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Agronomic performance of a high ash biochar in two contrasting soils

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ABSTRACT

Intensive greenhouse industry wastes large amounts of nutrient-rich green waste through improper disposal practices. Converting this greenhouse waste into biochar for soil application offers a viable option to recycle nutrients and long-term C storage. This study was carried out to evaluate the agronomic potential of a biochar produced from tomato green waste in two contrasting soils. We also estimated the amount of waste generated from intensive greenhouse tomato production in Australia. From weekly measurements of leaf picking over a 13-week period, we estimate approximately 133 Mg ha^{-1} $year^{-1}$ of green waste on fresh weight basis. Biochar, produced by slowly pyrolysing the green waste at 550 °C, had very high-pH (12.1), electrical conductivity (EC, 54.2 dS m^{-1}), ash content (560 g kg^{-1}) and $CaCO_3$ equivalence (330 g kg^{-1}). Agronomic performance of the biochar was evaluated by growing Hybrid sweet corn (*Zea mays* var. *rugosa* cv – Sentinel) in the greenhouse for 7 weeks. We used three levels of biochar (0, 5 and 15 g kg^{-1} soil) in a factorial combination with three fertiliser rates (0, 50 and 100% of the recommended rate) applied to two contrasting soils (an Orthic Tenosol and a Red Ferrosol). Biochar application to the Ferrosol significantly increased the shoot dry matter of corn and contrastingly decreased the yield in case of the Tenosol. The positive effect of the biochar in the Ferrosol was attributed to release of nutrients from the biochar and biochar's liming effect and associated increased availability of nutrients. However, in poorly buffered Tenosol the application of biochar produced phytotoxic effects due to excessive soluble salts and high pH. The uptake of most nutrient elements increased in the corn shoot in the Ferrosol and decreased in the Tenosol. Although the biochar produced from green waste was highly alkaline and contained excessive soluble salts, given the right soil properties it can be a good soil ameliorant. The true agronomic potential of the biochar should be further evaluated in different soil types under field conditions.

1. Introduction

Intensive greenhouse facilities generate large quantities of green waste as a consequence of optimising production conditions (Parra et al., 2000). Green waste consists mainly of stems, leaves, fruit and roots (Heuvelink, 2005). The largest source of green waste in tomato production is derived from weekly leaf pruning that involves removing fully grown leaves from below and above the 6th to 8th truss (Heuvelink, 2005). Given, the consistent growth rate of this indeterminate crop at the average temperature of 20 °C leaf pruning practice usually results in the removal of 2–3 leaves $plant^{-1}$ $week^{-1}$ (de Koning, 1994). Leaf pruning is performed to maintain generative/vegetative sink ratio and to optimise the harvest index (Heuvelink, 1995). Additionally, leaf pruning is important in maintaining airflow and optimal light interception in the greenhouse environment.

Traditionally green waste has been left to decompose on the greenhouse floor, wasting valuable plant nutrients (Parra et al., 2000) and this may also host pests and diseases. Limited success has been achieved through alternative disposal methods including combustion, composting and vermi-composting. Overall, recycling of nutrients through composting of green waste has been found to be the most economically viable strategy. However, this option may not be feasible for the producers in the densely populated areas (Parra et al., 2008). Therefore, the industry is looking for practical and feasible strategies for the utilisation of the green waste. The conversion of green waste from tomato production into biochar, using pyrolysis process, offers a potentially viable alternative that has economic and environmental benefits. The green waste that is rich in nutrients should yield high ash biochar with a potential capacity to supply various nutrient elements. Additionally, the presence of biochemically recalcitrant and predominantly aromatic carbon in biochar should allow the long-term carbon storage in soils (McBeath and Smernik, 2009; Zimmerman, 2010; Keith et al., 2011). Biochar can also improve soil structure and water retention, enhance availability and retention of nutrients, ameliorate acidity and improve soil biology (Glaser et al., 2002; Kookana et al., 2011).

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Over the last few years a number of agronomic trials have assessed biochar application at application rates from 0.5 to 135 t ha^{-1} and revealing a broad range of biomass production responses from −29 to 324% (Glaser et al., 2002). In a recent meta-analysis using data from 16 studies, Jeffery et al. (2011) observed an overall small but statistically significant benefit on crop productivity from biochar application to soils; the greatest positive effects of biochar were observed in acidic and neutral soils with coarse to medium textures. The highly variable response of biochar to soil application reflects the effects of properties of both biochar and soil. For example, Chan et al. (2007) observed no significant increase in radish yield from the addition of a biochar (up to 100 t ha^{-1}) to an acidic soil; the biochar was produced from glass clippings, cotton trash and plant trimmings. Contrastingly, significant positive effects on radish yield were observed in the same soil from biochars made from litter; these biochars were rich in nutrients (Chan et al., 2008).

To the best of our knowledge, there is no published research on the composition and soil fertility value of a biochar derived from tomato green waste; however, it is expected that green waste from tomatoes grown in a nutrient-rich hydroponic system will produce a biochar with high ash and nutrient contents. This study was undertaken to evaluate the agronomic potential of the tomato green waste biochar on corn shoot yield and nutrient uptake in two contrasting soils. The two soils, a low fertility sandy soil (a Tenosol) and an acidic clayey soil dominated by variable charge minerals (a Ferrosol), were chosen for the study. We hypothesised that the high ash biochar would positively affect corn yield in acidic and near neutral soils due to increased soil fertility and liming effect, and that soil properties would moderate these effects. The study also estimated the mass of greenhouse waste generated from intensive tomato production in Australia.

2. Materials and methods

2.1. Quantitative assessment of green waste production

Green waste (feedstock) utilised for making biochar in this study was sourced from a commercial greenhouse located in Nelsons Plains, New South Wales, Australia. During the trial the indeterminate hydroponic, truss tomato variety of “Tomarlia” was grown under standard industry practices. Fresh and dry weight yield (DMY) of green waste was recorded from 10 randomly allocated sample groups on a weekly basis over a 15-week period (1 April 2012–10 July 2012). The uniform data over the 13-week period (excluding the first 2 week’s observations) were used to estimate the total amount of green waste produced over the 11-month duration of the crop. A representative portion of the green waste collected over the 13-week period was used for making biochar.

2.2. Feedstock and biochar characterisation

Biochar was produced using slow pyrolysis process (heating rate 7–10 °C min^{-1} and 40 min residence time) at a temperature of 550 °C and using the Daisy Reactor, at Pacific Pyrolysis, Somersby, Australia. Biochar and feedstock were homogenised and ground to <200 μm for various chemical analyses. The pH and electrical conductivity (EC) of the feedstock and biochar were measured using a 1:5 solid:solution after shaking for 24 h in reverse osmosis (RO) water. Total C and N concentrations were measured using a Vario Max CNS analyser. The concentration of other major- and micro-nutrients was determined after digesting the feedstock and biochar samples in a mixture of nitric (HNO_3) and perchloric ($HClO_4$) acids (Miller and Kalra, 1998). These digests were subsequently analysed for various elements using a Varian Vista AX inductively coupled plasma atomic emission spectrophotometer. Soluble salts were removed by repeated washing with RO water and cation exchange capacity (CEC) was determined for the washed biochar using the silver thiourea method (Rayment and Higginson, 1992). Ash content of the biochar was determined by dry combustion in a muffle furnace at 750 °C for 6 h (ASTM, 1989).

Calcium carbonate equivalence was measured using the rapid titration procedure described by Rayment and Higginson (1992). For the identification of minerals in the biochar, a randomly oriented specimen was analysed by X-ray diffraction. Powdered biochar sample was scanned from 4 to 70° 2θ on a GBC MMA diffractometer using monochromatised CuKα radiation (35 kV, 28.5 mA), a step size of 0.02° 2θ and scan speed of 1.0° 2θ/min. Minerals were identified by comparing d-spacings in the diffraction pattern to the ICDD-PDF mineral database.

2.3. Pot experiments

In order to evaluate the agronomic potential of the biochar, two separate 7-week pot experiments were carried out at the Darlington greenhouse facilities of the University of Sydney. We used two surface soils (0–0.15 m; <2 mm), an Orthic Tenosol (Cobbitty, New South Wales) and Red Ferrosol (Wollongbar, New South Wales) for the pot experiments. Plastic pots (12 cm top diameter) lined with polyethylene bags were filled with 1 kg of air dried soil. In both experiments the treatment structure was identical and consisted of three levels of biochar (0, 5, and 15 g kg^{-1} soil) combined with three fertiliser rates (0, 50 and 100% of the recommended rates) in a factorial design, with four replications of each treatment. Biochar was ground (<2 mm) before adding to the polyethylene bags containing 1 kg of soil (oven dry weight basis) where it was mixed to make a homogeneous substrate. The 100% fertiliser treatment consisted application of 100, 40, 70, 16, 5, 5, 5 mg kg^{-1} for N, P, K, S, Cu, Zn, Fe, respectively, using analytical-grade NH_4NO_3, KH_2PO_4, K_2SO_4, $CuSO_4$, $ZnSO_4$, and $FeSO_4$ salts; the rates were reduced to half for each of the nutrients for the 50% fertilizer treatment. Following the addition of fertilizer solutions, all pots were brought to field capacity by adding the required volume of RO water. The pots were lined with plastic bags to prevent any loss of nutrients by leaching. Pots were left for 3 days to equilibrate, after which eight hybrid sweet corn seeds (*Zea mays* var. *rugosa* cv – Sentinel) were sown in each pot and thinned to keep four plants per pot after germination. Some pots with the highest biochar treatment required replanting due to poor germination. Throughout the experiment plants were regularly watered with RO water to maintain field capacity moisture content.

After 7 weeks of growth the above ground shoot biomass was harvested using stainless steel scissors. Harvested biomass was thoroughly washed using a three-step procedure, firstly rinsed in dilute HCl (0.01%) that was followed by two separate rinses in RO water (Kachenko and Singh, 2006). The plant samples were then oven dried at 70 °C in a paper bag for 72 h. The shoot dry matter yield of each pot was recorded and then samples were ground and digested in a mixture of nitric and perchloric acid for nutrient analysis (Miller and Kalra, 1998). The digests were analysed for P, S, Ca, Mg, K, Na, Cu, Zn, Mn and Fe using a Varian Vista AX CCD inductively coupled plasma atomic spectrometer. Total C and N were analysed using a Vario CNS analyser.

2.4. Soil analysis

Important properties of the bulk soil samples (Table 1) used for the pot experiments were measured using routine