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Biochar's fitness as an amendment in bell pepper transplant and field production

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Biochar’s fitness as an amendment in bell pepper transplant and field production

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ABSTRACT.

Biochar, a carbon-rich co-product derived from the pyrolysis of biomass for fuel for energy production, often exhibits beneficial chemical and physical properties when added to soils and soilless substrates. Research into the use of biochar to improve plant productivity and growth has increased over the past decade. Much of this research has been done in controlled environments, and often these experiments focus on using biochar as an alternative to sphagnum peat, or on how biochar affects plants grown in soil. Few studies have investigated biochar's effects on a specific plant in both greenhouse and field production, and from seed to harvest. The objective of this research was to explore the possibility of using biochar in both the transplant and field production of bell pepper *Capsicum annuum* L.

In the transplant experiment using a randomized split-plot design biochar was mixed in a retail substrate (Jiffy Mix® Growers Choice #901, Lorain, OH. Biochar was added to Jiffy Mix® at rates of 0%, 20%, 40%, 60%, and 80% (w/w). Bell pepper var. 'Paladin' was direct-seeded and grown 53 days in cell-flat sizes of 50, 72, and 98 at each of the five levels of biochar addition. In the field experiment biochar was incorporated into a Clarion loam and an Anthrosol consisting of sand and pea gravel at the rates of 0 $kg \cdot m^{-2}$ (control), 1.1, 2.2, and 4.5 $kg \cdot m^{-2}$ in 2012. Bell peppers were then grown on black plastic mulch and bare soil beds for two seasons.

Pepper seed germination increased as compared to the control in the 50- and 72- cell-trays with additions of 20%, 40%, and 60% biochar; however, biochar had no effect on germination in the 98-cell-tray. Plant height and dry weight were reduced as the biochar percentage increased, and as cell size decreased. Height and dry weight, measured at 53 days, decreased at differing rates within both factors, showing less variation between biochar treatments in the 98-cell-flat and less variation between cell volumes at the 80% biochar treatment level. Indirect estimate of chlorophyll using SPAD readings showed similar trends to the height and dry weight. Nitrate-N in the substrate was reduced by the end of the experiment except in the 60% and 80% biochar mixes, which had more nitrates at 53 days after planting.

Field trial results indicated biochar did not increase marketable fruit production in either soil type. Biochar did, however, affect leaf chlorophyll content in both fields, although not in the same year. Biochar decreased extractable NO_3-N in both fields (2012). Potassium concentrations were increased in the Clarion loam field both years. Biochar also decreased the amount of nitrate that was leached from the root zone into lysimeters in Clarion loam (2012) and sand Anthrosol (2013). Reductions in leaf chlorophyll content were seen in the same field in the same years as reductions in the nitrates leached from the root zone were seen. Our results indicated that biochar can be added to commercial soilless substrate at rates up to 40% without detrimental effects on pepper transplant production. We also concluded that additions of biochar up to 4.5 $kg \cdot m^{-2}$ are possible without causing losses in production; however productivity was not increased, so growers may have difficulty justifying the extra expense associated with biochar application. Our results also suggest that nitrates may be a concern when higher rates of biochar are added. This indicates that adding biochar to soils with the express purpose of sequestering carbon is possible, but more work should be done to insure no losses in productivity are seen.

CHAPTER 1. GENERAL INTRODUCTION

A rapidly growing global population combined with an increasing demand for energy has generated interest and research into technologies that seek to improve land use efficiencies and/or utilize biomass for energy. Often these technologies address one problem, but not the other. One technology that is gaining interest may hold keys to both increasing agricultural soil productivity and utilizing biomass for energy. That technology is pyrolysis. Pyrolysis is the thermal decomposition of biomass in a low oxygen environment. Pyrolysis is unique among processes of extracting energy from biomass in that often once the process is underway it does not require exogenous energy to maintain (Laird, 2008). Depending on the method employed, pyrolysis can yield differing ratios of bio-oils (Bridgwater, 2003), syngas, and black carbon, otherwise known as biochar (Lehmann, 2007).

Biochar is thought to have possibilities for increasing food production, and reducing nutrient and agro-chemical leaching, all while possibly mitigating climate change (Lehmann & Josephs, 2009). Biochar is the term coined for “char” when it is used as a soil amendment. Some research studies indicate possible beneficial effects on plant growth when biochar is added to soils (Blackwell et al., 2009) Another benefit of applying biochar to the soil is the possibility of sequestering carbon. A large portion of the carbon in biochar is believed to be recalcitrant and resistant to oxidation when added to soils (Lehmann et al., 2009). This makes biochar uniquely suited as a candidate for carbon sequestration and hence may provide an opportunity to reduce levels of CO_2 in the atmosphere (Lehmann & Josephs, 2009). Biochar may also assist in mitigating climate change by reducing emissions of other greenhouse gasses from soils (Bhupinder et al., 2010; Rondon et al., 2005). While field trials have been performed that show possible increases in agronomic production due to the addition of biochar, there is little consensus on biochar's fitness for use in temperate climates. This is because many of the studies to date have been performed in poor quality, acidic tropical soils and in soils with low productivity (Atkinson, et al., 2010). It is also important to note that few field studies on effects of biochar in temperate soils have been performed (Jones et al., 2012).

There are a number of forces driving the production of biochar, of which the search for alternative energies is the most significant. Two types of pyrolysis are employed depending on the desired products and their intended use (Lehmann, 2007). These processes are termed fast and slow pyrolysis (Brown, 2009). The names of these processes indicate the speed at which the product is heated and residency time in the pyrolysis chamber (Brown, 2009). Many of the fast pyrolysis techniques yield more bio-oils, and lower amounts of biochar, while slow pyrolysis yields higher levels of biochar and are not often used for bio-oil production (Bridgwater, 2003). Economic factors will likely drive pyrolysis technology, and with the rising cost of fuel, the extraction of bio-oils and syngas will be major factors behind technology's advancement. Because of costs associated with shipping, pyrolysis of biomass will likely be performed close to the source of the biomass (Laird, 2008). The same is likely true about the utilization of the biochar produced.

As with other new technologies it is important that research into biochar's use be performed before recommendations are made. The highly variable physical and chemical properties of biochar (Mukherjee, 2011) increase the importance of a thorough investigation before wide spread use is recommended. Internet blogs and special interest groups hail biochar as the solution for many of the world's problems, but not all of the research supports these claims. Studies like those performed by Wardel et al. (2008) and Makan and Abrams (1996) have shown detrimental effects of naturally derived chars on forests in temperate regions. Biochar may also have an effect on other aspects of agronomic production. Rogovska et al. (2011) found that the germination of corn (*Zea mays* L.) was influenced by organic compounds possibly adsorbed to surface of biochar during pyrolysis. Atkinson et al. (2010) states the importance of further critical analysis of biochar in temperate soil because of the variability of biochar and the lack of research to date. It is therefore important that research be conducted to insure the best information possible for farmers interested in learning about and implementing biochar technology.

There are economic and environmental rationales for conducting research on biochar as well. Certain biochars have been shown to have some potential as a liming agent for soils (Chan et al., 2007). Limestone is widely used to control pH in soils under agronomic production. Biochar also exhibits a possibility for use as a liming agent due to high levels of inorganic carbonates found in its ash fraction (Yuan et al., 2011). Other potential interactions between biochar and soil nutrients offer environmental and economic possibilities. Biochar has been shown to help with nutrient availability, increasing the NO_3-N in the rhizosphere (Prendergast-Miller et al., 2011). This could allow for decreased application rates as well the amount of nitrogen that is leached from soils. Biochar has also been shown to improve water holding capacity of some soils (Karhu et al., 2011), and possibly improve plant adaptation to water stress (Kammann et al., 2011).

Research to find value in using biochar is also important because of potential economic factors that might arise in the search for bioenergy, including lack of incentives to convert any biomass into biochar, which would reduce biochar’s potential in mitigating climate change (Laird, 2008). It, therefore, makes sense to look for benefits from the use of biochar that will add farm value, consequently making biochar a valuable co-product of pyrolysis and not simply a by-product in the extraction of energy. One possibility for increasing biochar's value may be in vegetable production. Bell peppers are a high-value crop, so increases in production from biochar might be of greater economic value than gains in commodity crops like corn or soybeans.

One group of farmers who are interested in learning and implementing new techniques are beginning farmers. Beginning farmers are increasingly turning to vegetable production as a means of maximizing income on small acreages. This trend has been recognized by organizations like SARE and National Center for Appropriate Technology (NCAT). Much of the NCAT literature is aimed at educating and preparing small scale farmers to be profitable while maintaining and/or improving their agricultural ecosystems (National Center for Appropiate Technology, 2014). The NCAT recognizes that these new farmers range from young adults to retirees, and that their experience and expertise is as varied as their age, but they also recognize that beginning farmers are open to new ideas and technologies.

The objective of our research was to look at biochar in two aspects of vegetable production. The first experiment looked at the suitability of biochar in bell pepper, *Capsicum annuum* L, transplant production. The second experiment investigated the effect biochar additions would have on field production of bell peppers in Iowa. Our specific objectives were to: 1) determine the optimal amount of hardwood-based biochar that could be added to soilless, peat moss-based growing medium for pepper transplant production, 2) determine what effects biochar would have on bell pepper production in two soils, a healthy Clarion loam, as well as an Anthrosol consisting of sand and pea gravel, 3) determine if biochar affects plant growth differently when black plastic mulch is used as compared to bare soil, and 4) to investigate what effect biochar would have on soil nutrients and nitrate leaching in both soil types.

Thesis organization

This thesis is organized in journal paper format. Chapter 1 contains a general introduction with background and a review of the subject literature. Chapter 2 and 3 are manuscripts to be submitted to HortScience. These two chapters correspond to the objectives listed above. Chapter 2 details the research done on the fitness of biochar in pepper transplant production. Chapter 3 details our research on how biochar affects bell pepper production and plant growth in a temperate climate. Chapter 3 also covers how biochar affects nutrients in two very different soil types. The fourth chapter provides a summary, and conclusions, along with recommendations for future research. References to previous work are provided at the end of each chapter. Tables and figures also follow the chapter in which they are first discussed.

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CHAPTER 2. BIOCHAR ADDED TO COMMERCIAL SOILLESS SUBSTRATE IN HIGHER CONCENTRATIONS DECREASED TRANSPLANT GROWTH BUT INCREASED NUTRIENT RETENTION IN PEPPER TRANSPLANT PRODUCTION

A paper to be submitted to HortScience

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Abstract.

Biochar, a carbon-rich material derived from the pyrolysis of dry weight, exhibits beneficial chemical and physical properties when added to a soilless substrate. Research into the use of biochar to improve plant productivity and growth has increased over the past decade, and research has focused on using biochar as an alternative to sphagnum peat. However, little work has been done to determine whether biochar can be added to commercially available greenhouse substrate in vegetable transplant production. Our goal was to explore the possibility of supplementing a retail substrate (Jiffy Mix® Growers Choice #901, Lorain, OH) with biochar. Biochar was added to Jiffy Mix® at rates of 0%, 20%, 40%, 60%, and 80% (w/w). Bell pepper *Capsicum annuum* L. var. 'Paladin', was direct-seeded and grown for 53 days in cell-flat sizes of 50, 72, and 98 at each of the five levels of biochar addition. Germination increased in the 50 and 72 cell-trays with 20%, 40%, and 60% biochar; however, biochar had no effect on germination in the 98 cell-tray. Plant height and dry weight were reduced as the biochar percentage increased, and as cell size decreased. Height and dry weight decreased at differing rates within both factors, showing less variation between biochar treatments in the 98 cell-flat and less variation

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between cell volumes at the 80% biochar treatment level. Indirect estimate of chlorophyll using SPAD readings showed similar trends to the height and dry weight. Nitrate-N in the substrate was leached except in the 60% and 80% biochar mixes, which had more nitrates at the end of the experiment, than in the beginning. These results indicate that biochar can be added to commercial soilless substrate at rates up to 40% without detrimental effects on pepper transplant production.

Introduction

Bell pepper (*Capsicum annuum.* L.) is an important vegetable crop in the United States, and more than 20,200 hectares planted annually (USDA NASS, 2012). Transplant production in greenhouses, especially in temperate regions, can increase earliness, establish uniform plantings, and lower costs associated with thinning seedlings in the field (Schrader, 2000; Biai et al., 2011). High quality transplant growing medium is essential to transplant production as it provides uniform seed germination, proper pH, aeration, as well as water and nutrient retention. Leskovar and Stoffella (1995) noted the importance of a healthy root system in the vigor and productivity of transplants after field planting.

Growers, whether they make their own substrate or purchase it pre-mixed, use a medium that contains sphagnum peat, vermiculite and/or perlite, and calcium carbonate. Sphagnum peat often makes up greater than half the volume in a transplant plug substrate because it holds water well while maintaining adequate pore aeration (Pill and Ridley, 1998; Schmilewski, 2008). Despite the benefits of using sphagnum peat in transplant mixes, much research is focused on finding environmentally friendly alternatives to sphagnum peat. This research is partially driven by the desire to preserve natural habitats (Barkham, 1993), as well as concerns about using a slow-growing resource like sphagnum peat (Schilstra, 2001). Some alternatives to sphagnum peat that have been investigated for their fitness in substrates include the following: coir, compost, bark, composted bark, and wood fiber (Schmilewski, 2008). Another alternative component is biochar, but it has not been tested extensively in transplant production.

Biochar is the term used for a soil amendment made of charred organic matter and ash that remains after dry weight is thermally decomposed in a low-oxygen environment (Lehmann and Josephs, 2009). Biochar has been shown to impart beneficial chemical and physical attributes to mineral soils (Barrow, 2012; Laird, 2008). Some benefits of adding biochar to soils are increased soil pH in low pH soils (Novak et al., 2009), and increased retention of nutrients in soil (Clough and Condron, 2010; Laird et al., 2010). Until now, research on biochar as a component in growing substrate has been limited, focusing on its suitability for nursery crops (Dumroese et al., 2011), or on its physical and chemical properties that contribute to retention of nutrients in soilless substrates (Altland and Locke, 2012; Santiago and Santiago, 1989; Graber et al., 2010). These and similar studies have focused on either the complete replacement of sphagnum peat, or on the use of biochar in substrates for greenhouse production of mature plants. An important consideration to take into account, when growing vegetable transplants in biochar, is germination inhibition. The increased materials and labor required to transfer seedlings from a flat to cell tray dictates that most vegetable transplants are produced start to finish as plug transplants. Rogovska et al. (2012) proposed using germination as one of the tests for biochar quality.

The objectives of this study were to: 1) determine the optimal amount of hardwood-based biochar that could be added to soilless peatmoss-based growing medium for pepper transplant production, 2) study the effect biochar on seed germination, plant growth and development, and substrate nutrient characteristics, and 3) determine if transplant flat cell size is an important factor when determining optimal rates of biochar.

Materials and Methods

A standard commercial soilless, sphagnum peat moss-based substrate, Jiffy Mix® Growers Choice (Jiffy Products of America, Lorain, OH), was used as the base substrate for this study. Biochar for this study was a commercial hardwood-based granular charcoal (Royal Oak Charcoal, Roswell, GA), with a particle size of 0.42 to 0.84 mm diameter. The base substrate was amended with biochar in following proportion on a weight-by-weight basis: 0% (control), 20%, 40%, 60%, or 80%. Data obtained from Jiffy Products of America states bulk density of their Growers Choice Mix is between 0.080 and 0.090 $g \cdot cm^3$, with an average moisture content of 55 to 60 percent. Royal Oak granular charcoal has a bulk density of 0.267 $g \cdot cm^3$, and moisture content of 3 to 5 percent. Water was added (about 20% by volume) to the base substrate and biochar blend and thoroughly mixed by hand in a large plastic tote. Hand mixing with water insured a uniform mix and aided in the medium's ability to accept water. This substrate was then filled into 50, 72, or 98-celled square plug trays (Blackmore Plastics, Bellville, MI). Volumes of the 50, 72, and 98-cell plug trays were 96, 56, and 35 cm^3 respectively. Pelleted bell pepper 'Paladin' seeds (Siegers Seed Company, Holland, MI), were seeded into substrate-filled polyethylene cell trays on 8 April 2012, and maintained in the greenhouse until 31 May 2012.

The substrate medium was kept moist by water evenly every morning, and spot watering throughout the day as needed, until seed germination using tempered tap water (19-21˚C). Temperature inside the greenhouse was set at 21˚C. Starting 14 days after seeding, we fertilized all treatments on Tuesdays and Fridays. This schedule was maintained until one week before the end of the experiment. Fertilization was achieved using Peters Excel® Multi-Purpose and Cal-

Mag (Everris International B.V., The Netherlands) mixed in a concentration containing 16.6–5–16.3 (N-P-K), and metered through a Dosatron® D45RE 15-20 GPM (Dosatron International, Clearwater, FL 33765). A final N concentration of 150 $mg \cdot L^{-1}$ was used from 14 to 35 days, at which time the concentration of N was increased to 250 $mg \cdot L^{-1}$.

Germination percentage was recorded 14 days after seeding by counting the percentage of seedlings emerged from each tray. We collected data on plant height, stem diameter, Soil Plant Analysis Development (SPAD), and dry weight 53 days after seeding. Height, stem diameter, SPAD, and root and shoot dry weight were measured from 10, 12, and 14 plants sampled from the middle two rows of 50, 72, and 98-celled trays, respectively. Height measurements were taken from the top of the substrate to the growing point of each transplant. Stem diameter was measured just above the cotyledons using digital calipers (Fisher Scientific, San Diego, CA). Indirect measurement of leaf chlorophyll was recorded using a SPAD meter (SPAD-502 plus, Konica Minolta, Plainfield, IL). The SPAD values were means of SPAD readings from the first recently matured leaf from the top on 10 plants per tray. To determine root and shoot dry weight, roots were gently teased to remove substrate, washed and cut at the substrate line. Roots and shoots were then dried for three days at 67 ˚C then weighed. Dry weight was taken on a precision balance (Denver Instruments XE 510, Bohemia, NY). Substrate collected at the time of cleaning roots was used for nutrient extraction and analysis. Nitrate nitrogen was extracted from the substrate using 2 M potassium chloride solution (Dahnke & Johnson, 1990), and analyzed using injection technology (Lachat Instruments, Milwaukee, WI). Electric conductivity and pH were measured using a water to medium (2:1 volume) mixture with a hand held pH/EC meter (Hanna Instruments HI 9813, Hanna Instruments, Woonsocket, RI).

The 3 (plug cell volume) x 5 (biochar concentration) factors were arranged in a randomized complete block design with 4 replications. Statistical analyses were conducted using SAS statistical software (SAS version 9.3; SAS Institute Inc., Cary, NC). An Analysis of Variance was conducted using type three sums of squares with the Satterthwaite approximation to compute degrees of freedom. The PROC MIXED procedure was used to determine means separation using “lsmeans” and “pdiff” statements in SAS ($P \leq 0.05$ level).

Results

Seed Germination

Plug cell volume and biochar concentration interacted to affect germination (Fig. 2.1). Germination percentages in 20%-, 40%-, or 60%-biochar treatments were increased over the control and 80% biochar treatments for both 50 and 72 cell trays. The 98 cell tray showed no difference due to biochar concentration. There was variability in seed germination due to cell size.

Plant growth characteristics

Seedling height

Seedling height was reduced as cell volume decreased and as biochar concentration increased (Table 2.1). Tray cell size by biochar rate interactions were significant with lower concentrations of biochar showing greater differences in height between cell volumes (Fig. 2.2), whereas differences were not seen between cell volumes in 80% biochar treatments. The ANOVA also showed a linear relationship in seedling height according to concentration of biochar. Bell pepper seedling heights were similar in media containing 0%, 20% and 40% biochar. In 72-celled trays, the 20% biochar treatment plant were 1.3 cm taller than the control. The shortest transplants were recorded in the 80% biochar treatment. Seedlings in media with

0% to 60% biochar were tallest in the 50-cell trays and shortest in the 98-cell trays. There was no difference between the 50 and 72-cell trays with media containing 60% biochar. With 80% biochar in the media transplant height was unaffected by cell volume.

Transplant dry weight

Transplant total dry weight was influenced by the interaction of plug cell volume with media biochar concentrations in a similar manner as seedling height. Regardless of plug cell volume, 80% biochar in the medium resulted in lower transplant dry weight than occurred in media without biochar. Plants in the 50-cell trays produced more biomass than those in the 72 or 98-cell trays. Plug cell volume had no effect on the root/shoot ratio of pepper transplants (Table 2.1). However media with 80% biochar increased the root/shoot ratio over that of the control. The relationship between biochar and root/shoot ratio was linear with an intercept at 0.35 and a slope of 0.0156 and a R^2 = 0. 9051.

Stem diameter

No interaction was observed between cell volumes and biochar concentration for stem diameter. Stem diameter decreased with increasing biochar concentrations in the media and with decreasing plug cell volumes (Table 2.1).

Chlorophyll content

Plug cell volumes and biochar concentrations failed to interact in affecting SPAD values. Leaf chlorophyll decreased as the concentration of biochar increased in the medium. Cell volume did affect SPAD values with higher SPAD values found in the 50-cell trays.

Nutrient analysis

Nitrate-nitrogen (NO_3-N) concentrations in the media solutions at the time of seed sowing for media containing 0%, 20%, 40%, 60%, and 80% biochar were 53.8, 32.5, 11.0, 1.7, and 0.7 $mg.L^{-1}$, respectively. By the end of the 8-week study almost 100% of the NO_3-N was leached from treatments containing less than 40% biochar, whereas the 60% or 80%, biochar treatments had gained 25% or 300%, respectively, averaged across plug cell volumes (Fig. 2.3). Ending NO_3-N for the 0%, 20%, 40%, 60%, and 80% biochar substrate mixes were 0.9, 1.4, 1.8, 2.2, and 2.9 $mg.L^{-1}$, respectively. Initial medium pH values were 5.2, 6.3, 6.9, 7.4, and 7.8, and electrical conductivity levels were 0.84, 0.88, 0.72, 0.32, and 0.26 for the 0%, 20%, 40%, 60%, and 80% biochar substrates, respectively.

Discussion

Our results show that germination of pepper is improved over the control with mixes containing 20%, 40% or 60% biochar, when using 50- or 72-cell trays. This could be due to water and temperature fluctuations, as Watkins and Cantliffe (1983) noted that temperature plays a role in the seed's ability to take up water. They found that the endosperm was more resistant to water when the temperatures were cool. Addition of biochar to the growing medium at 20%, 40%, or 60% rate, could have elevated the resulting media temperatures by increasing absorption of solar radiation with the increasing darkness of the media. In contrast to this theory, reduction in seed germination at higher biochar concentration rates such as 80% biochar used in this study could be due to higher than optimum medium temperature and/or drying of the medium. We observed enhanced drying of the growing medium with increasing biochar rates (data not shown), with the 80% biochar treatment drying the quickest. Pinto et al. (2009) reported effects of grit color and irrigation frequency on germination of Lodgepole pine (*Pinus contorta* var. 'Latifolia'). They found a decrease in germination speed but no change in percentage of germination with greater irrigation frequency. This is important when considering our germination data were recorded at 2 weeks. Some of the differences in our study, like that in the 72 cell tray control, may have been caused by delays in germination.

In our study, transplant height decreased at higher biochar concentrations within individual cell numbers; however, 20% or 40% biochar treatments were not different from the control. Graber et al. (2010) reported no difference in pepper plant height compared to a control when grown in coconut coir-based substrate amended with up to 5% biochar. Our study was consistent with these findings suggesting that biochar additions up to 40% are possible without decreasing plant height. Pepper canopy dry weight also increased when grown in coconut coir-based substrate amended with 3 or 5% biochar (Graber et al., 2010). In our study transplant dry weight for 20%, 40%, or 60% biochar concentration was similar to the control in the 72 or 98-cell trays. This was similar to results reported by Northup (2013). Transplant dry weight decreased when the biochar concentration was 80% of the growing substrate. This could be attributed to the initial fertilizer in the Jiffy Mix® used. Media with the greatest biochar rate had the lowest amount of peat based media, contributing to low initial 0.7 $mg \cdot L^{-1}$ NO_3-N compared to 53.8 $mg \cdot L^{-1}$ nitrate in the media containing no biochar.

Both transplant height and dry weight decreased as plug cell volume decreased, although this trend was not significant for plant height in the 80% biochar treatment. NeSmith and Duval (1998) indicated smaller plug cell volumes can reduce plant size and this reduction could be due to a number of factors. One of them is the competition between leaves for light and roots for oxygen. In our study increased plant density and reduced medium and root space per plant in the 98-celled tray contributed to lower nutrient retention, competition for light, and constriction of plant roots. In addition, root restriction could have reduced the photosynthesis efficiency of transplants (NeSmith and Duval, 1998). Reduction in plant height may have important implications in vegetable transplant production, especially considering that transplant producers use costly or labor intensive practices to decrease transplant height for automated transplanting (Garner and Björkman, 1996). Although our study shows that higher biochar concentration in the medium could reduce plant height, it is not desired, since higher concentrations also reduced transplant dry weight. Transplants with higher dry weight are often more vigorous, having the ability to quickly overcome transplant shock, and exhibit higher productivity.

Indirect measurement of chlorophyll through SPAD measurement indicated lower chlorophyll in higher biochar concentration treatments. Although Laird et al. (2010) suggested increased nitrate immobilization by biochar, nitrate nitrogen measured at the end of eight weeks was higher in the 60% and 80% biochar treatments (Fig. 2.3). All treatments received equal amounts of fertilizer through irrigation. Percent loss of NO_3-N, between the start and the end of the experiment, in the control, 20%, or 40% treatments was nearly 100% which was due to plant absorption and leaching during irrigation. Higher rates of biochar (60% or 80%) showed a net gain of NO_3-N primarily because of the ability of the biochar to retain nutrients (Laird et al., 2010). It is has been reported that the porous nature and large surface area associated with biochar particles, combined with the different functional groups associated with these surface areas, combine to allow biochar to retain nutrients added to the soil (Major et al., 2009).

In conclusion our study demonstrates potential use of biochar for vegetable transplant production. Our overall finding is that addition of 20% to 40% biochar to peat-based substrate improved seed germination and failed to diminish transplant growth. However, higher rates of biochar (60 or 80%) reduced transplant growth. In addition this research was conducted using an oak-based biochar produced by slow pyrolysis and the results are specific to this material. Similarly produced biochar products are widely available from commercial sources; however, ‘slow pyrolysis hardwood biochar’ does not guarantee similar properties. Within an environmental perspective, biochar has the ability to reduce nutrient leaching and allow for replacement of sphagnum peatmoss in transplant production medium. With the increasing cost of growing medium combined with growers’ interest in utilizing environmentally-friendly products, biochar could serve as a suitable amendment in the transplant production phase. At this time, however, demand for biochar is high and the numbers of producers are limited, leading to relatively high costs compared to sphagnum products. There are also costs associated with shipping and handling due to distance from producer and the flammable nature of biochar. These factors reduce the feasibility of using biochar as a potential peat substitute at this time, but advances in technologies that seek to extract fuels from biomass may lead to increases in local production of biochars. This would increase supply and reduce costs associated shipping and handling. More research is needed to identify biochars from different sources that may also help promote transplant growth and contribute to sustainability of vegetable production systems.

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Table 2.1.'Paladin' bell pepper plant growth indicators eight weeks after seeding in transplant trays (50-, 72- or 98-cell trays) with biochar [0%, 20%, 40%, 60%, or 80% (w/w)] supplemented medium.

	Height (cm)[z]	**Total dry wt. (g)**	**Root/shoot ratio**	**Stem diameter (mm)[y]**	**SPAD[x] value**
Cell number					
50	26.3 a[w]	1.03 a	0.40	4.5 a	39.1 a
72	23.6 b	0.67 b	0.40	3.9 b	37.3 b
98	21.8 c	0.49 c	0.39	3.5 c	36.3 b
Biochar % (w/w)					
0	24.9 a	0.85 a	0.37 b	4.2 a	38.2 b
20	25.2 a	0.83 a	0.39 ab	4.1 ab	40.3 a
40	25.2 a	0.78 a	0.39 ab	4.0 b	37.5 b
60	23.9 b	0.70 b	0.40 ab	3.9 b	36.5 bc
80	20.1 c	0.50 c	0.43 a	3.6 c	35.3 c
Interaction					
Cell x Biochar	**	**	NS	NS	NS
Regression					
Biochar line	***	***	*	***	**
Biochar quad	***	**	NS	NS	*

[z] Height measured in cm from top of the substrate to growing point of the shoot.2

[y] Stem diameter measured above the cotyledons.

[x] Leaf chlorophyll was measured using a chlorophyll meter (SPAD-502 plus, Konica Minolta Sensing, Plainfield, IL).

[w] Means within columns with the same letter are not significantly different (least significant difference; $P \le 0.05$). NS, *, **, *** Nonsignificant at $P \le 0.05$ or significant at $P \le 0.05$, 0.01, or 0.001, respectively.

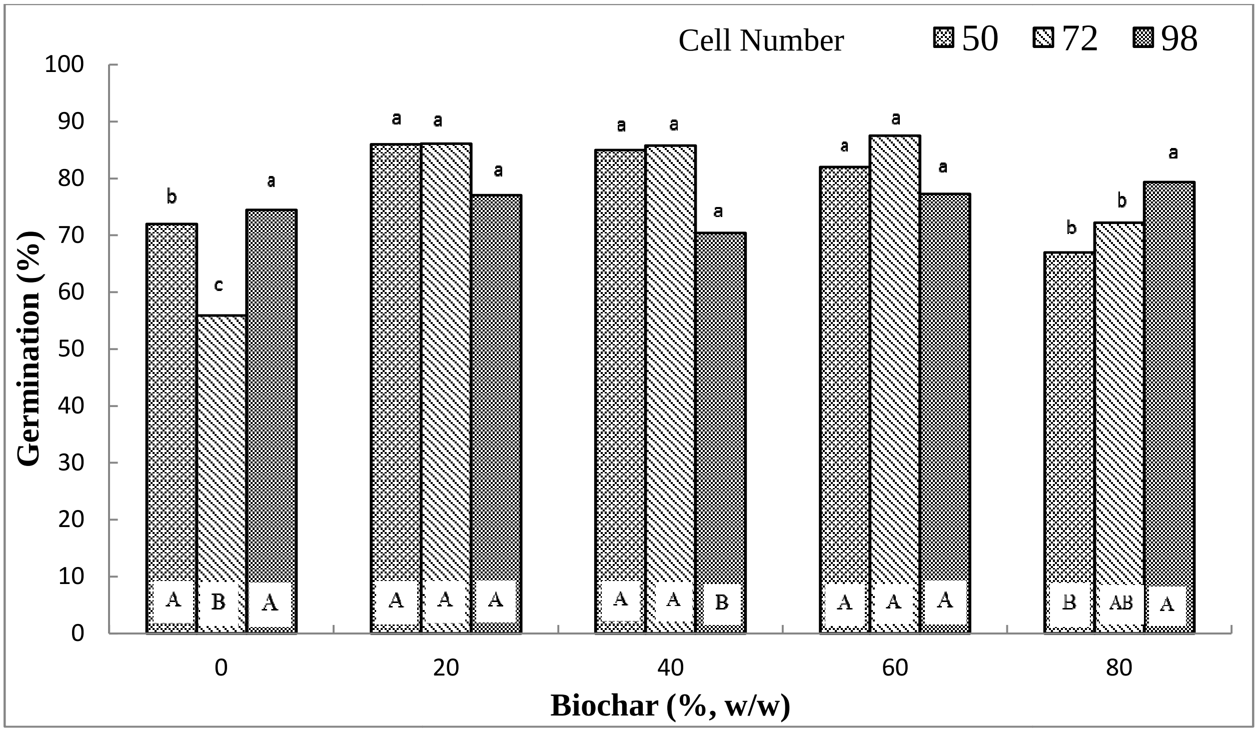

Fig. 2.1. Effect of biochar [0%, 20%, 40%, 60%, or 80% (w/w)] and transplant tray cell size (50-, 72- or 98-cell trays) on pepper seed germination, collected eight weeks after seeding. Lower case letters indicate mean separation ($P \leq 0.05$) among biochar concentration within a particular cell number. Uppercase letters indicate means separation among cell numbers within a particular biochar concentration.

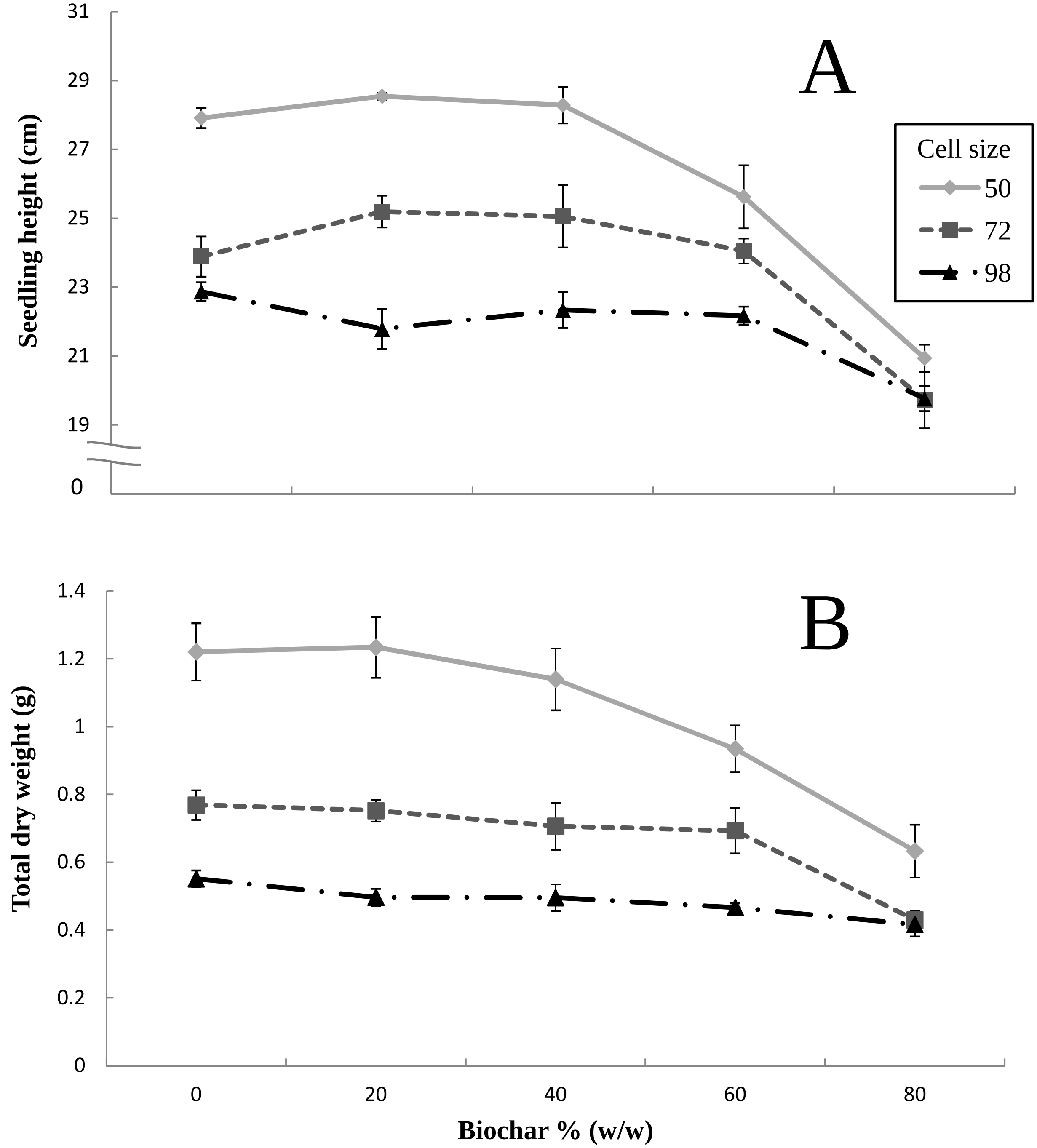

Fig. 2.2. Effects of cell volume and biochar concentration on plant height (A) and total dry weight (B). Vertical bars are means ± SE.

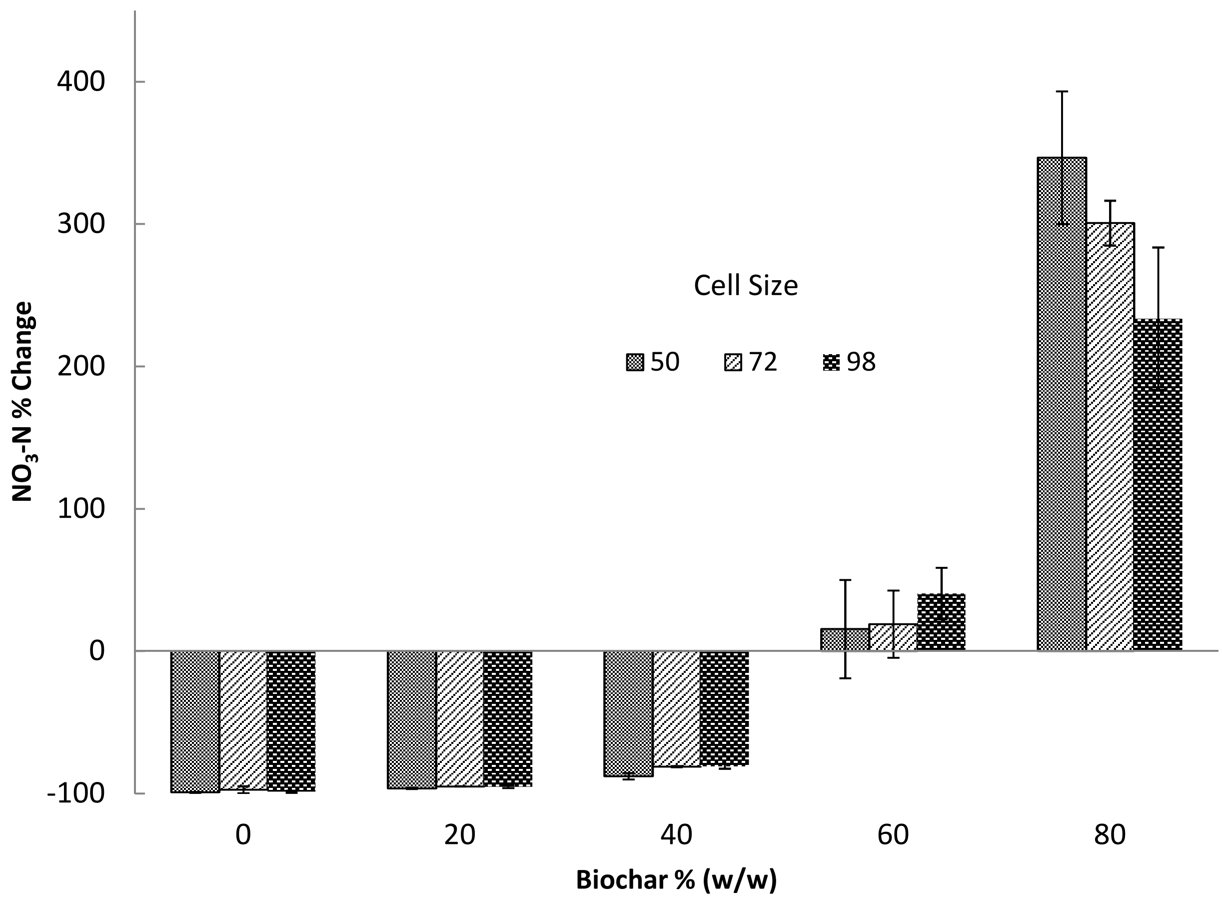

Fig. 2.3. Percent change in nitrate-N (gain or loss) from the time of seeding to the end of the experiment (eight weeks after seeding). Error bars indicate standard error of the mean.

CHAPTER 3. BIOCHAR'S EFFECTS ON BELL PEPPER FRUIT PRODUCTION, PLANT GROWTH AND SOIL NUTRIENTS IN TWO TEMPERATE SOIL TYPES

A paper to be submitted to *HortScience*

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Abstract

Biochar is the term used for black carbon and ash available after biomass has been pyrolyzed. Pyrolysis is the process of thermally decomposing biomass in the absence of oxygen. Studies have shown some beneficial effects to plant growth when biochar is added to soils. Possible benefits of applying biochar to the soils include increased plant fitness, nutrient retention in soils, and the possibility of sequestering atmospheric carbon. Many of the studies involving addition of biochars to soils have been performed on unproductive soils in tropical and subtropical climates. Research on productive temperate soils, like those found in the Midwest United States have been limited to laboratory and controlled environments. Our objective was to determine what effects biochar would have on bell pepper, *Capsicum annuum* L., plant fitness and soil nutrients in two distinct Midwest soils, and under two different soil mulches. We added biochar to a Clarion loam and sand Anthrosol at the rates of 0 (control), 1.1, 2.2, and 4.5 $kg \cdot m^{-2}$. We then raised bell peppers on black plastic mulch and bare soil beds in both the first and second seasons after biochar application. Results show that biochar does not affect marketable fruit production in either Anthrosol or loam soil. Biochar did, however, decrease numbers for some

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[3] Major Professor

categories of nonmarketable fruit, as well as leaf chlorophyll content. Decreases, however, were not consistent between soil types or between years. Biochar decreased extractable NO_3-N in both fields (2012). Potassium concentration was increased in the loam field both years. Biochar also decreased the amount of nitrate leached from the root zone collected in lysimeters (loam 2012, Anthrosol 2013). Reductions in leaf chlorophyll content were seen in the same field in the same years as reductions in the nitrates leached from the root zone were seen. These results suggest that field applications of biochar to temperate soils do not affect plant productivity. Results indicate that additions of biochar rates up to 4.5 $kg \cdot m^{-2}$ are possible without causing losses to production. Our results also suggest that nitrates may be a concern when higher rates of biochar are added. This indicates that adding biochar to soils with the express purpose of sequestering carbon is possible; however, more work should be done to insure no losses in productivity occur as a result of biochar applications.

Introduction

Concerns over fossil fuel depletion and global climate change have increased interest into alternative energy sources. Energy from biomass has the potential to provide a renewable carbon neutral fuel sources (Laird D., 2008). Pyrolysis is a process that is gaining interest as well as funding because of its potential to use waste biomass like rapeseed cake, a byproduct of pressing rapeseed to extract oils (Ozcimen & Karaosmanoglu, 2004). Pyrolysis is the process of thermally decomposing biomass in a low oxygen environment. Pyrolysis yields bio-oils, syngas, and heat, as well as black carbon (Bridgwater, 2003). All three of these products demonstrate potential in providing energy and fuels.

The black carbon that remains after biomass has been pyrolyzed is called biochar when its intended use is as a soil amendment. Biochar has demonstrated potential to increase plant fitness and production, decrease nutrient leaching, while also mitigating climate change (Lehmann & Josephs, 2009). Studies have shown some beneficial effects on plant growth when biochar is added to soils (Blackwell et al., 2009). A large portion of the carbon in biochar is believed to be recalcitrant and resistant to oxidation in soils (Lehmann et al., 2009). This makes biochar a candidate for carbon sequestration, providing an opportunity to decrease atmospheric CO_2 levels, and mitigate climate change (Lehmann & Josephs, 2009).

Laboratory trials have shown possible agronomic benefits due to the addition of biochar in temperate climates. There is little evidence, however, that these benefits carry over to field trials (Jones et al., 2012). There is, in fact, some evidence to indicate high levels of black carbon may actually inhibit plant growth because of changes in nutrient availability (Mikan & Abrams, 1996). It is important to note many of the field studies showing benefits have been performed in poor tropical soils and soils with otherwise low productivity (Atkinson et al., 2010). Research into biochar's effects on plants and soils must therefore consider possible differences between locations and soil types. Soils with differing physical and chemical properties are likely to be affected differently by additions of biochar. Atkinson et al. (2010) conclude that biochar may better improve land use efficiencies in soils that are degraded and otherwise not productive.

Economics will likely dictate that pyrolysis and other bioenergy processes will be performed close to their sources of feedstock (Badger & Fransham, 2006; Laird, 2008). Costs and hazards associated with shipping biochars will also likely limit their use to the region where they originate. Laird (2008) identifies an economic obstacle to the use of biochar, principally that bio-energy producers will have little incentive to produce biochar if energy prices are high and biochar's value to farmers is low.

Intended crops are also an important consideration. Tropical field studies have been performed on crops ranging from grains and pulses to fruits and vegetables including bananas and carrots (Lehmann & Rondon, 2006), whereas temperate field studies have been limited to grains and grasses (Jones, et al., 2012), Studies on vegetables like peppers and tomatoes have been limited to greenhouse studies (Revell et al., 2012b; Kolton et al., 2011).

Bell pepper production in the United States has been steady over the last decade with around 16 to 17 million cwt produced annually on around 22,000 hectares (USDA NASS, 2014). Bell peppers are a warm season crop considered easy to grow. As a result, peppers are popular with small scale producers, and community gardens (Bosland & Votava, 2000). Bell peppers are often grown with black plastic mulch (Bosland & Votava, 2000). Black plastic increases root growth early in the season and reduces weed growth by reducing light.

The objectives of this study were to: 1) determine what effects biochar would have on bell pepper production in two soils types, 2) determine if biochar affects plant growth differently when black plastic mulch is used as compared to bare soil, and 3) to investigate what effect biochar would have on soil nutrients and leaching in both soil types.

Materials and Methods

Plot preparation. This experiment was conducted at the Iowa State University Horticulture Research Station in Gilbert, IA. Two different soil types were utilized. The first field selected was a Clarion loam soil on a 2% - 6% slope. Clarion series soils are moderately well drained glacial till soils with a fine-loamy, mixed, mesic, Typic Hapludoll taxonomic classification. The second field was an Anthrosol consisting of pure sand and pea gravel base used in sub-surface heating trials for non-cold hardy turf grasses. Prior to biochar application the loam field was under a corn-soybean rotation with corn planted the year before treatment establishment. Two years prior to biochar application one half of the Anthrosol field had been excavated to remove the system that housed the ethylene glycol used in the heating system. The pea gravel and sand were mixed as a result. The other half of the field was left unaltered since a hot air system was in place and did not pose an environmental risk. The unaltered side consists of 30 cm of sand on top of a 10-15 cm pea gravel base. After removal of the heating system both side of the field were planted to perennial rye grass. Biochar with a particle size between 0.54 mm and 2.38 mm was obtained from a commercial charcoal production company (Royal Oak Charcoal, Roswell, GA). Biochar treatments (subplot) were established in both fields on 08 May 2012. Application of biochar to 6.1 m x 6.1 m plots at four rates, 0.0, 1.1, 2.2 and 4.5 $kg \cdot m^{-2}$, following application fields were tilled to a depth of 15 cm.

Two 1.5 m beds (whole plots) were established, one with black embossed plastic mulch 0.032 mm thickness (Pliant Plastics, Spring Lake, MI), and the other as bare soil. Plastic was placed on raised beds using a Model RB448 Compact Raised Bed Mulch Layer (Nolts Equipment, Leola, PA). Irrigation requirements were met using John Deere T-Tape 502-12-220 (John Deere Irrigation, Moline, IL) buried in the center of the plastic beds, and pinned on the soil surface in the bare soil beds. Water was applied when soil moisture was 30 cbars (loam) and 20 cbars (Anthrosol) as read on Watermark® 200SS water sensors (Irrometer Company, Riverside, CA).

‘Paladin’ pepper transplants were seeded in the greenhouse on 25 March 2012 and 28 March 2013. Transplants were produced by directly seeding pelleted ‘Paladin’ seeds (Siegers Seed Company, Holland, MI), into 98 cell plug trays with $35 cm^3$ of volume (Blackmore Plastics, Bellville, MI) using a standard greenhouse growing mix (Sunshine LC1, Sun Gro Horticulture, Agawam, MA).

Pepper seedlings were transplanted on 27 May 2012 and 10 June 2013. Peppers were placed in double rows spaced 30 cm apart with 38 cm between plants. The last two or three plants on each bed within a plot were replaced with Anaheim style chili peppers, leaving 28 bell pepper plants per bed. The Anaheim plants acted as guard plants to protect against edge effect from possible biochar movement due to tillage and field preparation. Soil samples were taken from each plot before addition of biochar in 2012 and before application of plastic mulch in 2013. Half of the N-P-K requirement according to soil test recommendations was broadcast within the rows just before applying plastic mulch. On the bare soil beds, fertilizer was applied and raked in by hand. The other half of the N-P-K was applied through irrigation using Peters Profesional® (Everris International B.V., The Netherlands) mixed in a concentration containing 20N–5P–20K, and metered through a Dosamatic ® A15 (Hydro Systems, Cincinnati, OH). We used fertilized with a final concentration of 200 mg-N/L. Fertilizer was applied weekly starting two weeks after transplanting and continued until harvests started.

Plant Data. Yield data (loam field) were collected over seven harvests in 2012 and 2013. Harvest started on 24 July and 26 Aug. and ended on 20 September and 17 Oct., in 2012 and 2013, respectively. In the Anthrosol field, 4 harvests were conducted in 2012 from 27 July to 23 Aug. In 2013 six harvests were conducted from 30 Aug. to 24 Sept. Peppers were counted and sorted into marketable and non-marketable fruit. USDA standards were used to classify marketable fruit (USDA-AMS, 2005). We classified the non-marketable fruit into two sub-categories during the first harvest in 2012. The categories included: 1) Blossom end rot (BER), and 2) all other non-marketable problems, including, but not limited to, sun scald, size, shape, and insect damage. After noticing a relatively large number of sun-scalded fruit in the second harvest, we included a category for sun scald in all subsequent harvests.

Data on plant development was also recorded. Ten plants in each plot were measured for plant height and chlorophyll content within two weeks of the first harvest. We measured plant height from the soil surface to the meristem of the main trunk. Leaf chlorophyll was measured indirectly using a SPAD meter (SPAD-502 plus, Konica Minolta, Japan). Crop biomass was collected on four plants per plot the day after the last harvest. Plants were removed from the soil with a shovel by inserting the shovel into the soil one foot out from the stem. Soil was then washed from the roots. Roots were cut from the stem at the root flair, and both were dried in an oven at 67 °C for 72 hours or until their weight was unchanged.

Soil data. Soil samples were taken in the middle and after each growing season. The mid-season samples were taken during plant growth on 19 June 2012 and 18 June 2013. Post-season samples were taken on 04 Oct. 2012 and 12 Nov. 2013. We took ten soil cores (3.2 cm in diameter) to a depth of 15 cm from each bed for analysis. Soil samples were air dried and sieved through a 2-mm mesh before being analyzed for NH_4-N, NO_3-N, P and K concentrations. Inorganic N was extracted using a 2 M KCl solution and analyzed using injection technology (Lachat Instruments, Milwaukee, WI). Phosphorous and potassium were extracted using a Melich III extraction solution and an inductively coupled plasma emission spectroscopy (ICP). Extractions were sent to the Iowa State University Soil and Plant Analysis Laboratory for analysis.

Lysimeter data. Lysimeters, model 1900 soil moisture samplers (Soilmoisture Equipment Corp, Santa Barbra, CA), were placed in two of the replications in each field. A 5.1 cm hole was dug to a depth of 60 cm. A 0.45 kg of Sil-Co-Sil silica powder (Soilmoisture Equipment Corp, Santa Barbra, CA), was mixed with 200 ml of water to make silica slurry. One fourth of the slurry was placed in the bottom of the hole, followed by the setting of a lysimeter in the hole.

The remaining silica slurry was poured around the lysimeter followed by spreading of 100 g of Bentonite Seal (Soilmoisture Equipment Corp, Santa Barbra, CA), around the lysimeter. The bentonite was given time to absorb water and seal the top portion of the silica slurry. Finally, remaining soil was filled back inside the hole by gradually tapping it around the lysimeter. Water from lysimeters was collected weekly throughout the growing season using a 1900K Soil Sample Extraction Kit (Soilmoisture Equipment Corp, Santa Barbra, CA). Samples were analyzed for NO_3-N (Lachat Instruments, Milwaukee, WI) at the Soil and Plant Analysis Laboratory, Iowa State University.

Statistical analysis. The 4 (biochar rate) x 3 (soil cover) factorial experiments were arranged in a split plot randomized complete block design with four replications. Loam and Anthrosol fields were analyzed and reported separately. Statistical analyses were conducted using SAS Statistical Software (SAS version 9.3; SAS Institute Inc., Cary, NC). An Analysis of Variance was conducted using type three sums of squares with the Satterthwaite approximation to compute degrees of freedom. The PROC MIXED procedure was used to determine means separation using “lsmeans” and “pdiff” statements in SAS ($P \leq 0.05$ level). Linear and quadratic relationships to the biochar treatment were determined using the estimate statement in PROC MIXED.

Results

Plant measurements

Fruit yield and quality

Biochar had no effect on marketable pepper production; however, numbers and yields of non-marketable fruit were affected by biochar additions. Interaction between soil cover and biochar treatment on fruit numbers and yield were not significant for any of the fruit yield and quality measurements so data were pooled within treatment levels. Biochar did not affect the number or yield of marketable fruit in either loam or Anthrosol fields either year; however, there were non-significant numerical trends seen in both fields (Tables 1 and 2). These trends were different from the first year to the second year. In 2012 the numbers and yield of marketable fruit decreased as the rate of biochar increased, whereas the trend reversed in 2013 with average means tending to be greater in plots with more biochar.

Biochar did have an effect on non-marketable fruit; however, the effect was different in the loam (Table 3.1) than in Anthrosol (Table 3.2). Differences were also not consistent between 2012 and 2013. Numbers and yield of non-marketable fruit in the loam field were similar to the marketable fruit in that there was no effect on either caused from biochar (Table 3.1). However, in the Anthrosol field in 2012, a negative linear relationship was noted between non-marketable fruit number/yield and biochar application rate (Table 3.2). Also in the Anthrosol field in 2013, we recorded an increased number and yield of non-marketable fruit in the 1.1 $kg \cdot m^{-2}$, over that of the control.

The rate of peppers with BER symptoms had a negative linear relationship with biochar application rates in the loam field in 2012 (Table 3.1); however, differences were not seen in 2013. The BER rate was not decreased in the Anthrosol field with increasing biochar rates although the means were numerically smaller in the plots with biochar added (Table 3.2). There were fewer incidents of BER in both loam and Anthrosol soils in 2013 verses 2012, and neither soil had any differences in numbers of fruit with BER according to biochar application rates. Sun scald was not affected by the addition of biochar to a loam soil in 2012; however, there was less sun scald in the 2.2 $kg \cdot m^{-2}$ than in the 4.5 $kg \cdot m^{-2}$ in 2013 (Table 3.1). Biochar reduced sunscald in the Anthrosol field the first year at the higher rates of 2.2 and 4.5 $kg^{\cdot}m^{-2}$ (Table 3.2), but had no effect the second year.

Black plastic mulch decreased productivity of peppers in both loam (Table 3.1) and Anthrosol (Table 3.2). This decrease was also consistent between years. In both fields total yield of non-marketable fruit was decreased in 2013, and both non-marketable fruit numbers and yield were decreased in the Anthrosol field in 2012. More BER was seen on the black plastic in 2012 as well as in the sa Anthrosol nd field in 2013. Less sun scald was recorded with the use of black plastic in the Anthrosol field both years.

Plant growth

Biochar had an effect on plant height, root dry weight and chlorophyll content, while having no effect on dry biomass and shoot weight. Biochar affected plant height in 2012 but not in 2013. We saw a quadratic relationship on plant height due to biochar treatment level in the loam field in 2012 (Table 3.3). This effect caused a decrease in plant height at the 2.2 $kg^{\cdot}m^{-2}$ biochar treatment level, while plant height at the 1.1 $kg^{\cdot}m^{-2}$ was numerically smaller but not significantly different from the control and 4.5 biochar treatments. In 2012 plant height in the Anthrosol field was increased as biochar rate increased (Table 3.4). There was no effect on plant height in the Anthrosol field in 2013.

Biochar had no effect on dry biomass, shoot weight or root weight in either 2012 or 2013 in the loam plot (Table 3.3). Biochar had no effect on dry biomass or shoot weight in the Anthrosol plot (Table 3.4). There was, however, a decrease in root weight at the 2.2 $kg^{\cdot}m^{-2}$ biochar treatment level.

A decrease in chlorophyll content was measured in the loam field 2012 at the greater biochar rates (Table 3.3), as well as in the Anthrosol field in 2013 (Table 3.4). This decrease was negatively linear in both instances with chlorophyll content decreasing as biochar application rate was increased.

Soil nutrients

Soil sample extractions

Biochar concentration affected soil nutrients differently in loam and Anthrosol soils. The only significant biochar by soil cover interaction was seen in NH_4-N in the loam plot mid-season sample taken in 2013 (Table 3.6). The bare soil had a weak positive linear relationship whereas the plastic mulch did not (Fig. 3.1). This was the only difference in NH_4-N caused by biochar. Plastic mulch reduced the amount of NH_4-N in the loam plot both years (Tables 3.5 and 3.6), while an increase was seen in the Anthrosol field in the end of season sample in 2013 (Table 3.8).

In both soils biochar reduced the amount of NO_3-N that could be extracted in 2012 (Tables 5 and 7). In the loam soil the reduction was only recorded at the end of the season (Table 3.5), whereas a reduction was seen in both the middle and end of season Anthrosol samples (Table 3.7). In each instance the reduction in nitrates had a linear relationship to the amount of biochar added with greater amounts of biochar reducing NO_3-N concentration. We did not see an effect on NO_3-N in either soil in 2013 (Tables 6 and 8). Use of black plastic caused an increase in the retention of nitrates in the loam plot in both the middle and end of season samples in 2012 (Table 3.5), and in the end of season sample in 2013 (Table 3.6). This trend was also recorded in the Anthrosol field in 2013 (Table 3.8); however, black plastic reduced nitrate concentration in mid-season samples in 2012 (Table 3.7).

The only differences we recorded in phosphorous were in the mid-season samples from the loam field in 2013 (Table 3.6), and from the Anthrosol field in 2012 (Table 3.7). In the loam field 2013, P concentration increased as biochar addition was increased. In the Anthrosol field we recorded a decrease in P concentration at the 2.2 $kg \cdot m^{-2}$ of biochar treatment level. Black plastic increased P concentration in the loam field mid-season in 2012 (Table 3.5), while decreasing it mid-season 2013 (Table 3.6).

Potassium was only affected by biochar in the loam plot (Tables 3.5 and 3.6). The effect was seen only in the mid-season samples, and it was linear in both cases with potassium increasing as the concentration of biochar increased. We only observed one difference in potassium concentration caused by soil cover, and that was in the mid-season 2012 sample (Table 3.5).

Leachate NO_3-N concentration

Biochar application rate affected NO_3-N concentration leached from the root zone. In the loam plot in 2012 the amount of nitrates in the leachate was greater early in the season in the control and 1.1 $kg \cdot m^{-2}$ biochar treatments than in the 2.2 and 4.5 $kg \cdot m^{-2}$ treatments (Fig. 3.2A). Later samples in 2012 showed all NO_3-N concentrations to decrease to nearly zero with no differences between biochar treatment levels. This trend was also seen in the Anthrosol field in 2013 (Fig. 3.3B). In the first five weeks in 2013 the loam field had a greater or equal concentration of NO_3-N in the 4.5 $kg \cdot m^{-2}$ treatment, as compared to the other treatments (Fig. 3.2B). In the Anthrosol field in 2012 there were no conclusive trends in NO_3-N concentration due to biochar treatment level. There were differences week to week in both fields.

Discussion

Biochar had no effect on marketable fruit production in either soil type. However, there was a decrease in total non-marketable fruit with increasing levels of biochar in the Anthrosol field, as well as a decrease in blossom end rot (loam 2012) and sunscald (Anthrosol 2012).

Biochar affected plant growth indicators (height and chlorophyll content) in both loam and Anthrosol fields. There were no significant interactions between biochar and the use of black plastic mulch. Black plastic mulch did, however, decrease fruit production and plant growth in most of the variables collected. Soil nutrients were affected by biochar, although results were not consistent between loam and Anthrosol soil types. Leaching of NO_3-N was decreased with greater rates of biochar in the loam field (2012), as well as in the Anthrosol field (2013). Decreases in NO_3-N leaching were seen in conjunction with decreases in leaf chlorophyll content possibly indicating reduced extractability of nitrates.

In our study biochar did not affect marketable pepper production (Tables 1 and 2). Our findings that biochar had no effect on bell pepper fruit production were consistent with other research on biochar in soils in temperate climates (Revell et al., 2012a). Jones et al. (2012) found no differences in maize (*Zea mays* L.) caused from biochar additions the first year after biochar application; however, they saw a difference in years two and three in hay grass (*Dactylis glomerata* L.). They speculated that the lack of results in maize could be due to the deep root system scavenging nutrients from below the biochar application depth, while the hay grass has a shallow root system so it was more likely to be affected. Lack of differences in our experiment are less likely due to rooting depth as peppers are a shallow rooted crop with up to 70% of their roots in the top 10 cm of the soil profile (Gough, 2001). Although we did not see statistical differences between treatments; the means of marketable fruit in both loam and Anthrosol were reduced numerically with increasing rates of biochar (2012). In 2013 this trend was reversed, but still did not reach the level of significance.

The number of total non-marketable fruit was reduced with increased levels of biochar in the Anthrosol plot in 2012. Since this variable includes all categories of non-marketable fruit, and there was no difference ($p \leq 0.05$), in either field, for the category that included size, shape, or insect damage (data not shown), the difference may have been derived from a combination of all three categories. It is possible that decreases in non-marketable fruit in the Anthrosol field are indicative of the reduction in overall productivity seen in the first year after addition. The trend of decreasing fruit production in 2012, although not significant in most instances, is evident in all of the variables measured. In 2013 this trend was reversed so the plots with biochar had greater mean values numerically; however, due to high variability, differences were still not significant. We speculated that fresh biochar additions interact with microbial communities and nutrients in the soil the first year, reducing plant productivity, as indicated by Bruun et al. (2011). It is also possible that differences in variables like climatic conditions cause differences in some field trials and not in trials performed in controlled environments. Daily temperatures in 2012 were higher than normal (Table 3.9), which could have made it difficult to find differences in marketable fruit, while contributing to the differences seen in solar injury and BER.

We found reduced blossom end rot in the loam field with increasing levels of biochar in 2012 (Table 3.1). The Anthrosol field followed the same trend in 2012; however, differences were not significant. In 2013 levels of BER overall were greatly reduced, so no differences were seen. Blossom end rot is a physiological disorder that appears when pepper plants are unable to translocate adequate calcium to the fruit. This can occur from insufficient amounts of calcium in the soil, or as a result of insufficient soil moisture (Bosland & Votava, 2000). Additions of biochar have been reported to increase extractable calcium in temperate loam soils (Laird, et al., 2010). Biochar had the greatest influence on plant growth in 2012 (Tables 3 and 4). In 2012 biochar affected plant height in loam and Anthrosol soils, as well as root weight (Anthrosol) and chlorophyll content (loam). The only effect of biochar in 2013 was in the chlorophyll content in the Anthrosol field where chlorophyll decreased with increasing levels of biochar.

We hypothesized biochar would increase the ability of both soils to capture and hold nutrients. Previous studies had shown that biochar can increase NH_4^+, and K^+ retention by increasing CEC and surface area (Glaser et al., 2002; Laird et al., 2010a), and NO_3^-N (Knowles et al., 2011). We found that biochar increased retention of K in the loam soil both years especially in the midseason samples (Tables 3.5 and 3.6). The trend of increased K retention is also seen in the late season samples; however, the differences are not significant. Extractable nitrogen did not decrease with increased biochar in either plot. The only difference in NH_4 was in the loam plot in 2013. In 2013 extractable NH_4-N increased with increasing biochar additions in the bare soil treatment but not in the black plastic (Fig. 3.1). We speculated that the plastic mulch increased the temperature, which in turn increased microbial activity increasing nitrification of ammonium. Although not significant, the trend of increased nitrification was observed over the same time period increasing amounts of biochar. This is in line with the review of biochar's effect on soil nitrogen made by Deluca et al. (2009) except their review indicated more nitrification in boreal soils where nitrification rates are generally low. Phosphorous only increased with biochar in the loam field in 2013 and in the Anthrosol field in 2012. The effect was not consistent between the two fields. One reason for inconsistent results could be due to phosphorous reactions in the soil being complex including physical and chemical reactions as well as microbial sequestration (Laird et al., 2010b). Complexity in microbial reaction could also explain the reduction in nitrate leaching in the loam field in 2013 (Fig 3.2A) as well as the Anthrosol field in 2013 (Fig. 3.3B). It is likely that nitrogen was reduced in the leachate by immobilization by microorganisms (Theis & Rilig, 2009). This finding is consistent with the reduction of chlorophyll in the leaves. Chlorophyll content, as indicated by SPAD values, have been shown to be correlated with petiole N concentration (Sexton & Carroll, 2002).

Our research indicated that biochar does not increase or decrease marketable fruit production when added to productive agricultural soils, or to nonproductive Anthrosols. This is consistent with other field trials in temperate soils (Jones et al., 2012; Revell et al., 2012a). Our study did, however, provide evidence that overall productivity of the plants was reduced in the first year. These reductions were mainly due to decreases in non-marketable fruit, and may be intensified by poor weather conditions (Table 3.9). It has been proposed that biochar additions to freely draining and degraded soils may show greater benefits over productive soils in temperate regions (Atkinson et al. 2012). Our study did not confirm this hypothesis. It should be noted, however that the mechanism proposed for increasing plant productivity in Atkinson et al.(2010) are soil nutrients and water. In our experiment we provided water as needed. It is also important to recognize that biochar is not completely inert when added to the soil. Once biochar is added to soils it undergoes physical, chemical, and microbial changes (Hammes & Schmidt, 2009). Continued and long term research is needed to determine if benefits of biochar additions to soils are slow to appear.

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Table 3.1. Fruit yield of ‘Paladin’ peppers grown in a Clarion loam soil. Means are averages of seven harvests. Experimental design was a split plot with four replications, on bare soil or black plastic mulch (whole plot), and four levels of biochar (0.0, 1.1, 2.2, and 4.5 $kg \cdot m^{-2}$) as sub-plot factors.

	Marketable number/ha (thousands)		**Marketable weight (Mg/ha^{-1})**		**Total Non-marketable[z] number/ha (thousands)**		**Total Non-marketable weight (Mg/ha^{-1})**		**Blossom End Rot number/ha (thousands)**		**Sun Scald number/ha (thousands)**	
	Year											
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Biochar ($kg \cdot m^{-2}$)												
0.0	190.2[y]	111.9	25.8	18.5	133.9	95.2	11.4	12.8	23.0 a	1.7	10.5	13.6 ab
1.1	180.2	132.6	23.6	21.7	120.2	97.9	10.1	13.2	20.8 ab	3.3	7.5	14.1 ab
2.2	178.8	137.7	24.7	22.7	122.2	97.0	11.0	12.6	18.9 ab	1.5	7.5	13.1 b
4.5	180.8	144.8	23.6	22.7	114.0	110.8	9.7	14.2	14.3 b	2.8	6.3	18.4 a
Cover												
Bare soil	196.8 a	149.8 a	27.1 a	24.5 a	119.5	107.3	10.6	14.4 a	12.3 b	2.0	7.4	16.4
Black plastic	168.1 b	113.6 b	21.7 b	18.4 b	125.7	93.2	10.5	12.0 b	26.1 a	2.7	8.5	13.1
Interaction												
B*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Regression												
Bio Linear	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Bio Quad	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Sum of three categories of non-marketable fruit: 1) blossom end rot, 2) sun scald, and 3) size, shape, insect damage and other.

[y] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). NS = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.2. Fruit yield of ‘Paladin’ peppers grown in a sand Anthrosol. Means are averages of seven harvests. Experimental design was a split plot with four replications, on bare soil or black plastic mulch were the whole plot factors and four levels of biochar (0.0, 1.1, 2.2, and 4.5 $kg \cdot m^{-2}$) as the sub-plot factors.

	Marketable number/ha (thousands)		**Marketable (Mg/ha^{-1})**		**Total Non-marketable[z] number/ha (thousands)**		**Total Non-marketable (Mg/ha^{-1})**		**Blossom End Rot number/ha (thousands)**		**Sun Scald number/ha (thousands)**	
	Year											
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Biochar ($kg \cdot m^{-2}$)												
0.0	105.6	98.9	11.3	15.5	188.3 a	76.6 b	12.3 a	8.7 b	29.6	8.3	32.6 ab	12.0
1.1	87.3	98.5	9.3	15.4	185.0 a	98.8 a	12.1 ab	11.1 a	23.8	7.8	35.0 a	17.6
2.2	88.1	102.2	9.6	16.3	168.7 ab	83.1 ab	11.7 ab	8.7 b	21.7	8.9	21.9 c	11.9
4.5	91.1	102.2	9.9	16.8	156.7 b	82.3 ab	10.8 b	9.5 ab	24.4	8.5	24.2 bc	14.3
Cover												
Bare soil	103.9 a	109.7 a	11.3 a	17.6 a	189.7 a	86.2	12.8 a	10.3 a	30.4 a	4.5 b	34.9 a	16.6 a
Black plastic	81.5 b	91.1 b	8.7 b	14.4 b	159.9 b	84.2	10.8 b	8.7 b	19.3 b	12.2 a	21.9 b	11.4 b
Interaction												
B*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Regression												
Bio Linear	NS	NS	NS	NS	**	NS	*	NS	NS	NS	NS	NS
Bio Quad	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Sum of three categories of non-marketable fruit: 1) blossom end rot, 2) sun scald, and 3) size, shape, insect damage and other.

[y] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.3. Plant growth indicators of ‘Paladin’ peppers, grown in a Clarion loam soil. Plant height and stem diameter taken during fruit production, early August 2012 and late July 2013. Biomass measurements were taken after final harvest. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	Plant Height (cm)[z]		**Dry Biomass (kg)**[y]		**Shoot Weight (kg)**		**Root Weight (kg)**		**SPAD**[x]	
	Year									
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Biochar ($kg \cdot m^{-2}$)										
0.0	51.9 a[w]	36.4	166.9	77.9	106.3	64.8	60.6	13.2	64.5 a	50.1
1.1	50.1 ab	37.8	155.1	83.6	100.3	69.4	54.8	14.2	59.9 ab	52.2
2.2	49.7 b	37.6	155.2	80.1	102.1	67.5	53.2	12.6	59.9 ab	50.5
4.5	51.7 ab	42.0	165.1	89.1	107.1	73.9	58.1	15.2	58.1 b	51.1
Cover										
Bare soil	52.3 a	39.4	160.2	86.1 a	109.3 a	72.1 a	50.9 b	14.0	61.9 a	53.4 a
Black plastic	49.4 b	37.5	161.0	79.2 b	98.5 b	65.7 b	62.4 a	13.5	57.7 b	48.6 b
Interaction										
B*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Regression										
Bio Linear	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Bio Quad	**	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Height measured on ten plants per treatment on both bare soil and plastic mulch. Measurements are from soil to meristem on the main stem.

[y] Dry biomass measurements average of four plants per plot .

[x] SPAD values are averages of five leaves taken on ten plants per treatment.

[w] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.4. Plant growth indicators of ‘Paladin’ peppers grown in a sand Anthrosol. Plat height and stem diameter taken during fruit production, early August 2012 and late July 2013. Biomass measurements were taken after final harvest. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	Plant Height (cm)[z]		Dry Biomass (kg)[x]		Shoot Weight (kg)		Root Weight (kg)		SPAD[w]	
	Year									
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Biochar ($kg \cdot m^{-2}$)										
0.0	36.4 b[v]	33.1	72.1	75.0	55.4	63.6	16.7 ab	11.3	56.7	63.6 a
1.1	36.3 b	33.8	65.4	71.5	49.0	58.7	16.4 ab	12.8	53.8	63.5 a
2.2	37.4 ab	35.8	66.3	66.8	51.2	54.8	15.2 b	12.0	53.9	62.3 ab
4.5	39.7 a	33.8	71.0	68.1	51.5	56.3	19.4 a	11.8	53.7	60.4 b
Cover										
Bare soil	37.3	34.0	76.6 a	78.7 a	58.2 a	66.2	18.4 a	12.4	55.3	62.3
Black plastic	37.5	34.3	60.8 b	62.0 b	45.4 b	50.4	15.4 b	11.5	53.7	62.6
Interaction										
B*C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Regression										
Linear	**	NS	NS	NS	NS	NS	NS	NS	NS	*
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Height measured on ten plants per treatment on both bare soil and plastic mulch. Measurements are from soil to main stem meristem.

[y] Dry biomass measurements average of four plants per plot.

[x] SPAD values are averages of five leaves taken on ten plants per treatment.

[w] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.5. Soil nutrients in Clarion loam 2012. Samples were taken 7-19-2012 (middle) and 10-04-2012 (late). Nitrogen was extracted using a 2N KCl extraction method, while P and K were both extracted with a Mehlich III method. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	NH_4-N ($mg \cdot L^{-1}$)		NO_3-N ($mg \cdot L^{-1}$)		P ($mg \cdot L^{-1}$)		K ($mg \cdot L^{-1}$)	
	Season							
	Middle	**Late**	**Middle**	**Late**	**Middle**	**Late**	**Middle**	**Late**
Biochar ($kg \cdot m^{-2}$)								
0.0	1.35[z]	0.38	3.11	2.08 a	9.43	7.38	17.68 b	16.98
1.1	1.47	0.38	2.91	1.75 ab	9.10	7.33	18.66 ab	17.42
2.2	1.35	0.36	2.78	1.88 a	9.74	7.90	20.02 ab	17.58
4.5	1.36	0.34	2.85	1.30 b	9.71	8.12	20.55 a	18.00
Cover								
Bare soil	1.46 a	0.38	1.36 b	1.46 b	8.83 b	7.74	18.23 b	16.97
Black Plastic	1.31 b	0.35	4.46 a	2.04 a	10.16 a	7.62	20.23 a	18.01
Interaction								
B X C	NS	NS	NS	NS	NS	NS	NS	NS
Regression								
Biochar linear	NS	NS	NS	*	NS	NS	*	NS
Biochar quad	NS	NS	NS	NS	NS	NS	NS	NS

[z] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.6. Soil nutrients in Clarion loam 2013. Samples were taken 06-18-2013 (middle) and 11-12-2013 (late). Nitrogen was extracted using a 2N KCl extraction method, while P and K were both extracted with a Mehlich III method. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	NH_4-N ($mg \cdot L^{-1}$)		**NO_3-N ($mg \cdot L^{-1}$)**		**P ($mg \cdot L^{-1}$)**		**K ($mg \cdot L^{-1}$)**	
	Season							
	Middle	**Late**	**Middle**	**Late**	**Middle**	**Late**	**Middle**	**Late**
Biochar ($kg \cdot m^{-2}$)								
0.0	4.89 ab[z]	1.65	7.08	2.10	6.57 b	7.21	20.24 b	18.35
1.1	5.09 ab	1.48	6.98	1.60	6.76 b	7.08	20.88 ab	19.38
2.2	4.80 b	1.55	7.66	2.34	7.63 ab	7.62	22.76 ab	19.88
4.5	5.74 a	1.51	8.42	1.43	8.39 a	8.02	24.06 a	19.06
Cover								
Bare soil	6.67 a	1.65 a	7.76	1.26 b	7.64 a	7.61	22.74	19.16
Black Plastic	3.59 b	1.44 b	7.31	2.46 a	7.04 b	7.36	21.23	19.17
Interaction								
B X C	*	NS	NS	NS	NS	NS	NS	NS
Regression								
Biochar linear	NS	NS	NS	NS	**	NS	**	NS
Biochar quad	NS	NS	NS	NS	NS	NS	NS	NS

[z] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.7. Soil nutrients in a sand Anthrosol 2012. Samples were taken 7-19-2012 (middle) and 10-04-2012 (late). Nitrogen was extracted using a 2N KCl extraction method, while P and K were both extracted with a Mehlich III method. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	NH_4-N ($mg \cdot L^{-1}$)		**NO_3-N ($mg \cdot L^{-1}$)**		**P ($mg \cdot L^{-1}$)**		**K ($mg \cdot L^{-1}$)**	
	Season							
	Middle	**Late**	**Middle**	**Late**	**Middle**	**Late**	**Middle**	**Late**
Biochar ($kg \cdot m^{-2}$)								
0.0	0.19[z]	0.16	2.27 a	2.23 a	2.09 ab	2.03	10.74	6.85
1.1	0.14	0.17	1.66 b	1.58 b	2.39 a	2.11	14.08	6.89
2.2	0.14	0.22	1.32 bc	1.48 bc	1.94 b	2.00	8.75	6.90
4.5	0.14	0.16	1.15 c	0.95 c	2.27 ab	2.21	11.57	7.38
Cover								
Bare soil	0.16	0.20	1.78 a	1.46	2.89 a	2.27 a	10.63	7.03
Black Plastic	0.15	0.15	1.42 b	1.66	1.45 b	1.91 b	11.94	6.98
Interaction								
B X C	NS	NS	NS	NS	NS	NS	NS	NS
Regression								
Biochar linear	NS	NS	***	**	NS	NS	NS	NS
Biochar quad	NS	NS	NS	NS	NS	NS	NS	NS

[z] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). NS = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$

Table 3.8. Soil nutrients in a sand Anthrosol 2013. Samples were taken 06-18-2013 (middle) and 11-12-2013 (late). Nitrogen was extracted using a 2N KCl extraction method, while P and K were both extracted with a Mehlich III method. Experimental design was a split plot with four replications, bare soil or black plastic mulch (whole plot) and four levels of biochar as (sub plot).

	NH_4-N (mg·L^{-1})		NO_3-N (mg·L^{-1})		P (mg·L^{-1})		K (mg·L^{-1})	
	Season							
	Middle	Late	Middle	Late	Middle	Late	Middle	Late
Biochar (kg·m^{-2})								
0.0	4.65[z]	0.54	4.78	2.87	5.34	5.45	19.60	7.83
1.1	3.97	0.45	3.86	2.08	8.28	5.47	17.55	8.11
2.2	4.04	0.56	5.58	2.42	6.75	5.12	19.61	7.97
4.5	4.83	0.46	4.35	2.39	6.17	6.06	18.99	9.10
Cover								
Bare soil	4.11	0.32 b	3.55 b	0.59 b	5.43 b	5.24	16.79	7.48
Black Plastic	4.63	0.68 a	5.64 a	4.29 a	7.85 a	5.81	21.09	9.03
Interaction								
B X C	NS	NS	NS	NS	NS	NS	NS	NS
Regression								
Biochar linear	NS	NS	NS	NS	NS	NS	NS	NS
Biochar quad	NS	NS	NS	NS	NS	NS	NS	NS

[z] Means within columns with the same letter are not significantly different (least significant difference; $P \leq 0.05$). [NS] = non-significant, * = $P \leq 0.05$, ** = $P \leq 0.01$

Table 3.9. Daily high and low temperature comparisons of 2012 and 2013 growing seasons and the 15 year average.

	Average High Temp (□C)			**Average Low Temp (□C)**		
	2012	**2013**	**15 year**	**2012**	**2013**	**15 year**
Month						
June	28.6	26.1	26.6	16.4	16.1	15.6
July	32.7	28.8	28.9	19.7	17.1	18.0
August	28.5	29.1	27.6	15.2	16.9	16.4
September	24.9	26.4	24.0	9.6	13.1	11.0

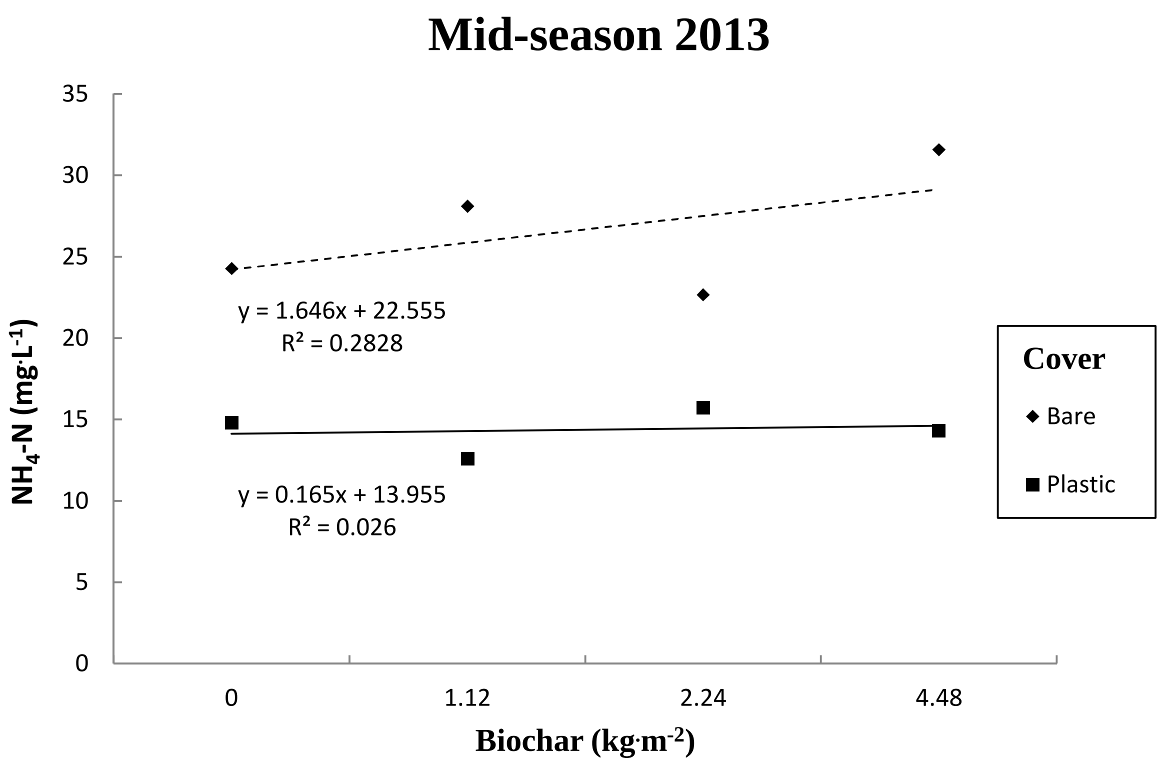


Fig. 3.1. Effects of biochar rate and soil cover on concentration of ammonium in a Clarion loam soil on 6-18-2013.

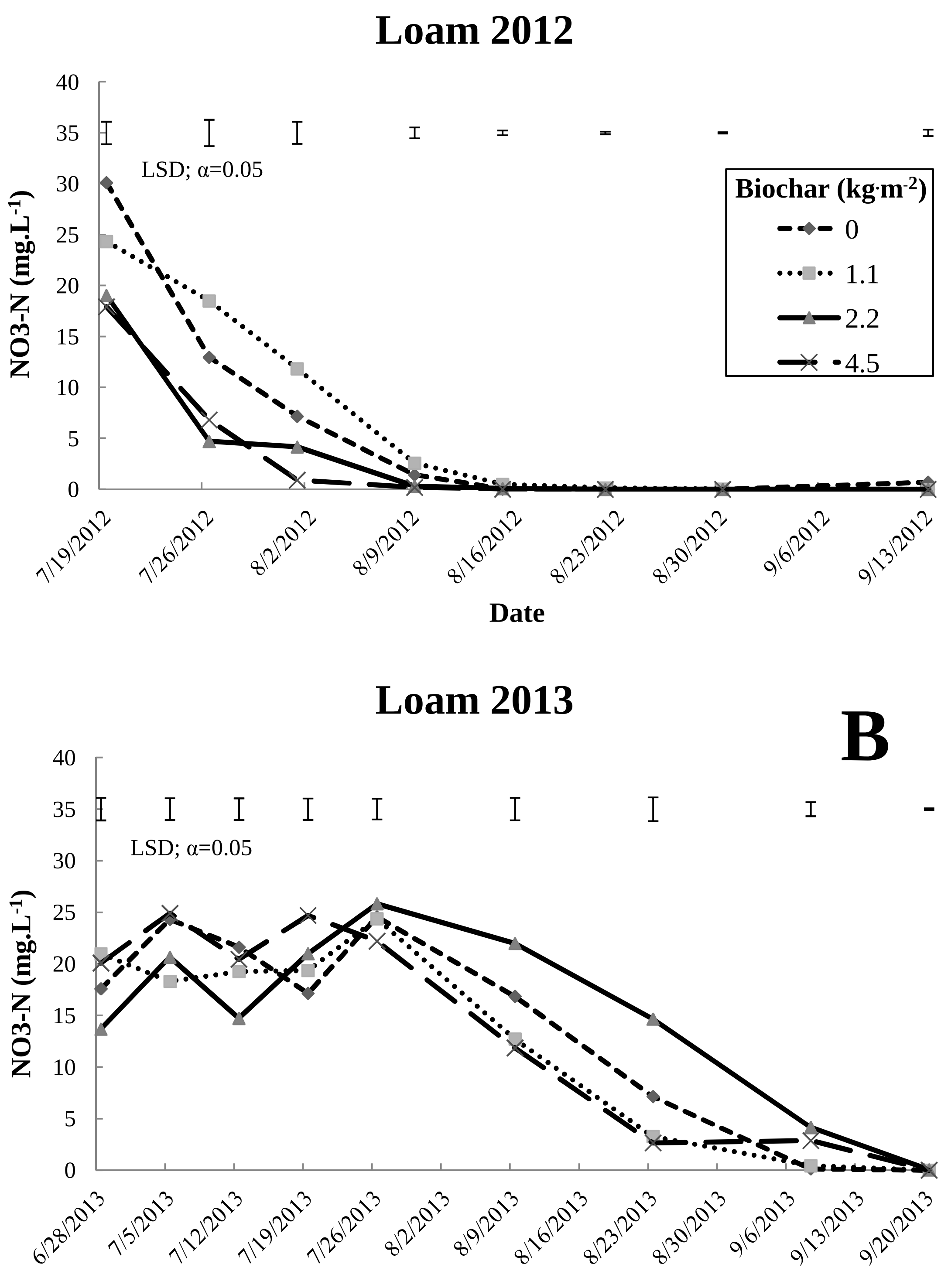
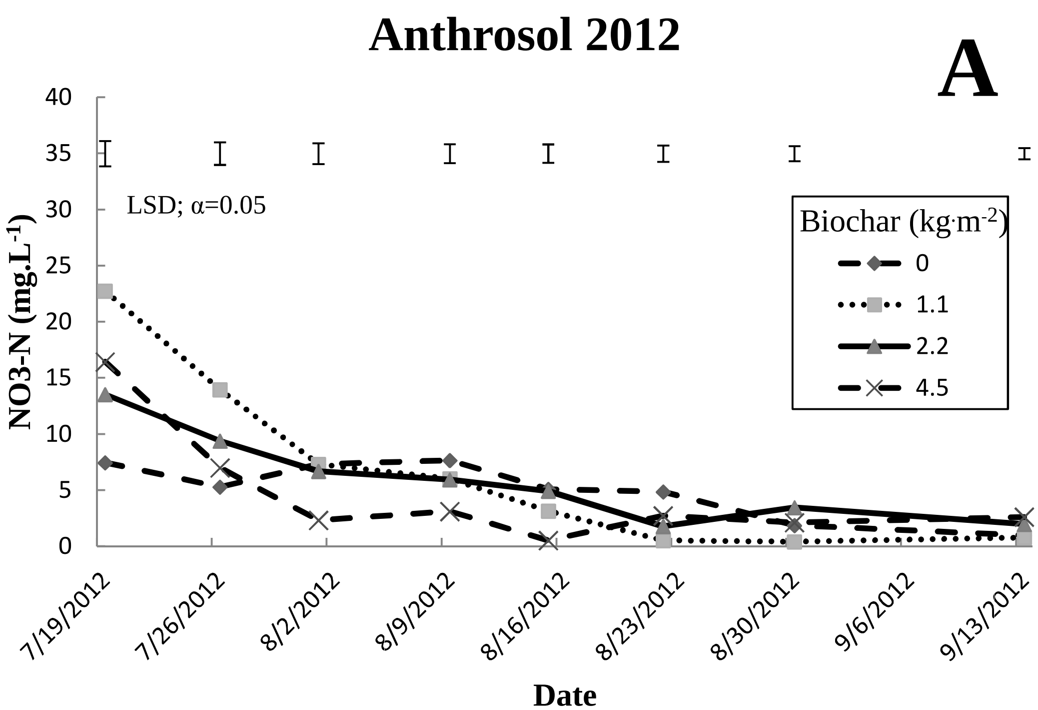


Fig. 3.2. Nitrate concentration of soil water samples taken at a depth of two feet in a Clarion loam soil. Samples were obtained using lysimeters. Means are averages of four samples. Bars indicate LSD of means for a specific date.



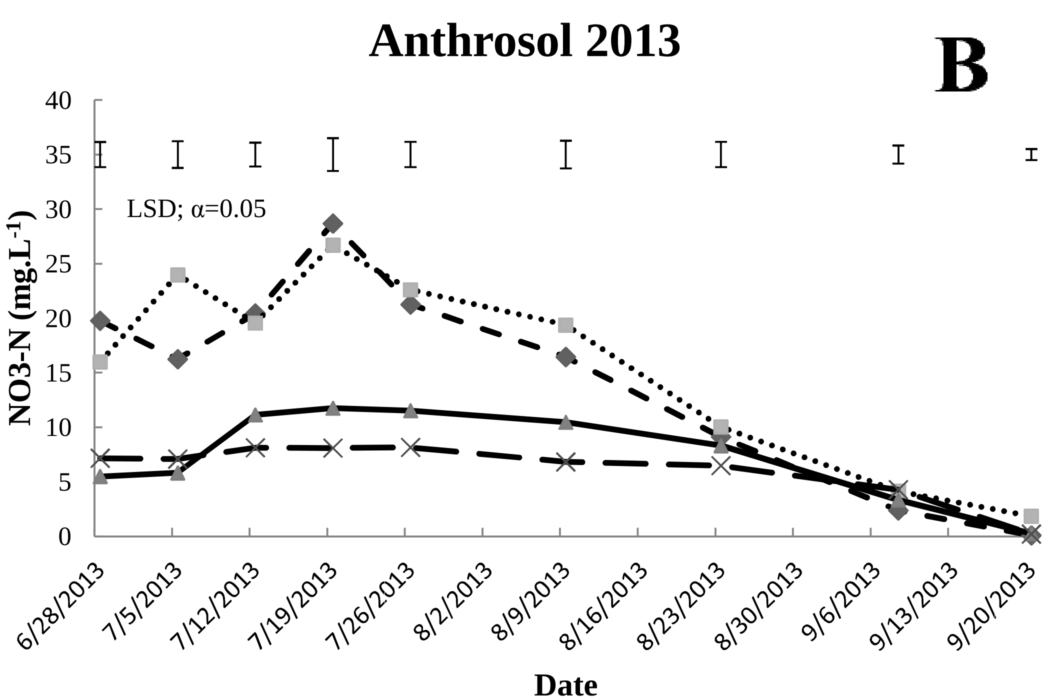


Fig.3.3. Nitrate concentration of soil water samples taken at a depth of two feet in a highly altered Anthrosol soil. Samples were obtained using lysimeters. Means are averages of four samples. Bars indicate LSD of means for a specific date.

CHAPTER 4. SUMMARY AND CONCLUSION

Summary

Biochar shows potential for use in vegetable production systems involving bell pepper, *Capsicum annum* L. Bell peppers are often transplanted and many small operations will produce their own transplants from seed. Our research shows concentration is an important consideration when adding biochar to commercially available greenhouse media. Field trials indicated application rate of biochar in temperate soils is also an important consideration in vegetable operations.

Transplant production. Our results show that, in general, germination of pepper improved with mixes containing 20%, 40% or 60% biochar, when using 50- or 72-cell trays (Fig. 2.1). It is unclear what caused increased germination; however, we speculated increases are likely due to water and/or temperature fluctuations. Temperature has been shown to affect a seed's ability to take up water (Watkins & Cantiffe, 1983). They found that the endosperm was more resistant to water at cool temperatures. If temperature caused increased germination, higher than optimum temperatures may have occurred in the 80% biochar mixtures. Biochar's effect on germination could also be a result of water. We observed enhanced drying of the growing medium with increasing biochar rates. Pinto et al. (2009) reported effects of grit color and irrigation frequency on germination of lodgepole pine (*Pinus contorta* var. 'Latifolia').

Transplant height decreased at greater biochar concentrations within individual cell numbers; however, 20% or 40% biochar treatments did not differ from the control (Table 2.1). This is consistent with other studies that report no difference in pepper plant height when grown in coconut coir-based substrate amended with up to 5% biochar (Graber et al., 2010). Our results indicated that rates as high as 40% biochar are possible without decreasing plant height. Graber et al. (2010) reported pepper dry weight increased when grown in coconut coir-based substrate amended with 3 to 5% biochar. Our transplant dry weights for 20%, 40%, or 60% biochar concentration were similar to the controls in the 72 and 98-cell trays, and thus in line with findings by Northup (2013). Cell volume also affected transplant size, as NeSmith and Duval (1998) indicated smaller plug cell volumes can reduce plant size and this reduction could be due to a number of factors including competition between leaves for light and roots for oxygen.

Field production. Biochar (up to 4.5 $kg \cdot m^{-2}$) did not decrease numbers or yield of marketable fruit, in either the first of second year after application (Tables 3.1 and 3.2). We did however record decreased total non-marketable fruit (Anthrosol 2012), increased total non-marketable fruit (Anthrosol 2013), blossom end rot (loam 2012) and sunscald (Anthrosol 2012). Our findings that biochar had no effect on bell pepper fruit production were consistent with other research on biochar in soils in temperate climates (Jones et al., 2012; Revell et al., 2012). We did not see statistical differences in marketable fruit caused by biochar treatments; however, there was a numerical trend both years, and in both plots. In 2012 marketable fruit decreased with increasing rates of biochar; while in 2013 this trend reversed. This suggests a chance of decreased production the first year followed by a possibility of increase the second year.

Blossom end rot was reduced in the loam field with increasing levels of biochar in 2012 (Table 3.1). The Anthrosol field followed the same trend in 2012; however, differences were not significant. Blossom end rot is a physiological disorder that appears when pepper plants are unable to translocate adequate calcium to the fruit. This can occur from insufficient amounts of calcium in the soil, or as a result of insufficient soil moisture (Bosland & Votava, 2000). Our results could be due to either since biochar has been shown to increase water holding capacity as well as extractable calcium (Laird et al., 2010a). In 2012 biochar affected plant height in loam and Anthrosol soils, as well as root weight (Anthrosol) and chlorophyll content (loam). The only effect of biochar in 2013 was in the chlorophyll content in the Anthrosol field where chlorophyll decreased with increasing levels of biochar. There were no significant interactions between biochar and the use of black plastic mulch in either fruit production or plant fitness. Black plastic mulch did, however, decrease fruit production and plant growth in most of the variables collected. This is consistent with findings by others like Roberts and Anderson (1994). In two of the three years their experiment ran, black plastic mulch reduced pepper yields. They attribute the reductions to higher soil temperatures under the black plastic mulch.

Soil nutrients were affected by biochar, although results were not consistent between soil types. Previous studies had shown that biochar can increase NH_4^+, and K^+ retention by increasing CEC and surface area (Glaser et al., 2002; Laird et al., 2010a) and NO_3^-N (Knowles et al., 2011). We found that biochar increased retention of K^+ in the loam soil both years (Tables 5 and 6). Extractable nitrogen did not decrease with increased biochar in either field. In 2013 extractable NH_4-N increased with increasing biochar additions in the bare soil treatment but not in the black plastic (Fig. 3.1). Increased nitrification is a possible cause for non-significant differences in nitrate means over the same time period. This is in line with the review of biochars effect on soil nitrogen made by Deluca et al. (2009). Phosphorous was only affected by biochar in loam soil in 2013 and in Anthrosol soil in 2012. Reductions in nitrate leaching were also seen in the loam field in 2013 (Fig 3.2A) as well as in the Anthrosol field in 2013 (Fig. 3.3B). It is likely that nitrogen was reduced in the leachate by immobilization by microorganisms (Theis & Rilig, 2009).This finding is also consistent with the reduction of chlorophyll recorded in the leaves of the pepper plants. Chlorophyll content, as indicated by SPAD values, has been shown to be correlated with petiole N concentration (Sexton & Carroll, 2002). There are two possible causes for the reduction in chlorophyll content and NO_3-N leaching seen in both fields. One is that biochar sorption of NH_4-N reduced the nitrification rate limiting the amount of NO_3-N in the soil (Laird et al., 2010b) react with microbial communities and nutrients in the soil the first year reducing available nitrates indicated by DeLuca et al. (2009).

Conclusion

Our study demonstrates potential use of biochar for vegetable transplant production. Our overall finding is that addition of 20% to 40% biochar to peat-based substrate improved seed germination while failing to diminish transplant growth. However, higher rates of biochar (60 or 80%) reduced transplant growth. From an environmental perspective, biochar has potential to reduce nutrient leaching and allow for supplementation of sphagnum peatmoss in transplant production. With increasing costs of growing medium combined with growers' interest in utilizing environmentally-friendly products, biochar could serve as a suitable amendment in the transplant production phase of pepper production.

Our research also indicates biochar does not increase or decrease marketable fruit production in the first two seasons after application. This is consistent with other field trials in temperate soils (Jones et al., 2012; Revell et al., 2012). Our study did however provide evidence that overall productivity of pepper plants is reduced in the first year after biochar application. These reductions were likely due to decreases in non-marketable fruit. Our findings did not support findings like those of Atkinson, et al. (2010), who indicated that biochar may have greater benefits to freely draining and degraded soils in temperate regions. It should be noted, however, that the mechanism proposed for increasing plant productivity in Atkinson (2010), are soil nutrients and water. In our experiment we provided water as needed.

Future Research

It is important to highlight that biochars, like soils, have a wide range of chemical and physical characteristics. Properties like porosity and pH can change depending on the biomass used as feedstock, as well as on the temperatures and duration of pyrolysis (Lehmann & Josephs, 2009). This research was conducted using a commercially available hardwood biochar produced in a slow pyrolysis retort. Biochars produced by other commercial biochar companies, as well as other biochars produced by Royal Oak® (Royal Oak Charcoal, Roswell, GA), may have differences in their physical and chemical properties. Subsequently, a thorough characterization of the physical and chemical properties of the biochar used in this research is needed to draw more specific conclusions.

It is also important to recognize that biochar is not inert when added to the soil. Once biochar is added to soils it undergoes physical, chemical, and microbial changes (Hammes & Schmidt, 2009). For this reason, continued and long term research is needed to better determine possible benefits of biochar additions to soils.

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