Effect of charcoal (biochar) amendments in Manawatu sandy-loam soil (New Zealand) on white clover growth and nodulation

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Abstract
New Zealand primary industries such as dairying produce significant amounts of greenhouse gases, particularly methane. Storage of carbon in agricultural soils in the form of biochar has been proposed as a means of offsetting carbon emissions. Biochar could also improve soil conditions for plant growth. This paper reports the effects of biochar as a soil amendment added to a Manawatu sandy-loam soil, on the soil pH, soil carbon and nitrogen, mineralisable nitrogen and hot water extractable carbon, together with root and shoot growth for white clover (*Trifolium repens* var Emerald). Biochar was added to the soil in differing proportions. The proportions were 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0, biochar to soil. Each of these six treatments was replicated four times and set up in a pot trial in a glass house configured with a Randomised Complete Block Design (RCBD). The addition of biochar reduced the growth of white clover shoot and root dry matter. The increased carbon content of soil and reduced supply of plant nutrients may be the reason for the reduced growth of white clover and biochar increased the pH.

Key Words
Biochar, carbon, soil properties, white clover, nitrogen, Randomised Complete Block Design (RCBD).

Introduction
The release of carbon (C) into the atmosphere far outweighs the fixation of carbon by soil organisms. Considering the incessantly increasing quantity of carbon dioxide (CO_2) in the atmosphere, retaining carbon in the soil is a concern now and in the future. A proposed simple way of retaining carbon in the soil is through addition of biochar. Biochar is a term reserved for the plant biomass derived materials contained within the black carbon (BC) continuum. This definition includes chars and charcoal, and excludes fossil fuel products or geogenic carbon (Lehmann *et al.* 2006). Materials forming the BC continuum are produced by partially combusting (charring) carbonaceous source materials, e.g. plant tissues (Schmidt and Noack 2000), and have both natural as well as anthropogenic sources. Depending on the temperatures reached during combustion and the species identity of the source material, a biochar's chemical and physical properties may vary (Keech *et al.* 2005). For example, coniferous biochars generated at lower temperatures, e.g. 350°C, can contain larger amounts of available nutrients, while having a smaller sorptive capacity for cations than biochars generated at higher temperatures, e.g. 800°C (Gundale and DeLuca 2006). However, the effects of biochar as a soil supplement are not fully understood; and need further investigation to determine how it confers benefits on soil.

Figure 5. White Clover in RCBD

A proposed way of testing biochar as a beneficial soil amendment involves investigating its effect on white clover growth. White clover (*Trifolium repens*; Figure.1) is a key component of New Zealand pastural agriculture, which is dependent on an inexpensive, high quality, feed source. In pastures, white clover provides a cheap, continual source of nitrogen (N), has high nutritive value, improves forage intake, utilisation rates of livestock, and complements perennial ryegrass growth. It is also considered environmentally friendly and therefore contributes to New Zealand's "clean-green" image. To add to this, white clover has a fast growth rate, making this species excellent to test benefits of biochar-supplemented soils in a limited time frame and in a pot study. The objective of this study was to measure the effect of charcoal (biochar) amendments in Manawatu sandy-loam soil (New Zealand) on white clover growth and nodulation and also changes to soil total carbon and nitrogen, pH, Hot water extractable carbon (HWC) and mineral-N (nitrogen) content.

Methods

Production of the charcoal powder (biochar)

The source material is Malaysian Mangrove wood as a renewable resource, *Rhizophora* species, preferably *Rhizophora apiculata*. It is a common tree found in swamps, especially at river mouths. Mostly only thirty year old mangroves are harvested for logs. The Charcoal that is made from mangrove wood has a strong and high density structure; the charcoal is hard and heavy. The logs are kilned at a temperature of 220°C. The first stage of the kilning process takes around 8 to 10 days. The log condition inside the kiln is determined by the smoke that comes out of the holes of the kiln. After 10 days the kiln is completely shut off and the baking process continues on a temperature of around 83°C. This takes another 12 to 14 days. Then the cooling process starts, this takes another 8 days before the hole in the kiln is opened. The material is then crushed to various sizes and powders

Soil and Plant measurements

Manawatu sandy-loam soil of the Recent Soil group ('Dystric Fluventic Eutrudept' in US Soil Taxonomic Classification as reported by (Hewitt 1998) was collected and mixed in appropriate proportions with the biochar by weight (Table 1). The mixtures were sieved, and left for one month before sowing. The white clover seeds (0.1 g) were sown into each of the soil mixes on 2nd October 2009 and regularly watered to maintain soil moisture. The white clover foliage was harvested after 93 days of growth (13th January 2010) and after 111 days of growth (31st January 2010) the whole plant was removed from the treatment medium, separated into shoots and roots and oven-dried at 70ºC for 72 h. A sample of fresh root was fixed in FAA (contains ethanol (70%), formaldehyde and acetic acid at a ratio of 90:5:5 by volume) to count nodulation.

Table 2. Project Treatments

Treatment	Biochar:Soil ratio
B0S5	0:5
B1S4	1:4
B2S3	2:3
B3S2	3:2
B4S1	4:1
B5S0	5:0

Soil total Carbon and Nitrogen, Hot water extractable carbon (HWC) (Ghani *et al*. 2003), mineral-N (nitrogen) content (Keeney and Nelson 1982) and pH in water were measured at the start and at the end of the experiment.

Results

Shoot and root dry matter biomass

In the first harvest, plant dry matter harvested in treatment B0S5 was significantly higher than treatments B1S4, B2S3, B3S2 and B5S0 but treatments B2S3, B3S2, and B4S1 had the same shoot growth. Treatment B5S0 inhibited growth of white clover but did not kill the plants (Figure 2). At the final harvest also B0S5 showed significantly higher shoot growth than treatments B1S4, B2S3, B3S2, B4S1 and B5S0. When compared to the treatment B1S4, B2S3, B3S2 and B4S1 showed higher shoot growth (Figure 3). The roots also showed similar trend in treatments B0S5, B2S3, B3S2 and B4S1 like shoot growth at final harvest (Figure 4) but B1S4 did not but was similar to B2S3.The final dry mass of shoot and root suggested that the addition of biochar reduced the yield of white clover. However, there is a trend in increment of dry matter on root from B1S4 to B3S2 suggesting better combination effect on growth and detailed study required to confirm this effect.

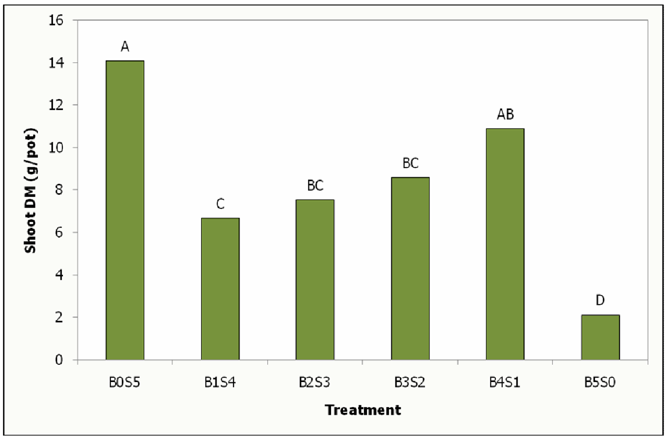

Figure 6. Clover shoot dry matter (DM) at first harvest at different treatment levels (Bars with different letters are significantly different (P<0.0001))

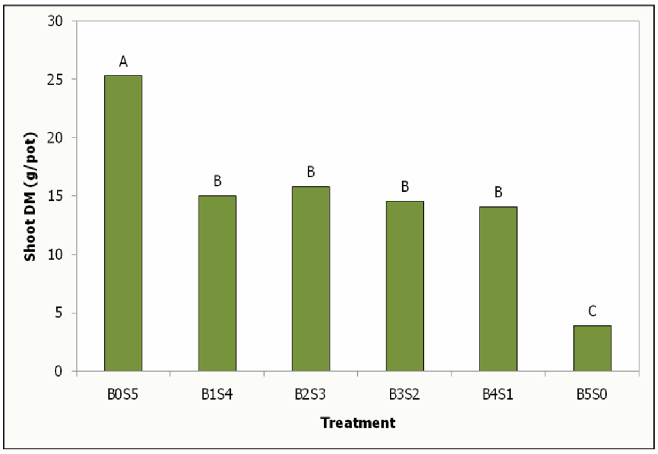

Figure 7. Clover shoot dry matter (DM) at final harvest at different treatment levels (Bars with different letters are significantly different (P<0.0001))

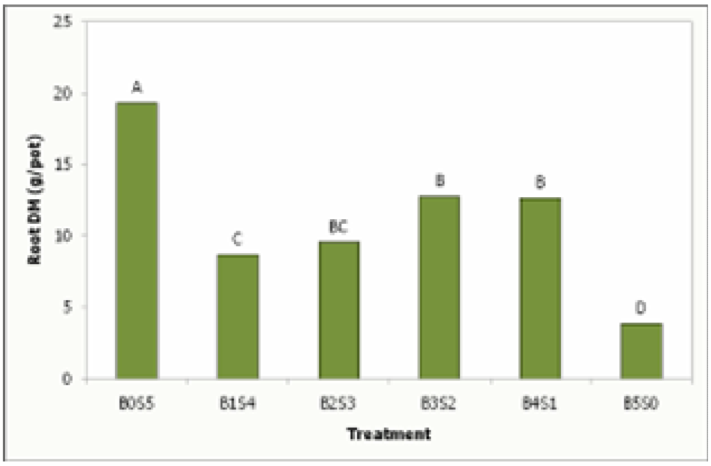

Figure 8. Clover root dry matter (DM) at different treatment levels (Bars with different letters are significantly different (P<0.0001))

Soil properties

Total carbon

The percentage of soil carbon increased from 1.14 to 40.81 as the addition of biochar to soil ratio was increased. The increased carbon content of soil may be the reason for the reduced growth of white clover (Table 2) or the reduced supply of plant nutrients (e.g. N) resulting from the reduction in soil.

Table 2. Measurement of total carbon, pH and Nitrogen mineralisation

Label	% of soil carbon		Initial pH		Final pH		Initial Nitrogen (N) mineralisation (µg/g)		Final Nitrogen mineralisation(µg/g)	
B0S5	1.14	(±0.01)	5.49	(±0.05)	5.16	(±0.05)	129.67	(±9.42)	2.90	(±0.40)
B1S4	11.5	(±0.36)	7.04	(±0.03)	7.26	(±0.03	102.13	(±3.12)	6.49	(±1.02)
B2S3	24.43	(±3.03)	6.47	(±0.07)	7.28	(±0.06)	78.03	(±22.95)	6.77	(±1.41)
B3S2	31.28	(±0.80)	6.06	(±0.05)	6.88	(±0.07)	132.10	(±24.99)	7.00	(±1.13)
B4S1	35.79	(±1.03)	6.09	(±0.02)	6.81	(±0.04)	85.53	(±14.69)	9.29	(±1.68)
B5S0	40.81	(±0.42)	6.40	(±0.12)	7.64	(±0.05)	62.74	(±15.76)	10.05	(±0.83)

pH in water

The initial pH on addition of biochar varied from 5.49 to 6.4 and the final pH was from 5.16 to 7.64, confirming that the addition of biochar has increased the pH (Table 2).

Conclusion

In this investigation the addition of biochar to soil reduced the biomass of both white clover shoot and root. The increased carbon content of soil and reduced supply of plant nutrients may be the reason for the reduced growth of white clover and biochar has increased the pH. Further research is needed in the area of addition of biochar to different soil types.

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