again, every seven days thereafter at a rate of 5 mL per site, until day 42. Upon the emergence of seedlings, soil canopy cover and leaf index readings were taken approximately every two to four days, using the Viti canopy app, developed by the School of Agriculture at the University of Adelaide in Australia. Viticanopy was chosen to evaluate leaf area index (LAI) and canopy cover of the lettuce once germination occurred. LAI was chosen because it is an efficient and non-invasive way to gauge the rate of above-ground biomass growth throughout the experiment. Photographs of each box were taken from the same height and angle approximately every two or three days, beginning at 21 days after planting and seven days after culling with initial fertilization. LAI is defined as the leaf area per unit ground surface area. LAI and canopy cover data were recorded and statistically analyzed to determine significance.

At day 45 the lettuce plants were cut right above the soil, and each plant was weighed and recorded individually on site. The samples were then placed in an oven and dried at 60 ℃ for 48 hours and weighed again after drying. Upon harvest at day 45, wet and dry weights of the lettuce were compared for each biochar concentration to compare the affect different biochar

ISSN: 2651-9003

concentrations had on above-ground biomass growth.

Throughout each trial, data measurements were taken and recorded daily. A soil thermometer was used for soil temperature (Luster Leaf, Walmart, Reno, NV), and a pH meter combined with a soil moisture meter was also used. Soil temperature, pH, and moisture readings were collected at two places along each of the three rows within each box for a total of six readings per box per day. Scheduling was set so that each student participant/volunteer could take the readings at roughly the same timeframe each day. Each participant was trained so that the data collection procedure was conducted similarly as possible by everyone. The probes were placed at the same depth at each measurement site and they were wiped clean between each measurement with Kimwipes (Kimtech, Kimberly-Clark). The data was recorded in logbooks and later keyed into and electronically filed to prepare for data analysis.

For both trials, a combination of data from trial 1 and trial 2, a two-way ANOVA analysis and t-test were conducted using Statistical Analysis System (SAS, SAS Institute, North Carolina State University) to look at the effects of different biochar concentrations on biomass growth, soil moisture, temperature and pH to determine statistical significance. It was determined that the results between trial 1 and 2 were not statistically significant different. Therefore, the data for fresh and dry weights, Vitacanopy, and soil health indices from both trials were combined, analyzed, and shown below.

Results

Germination Data

Trial 1: Lettuce germination for trial 1 occurred between 04/21/2017-05/02/2017 and the ambient temperature range was 11.7 to 34.5 °C, and humidity was 15-68%. Germination rates decreased as CM biochar concentration increased. For PM, the highest germination rate was 77% for the 0% biochar concentration. Germination rates decreased as the biochar concentration increased.

Trial 2: Germination occurred between 10/22/2017 to 11/06/2017 and the temperature range within the greenhouse was 5.1-44.6 °C and the humidity range was 15-90%. The highest germination rates for CM were for the 0% and 2.5% biochar concentrations at 100% germination, followed by 90% germination for the 5% and 10% biochar concentrations. The PM germination rates were 100% for the 0%, 2.5%, and 10% biochar concentrations and 93% germination for the 5% biochar concentration.

Soil temperature

For trial 1 and trial 2, no significant changes were found for soil temperature (CM, $F = 0.65$, $P > 0.5856$; PM, $F = 0.67$, $P > 0.5682$)

Biomass growth

There was no statistical trend between fresh weight (CM, $F=0.49$, $P > 0.6912$; PM, $F=3.25$, $P > 0.0226$) or dry weight (CM, $F=0.26$, $P > 0.857$; PM, $F=1.33$, $P > 0.2667$) of lettuce and percentage of biochar added either to the CM or PM. A slight trend; however, not statistically significant, for PM, fresh weight increased biomass with increasing biochar concentrations in the soil.

Viticanopy data

The Viticanopy data for leaf area index (LAI) was compiled and graphed for each soil type in **(Figure 1A)** for CM and **(Figure 1B)** for PM, respectively. A statistically significant trend was observed for CM LAI ($F = 6.19$, $P > 0.0005$) decreasing as a percentage of added biochar increased. A similar trend was illustrated for PM but the trend was not significant ($F = 3.18$, $P > 0.0254$).

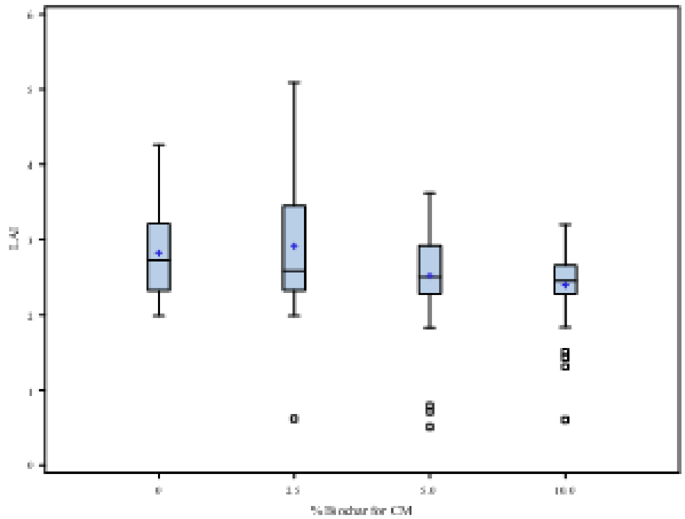

Figure 1A: Effect of biochar concentrations in Compost Mixture (CM) on Viticanopy, leaf area index (LAI). Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

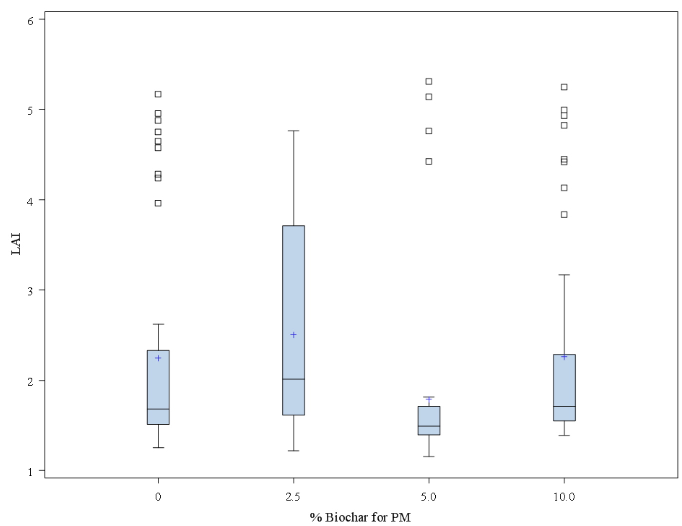

Figure 1B: Effect of biochar concentrations in Promix (PM) on Viticanopy, leaf area index (LAI). Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

Soil health, pH

Figure 2A shows the distribution of the soil pH for CM falling

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just outside the statistically significant level (F=1.56, p > 0.06). The pH of Promix soil showed a curious inverse relationship with biochar concentrations within the soil as shown in Figure 2B at a significant level (F=54.24, p > 0.0001), with the highest pH at 0% concentration and the lowest pH at 10% biochar concentration in the soil.

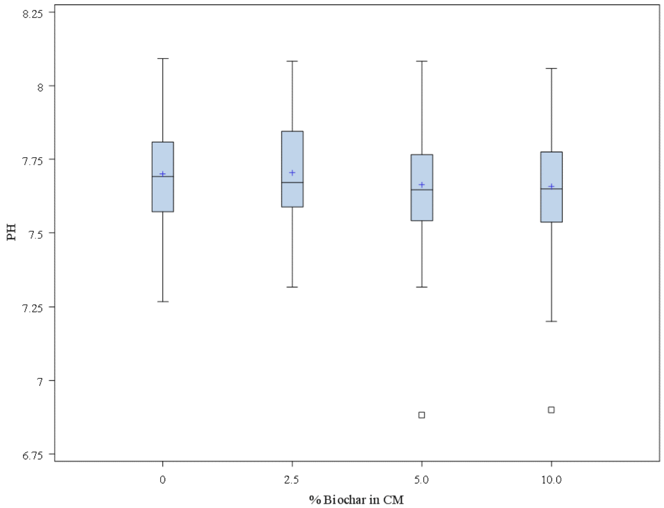

Figure 2A: Effect of biochar concentrations in Compost Mixture (CM) on soil pH. Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

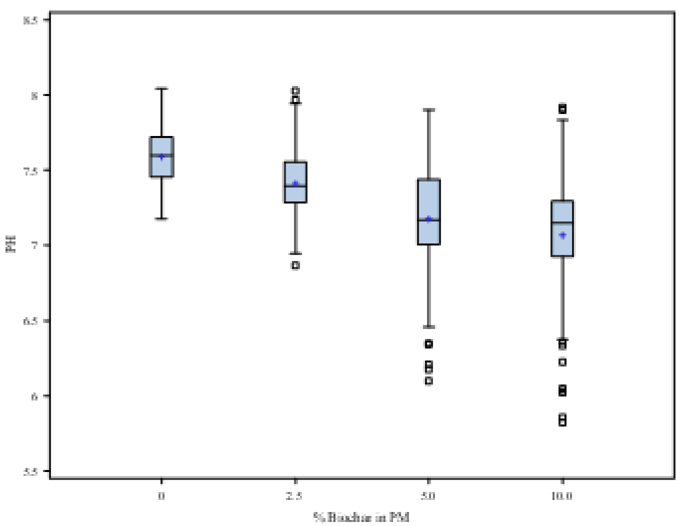

Figure 2B: Effect of biochar concentrations in Promix (PM) on soil pH. Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

Soil health, moisture

Figure 3A shows the distribution of soil moisture for CM as statistically significant (F=10.15, p > 0.00001) with a general decreasing relationship as the biochar concentration within the soil increased, the soil moisture generally decreased. For PM soil moisture, **Figure 3B** shows that the distribution of soil moisture was not statistically significantly related to biochar concentration (F=3.24, p > 0.0221).

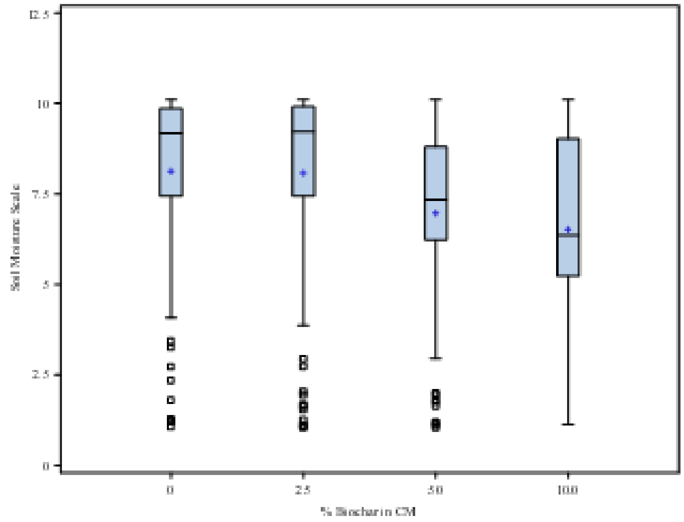

Figure 3A: Effect of biochar concentrations in Compost Mixture (CM) on soil moisture. Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

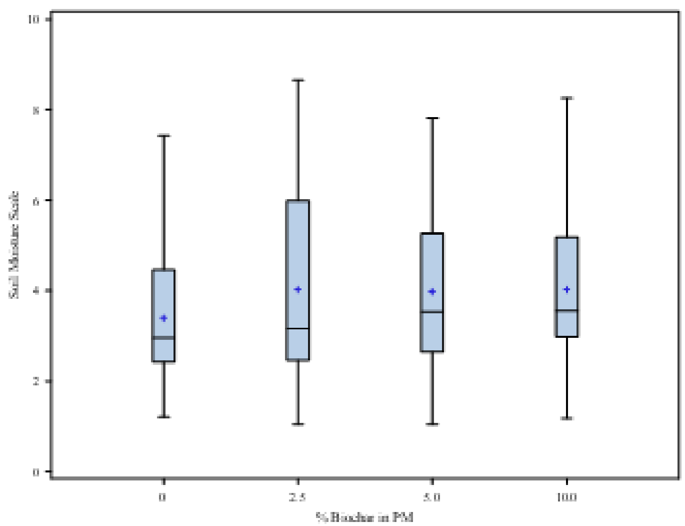

Figure 3B: Effect of biochar concentrations in Promix (PM) on soil moisture. Box Plots; highest value, upper quartile, median, lower quartile and lowest value respectively. Data points that differs significantly from other observations are designated as (▫).

Discussion

The heterogeneous nature of biochar presents many difficulties in doing controlled efficacy studies for growing plants [10]. Due to biochar's resistance to degradation within the soil, it persists for hundreds, perhaps thousands of years. The fate of biochar is unclear as no field study has been conducted to date that lasts over the term of biochar's persistence [16-19]. However, [20] noted that the persistence of biochar in soil could be advantageous by contributing to better water and nutrient availability in the long-term, mitigation of toxins, because as surface oxidation of biochar progresses, so does cation retention ability. Conversely, biochar's persistence could be disadvantageous as its properties change upon prolonged exposure to soil, such as ability to adsorb polycyclic aromatic hydrocarbons (PAH's) and loss of its acid-neutralizing ability [21-26].

We speculated that the use of biochar as a soil amendment would increase soil productivity and, thus, biomass growth of red leaf lettuce (*Lactuca sativa)*. Such implications could be expanded to other crops for increased yield to feed the world's increasing population, as they have been shown to do in yield studies conducted previously [9,10]. However, in contrast to our expectation, the germination rates decreased with added biochar, 0% to 10%. Seed stock, germination methods, irrigation methods, fertilization procedures, harvest, and weighing methods were identical for CM and PM for both trials. The humidity and temperature ranges were similar. There was no relationship between increasing biochar concentrations to biomass growth and viticanopy. Soil moisture and pH was inversely related to biochar concentration. The apparent lack of beneficial concentration-dependent effects of biochar on lettuce growth, soil pH, and moisture content in this study may be reflective of defined as well as potentially undefined properties of biochar. The use of biochar to improve agronomic productivity likely requires the additional input of nutrients either through compost, or synthetic fertilizers [9]. In this study, the lowest % biochar soils provided better plant growth and higher accumulation of water in plants, suggesting the nutrient availability within the biochar might be in question. Biochar varies drastically in its characteristics depending on its production methods such as primary feedstock, residence time, and temperature. These attributes may be due to the lessening tensile strength of the soil used in the study, increased organic carbon, increased cation exchange capacity, and increases in field capacity (water holding capacity) [27]. Similar to our findings [27], we noted no crop yield improvement with the application of biochar alone. It is only in studies where added nitrogen fertilizer with biochar, significant increases in crop yield, suggesting biochar plays an important role in increasing a crop's nutrient use efficiency. Others [26,28] found on biochar research that biochar-compost application proved to be more effective in increasing soil properties and that lends to soil health and improved crop yields. Other research indicates that plant growth indicators are increased as the second and third trials progress over the first, assumed due to biochar becoming more nutrient loaded [11]; thereby, not immobilizing nutrient from the soil and reducing nutrient availability.

Overall, if biochar preparation is not adequately addressed for optimal biochar quality, adding, biochar to the soil for soil improvement or increased crop yield can be problematic. Those interested in the use of biochar must fully understand the production processes and how biochar differs in characteristics based on the different feedstocks and production methods [29]. With appropriate defined research, researchers can determine the usefulness of this material as an agricultural soil amendment [30]. There is a need for better definition of the characteristic of biochar and having consistency of the product [26].

Conclusion

The lack of concentration-dependent effects of biochar on lettuce growth and inversed effects on soil health in this controlled study is inconsistent with some historical observations; some of which were more subjective and limited in defining quantification of concentration effects. If the use of biochar to improve agronomic productivity requires additional input of nutrients either through compost or synthetic fertilizers, this could problematic and economically discouraging. The cost of synthetic fertilizers is rising and the stock of required nutrients (such as phosphorous) is dwindling at the current rate of consumption [9]. Biochar varies drastically in its characteristics depending on its production methods such as initial feedstock, residence time, and temperature. In studies showing a positive effect of biochar on plant growth, the specific aspects of soil health that are shown to improve are porosity, bulk density, soil compaction, water holding capacity, and nutrient-holding capacity [13,25,31-33]. However, others have noted no crop yield improvement with the application of biochar [34].

Recommendation

It is only in studies where added nitrogen fertilizer with biochar, lead to significant increases in crop yield, suggesting biochar plays a vital role in increasing a crop's nutrient use efficiency. There is a need for additional long-term research on biochar degradation to determine agricultural effectiveness and application. Biochar is reported to be stable for hundreds if not thousands of years [35]. Such long-term research has not been done as concluded a previous meta-analysis evaluating 177 studies. Overall, biochar preparation is not adequately addressed for optimal biochar quality when returning biochar to the soil for soil improvement or increased crop yield [26]. Therefore, future research must consider and fully understand the production processes and how biochar differs in characteristics based on the different feedstocks and production methods [29]. Research is increasing in the use of biochar as an agricultural soil amendment and there is a need for better understanding the makeup of biochar and development of consistency of sources [30].

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