Soil and pasture responses to poultry litter biochar combined with nitrogen fertiliser on a degraded red Vertosol in Tamworth, NSW Australia

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Abstract
Biochar contains a high percentage of stable carbon and can improve soil quality by increasing the soil's capacity to hold water and nutrients, and by enhancing biological activity. This paper shows how herbage mass (HM) of tropical grass pasture (*Digitaria eriantha* cv. Premier) grown on a degraded Vertosol was affected when poultry litter biochar was applied. Biochar at 10 ton/ha was mixed into the soil to a depth of 10 cm on 12 of 24 experimental plots on 18 December 2009. The 12 remaining plots received no biochar. Pasture was sown on 6 January 2010 and allowed to mature until May 2010. In the subsequent growing seasons three different rates of nitrogen (N) fertiliser as urea (0, 50, and 100 kg N/ha/year) were applied. Half of the urea was applied in October and half in December. This produced six combinations of treatment, each with four replicates. Phosphorus fertiliser was applied annually as single superphosphate (200 kg/ha) to all plots. Growth was influenced by the change to the soil nitrogen level and available soil water. During the September 2010 to May 2011 growing season, the combined application of biochar and N fertiliser increased dry HM of the digit grass by 13-19%. Without N fertiliser, biochar had no significant effect on HM. During the same period, biochar improved the agronomic efficiency of applied N (AE_N) of the digit grass by 21% in the 50 kg N/ha treatment and by 13% in the 100 kg N/ha treatment. The cumulative pasture water use during the same period was similar for all treatments, but there was a trend of higher water use efficiency from the biochar amended plots when combined with fertiliser application.

Key Words
digit grass, water use, nitrogen use efficiency

Introduction
Biochar contains a high percentage of carbon (C) in a highly stable form. When applied to soil it can improve soil quality by increasing soil C content, soil water holding capacity and water and fertiliser use efficiency (Chan 2008; Van Zwieten *et al*., 2010). However, long term data to support these claims are lacking for Australian farming systems. This study evaluated whether biochar made from poultry litter could enhance soil quality, water and fertiliser use efficiency and the production of sown tropical grass (*Digitaria eriantha* cv. Premier – digit grass) pasture in the North-West Slopes of northern NSW, Australia.

Methods
A field trial was established on 24 experimental plots (9 x 7m each) on a degraded red Vertosol in Tamworth, and consisted of six combinations of nitrogen (N) fertiliser as urea and poultry litter biochar (BC) treatments, each with 4 replicates: (1) nil N, nil BC, (2) nil N + 10 t/ha BC, (3) 50 kg N, nil BC, (4) 50 kg N + 10 t/ha BC, (5) 100 kg N, nil BC, and (6) 100 kg N + 10 t/ha BC. Biochar used in this experiment was produced by Pacific Pyrolysis from wood base poultry litter at 550^{o}C. Prior to sowing grass, the biochar was incorporated into the top 10 cm of soil for biochar amended plots by spreading and raking on 18 December 2009. All 24 plots were then rotary hoed. The digit grass was sown on 6 January 2010 and was allowed to establish and mature before it was cut down to 45 mm above ground in May 2010. No fertiliser was applied to any plots during the establishment period. All plots were fertilised with 200 kg of single superphosphate and a half of N rate (urea) on 2 October 2010. The other half of the urea was applied on 26 December 2010. Herbage mass (HM) was assessed monthly from September 2010 using the calibrated scoring method (Boschma *et al*., 2009) in three strata within each plot. Plant samples were collected at each HM assessment date for N and Phosphorus (P) analysis. Soil water to 200 cm depth at 20 cm depth intervals was measured at each HM assessment date using a neutron moisture meter probe. Soil samples from 0-10 cm depth were collected at the beginning and end of each growing period for C, N, pH and P analysis.

HM assessment from the three strata for each sample date were analysed by ANOVA, with fertiliser, biochar and their interaction as terms in the model. The trial has a split plot design of four replicates with fertiliser as main plots and biochar as subplots. Hence the blocking terms were replicate, main plot within replicate, and subplot within main plot. For each subplot the water used (WU) was calculated from the difference in profile water stored (within 200 cm soil depth) at the beginning and end of each season plus the cumulative rainfall recorded over the period. Total HM was calculated as the sum of all monthly HM data over the growing season. Water use efficiency (WUE) as kg DM/mm water was calculated using herbage mass and water use data. These were analysed by ANOVA with the same model as for HM but with replicate and main plot within replicate as the blocking terms. Total N uptake was calculated from the sum of N content of plant tissue on each HM assessment date for the whole growing season. The agronomic efficiency of applied N (AE_N) was calculated as per Dobermann (2005) as kg yield increase per kg N applied.

Results

Properties of biochar and soil

The biochar used in this study contained 40% C, 1.7% N, and 2900 mg/kg Colwell P. Total N, C and available P were higher in plots amended with biochar compared to those without biochar (Table 1). The average increase of these elements in biochar amended plots was mainly due to the contribution of biochar added (0.26% of C, 18.8 mg/kg of P and 0.01% of N).

Table 1. Chemical properties of soil across treatments over time

Treatment	Total N (%)			Total C (%)			Colwell P (mg/kg)		
	6/1/10*	1/9/10*	12/5/11	6/1/10*	1/9/10*	12/5/11	6/1/10*	1/9/10*	12/5/11
Nil N, Nil BC	0.14	0.10	0.13	1.83	1.80	1.85	33.5	31.80	32.8
Nil N + BC	0.15	0.12	0.13	2.20	2.05	2.05	58.3	51.8	55.5
50 kg N, Nil BC	0.14	0.11	0.13	1.90	1.83	1.83	32.8	32.3	29.5
50 kg N + BC	0.15	0.11	0.14	2.08	1.98	2.03	50.0	48.8	46.3
100 kg N, Nil BC	0.14	0.10	0.13	1.78	1.73	1.80	30.5	31.3	27.8
100 kg N + BC	0.16	0.11	0.15	2.30	2.08	2.23	52.5	47.3	48.8
LSD(P=0.05)	0.02	0.010	0.005	0.10	0.10	0.12	6.10	6.18	4.50

**Measurements made before application of fertiliser.*

Herbage mass

The average dry HM for Jan -May 2010 period was 5664 ± 288 kg DM/ha for plots with biochar and 4935 ± 167 kg DM/ha for plots without biochar. This growth was most likely supported by stored N in the soil profile which explained the reduction of soil N over Jan- Sept 2010 period (Table 1). Digit grass grown on a non-degraded red Chromosol near Tamworth yielded 6800 kg DM/ha (Murphy, pers. comm 2012).

Between 1 September 2010 and 11 May 2011, the monthly dry HM fluctuated but was highest in January 2011 when it was warm and soil water was abundant. The cumulative HM during this first cutting season was highest in plots with biochar + 100 kg N/ha (Table 2), but was below the 16157 kg DM/ha reported by Murphy *et al.*, (2008) for the first cutting season on a non degraded red Chromosol. The digit grass in the current study was grown on a degraded cropping soil that had been subjected to prolonged topsoil erosion.

The cumulative dry HM was strongly affected by urea application indicating soil N was limiting. Biochar effect only became significant when it was applied in combination with N fertiliser (Table 2) and increased dry HM yield by 13-19 % for the 2010-2011 growing season. This yield increase was similar to that found in a parralel study in a rice system in Indonesia (Slavich *et al.*, 2011). The effect of biochar on yield was stronger at 50kg N/ha than at 100 kg N/ha. Yield increase from Nil to 50 kg N/ha treatment was doubled on biochar plots, whilst yield increase from 50 kg to 100 kg N/ha was similar for biochar and non-biochar treatments. Adding biochar to soil without adding N fertiliser had no effect on yield.

Table 2. Average cumulative dry herbage mass (kg DM/ha) during 1 Sept 10-11 May 11

N-rates (kg/ha/year)	Nil Biochar	10 t/ha Biochar
0	5651^{aA}	5572^{aA}
50	6921^{abA}	8217^{bcB}
100	9256^{cdA}	10465^{dB}

Letter following the number in lower case indicates differences ($LSD_{0.05}$=2127.5); capital letter is used when comparing the effect of biochar within the same level(s) of fertiliser ($LSD_{0.05}$=1131.4)

Nitrogen and water use

Cumulative N uptake between September 2010 and May 2011 increased with N rate, and it was higher in plots amended with biochar (Table 3). In plots without biochar the total above ground biomass N was 46-71% of applied N, while in plots with biochar it was 88-95% of applied N. One or a combination of four possible explanations are: (1) the N retention capacity of the biochar is likely to have caused higher uptake of

N in the biochar amendend plot. A reduction in N leaching was found in biochar amended soil in a glass house study (Ding *et al.*, 2010) and in a field study (Brockhoff *et al.*, 2010); (2) if below ground N is assumed to be 32-36% of the total N (Evans *et al.*, 1987; Khan *et al.*, 2003), the total N uptake would exceed the sum of applied and stored soil N. This could be due to the contribution of native soil N mineralisation (priming effect) under biochar (Chan *et al.*, 2008) or the contribution of bioavailable N from the biochar itself (Tagoe *et al.*, 2008; Slavich *et al.*, unpublished); (3) higher available soil P in the biochar treatment may have induced the higher N uptake by plant as suggested by Duru and Ducrocq (1997) and has been demonstrated when biochar was applied onto acidic soil (Slavich *et al.*, unpublished). In our study, P uptake measured in the above ground biomass was higher in plots with biochar; and (4) N loss through volatilisation may have been reduced in the biochar amended soil (Wang *et al.*, 2012; Scheer *et al.*, 2011; Singh *et al.*, 2010). These processes were not the focus of this study and would require further investigation.

Table 3. Average cumulative N uptake (kg N) during 1 Sept 10-11 May 11 (excluding below ground N)

N-rates (kg/ha/year)	Nil Biochar	10 t/ha Biochar	Difference from Control	
			Nil Biochar	10 t/ha Biochar
0	74.0^{aA}	72.4^{aA}	-	-1.6
50	97.2^{abA}	116.4^{bcB}	23.2	44
100	144.6^{cdA}	167.4^{dB}	70.6	95

Letter following the number in lower case indicates differences ($LSD_{0.05}$ = 41.05); capital letter is used when comparing effect of biochar within the same level (s) of fertiliser ($LSD_{0.05}$=18.71)

The agronomic efficiency of applied N (AE_N) at 50 kg N/ha was better than that at 100 kg N/ha (Table 4). Fertiliser use efficiency is known to decrease as the fertilizer rate increases (Dobermann 2005). The increase in AE_N due to biochar was 20.6% at 50 kg N/ha compared with an increase of 13.6% at 100 kgN/ha.

Table 1. The agronomic efficiency of applied N (AE_N), kg DM increase per kg N applied

N-rates (kg/ha/year)	Nil Biochar	10 t/ha Biochar
50	129	155.47
100	86.81	98.63

Assuming water loss to deep drainage and runoff was negligible, the cumulative water use for the September 2010-May 2011 period was similar for all treatments ranging from 734 to 768 mm of water. This was made up of 140 to174 mm extracted from 0-200 cm soil depth plus 594 mm of cumulative rainfall over the period. Rooting depth as indicated by changes in soil water content over time was similar for all pasture (to about 120-140 cm depth) which is consistent with Murphy *et al.*, (2010) for the same pasture near Tamworth. In highly permeable sandy soil, biochar could minimise water loss and reduce overall profile water extraction (Gathorne-Hardy *et al.*, 2010; Brockhoff *et al.*, 2010). But in this study the application of biochar had not made a significant difference in water use, probably due to the high clay content of the red Vertosol on which the pasture was grown. The effect of biochar on soil water holding capacity is more likely to be more pronounced in sandier soil than in clay soil as shown in Baldock (unpublished *cited in* Krull *et al.*, 2004).

The cumulative water use efficiency (WUE) for September 2010 - May 2011 period tended to be higher on biochar + fertiliser treatments, but the effect was not significant. In contrast, the higher fertiliser rates significantly increased WUE (Table 5). On a monthly basis (data not presented), WUE at the beginning of the season (September and October 2010) was similar for all treatments and became increasingly different with fertiliser rate over time thereafter. During the fastest growing periods between Dec 2010 and Feb 2011, biochar amended plots had a significantly higher monthly WUE compared to the Nil Biochar treatments.

Table 5. Mean and standard error of water use efficiency (kg /ha/mm) 1 September 2010-5 May 2011

N-rates (kg/ha/year)	Nil Biochar	10 t/ha Biochar
0	6.77^{a}	6.74^{a}
50	8.59^{ab}	9.93^{b}
100	11.65^{cb}	12.60^{b}

Letter following the number in lower case indicates differences ($LSD_{0.05}$= 2.913)

Conclusion

Combined application of biochar + N fertiliser increased dry matter yield of digit grass by 13-19 % for the 2010-2011 growing season. Without N fertiliser, biochar had no effect on dry matter yield. When applied in combination with fertiliser, biochar increased the agronomic efficiency of applied N for the digit grass by

20.6% at 50 kg/ha N rate and by 13.6% at 100 kg/ha N rate. The cumulative pasture water use on this degraded red Vertosol was similar for all treatments for this season. There is a potential for biochar to increase water use efficiency of the digit grass when it is applied with fertiliser, particularly during periods of high growth. This tendency will be examined over the next two growing seasons.

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