Productivity and nutrient availability on a Ferrosol: biochar, lime and fertiliser

K Sinclair[A], P Slavich[A], L van Zwieten[A] and A Downie[B]

[A]Wollongbar Primary Industries Institute, Wollongbar NSW 2477, katrina.sinclair@dpi.nsw.gov.au;
[B]BEST Energies Australia

Abstract: *Biochar produced from the slow pyrolysis of organic materials has potential as a soil amendment, increasing soil organic C and nutrient availability. Ferrosols are naturally highly acidic with low cation exchange capacity and, hence, lime is commonly applied. A plot field study was conducted in a subtropical environment to determine the benefits of incorporating biochar and lime on annual ryegrass yield and nutrient uptake and soil health. In a factorial design, three biochar types (0, 10 t/ha cattle feedlot, 10 t/ha municipal greenwaste) and two rates of lime (0, 5 t/ha) were applied in November 2006 and then sown with forage peanut. In autumn 2007 and 2008 annual ryegrass was oversown with two rates of N fertiliser (0, 50 kg N/ha/month) applied throughout the ryegrass growing season. Phosphorus and potassium (0, (28 P:50 K kg/ha)) were applied as split applications. The highest total DM yield (17093 kg/ha) was harvested from the cattle feedlot biochar + NPK fertiliser plots. The addition of feedlot biochar increased the yield response to NPK fertiliser by 20%. The greenwaste biochar did not affect yield. Without fertiliser the feedlot biochar increased N, P and K uptake by 7, 14 and 26%, respectively in Year 1, whereas with fertiliser the gains were lower. The greenwaste biochar had no effect on N, P and K uptake with or without fertiliser. Changes in soil properties included increased soil extractable NO_3, P, K, Mg and Na in the cattle feedlot biochar plots. Both biochars increased the soil C by 0.5%. In the short-term statistically significant benefits to agronomic performance and soil properties were demonstrated by the use of cattle feedlot biochar.*

Key Words: *biochar, ryegrass response, nutrient uptake*

Introduction

Biochar is a high carbon material produced from the slow pyrolysis (heating in the absence of oxygen) of biomass. The properties of biochar depend principally on the type of organic matter used and the pyrolysis conditions (Glaser et al. 2002). Biochar has potential to sequester carbon in the soil and to act as a soil amendment by increasing soil organic C and nutrient availability. Biochar in soil is resilient, breaking down only sparingly over the long term. Soil nutrient availability is a direct result of intrinsic nutrients in the char, and indirectly from increased nutrient retention and microbial biomass (Lehmann et al 2003). In a pot study, Chan et al. (2007) showed a low nutrient biochar derived from greenwaste significantly increased nutrient use efficiency in a hard setting Alfisol.

Ferrosols are highly acidic with low cation exchange capacity (CEC) and P availability. The productivity of these soils can be limited not only by excessive Al, Mn and Fe but also by deficiencies in N, P and K. P availability is the most important due to its fixation with Al and Fe oxides (Moody 1994). To overcome the 'acid soil infertility' of these soils, lime is commonly applied as an ameliorant together with regular applications of NPK fertiliser.

This study was undertaken to determine the benefits of incorporating biochar and lime in a Ferrosol, assessed in terms of growth and nutrient uptake of annual ryegrass (*Lolium multiflorum*) and soil health.

Table 1. Chemical properties of soil and derived biochars.

$pH_{(CaCl2)}$	Total C (%)	Bray1 P (mg/kg)	Exchangeable cations (cmol(+)/kg)					CEC (cmol(+)/kg)
			Al	Ca	K	Mg	Na	
Soil								
4.7	4.7	12	0.47	5.23	0.49	0.76	0.18	7.2
Cattle feedlot biochar								
9.7	44	73	0.03	3.7	5.60	2.70	1.30	13.0
Greenwaste biochar								
7.8	76	6	0.03	0.46	0.40	0.06	0.22	1.1

Materials and methods

Site. A plot field study was established in November 2006 at Wollongbar Primary Industries Institute (28°50'S, 153°25'E, elevation 140 m). The climate is subtropical with a warm humid wet period followed by a cooler drier period. The plots were irrigated at intervals commensurate with the effective root depth of the sown pasture.

Soil and biochar characterisation. The soil was a red Ferrosol derived from basalt (Isbell 1996) that in the 0-15 cm layer had 0.4 % (w/w) oxalate extractable Al, 0.9% (w/w) oxalate extractable Fe and P sorption capacity of 2500 mg/kg (Table 1). The biochars were derived from either cattle feedlot or municipal greenwaste and were manufactured at 450°C in a pilot pyrolysis plant by BEST Energies Australia, Somersby, NSW.

Experimental design and treatments. Plots (4 m x 5 m) were laid out in a randomised complete block design with 3 replicates in a factorial arrangement. The treatment combinations imposed were two fertiliser rates (0 or NPK (46N: 28P:50K)) x two lime rates (0 or 5 t/ha) x three biochar types (0, cattle feedlot @ 10 t/ha or municipal greenwaste @ 10 t/ha).

In November 2006 the lime and biochars were incorporated to a depth of 15 cm and sown to forage peanut at 100 kg/ha. In autumn 2007 and 2008 annual ryegrass cv. Warrior at 30 kg/ha was oversown. The ryegrass was harvested at the 2.5–3 leaves/tiller regrowth stage.

From May to December N fertiliser was applied as urea at 100 kg/ha/month. Phosphorous was applied as superphosphate at 125 kg/ha and K as muriate of potash at 50 kg/ha in June and November.

Measurements

Forage dry matter (DM) yield. At each harvest the entire plot was cut to 5 cm above ground level using a rotary mower and a subsample of the mown material taken and dried at 80°C for 24h to determine DM yield.

Nutrient uptake in ryegrass. In September 2007 ryegrass leaf material cut to 5 cm above ground level was taken at the 3-leaf/tiller stage (21 days regrowth), oven-dried and ground to determine uptake of N, P and K.

Soil chemical properties and microbial activity. In November 2007 soil cores (0–15 cm) were taken to determine pH ($CaCl_2$), Bray P, KCL-extractable NO_3, CEC, exchangeable cations (Al, Ca, K, Mg, Na), microbial biomass carbon and soil enzyme activity.

Results

DM production and nutrient uptake.

The cattle feedlot biochar with NPK fertiliser achieved the highest annual ryegrass total DM yield, significantly higher than the nil char or greenwaste with NPK fertiliser treatments (Table 2). The addition of cattle feedlot biochar increased the response to NPK fertiliser by 20% and was evident in Year 1 and 2.

Table 2. Annual ryegrass yield (kg DM/ha) for Year 1, Year 2 and Total and uptake of N, P, and K (kg/ha) in Spring, Year 1 with nil lime and with and without biochar or fertiliser.

		Yield (kg DM/ha)			Nutrient uptake (kg /ha), Spring, Year 1		
Biochar	Fertiliser	Year 1	Year 2	Total	N	P	K
Nil	-	3677	3645	7323	21.0	3.83	30.7
	+	7444	6790	14234	56.3	4.44	61.0
Feedlot	-	4582	4061	8643	22.6	4.35	38.8
	+	8594	8499	17093	60.0	4.59	60.5
Greenwaste	-	3683	3536	7220	18.0	2.81	24.7
	+	7335	7489	14824	56.1	4.36	57.5
l.s.d. (P=0.05)		1170	977	1506	6.6	1.93	21.5

Table 3. Changes in soil chemical and biological properties (microbial activity, MA, µg fluorescein/ g dry soil/min) with nil lime and with and without biochar or fertiliser.

Biochar	Fertiliser	$pH_{(CaCl2)}$	Total C (%)	Bray 1 P (mg/kg)	KCL-NO_3 (mg/kg)	CEC (cmol(+)/kg)	MA
Nil	-	4.6	4.7	8.5	8.4	6.9	4.19
	+	4.5	4.8	8.7	7.2	6.6	5.39
Feedlot	-	4.7	5.1	12.3	9.7	7.7	5.06
	+	4.7	5.2	13.3	12.3	7.8	5.55
Greenwaste	-	4.6	5.2	8.0	8.4	7.4	5.19
	+	4.5	5.4	8.9	8.0	6.9	4.13
l.s.d (P=0.05)		0.4	0.3	2.6	2.7	2.2	2.57

The uptake of N and, in particular, P and K by ryegrass was increased by the application of the feedlot biochar, both with and without fertiliser. The feedlot biochar alone increased the uptake of N, P and K by 7, 14 and 26%, respectively compared with nil fertiliser. The greenwaste biochar with or without fertiliser did not affect the uptake of N, P or K.

Lime increased DM yield by 7% but had no significant effect on the uptake of N, P or K. There were no significant interactions between the biochars, lime and fertiliser.

Changes in soil chemical and biological properties.

Lime incorporated at 5 t/ha raised soil pH by 0.8 units from 4.6 to 5.4, irrespective of fertiliser and biochar additions. Both biochars significantly increased total soil C from 4.7 to 5.2 % (Table 3). The addition of lime reduced available P from 8.5 to 6.8 (mg/kg) whereas the feedlot—but not the greenwaste—biochar increased available P. Soil nitrate was higher with the feedlot biochar compared with the greenwaste biochar, more so when fertiliser was applied (12.3 v. 8.0 mg/kg).

Without fertiliser and lime the feedlot biochar soil had significantly higher exchangeable K, Mg and Na compared with the nil and greenwaste biochar treatments. Liming increased the CEC by substantially increasing and decreasing the exchangeable Ca and Al, respectively.

Conclusion

Significant increases in DM yield and uptake of nutrients in annual ryegrass occurred when cattle feedlot biochar was applied at 10 t/ha together with N, P, K fertiliser applied at recommended rates. The greenwaste biochar had a lower innate nutrient value compared with the cattle feedlot biochar and this was reflected in the lack of response in terms of yield and nutrient uptake by the ryegrass. In terms of soil parameters the two biochars used in this study significantly increased total C% although applying lime was more effective in increasing pH and CEC on this soil type.

References

Chan, KY, Van Zwieten, L, Meszaros, I, Downie, A & Joseph, S 2007 Agronomic values of greenwaste biochar as a soil amendment, *Australian Journal of Soil Research* 45, 629-634.

Glaser, B, Lehmann, J & Zech, W 2002 Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review, *Biology and Fertility of Soils* 35, 219-230.

Isbell, RF 1996 *The Australian Soil Classification*, CSIRO Publishing: Collingwood, Victoria.

Lehmann, J, da Silva, JP, Steiner, C, Nehls, T, Zech, W & Glaser, B 2003 Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin; fertilizer, manure and charcoal amendments, *Plant and Soil* 249, 343-357.

Moody, PW 1994 Chemical fertility of krasnozems: a review, *Australian Journal of Soil Research* 32, 1015-1041.