Biochar Improves Plant Growth and Reduces Nutrient Leaching in Red Clay Loam and Sandy Loam

Kalpana Pudasaini, Nanjappa Ashwath, Kerry Walsh and Thakur Bhattarai


Kalpana Pudasaini


Nanjappa Ashwath


Kerry Walsh


Thakur Bhattarai

Abstract: A factorial pot experiment was conducted using two types of soils (sandy loam and red clay loam) that are commonly used for commercial vegetable production in Bundaberg, region of Central Queensland Australia. The soils were amended with 0, 25, 50 and 75 t/ha of green waste biochar and minimum doses of N, P and K (30 kg/ha, 30 kg/ha and 40 kg/ha respectively). After two weeks of plant establishment, the pots were leached with 1.5 litres of deionised water at week intervals, and cation concentrations of the leachate were determined. In 25 t/ha biochar treatment, there was a significant ($P<0.05$) reduction in K and Ca leaching by 40% and 26% respectively from sandy loam, and of Ca by 23% from the red clay loam. Soil water holding capacity and soil organic carbon were also increased in both biochar treated soils. After 12 weeks of growth, shoot weight was significantly ($P<0.05$) higher in 25 t/ha biochar-treated sandy loam and red clay loam (32% and 31% respectively). These results clearly demonstrated that a higher yield of capsicum can be achieved from green waste biochar application in sandy loam and red clay loam at 25 t/ha biochar.

Key words: Green waste biochar, cation leaching, soil cation exchange capacity, carbon sequestration, Australia

Introduction

Nutrient leaching has a great impact on the environment as well as on nutrient cycling in agriculture (Brady and Weil 2008). Leaching usually occurs due to high rainfall and poor soil properties. Nutrient deficiency is often seen in tropical agricultural soils due to low nutrient retention capacity of the soil and rapid decomposition of the organic residues (Juo and Manu 1996). Nutrient leaching can range as high as to 80% of nitrogen (N) (Lehmann, Lilienfein et al 2004), 172% for calcium (Ca) (Omoti, Ataga and Isenmila 1983) and 136% for applied magnesium (Mg) (Cahn, Bouldin et al 1993). Research shows that application of biochar to soil may improve cation exchange capacity (CEC) of the soils, which in turn contributing to a reduction in nutrient leaching (Lehmann, da Silva et al 2003).

Biochar refers to black carbon, formed by heating biomass in an oxygen limited environment, the process commonly known as pyrolysis (Woolf 2008). During pyrolysis, labile biomass carbon changes into stable black carbon which may remain in the soil for thousands of years. Thus, biochar may be an appropriate tool for sequestering atmospheric carbon dioxide in the soil and reducing global warming. In addition, biochar may adsorb soluble nutrients such as ammonium (Lehmann, da Silva et al 2002), nitrate (Mizuta, Matsumoto et al 2004), phosphate (Beaton, Peterson and Baur 1960) and other ionic solutes (Radovic, Moreno-Castilla and Rivera-Utrilla 2001). It has also been reported that surface oxidation and CEC of biochar (Liang, Lehmann et al 2006) can increase over time (Cheng, Lehmann and Englehard 2008), leading to greater nutrient retention. Biochar may also help to retain water in its pores by capillary forces leading to an increase in water holding capacity (WHC) and a decrease in nutrient leaching.

Results of a greenhouse pot experiment indicate that the addition of hard wood biochar to a tropical oxisol led to 60% reduction in leaching of applied ammonium (NH_4) over 40 days of cropping with rice (*Oriza sativa*), as compared to the treatment not receiving biochar (Lehmann, da Silva et al 2003). Leaching of Ca and Mg was also reduced in this trial. Major (2009) also found a reduction in leaching of Ca by 23%, Mg by 28% and potassium (K) by 36% in a 20 t/ha biochar applied poor acidic soil. The present study was conducted to examine the effect of green waste biochar on soil CEC, soil WHC, cation leaching and plant growth for two soils of horticulture importance in Central Queensland. It was anticipated that biochar addition would result in a greater reduction in leachate from the sandy loam than the red clay loam.

Materials and Methods

Sandy loam and red clay loam soils that have been widely used for horticultural crop production were collected from a farm near Bundaberg, Central Queensland, Australia. Top soil (0 to 0.2m depth) was collected, and air dried. The soil was sieved sequentially through a 6 and then a 2 mm sieve. The <2 mm fraction was used in the pot experiment.

Green waste biochar produced by Pacific Pyrolysis, Australia was used in the experiment. This biochar was produced by slow heating of the green waste to a temperature of 550°C using a slow pyrolysis system. The green waste was a whole tree residue chipped and passed through a 15 mm screen. The biochar was alkaline in nature. It had high total carbon but low in total nitrogen and mineral nitrogen (Table 1). The biochar samples were ground and sieved through a 2 mm sieve. The <2 mm fraction was used in the experiment, with capsicum as a test plant. Capsicum was chosen, as this crop grown in this region using high doses of fertilizers (up to 1000 kg of N, P and K per year).

Pot Experiment

The three months pot experiment was conducted in a glasshouse at CQ University Rockhampton, Australia. A randomised complete block design was used with 8 treatments and three replications. The treatments were: soil types (red clay loam and sandy loam), biochar (0, 25, 50 and 75 t/ha) or (20%, 40% and 60%) and fertilizer (N-30, P-30 and K-40 kg/ha). Biochar was mixed thoroughly with eight kilograms air dry soil and filled the plastic pots. Deionised water was added to all pots to bring the soil moisture content up to field capacity. Three weeks old capsicum seedlings (Warlock) were planted in each pot.

After two weeks, pots were irrigated with excess water to allow collection of leachate. The leachate was filtered and stored in a refrigerator at 4°C prior to nutrient analysis. Each pot was provided with 1.5 litres of water above field capacity. Cation concentrations (Ca, Mg, K and Na) of the leachate sample were analysed using an Atomic Absorption Spectrometer (AAS). The leachate collection continued at weekly intervals for 12 weeks. After 12 weeks of growth in the pots, the capsicum plants were harvested. The leaves, stems and fruits from the harvested plants were separated and oven dried at 70°C for 72 hours to determine plant dry matter.

Soil Analysis

The soil samples were collected from selected treatment combinations: red clay loam with fertilizer, red clay loam with fertilizer and biochar (25 t/ha), sandy loam with fertilizer, and sandy loam with fertilizer and biochar (25 t/ha). The soil samples were air dried, crushed and passed through a 2 mm sieve and sent to CSBP laboratory, Perth, Western Australia for chemicals analysis. Soil and biochar samples were analysed before conducting experiments (Table 1). Soil and biochar CEC were determined by using Ammonium acetate method (Chapman 1965). Soil organic carbon was determined by Walkley Black method (Walkley 1947). Soil WHC of all treatment combinations was also measured.

Soil Properties	Biochar	Sandy Loam	Red Clay Loam
NH_4-N (mg/kg)	<1	<1	<1
NO_3-N (mg/Kg)	<1	6	4
Colwell Phosphorous (mg/kg)	79	188	272
Colwell K (mg/kg)	23	32	225
Sulphur (mg/kg)	<.5	57.1	5.66
Organic carbon (%)	0.06	0.65	0.89
Conductivity (dS/m)	0.29	0.118	0.063
pH(H_2O) Ph	7.2	6.7	6.7
pH($CaCl_2$) pH	7.4	7.4	7.2
DTPA Copper (mg/kg)	1.1	2.38	14.91
DTPA Iron (mg/kg)	23.14	12.16	16.42
DTPA Manganese (mg/kg)	3.05	1.01	9.88
DTPA Zinc (mg/kg)	2.67	2.66	12.59
Exc. Aluminium (meq/100 g)	<.001	<.001	<.001
Exc.Ca (meq/100 g)	1.77	4.73	6.8
Exc. Mg (meq/100 g)	0.7	0.17	1.75
Exc. K (meq/100 g)	<.01	0.05	0.56
Exc. Na (meq/100 g)	1.04	0.02	0.08
Boron Hot $CaCl_2$ (mg/kg)	0.1	0.2	1.2
Chloride (mg/kg)	<.01	1.1	0.6
Total carbon %	62.9	0.64	0.75

Table 1. Soil and Biochar Properties.

Statistical Analysis

All data were analysed by one-way analysis of variance (ANOVA) using GenStat (V13.1). The treatment means were compared using least significant differences for the main effects of biochar.

Results

Cation Leaching

The K leaching was significantly *($P<0.05$)* reduced by 40% in the biochar amended sandy loam compared to control (Figure 1). However, there was no significant change in response to biochar addition in red clay loam (Figure 1).

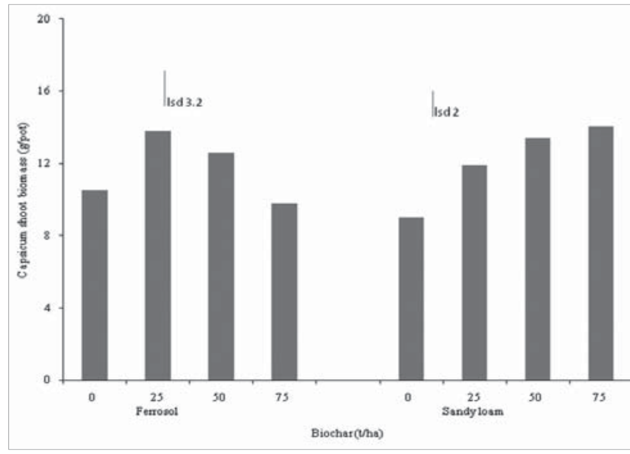

Figure 1. Leaching of K from Sandy Loam and Red Clay Loam in the Presence and Absence of Biochar.

Ca leaching was reduced significantly ($P<0.05$) at 25 t/ha biochar applied red clay loam compared to the control but biochar at higher applications rates had no effect (Figure 2a). Similarly, Mg leaching was reduced by 23% at 25 t/ha biochar compared to the control (Figure 3). Overall results showed that the higher rates of biochar application had no effect on Ca and Mg leaching in red clay loam.

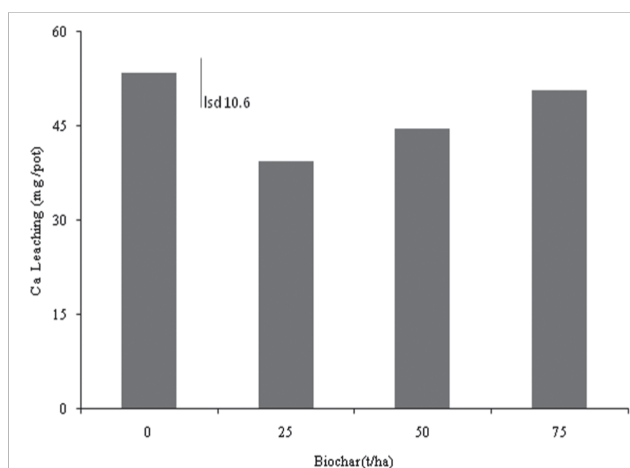

Figure 2a. Leaching of Ca from Biochar Applied and Non Applied Red Clay Loam.

In sandy loam, Ca leaching was significantly ($P<0.05$) reduced by 23% at 25 t/ha biochar compared to the control (Figure 2b). However, the leaching was increased significantly at 75 t/ha. In the case of Mg, biochar did not have any effect at 25 t/ha but it increased at 75 t/ha (Figure 3). Na leaching was significantly ($P<0.05$) increased with biochar application in both soils and at all applications rates, except at 50 t/ha in red clay loam (Figure 4).

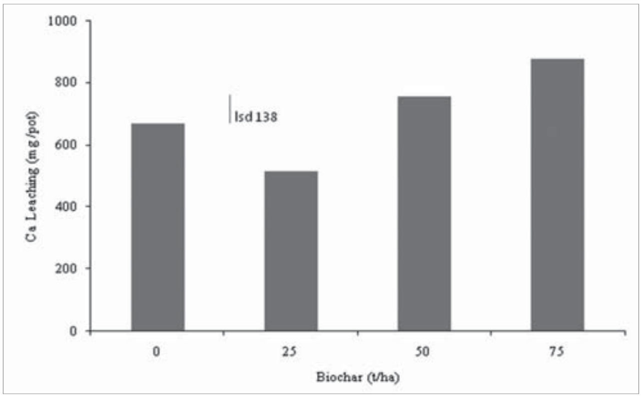

Figure 2b. Leaching of Ca from Biochar Applied and Non Applied Sandy Loam.

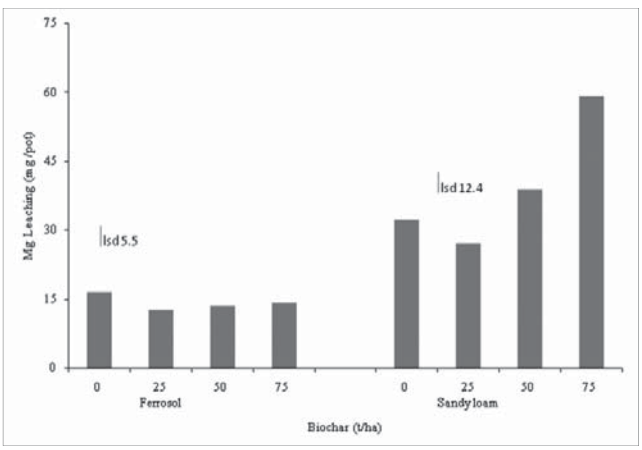

Figure 3. Leaching of Mg from Biochar Applied and Non Applied Red Clay Loam and Sandy Loam.

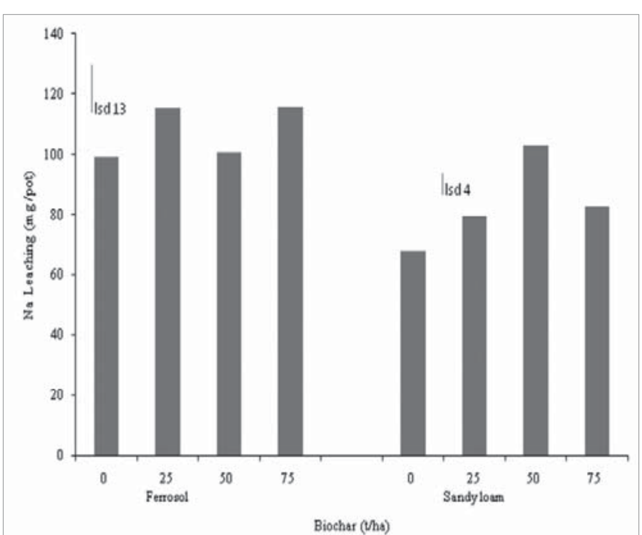

Figure 4. Leaching of Na from Biochar Applied and Non Applied Red Clay Loam and Sandy Loam.

The volume of leachate produced was significantly ($P<0.05$) reduced by 12% and 30% in sandy loam at 50 t/ha and 75 t/ha respectively. However, there was no differences in red clay loam at 25 t/ha and 50 t/ha biochar but significantly ($P<0.05$) reduced by 20% at the highest application rate (Figure 5).

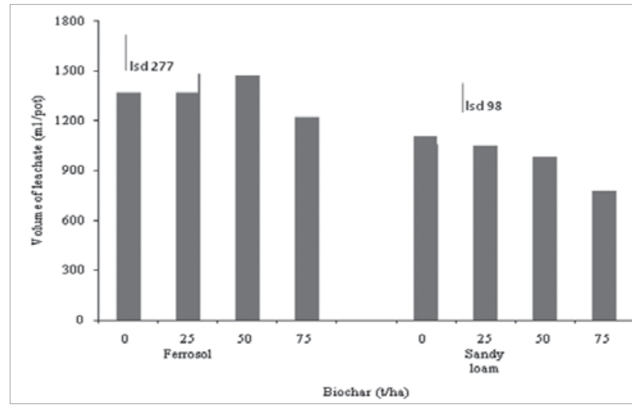

Figure 5. Volume of Leachate Collected from Red Clay Loam and Sandy Loam in the Presence and Absence of Biochar.

Soil Properties

The water holding capacity of both soils increased with biochar application, but the increment was significant only at 50 t/ha and 75 t/ha (Figure 6). This trend was negatively correlated (r-0.89) to the volume of the leachate produced.

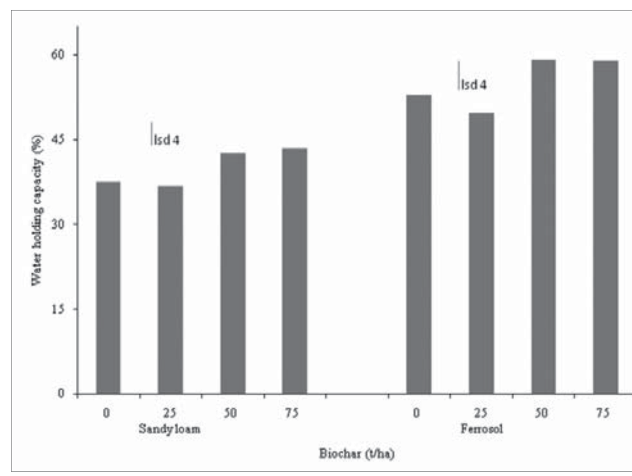

Figure 6. Water Holding Capacity of Red Clay Loam and Sandy Loam in the Presence and Absence of Biochar.

Only the soils that were amended with 25 t/ha biochar were analysed to determine CEC and soil organic carbon. The results showed a slight increase in CEC from 4.97 to 5.19 meq/100g in sandy loam and 8.19 to 8.63 meq/100g in red clay loam. The CEC of the biochar was 3.52 meq/100 g. Soil organic carbon increased by 23% in red clay loam and 19% in sandy loam at 25 t/ha biochar compared to the control.

Plant Yield

Capsicum shoot biomass significantly ($P<0.05$) increased in biochar applied treatments compared to the controls at 25 t/ha in sandy loam and red clay loam (Figure 7). In sandy loam, the biomass tended to increase with higher doses of biochar, but these increments were not significant compared to 25 t/ha. However, biochar had no effect in red clay loam at higher rates of application. The 25 t/ha biochar improved shoot biomass by 32% and 31% in sandy loam and red clay loam respectively, compared to the control (Figure 7).

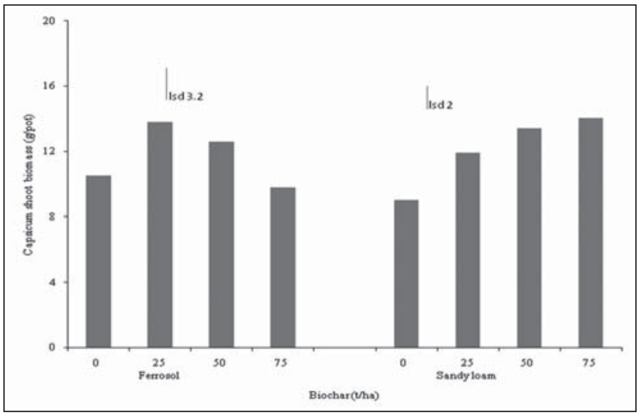

Figure 7. Total above Ground Capsicum Biomass in Red Clay Loam and Sandy Loam in the Presence and Absence of Biochar. The Bars Represent Least Significant Difference *(P<0.05))*.

Discussion

The current pot experiment has clearly demonstrated that the addition of biochar at 25 t/ha can significantly (*P<0.05*) improve shoot biomass of capsicum in sandy loam and red clay loam. The improved plant growth at 25 t/ha may be due to reduced leaching of Ca and K in sandy loam and Ca in red clay loam. Major (2009) also reported that the increased growth of maize was associated with reduced nutrient leaching in Savanna acidic Oxisol amended with 20 t/ha biochar. In her research, maize yield was improved by 140%, and K and Ca leaching were reduced by 36% and 23% respectively from biochar amended poor acidic soil, compared to the control.

Higher biochar application rates (50 t/ha and 75 t/ha) enhanced shoot biomass of capsicum compared to 25 t/ha in sandy loam, however the increments were not significant (*P>0.005)*. It is possible that N available in the soil at higher rates of biochar was reduced as green waste biochar contained high total carbon (62.9%) and low nitrogen (Table 1), and available N could also been used up by microbial activity and hence not allowing plants to enhance growth. This finding contrasts to a previous study by Chan, Van Zwieter et al (2007), who reported that radish yield was increased with increasing rates of green waste biochar application in the presence of nitrogen fertiliser in hard setting Alfisol. The yield increment was 266% at 100 t/ha green waste biochar applied soil compared to the control. The differences between two experiments are application of fertilizer rates. In the study of Chan, Van Zwieter et al (2007), the N fertiliser was applied at 100 kg/ha with 100 t/ha green waste biochar, where as in the current study, only 25 kg/ha N was applied with 50 t/ha and 75 t/ha green waste biochar.

Biochar amendment did not improve water holding capacity of both soils at 25 t/ha, possibly due to adequate time required for changes in physical properties of the soil. However, higher doses of biochar application did improve water holding capacity of both soils as biochar has higher WHC (2.75 ml/g) than soil. This suggests that the effects of biochar on soil physical properties might require longer term observations.

Higher doses (50 and 75 t/ha) of biochar produced varying effects in the two soils in terms of plant growth and cation leaching. For example, for plant growth, they showed positive (significant) effect in sandy loam and negative or neutral (non-significant) effect in red clay loam. Likewise, Ca and Mg leaching showed contrasting effects between two soils, and increased leaching of Na in both soils. These varying responses of the two soils to biochar application may be explained by differences in their ability to support plant growth, retain nutrients and water.

Overall, biochar application to sandy loam and red clay loam at 25 t/ha improved capsicum shoot biomass by 32% and 31% respectively over control. This also reduced leaching of K, Ca and Mg at 40%, 23% and 23% respectively. However, the responses of the two soils to higher doses of biochar application are not consistent and require further investigation.

In this study, biochar did not have an effect on soil CEC in this study. This may be due to shorter length of exposure (only three months) which might not be adequate for the oxidation on biochar surfaces in the soil and result in increased soil CEC as it increases as the biochar ages in soil (Cheng, Lehmann and Engelhard 2008).

Conclusions

The application of 25 t/ha green waste biochar significantly reduced K and Ca leaching in sandy loam, and Ca leaching in red clay loam. Biochar application (25 t/ha) also increased capsicum shoot biomass in both sandy loam and red clay loam. This experiment thus demonstrates that the addition of 25 t/ha green waste biochar can improve plant growth and it can also reduce cation leaching in both sandy loam and red clay loam soils. However, higher doses (50, 75 t/ha) of biochar produced varying effects in the two soils in terms of plant growth and cation leaching. Further research is therefore needed to explain the different responses shown in the two soils with higher rates of biochar. Furthermore, the trends recorded in the pot experiments must be tested in a field experiment to place any practical implications on the effects of biochar on plant growth and nutrient leaching.

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Kalpana Pudasaini *is a PhD candidate at Center for Plant and Water Science, CQ University, Australia. She is examining the role of biochar in changing soil properties and plant yield. She completed her Masters Degree in Environmental Science at Tribhuvan University in 2004 with distinction. She has more than five years of professional experience in environment, natural resource management and agriculture sectors specifically in Nepal, England and Australia.*
Corresponding address: k.pudasaini@cqu.edu.au

Nanjappa Ashwath, *PhD, Associate Professor, has been working with Center for Plant and Water Science, CQ University, Australia since 1995. He has been involved in wide range of research areas such as biochar, green waste, biofuel, phyto-capping, rehabilitation and*

restoration of native vegetation. He was a PhD Scholar between 1983 and 1986 at Australian National University (ANU), and after completing his PhD he worked as a Research Scientist for five years for the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Forestry and five years for Environment Australia in Northern Territory.

***Kerry Walsh,** PhD, Professor, is plant physiology professor and Deputy Director at Center for Plant and Water Science, and Associate Dean of Research and Innovation at CQ University, Australia. He completed his Masters in 1985 and PhD in 1988, both from Queens University, Canada.*

***Thakur Bhattarai,** is a PhD candidate at Center for Plant and Water Science, CQ University, Australia. He completed a MSc in natural resource management at Cranfield University in the UK in 2005. He has received several international and national awards and scholarships for his academic and professional qualifications and training. Prior to PhD studies he worked with government and non-governmental organisations in Nepal for more than 10 years and attended several sort-term courses, training, workshops and conference nationally and internationally.*

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