Sand-based turfgrass root-zone modification with biochar

by

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GENERAL INTRODUCTION

Sand-based profiles are used in the construction of sports fields and golf course putting greens, which limits compaction and provides sufficient drainage (USGA Green Section Staff, 2004). However, sand-based systems lack water-retention and nutrient-holding capacity necessary for healthy turf growth (Bigelow, 2001). Amendments, such as diatomite, expanded shale, perlite, calcined clay, pumice, vermiculite, and peat moss have been evaluated for their use in sand-based turf media. Peat moss is most commonly incorporated (Waddington, 1992); however, the decomposition of peat moss adversely affects its positive impacts on the root-zone (Bigelow et al., 2004). Over time, the peat moss can break down into fine particles and reduce water infiltration rates and lose some of its nutrient retention capacity in a sand-based system (Bigelow et al., 2004). The most beneficial amendment for a sand-based turfgrass root zone would be recalcitrant in the soil, and provide similar water holding and infiltration properties to peat moss (Bigelow et al., 2004).

Biochar derived from the fast pyrolysis of switchgrass requires intense thermal energy (~500º C) in the near absence of oxygen to burn biomass. Approximately 60% of the biomass is converted into bio-oil, 20% is converted to synthetic natural gas (syngas), and 20% becomes biochar (Laird, 2008). Bio-oil can be refined and used as an energy source, and the syngas provides energy for the pyrolysis process, or can be utilized for energy in other ways (Laird, 2008).

Improved nutrient retention and nutrient availability for plants in Amazonian soils, *terra preta*, have been linked to the presence of char in the soil profile (Glaser et al., 2002), which are found in Central Amazonia. Incomplete combustion of organic material, predominately from cooking fires of indigenous tribes, produced char which eventually was incorporated into the soil. *Terra preta* soils contain up to 70 times more char, and are more fertile and sustainable than non-*terra preta* humid tropic soils (Glaser et al., 2000). Research has shown that charcoal can improve agricultural soils. Charcoal additions to different soil types have shown increases of plant-available soil moisture (Tryon, 1948). Biochar increases cation exchange capacity of soils (Liang et al. 2006).

The biochar vision (Laird, 2008; Lehmann, 2007a,b; Fowels, 2007) describes the use of biochar as positive for many reasons. Because the half-life of the carbon found in biochar is greater than 1000 years (Laird, 2008), biochar, when applied to soil, is a carbon sequestration tool. As reported, 363 Tg C per year (~10% U.S. average annual CO_2-C emissions) would be sequestered if enough bio-oil was produced, and resulting biochar incorporated into soils, to replace 1.91 billion barrels of oil per year. Currently, 1.91 billion barrels of fossil fuel oil accounts for approximately 25% of current U.S. annual oil consumption. These estimates are based on the assumption that the U.S. can pyrolyze 1.1×10^9 Mg of biomass into bio-oil each year (Laird, 2008).

Biochar materials possess different particle size characteristics depending on the production temperature and method. Fast pyrolysis occurs at high temperatures with a short burn period and produces a fine-textured biochar (< .002mm diameter particle size). Conversely, slow pyrolysis produces a coarse-textured biochar with longer burn times (Dall'Ora et al., 2008).

An ideal sand-based turfgrass root-zone amendment has not been identified. Biochar has the potential to be a stable organic amendment that would be comparable to peat moss. Research has proven biochar to have positive impacts on agricultural soils around the world.

The objective of this research is to explore if biochar is applicable in sand-based turfgrass root-zones that are used in golf green construction.

Thesis Organization

This thesis is divided into four chapters. The first chapter outlines the general scope of the research and why it was needed. Chapter two is a manuscript to be submitted to *Agronomy Journal* describing the physical and chemical effects biochar has on sand-based root-zones. Chapter three is a summary of results and overall conclusions of the research conducted. The fourth chapter is an appendix containing all of the nutrient analyses results.

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PHYSICAL AND CHEMICAL PROPERTIES OF SAND-BASED TURFGRASS ROOT-ZONES AMENDED WITH BIOCHAR

A paper to be submitted to *Agronomy Journal*

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Abstract

Sand-based turfgrass root-zones are limited in nutrient retention and water holding capacity. Peat moss is often used to offset these deficiencies, but peat moss is prone to decomposition. Biochar, a co-product of the fast pyrolysis process used to produce bio-oil, may have similar benefits as peat moss while being less prone to decomposition. In addition, because biochar is relatively stable over time, sand-based turfgrass ecosystems established with biochar may become a viable long term carbon sequestration vehicle. At field capacity, sand-based media containing 25% biochar retained 63 and 73% more water compared to media containing 5% biochar and a pure sand control, respectively. Sand media containing 25% biochar resulted in a saturated hydraulic conductivity (K_{sat}) of 6.6 cm hr^{-1}, whereas, 5% biochar media and pure sand resulted in K_{sat} of 55.9 and 84.8 cm hr^{-1}, respectively. The rooting depth of bentgrass was reduced up to 46% at biochar concentrations greater than 10%. Leachate electroconductivity increased from 1.5 mmhos cm^{-2} to 3.4 mmhos cm^{-2} and dissolved total organic carbon increased from 20 ppm to 340 ppm as biochar concentrations increased from 0 to 25%. Leachate nitrate and ammonium concentrations decreased from 5 ppm to 0 ppm and 0.8 ppm to 0.2 ppm, respectively, as biochar concentrations increased.

Soil phosphorus and potassium increased from 0 ppm to 118 ppm and 21 ppm to 892 ppm, respectively, as biochar concentrations increased.

Introduction

Sand-based turfgrass root-zones should provide high infiltration and drainage rates, and prevent compaction. At the same time, sand-based root-zones must retain enough water and nutrients to support turfgrass health. Organic amendments like sphagnum peat moss are often incorporated to promote water and nutrient retention without adversely affecting infiltration and drainage (Juncker and Madison, 1967; Beard, 1982). However, organic materials can be prone to decomposition by microbial activity thus reducing their overall effectiveness in the profile (Bigelow et al., 2004). An excellent sand-based turfgrass root-zone amendment would provide adequate water and nutrient retention to maintain turfgrass health and be recalcitrant in the soil (Bigelow et al., 2004).

Biochar is a co-product of bio-oil production through a process called pyrolysis. There are many technologies developed to generate energy from biomass (Bridgewater, 2003), but pyrolysis is the only process that creates biochar (Lehmann, 2007b).

Biochar increases nutrient retention when added to soils (Glaser et al., 2002; Lehmann et al., 2003). Per unit of carbon, biochar expresses a higher affinity than other forms of organic matter to attract and hold cations (Sombroek et al., 2003). This increase is the result of greater surface areas and more negative surface charges per unit area (Liang et al., 2006). Plant-available soil moisture increases have resulted from additions of charcoal to soil (Tryon, 1948), but water-holding capacity of soils amended with biochar have not been examined (Lehmann, 2007b).

Low cation exchange capacity (CEC) and rapid drainage promote nutrient leaching through sand-based root-zones (Sartain and Brown, 1998; Bigelow et al., 2001; Petri and Petrovic, 2001). However, leaching rates of applied nitrogen are reduced by charcoal additions to soil (Lehmann et al., 2003). Biochar reduces leaching of chemicals and nutrients in agricultural soils (Laird, 2008; Lehmann, 2007a,b), but the effect biochar has on nutrient retention and pesticide leaching in sand-based turfgrass root-zones has not been studied.

The objectives of this research were to evaluate the impacts of six volume-to-volume mixtures of sand and biochar on (i) soil water retention, (ii) saturated hydraulic conductivity, (iii) rooting depth of 'T-1' creeping bentgrass, and (iv) chemical properties of sand-based root-zones.

Materials and Methods

Root-zone mixtures

Calcareous sand with a pH of 8.2 commonly used for sand-based root-zone construction and modification was purchased and used for treatment mixtures (Hallett Materials, Ames, IA). The composition of the sand was 8.2% very coarse, 35.3% coarse, 44.3% medium, 11.9% fine, 0.1% very fine, and 0.2% silt and clay. The switchgrass biochar used in this study came from the Center for Sustainable Environmental Technologies (CSET) at Iowa State University and was produced via fast pyrolysis. The CSET seeks to develop technology for the production of fuels and other products from biomass and other fossil fuels (CSET, 2008). The fast pyrolysis switchgrass biochar contained 55% ash by weight, a higher heating value comparable to coal, a particle density of 1.78 g cm^{-3}, a surface area of 21.6 m^2 g^{-1}, 0.6% nitrogen by weight, and 39% carbon by weight (Brewer et al., 2009). The sand and biochar mixtures were made on a volume-to-volume basis. Six biochar and sand treatment mixtures ranged from 0% biochar up to 25% biochar, increasing by 5% increments.

Soil water retention

For matric potential values of -0.98, -2.46, -4.90, -9.81, -19.61, and -32.66 kPa, pressure head chambers were used (Klute, 1986). Soil mixture cores were placed in 20 °C water and allowed to saturate from the bottom up for 24 hours. Chamber pressure was measured with a water manometer and mercury manometer.

For matric potential values of -50, -100, -500, and -1500 kPa, the pressure head method (Klute, 1986) was implemented using a Ceramic Plate Extractor (Soil Moisture Equipment Corp., Santa Barbara, CA). Two rings of each treatment mixture were analyzed at each pressure simultaneously in the chamber. Rings were allowed to saturate with water at 20 °C for 24 hours before pressure was applied.

Saturated hydraulic conductivity

Marriott bottles were used to determine saturated hydraulic conductivity (K_{sat}) via the constant head method (Klute and Dirksen, 1986). The soil cores used in the soil water retention study were resaturated for 24 hours in a water bath at 20 °C. Marriott bottles were filled with 20 °C water, and water flow was measured for sixty-second intervals three times for every core. The average volume of water outflow over the three runs was considered the K_{sat} value for each core.

Root tubes

In order to determine rooting depth of creeping bentgrass in the six sand and biochar mixtures, rooting tubes were constructed out of polyvinyl chloride (PVC) pipe (Bonos et al., 2004; Reicher and Christians, 1989). The top 30 cm of a polyethylene insert was filled with one of the soil mixtures, and the bottom 30 cm was filled with 1 cm diameter pea gravel to mimic a United States Golf Association (USGA) root-zone (USGA, 1993).

This experiment was repeated three times. Four replications of each treatment were evaluated in a completely randomized design in a controlled-environment greenhouse. A modified Hoagland's solution (Pellet and Roberts, 1963) was applied directly prior to seeding and again 70 days after seeding at 4.9 g-N m^{-2}. The cultivar of creeping bentgrass, 'T-1,' was seeded at 6 g m^{-2}. The creeping bentgrass cultivar 'T-1' is rated highly in many categories for putting green quality (National Turfgrass Evaluation Program, 2007); therefore, 'T-1' was chosen for use in this study. Mist-watering of 2 ml was applied four times daily with a spray bottle until the seeds germinated. Watering slowly decreased until 15 ml of water were being added once every week to each tube, approximately 21 days after germination. No supplemental light was provided, and daily irradiance throughout all three trials ranged from 350 to 385 μmol m^{-2} s^{-1}. The temperature ranged from 20 to 25 °C with an average temperature of 22 °C. Relative humidity ranged from 30-55% with an average relative humidity of 40%. Two trials were conducted late August through early December, and one trial was conducted late December through March.

Polyethylene inserts were removed from the PVC tubes and placed on a wire-mesh screen 110 days after seeding. The polyethylene was removed leaving only the root-zone material. The root-zones were shower-washed over the mesh screen, and root length was determined using a standard measuring tape after the air-dried roots were laid on a cleaned board.

Soil analyses

Four samples of each treatment mixture were sent to Harris Laboratories (Harris Laboratories, Division of AgSource Cooperative Services, Lincoln, NE) for nutrient content evaluation. Potassium (K) was extracted using ammonium acetate (Warncke and Brown, 1998), and Bray and Kurtz P-1 was used for phosphorus (P) extraction (Frank et al, 1998). Both K and P were analyzed by inductively coupled plasma mass spectrometry methods (ICP-MS). Cadmium reduction methodology was implemented for nitrate-nitrogen (NO_3-N) evaluation after potassium chloride extraction (Gelderman and Beegle, 1998).

Leachate analyses

Leachate samples were collected from the soil water retention study between -0.98 and -4.90 kPa. Total dissolved organic carbon (TOC), nutrient analyses, pH, and electroconductivity (EC) were measured on these samples. Four samples of leachate from each treatment were analyzed for all measurements.

The TOC analysis was performed using the TOC-5050 Total Organic Carbon Analyzer (Shimadzu, Columbia, MD). For leachate nutrient analyses other than NH_4-N and NO_3-N, ICP-MS methods were implemented at the Iowa State University Soil Testing Laboratory. A Lachat QuickChem 8000 analyzed NO_3-N and NH_4-N via QuickChem methods 12-107-04-1-B and 12-107-06-2-A, respectively (Lachat Instruments, 1992). The pH readings were measured with an Accumet pH meter, model 10 (Fisher Scientific, Hanover Park, IL) at 20 °C. Electroconductivity values were measured with a Cole-Parmer electroconductivity meter, model 1481-61 (Cole-Parmer Instrument Co., Vernon Hills, IL), at 20 °C.

Statistical analyses

Data were analyzed using the PROC GLM procedure in Statistical Analysis Software version 9.1.3 (SAS Institute Inc., Cary, NC). Root length data from all three trials were analyzed together due to the lack of interaction with the experiment variable ($P = 0.17$). Orthogonal contrasts were used to determine regression polynomial significance ($P \leq 0.05$).

Results and Discussion

Soil water retention, rooting depth, and K_{sat}

Water retention. Available water holding capacity (AWHC) of 10% biochar media was 170% greater than pure sand (Table 1). Available water holding capacity of 25% biochar soil was 370 and 260% greater than pure sand and 5% biochar media, respectively (Table 1). Water retention increased as the amount of biochar increased in the profile. However, a couple deviations from this trend were observed. At -0.98 kPa, pure sand retained more water than the 5 and 10% biochar media. At -2.45 kPa, pure sand retained more water than the 5% biochar mixture (Figure 1). This was likely attributable to measurement error. Difficulty in collecting the initial water drainage when the core was removed from the water bath is the most probable source of error in the measurement. However, the overall trends of the retention curves and increased water holding capacities are evidence that biochar increases soil water retention when mixed with sand.

Rooting depth. Rooting depth of creeping bentgrass was negatively affected only when biochar amounts were greater than 10% (Table 1). Rooting depths in pure sand, 5, and 10% biochar were not different. Rooting depths in 20 and 25% biochar root-zones were 31 and 43% shorter than rooting depth in 10% biochar mixtures, respectively (Table 1).

K_{sat}. Sand media containing 25% biochar resulted in a K_{sat} of 6.6 cm hr^{-1}, whereas, 5% biochar media and pure sand resulted in K_{sat} of 55.9 and 84.8 cm hr^{-1}, respectively (Table 1). Bulk density decreased from 1.75 to 1.57 g cm^{-3} as the amount of biochar increased from 0 to 25% (Table 1).

United States Golf Association (USGA) guidelines recommend K_{sat} values ranging from 15-30 cm h^{-1} (USGA, 1993). Media containing 25% biochar is the only treatment resulting in K_{sat} below 15 cm h^{-1}, and media containing 20% biochar is the only treatment that falls within the USGA guidelines (Table 1). It is important to note that conventional soil packing methods (USGA, 1993) could not be used due the powdery nature of the biochar. The K_{sat} ranges of biochar and sand media would likely change over time under actual field conditions.

The optimum amount of biochar in the sand profile is 10% based on the rooting depth of bentgrass and water holding capacity of the media. Increasing the amount of biochar beyond 10% in the profile has a detrimental effect on rooting depth and may decrease overall turfgrass quality. However, studies should be conducted to further evaluate the impacts biochar has on overall turfgrass quality in natural field conditions.

Chemical analyses

Leachate and soil nutrients. Leachate NO_3-N and NH_4-N concentrations decreased from 5 ppm to 0 ppm and 0.8 ppm to 0.2 ppm, respectively, as biochar concentrations increased from 0 to 25% (Figure 2). Leachate Na concentrations increased from 18 ppm to 24 ppm as biochar concentrations increased (Figure 2). Leachate pH increased from 7.7 to 8.4 and leachate TOC increased from 20 ppm to 340 ppm as biochar concentrations in the media increased from 0 to 25% (Figure 4). Leachate EC increased from 1.5 mmhos cm^{-2} to 3.4 mmhos cm^{-2} as biochar concentrations in the media increased (Figure 5).

Soil P and K increased from 0 ppm to 118 ppm and 21 ppm to 890 ppm, respectively, as biochar concentrations increased from 0 to 25% (Figure 6). No differences in media N or Na concentrations resulted (data not shown).

These results are similar to previously published data suggesting biochar may provide essential elements (Glaser et al., 2002) and promote nutrient retention (Laird, 2008; Lehmann, 2007a,b; Lehmann et al., 2003). The additional P and K leaching is most likely due to the fact that the organic carbon portion of biochar attracts these elements and is subsequently leaching out of the profile. The NO_3-N and NH_4-N may be immobilized by microorganisms in organic forms of nitrogen in media containing greater concentrations of biochar. This would result in a lower ICP-MS reading of NO_3-N and NH_4-N in the leachate and impact the results.

Biochar is a liming agent (Laird, 2008), but the liming effect of biochar would be buffered at a pH of 8.2 in a calcareous-based sand due to free calcium carbonate ($CaCO_3$) in the media. Further evaluation of the effects of having increased amounts of TOC leaching out of the soil profile should be studied. Even though EC increased, the leachate did not become saline (≥ 4 mmhos cm^{-2}) at any concentration of biochar in the soil. The increase in Na concentration is likely impacting EC. It is important to note that this leachate was the initial drainage collected from a freshly constructed profile. Leachate chemical analyses would likely stabilize over time.

The decreased rooting depth of creeping bentgrass is not fully understood. The increased water retention in media containing greater concentrations of biochar may allow the plants to survive without sending roots deeper into the profile. Anaerobic conditions may be present at higher concentrations of biochar limiting rooting depth. The increased Na concentrations at greater amounts of biochar may impact the rooting depth. Further research evaluating the cause of reduced rooting in sand and biochar root-zones needs to be conducted.

Conclusions

Increasing the amount of biochar that is produced from fast pyrolysis of switchgrass in sand and biochar root-zones will increase water retention and plant-available water holding capacity of the media and decrease saturated hydraulic conductivity. Rooting depth of ‘T-1’ creeping bentgrass is decreased if the amount of biochar in a sand-based root-zone is greater than 10%.

Leachate EC and TOC from sand and biochar root-zones increase as the amount of biochar increases. Concentrations of NO_3-N and NH_4-N in the leachate decreased as the amount of biochar increased in the media which may be partially due to immobilization of the nitrogen into organic forms by microorganism activity. Concentrations of P, Na, and K increased in the leachate as the amount of biochar increased in the media.

The concentration of P and K increased in the soil profile as the amount of biochar increased. Media Na and N concentrations did not change as concentrations of biochar changed.

The chemical and physical parameters of sand and biochar root-zones should be evaluated over time in a field setting to better evaluate the effects biochar has on sand-based root-zones.

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Table

Table 1. K_{sat}, 'T-1' creeping bentgrass rooting depth, AWHC, and bulk density of sand and biochar mixtures. K_{sat}, bulk density, and AWHC values represent means of four replications. Rooting depth values represent means of twelve replications.

Biochar percentage (v/v)	K_{sat}† ($cm\ hr^{-1}$)	Rooting depth‡ (cm)	AWHC§¶ ($cm^3\ cm^{-3}$)	Bulk density# ($g\ cm^{-3}$)
0	84.8	46	0.07	1.75
5	55.9	45	0.10	1.70
10	53.0	43	0.12	1.68
15	29.2	34	0.16	1.64
20	15.5	30	0.22	1.63
25	6.6	25	0.26	1.57
Significance				
Linear	***	***	***	***
Quadratic	ns£	**	ns	ns
Cubic	ns	ns	ns	ns

, * Orthogonal polynomial contrasts significant at the 0.01 and 0.001 levels, respectively (£ns = not significant)

§ AWHC = water retained at -4.90 kPa – water retained at -1500 kPa

† $y = -3.59x + 92.77$; $R^2 = 0.96$

‡ $y = -0.031x^2 - 0.15x + 46$; $R^2 = 0.60$

¶ $y = 0.008x + 0.059$; $R^2 = 0.98$

$y = -0.006x + 1.74$; $R^2 = 0.76$

Figure Captions

Figure 1. Soil water retention curves for six biochar and sand mixtures. Data were collected using the pressure head method (Klute, 1986).

Figure 2. ICP-MS results of biochar and sand leachate samples. Four leachate samples from each mixture were analyzed at Iowa State University's Soil Testing Lab (Ames, IA). *, **, *** Orthogonal polynomial contrasts significant at the 0.05, 0.01, and 0.001 level, respectively.

Figure 3. Leachate pH for six mixtures of biochar and sand. Readings were taken with an Accumet pH meter, model 10 (Fisher Scientific, Hanover Park, IL) at 20 °C. * Orthogonal polynomial contrast significant at the 0.05 level.

Figure 4. Leachate total dissolved organic carbon (TOC). Measurements were taken with a TOC-5050 Total Organic Carbon Analyzer (Shimadzu, Columbia, MD). Samples were diluted at a 1:25 ratio with distilled water. The TOC of the water was 0.30 mg L^{-1} (n=7). *** Orthogonal polynomial contrast significant at the 0.001 level.

Figure 5. Leachate electroconductivity (EC) for six mixtures of biochar and sand. Readings were taken with a Cole-Parmer EC meter (Cole-Parmer Instrument Co., Model 1481-61, Vernon Hills, IL) at 20 °C. The base EC of the water was 0.35 mmhos cm^{-2} (n=4). *** Orthogonal polynomial contrast significant at the 0.001 level.

Figure 6. Soil nutrient analyses for phosphorus (P) and potassium (K). Four samples of each biochar and sand mixture were analyzed by Harris Laboratories (AgSource Cooperative Services, Lincoln, NE). The K was analyzed using ammonium acetate extraction. The P was measured via Bray-I extraction. ** Orthogonal polynomial contrast significant at the 0.01 level.

Figures

Figure 1.

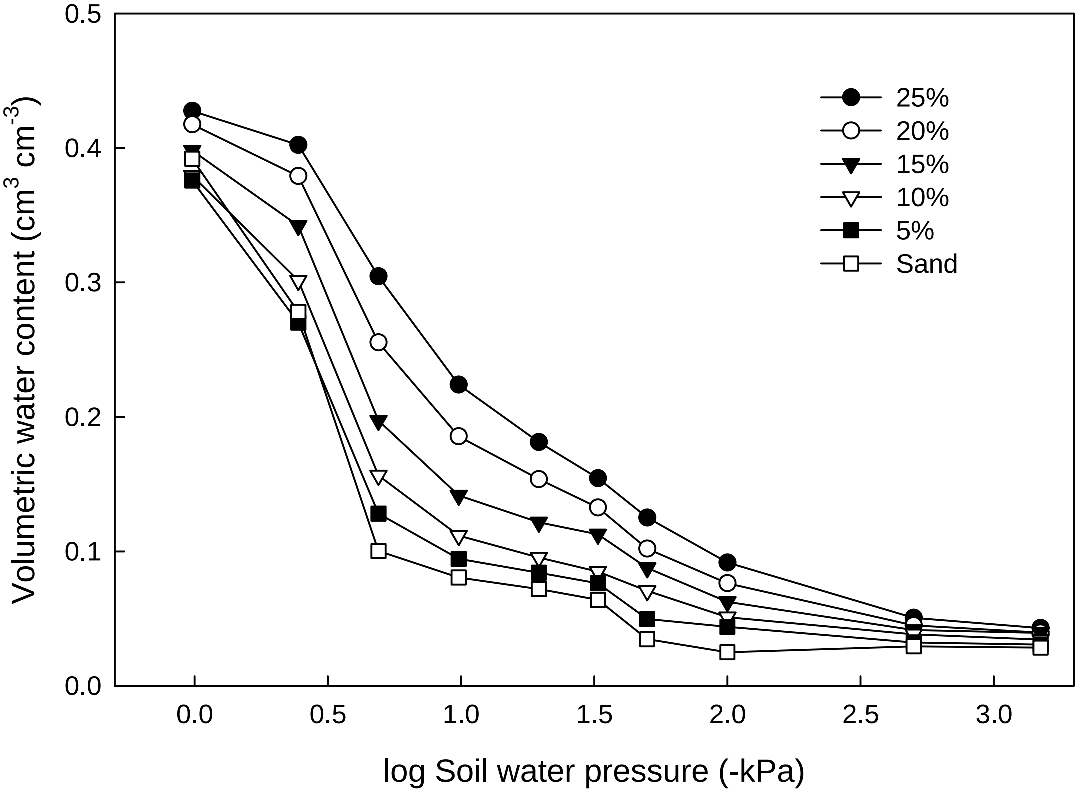


Figure 2.

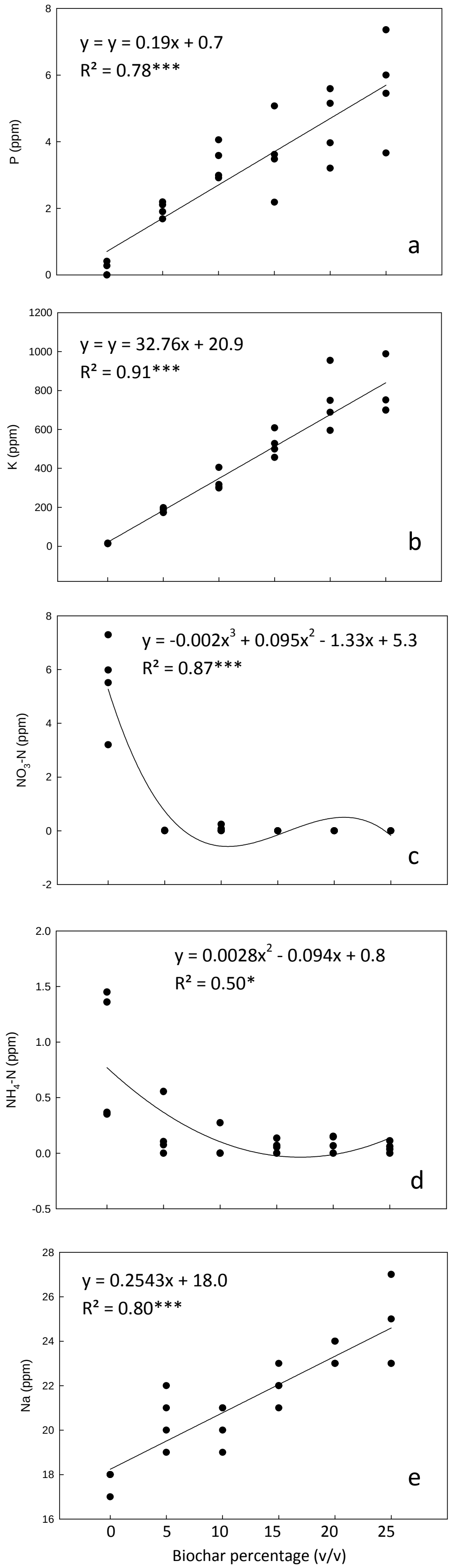

y = y = 0.19x + 0.7
R² = 0.78***
P (ppm)
0
2
4
6
8
a
y = y = 32.76x + 20.9
R² = 0.91***
K (ppm)
0
200
400
600
800
1000
1200
b
y = -0.002x^3 + 0.095x^2 - 1.33x + 5.3
R² = 0.87***
NO$_3$-N (ppm)
-2
0
2
4
6
8
c
y = 0.0028x^2 - 0.094x + 0.8
R² = 0.50*
NH$_4$-N (ppm)
-0.5
0.0
0.5
1.0
1.5
2.0
d
y = 0.2543x + 18.0
R² = 0.80***
Na (ppm)
16
18
20
22
24
26
28
e
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 3.

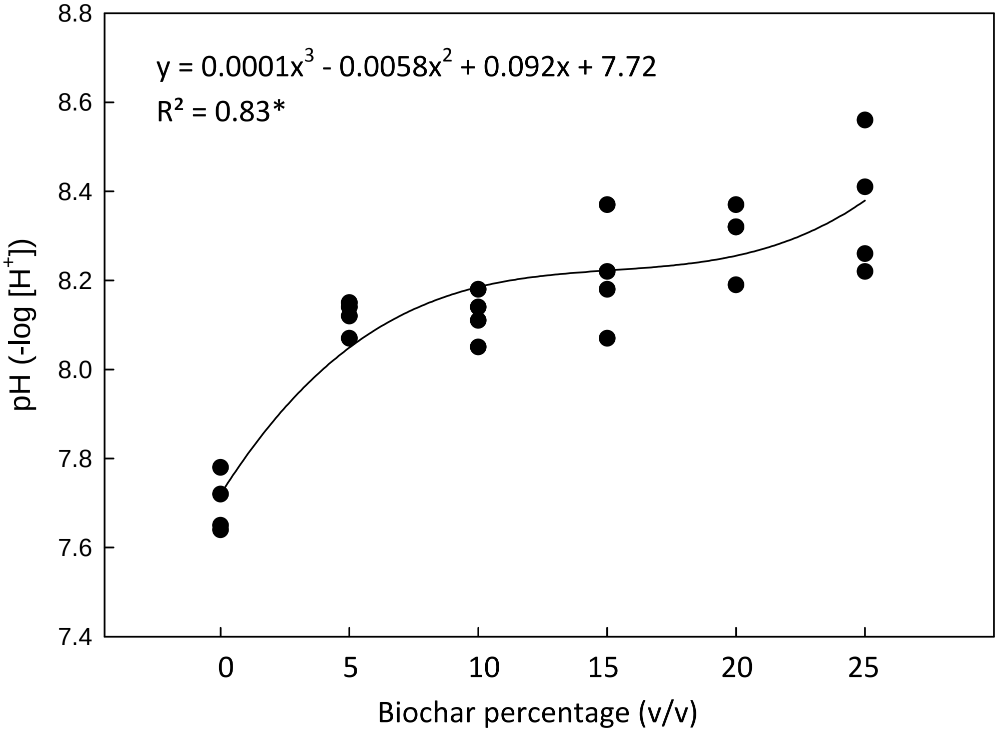

y = 0.0001x3 - 0.0058x2 + 0.092x + 7.72
R² = 0.83*
8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
pH (-log [H+])
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 4.

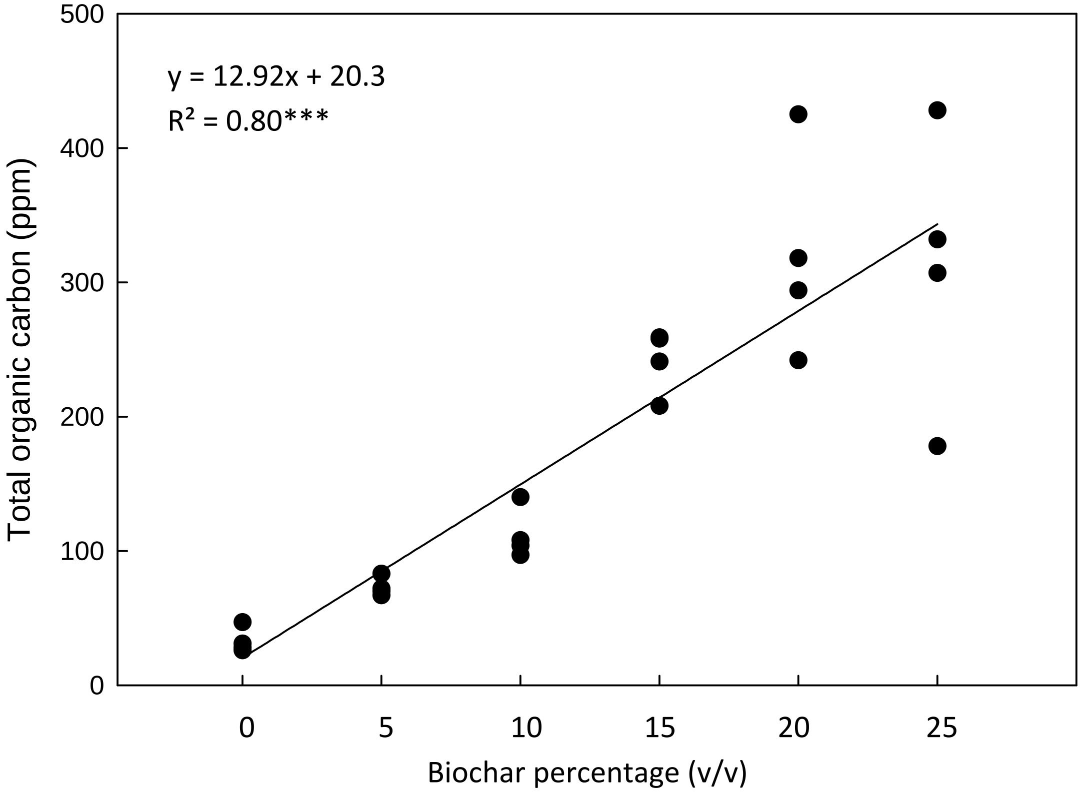

y = 12.92x + 20.3
R² = 0.80***
Total organic carbon (ppm)
0
100
200
300
400
500
Biochar percentage (v/v)
0
5
10
15
20
25

Figure 5.

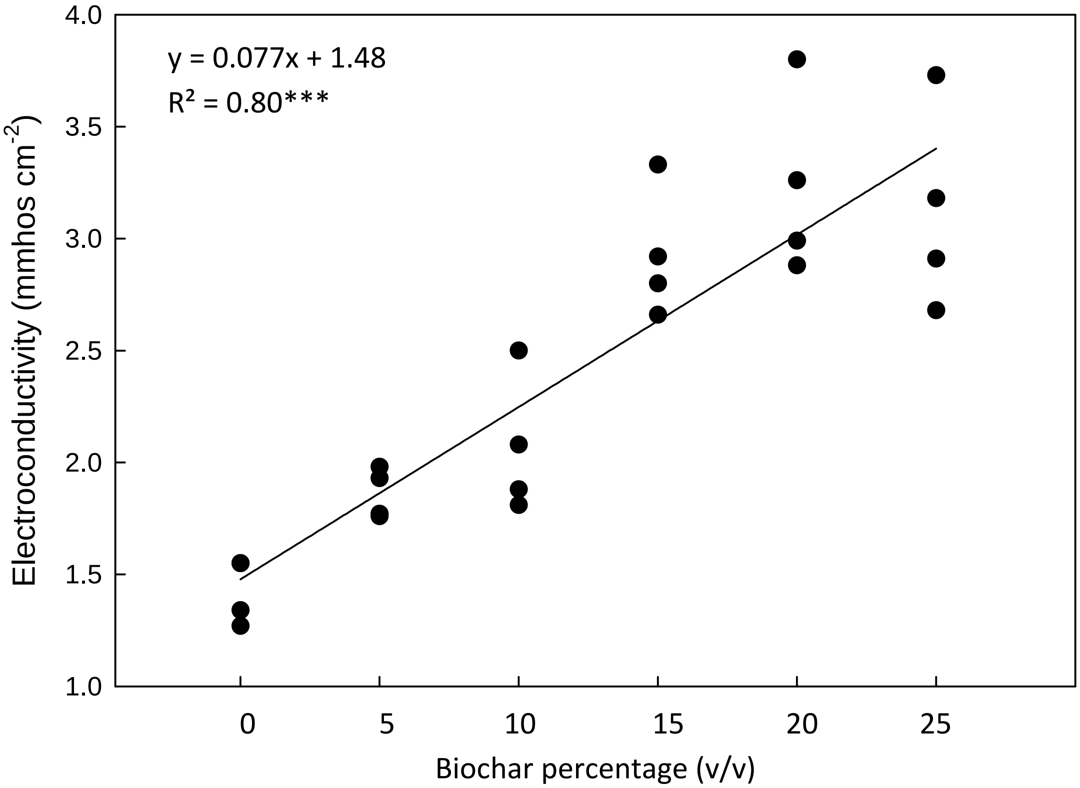
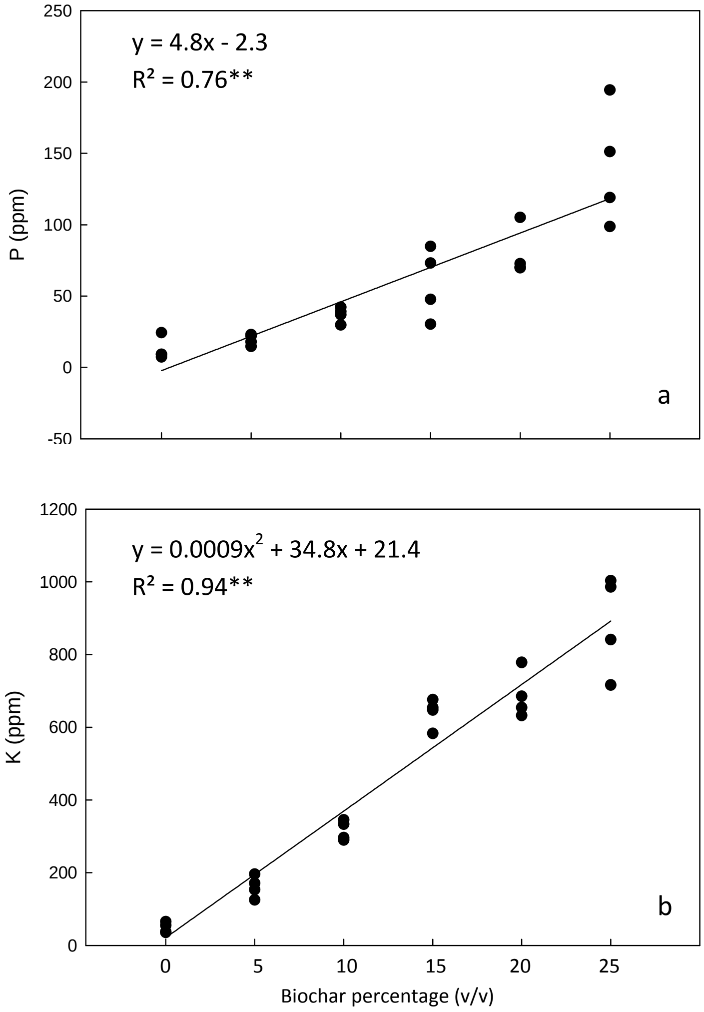

y = 0.077x + 1.48
R² = 0.80***
Electroconductivity (mmhos cm-2)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 6.


y = 4.8x - 2.3
R² = 0.76**
P (ppm)
250
200
150
100
50
0
-50
a
y = 0.0009x² + 34.8x + 21.4
R² = 0.94**
K (ppm)
1200
1000
800
600
400
200
0
b
0
5
10
15
20
25
Biochar percentage (v/v)

GENERAL CONCLUSIONS

Water retention and plant-available water holding capacity of sand and biochar root-zones increase as the amount of fast pyrolysis switchgrass biochar increases. Media containing a greater amount of biochar have slower K_{sat}. Bulk density values decrease as the amount of biochar increases in the profile. Rooting depth of 'T-1' creeping bentgrass is decreased if the amount of biochar in a sand-based root-zone is greater than 10%.

The EC and TOC of biochar and sand leachate increase as the amount of biochar increases. Biochar shows the affinity to have cation and anion exchange capacity, as increased amounts of biochar in the soil decreases the leaching of NO_3-N and NH_4-N. This may be partially due to immobilization of the nitrogen into organic forms as well. The concentration of P and K increased in the soil profile as the amount of biochar increased; therefore, biochar contains essential plant nutrients. These results are similar to previously published data (Lehmann et al., 2003; Laird, 2008; Lehmann, 2007a,b).

Fast pyrolysis switchgrass biochar appears to be an applicable sand-based root-zone amendment. This research shows that biochar is able to provide nutrients and increase nutrient retention as well as increase water retention. Previous research suggests biochar is recalcitrant in the soil (Laird, 2008). Therefore, biochar meets all of the objectives of an ideal sand-based root-zone amendment (Bigelow et al., 2004) at its first approximation. However, the chemical and physical parameters of sand and biochar root-zones should be evaluated over time in a field setting to better evaluate the effects biochar has on sand-based root-zones.

References

Bigelow, C. A., D. C. Bowman, D. K. Cassel. 2004. Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green rootzones. Crop Sci. 44:900-907.

Laird, D.A. 2008. The charcoal vision: a win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. Agron. J. 100:178-181.

Lehmann, J. 2007a. A handful of carbon. Nature 446: 143-144.

Lehmann, J. 2007b. Bio-energy in the black. Front Ecol Environ 5(7): 381-387.

Lehmann, J., J.P. da Silva, C. Steiner, T. Nehls, W. Zech, and B. Glaser. 2003. Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central amazon basin: fertilizer, manure and charcoal amendments. Plant Soil 249:343-357.

APPENDIX

Figure 1. ICP-MS results of biochar and sand leachate samples. Four leachate samples from each mixture were analyzed at Iowa State University's Soil Testing Lab.

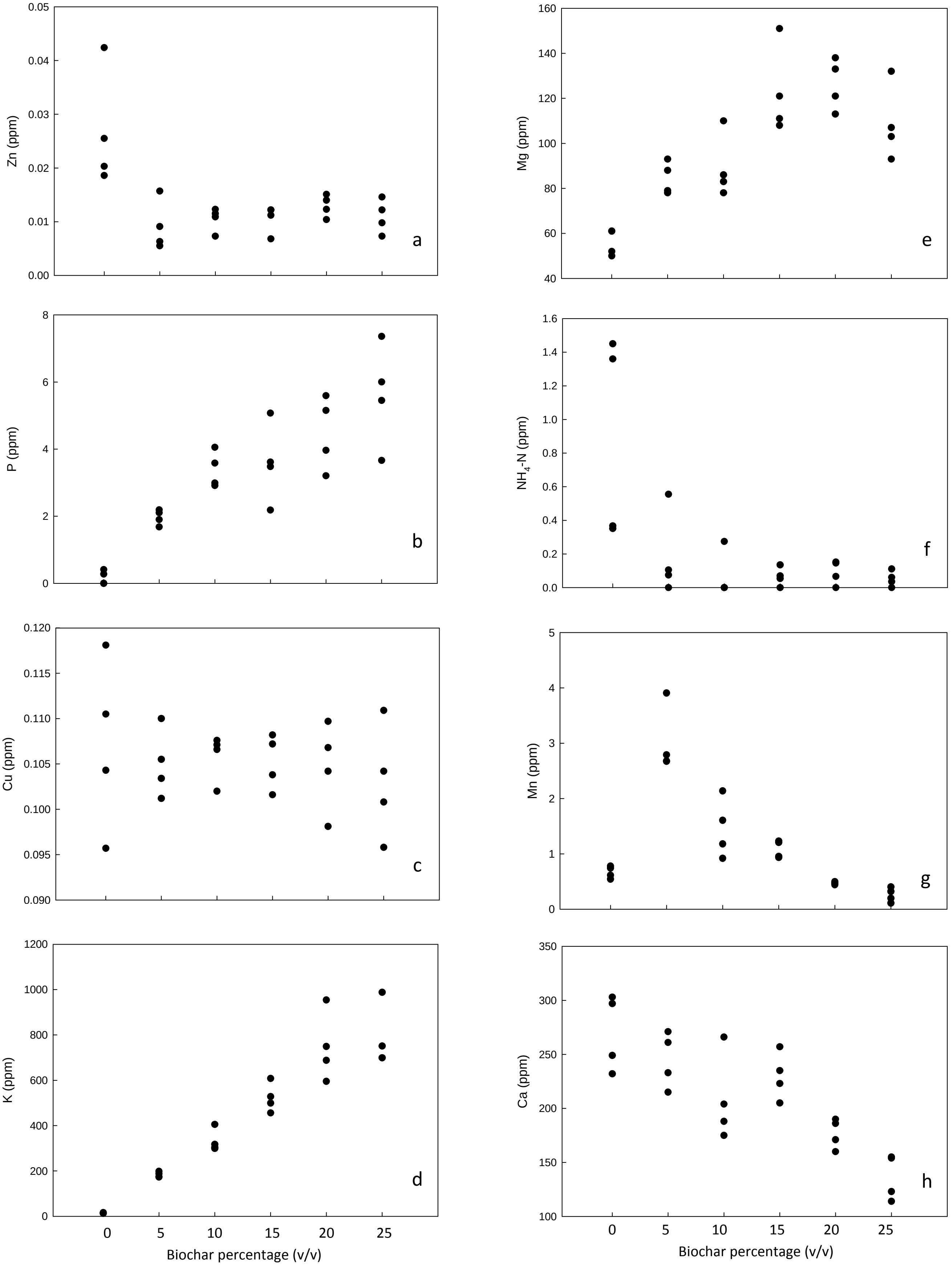
Figure 2. Results of soil nutrient analyses. Four samples of each biochar and sand mixture were analyzed by Harris Laboratories. Calcium, magnesium, potassium and sodium were analyzed using ammonium acetate extraction. Phosphorus was measured with Bray-I extraction. Zinc, manganese, iron, and copper were analyzed using DTPA extraction. Sulfur and boron contents were determined using ICP with monocalcium phosphate and hot water extraction, respectively. Cadmium reduction methodology was used for nitrate-nitrogen evaluation.

Figure 3. Leachate pH for six mixtures of biochar and sand. Readings were taken with an Accumet pH meter, model 10 (Fisher Scientific, Hanover Park, IL) at 20 °C.

Figure 4. Leachate total dissolved organic carbon (TOC). Measurements were taken with a TOC-5050 Total Organic Carbon Analyzer (Shimadzu, Columbia, MD). Samples were diluted at a 1:25 ratio with distilled water. The TOC of the water was 0.30 mg L^{-1} (n=7).

Figure 5. Leachate electroconductivity (EC) for six mixtures of biochar and sand. Readings were taken with a Cole-Parmer EC meter (Cole-Parmer Instrument Co., Model 1481-61, Vernon Hills, IL) at 20 °C. The base EC of the water was 0.35 mmhos cm^{-2} (n=4).

Figure 1.


Zn (ppm)
0.05
0.04
0.03
0.02
0.01
0.00
a
Mg (ppm)
160
140
120
100
80
60
40
e
P (ppm)
8
6
4
2
0
b
NH$_4$-N (ppm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
f
Cu (ppm)
0.120
0.115
0.110
0.105
0.100
0.095
0.090
c
Mn (ppm)
5
4
3
2
1
0
g
K (ppm)
1200
1000
800
600
400
200
0
d
Ca (ppm)
350
300
250
200
150
100
h
0
5
10
15
20
25
Biochar percentage (v/v)
Biochar percentage (v/v)

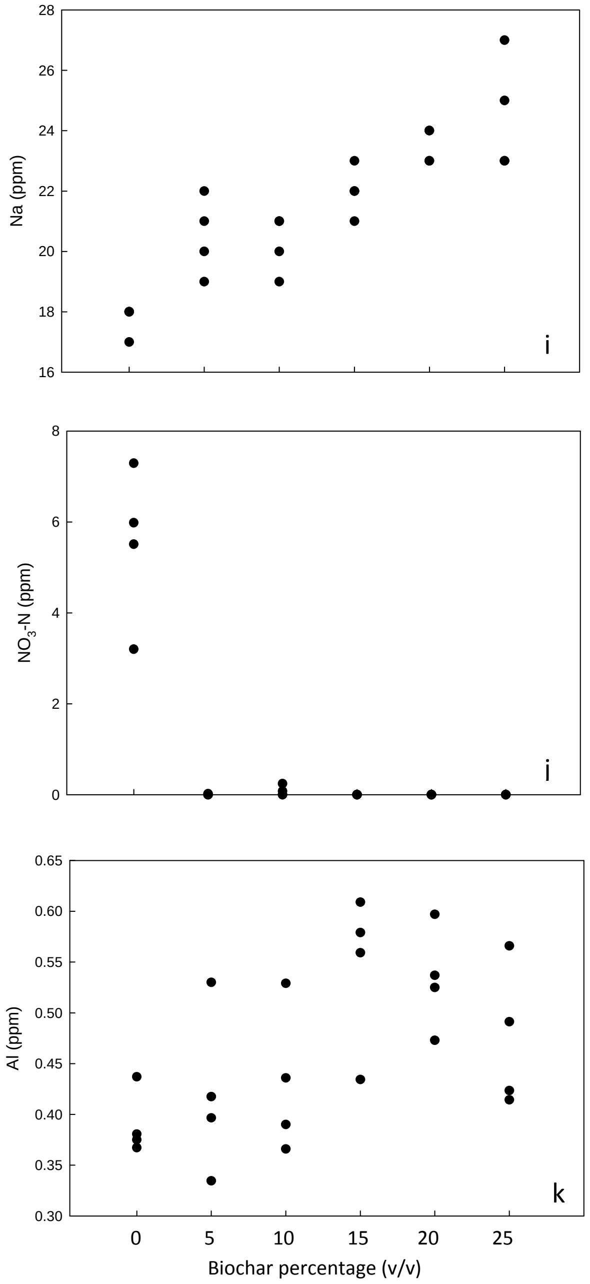
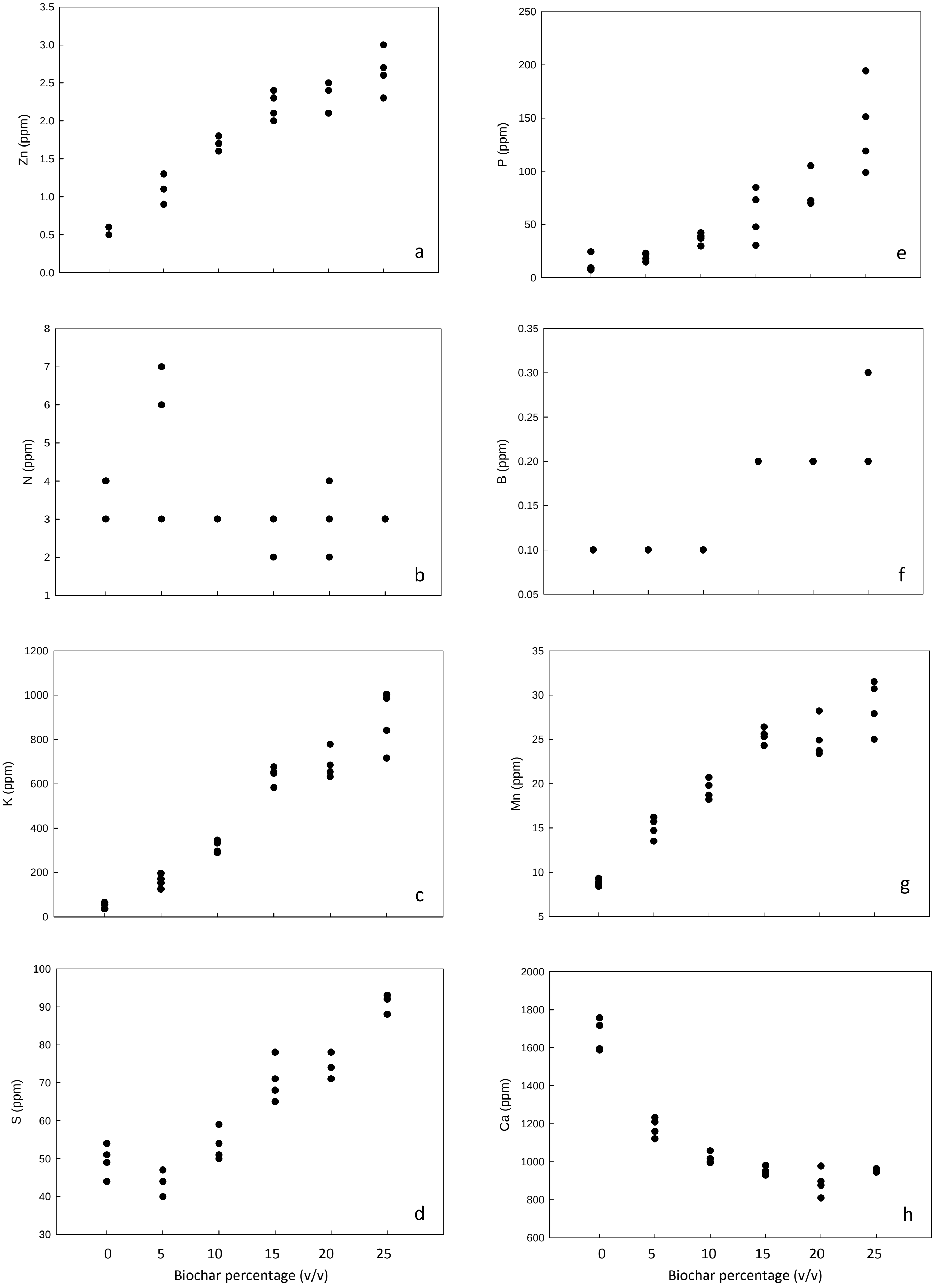

Na (ppm)
16
18
20
22
24
26
28
i
NO$_3$-N (ppm)
0
2
4
6
8
j
Al (ppm)
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
k
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 2.



Zn (ppm)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
a
P (ppm)
250
200
150
100
50
0
e
N (ppm)
8
7
6
5
4
3
2
1
b
B (ppm)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
f
K (ppm)
1200
1000
800
600
400
200
0
c
Mn (ppm)
35
30
25
20
15
10
5
g
S (ppm)
100
90
80
70
60
50
40
30
d
Ca (ppm)
2000
1800
1600
1400
1200
1000
800
600
h
0
5
10
15
20
25
Biochar percentage (v/v)
Biochar percentage (v/v)

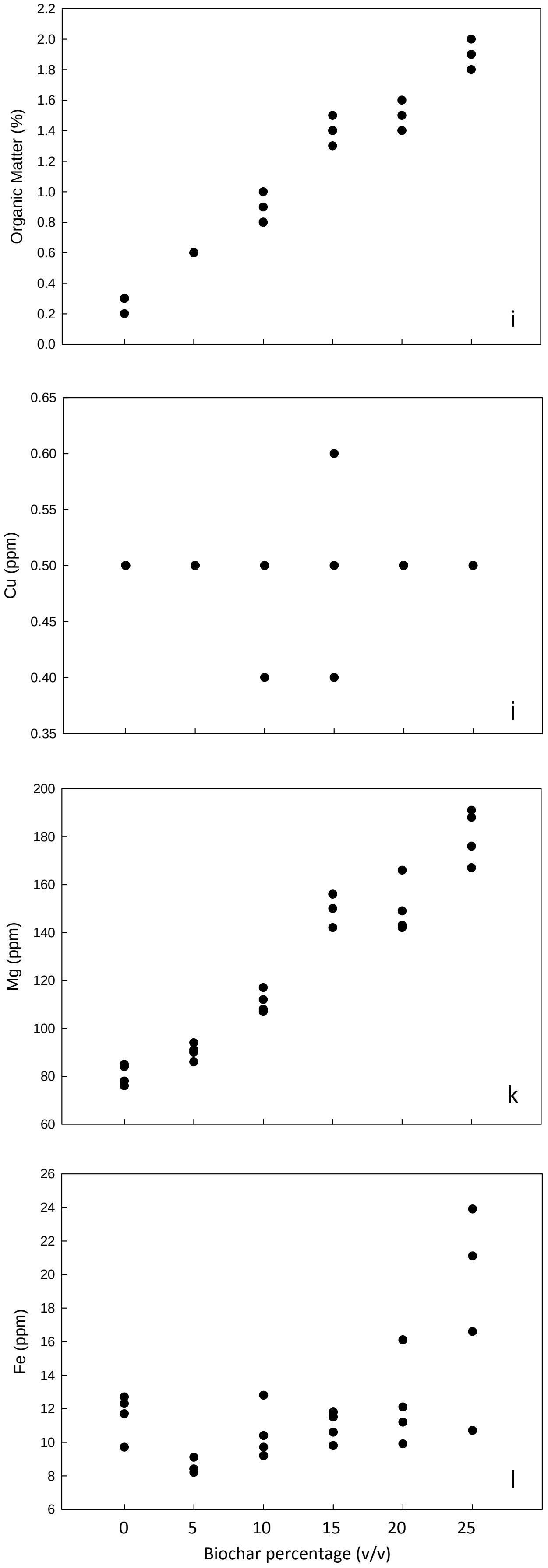

Organic Matter (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
i
Cu (ppm)
0.35
0.40
0.45
0.50
0.55
0.60
0.65
j
Mg (ppm)
60
80
100
120
140
160
180
200
k
Fe (ppm)
6
8
10
12
14
16
18
20
22
24
26
l
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 3.

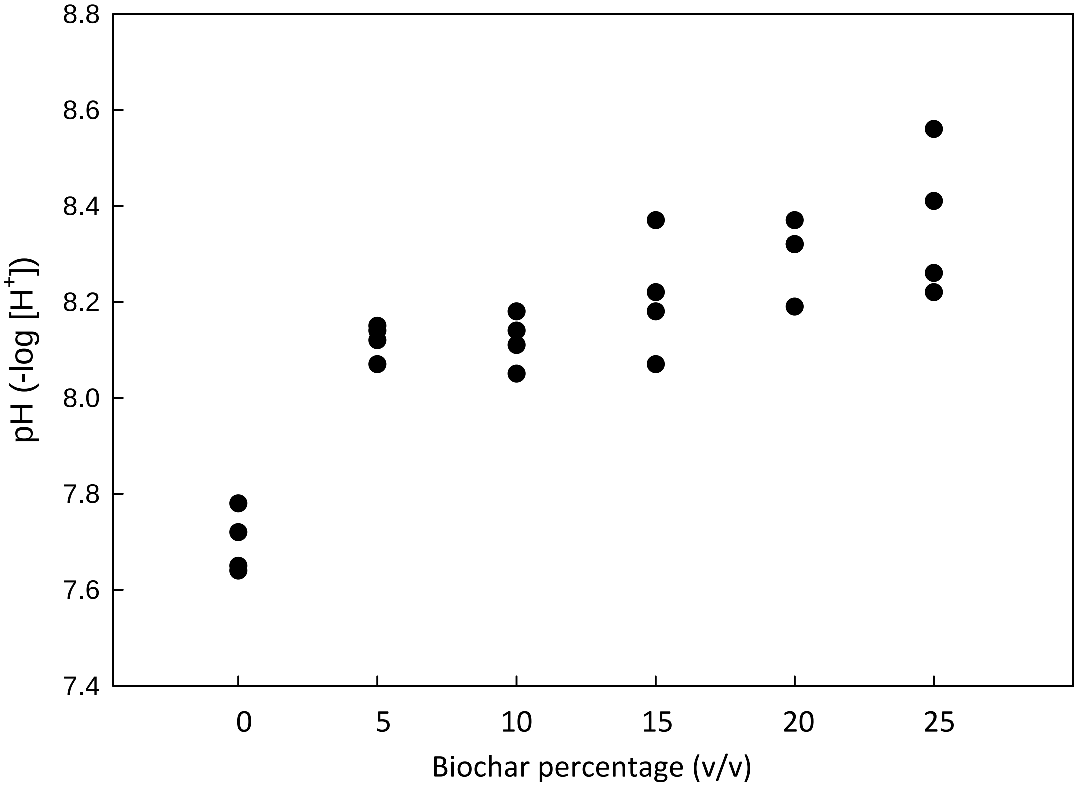

8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
pH (-log [H$^+$])
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 4.

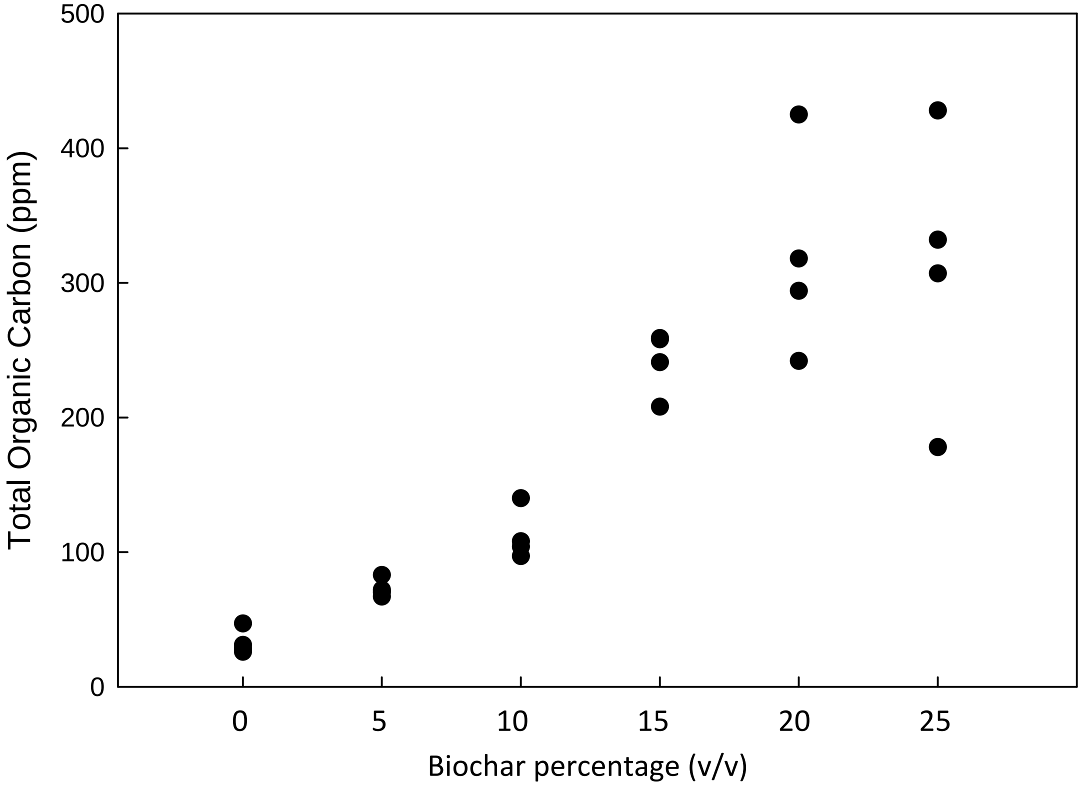
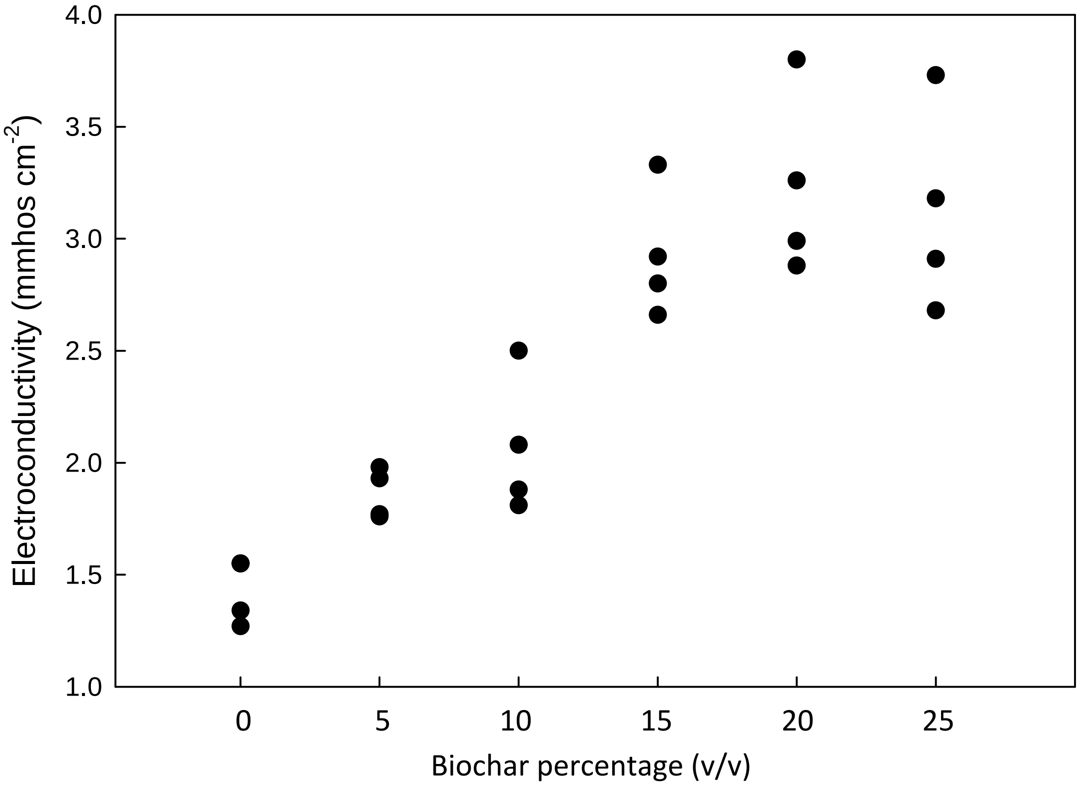

500
400
300
200
100
0
Total Organic Carbon (ppm)
0
5
10
15
20
25
Biochar percentage (v/v)

Figure 5.


Electroconductivity (mmhos cm-2)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
5
10
15
20
25
Biochar percentage (v/v)