Holbrook Landcare Network Biochar Trial Report

Summary

A field trial was set up at Holbrook in 2010 to investigate the effect of two different biochars on an agricultural soil and the subsequent plant response. Biochar was applied at three rates, combined in factorial design with three rates of mono ammonium phosphate (MAP). Soil and plant data were collected each year. However, after analysis of this data it is still not possible to make a recommendation regarding biochar for an agricultural business, as it was found that biochar can either assist or limit plant growth, and these effects will vary with biochar type, biochar rate, soil type and season. Continued monitoring of the trial is necessary to gain an understanding of the longer-term effects of biochar application.

Background

Biochar is a relatively stable and highly porous form of carbon created by heating biomass under low oxygen conditions at 400-900°C. It has been associated with improved retention of nutrients in soils resulting from reduced leaching or emissions. There is also some circumstantial evidence linking biochar to improvements in soil health including aggregate stability and water holding capacity.

Biochar benefits need to be investigated in different ecological and agricultural systems. To this end, Holbrook Landcare established a replicated field trial at Holbrook in 2010. This trial built on an existing three year project (2009-2012) which was funded by GRDC and FFI CRC, and managed by the Graham Centre (CSU and NSW DPI) in Wagga Wagga.

Aim

The major aim of the project was to investigate the mechanisms underpinning nutrient retention in biochar-amended dryland cropping soils of southern NSW. The Holbrook trial aimed to test a green waste (GW) biochar and poultry manure (PM) biochar under a mixed farming enterprise over three years.

The existing project commenced analysis of the two biochars, and their effect on soils. The project also analysed other physical and chemical components of the trial soils including structure, elemental analysis and pH amelioration. A review of the literature was completed and laboratory experiments commenced. Glasshouse trials commenced in June 2008, and a field trial on the Wagga Agricultural Institute farm was established the following season to validate the glasshouse results. It was envisaged that the establishment of a replicated field trial at Holbrook would enable a more comprehensive analysis of the agronomic mechanisms behind biochar-amended soils in southern NSW, and enhance the rigour of the scientific outcomes of the project.

Trial Design and Treatments

The trial site selected was three kilometres South of Holbrook on the property “Koombahla” owned by Peter and Skye Trescowthick. Three rates of both biochars (0, 7.5 and 15 t/ha) were combined in factorial design with three rates of mono ammonium phosphate (MAP) fertiliser (0, 50 and 100 kg/ha) in 4 x 7m plots with four replicates. The trial design is shown in Figure 1, below.

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1 PM 15t 0	2 PM 15t 100k g	3 GW 0 0	4 GW 7.5t 100k g	5 GW 7.5t 50kg	6 PM 7.5t 0	19 GW 0 0	20 PM 7.5t 100k g	21 PM 0 0	22 PM 0 100k g	23 GW 15t 0	24 GW 15t 50kg
7 GW 7.5t 0	8 PM 15t 50kg	9 GW 15t 50kg	10 GW 15t 0	11 GW 15t 100k g	12 PM 7.5t 50kg	25 GW 7.5 0	26 PM 15t 0	27 GW 7.5t 100k g	28 GW 7.5t 50kg	29 GW 0 100k g	30 PM 15t 50kg
13 GW 0 100k g	14 PM 0 50kg	15 PM 7.5t 100k g	16 PM 0 0	17 GW 0 50kg	18 PM 0 100k g	31 PM 7.5t 0	32 PM 7.5t 50kg	33 GW 15t 100k g	34 PM 0 50kg	35 PM 15t 100k g	36 GW 0 50kg
37 PM 15t 100k g	38 PM 0 0	39 PM 15t 0	40 PM 0 50kg	41 GW 0 50kg	42 GW 15t 50kg	55 PM 0 0	56 PM 15t 100k g	57 GW 0 100k g	58 GW 0 0	59 GW 15t 100k g	60 GW 15t 0
43 GW 15t 100k g	44 GW 15t 0	45 GW 0 0	46 PM 7.5t 50kg	47 PM 0 100k g	48 GW 7.5t 100k g	61 GW 7.5t 0	62 GW 7.5t 50kg	63 PM 7.5t 50kg	64 GW 0 50kg	65 PM 0 50kg	66 PM 15t 0
49 GW 0 100k g	50 PM 15t 50kg	51 PM 7.5t 0	52 GW 7.5t 0	53 GW 7.5t 50kg	54 PM 7.5t 100k g	67 PM 15t 50kg	68 GW 15t 50kg	69 PM 7.5t 100k g	70 PM 7.5t 0	71 GW 7.5t 100k g	72 PM 0 100k g

Plots: 4 x 7 m (sown 3.8 x 7)
PM = Poultry manure Biochar
GW = Green Waste Biochar
Rates: 7.5t/ha = 20 kg/plot
15t/ha = 40 kg/plot

Fertiliser: MAP

Plot Key:
Plot no.
Char type
Char kg
Fert kg

Figure 1. Trial design and treatments

The two types of biochar were purchased from Pacific Pyrolysis and incorporated into the top 8 cm of a Yellow Chromosol soil in April 2010. The biochars were individually bagged according to the various plot treatments, and surface spread manually with rakes. Two passes of an air disc seeder was then applied to the soil of all the trial plots, incorporating the biochar into the top 8cm of the appropriate plots, as well as providing a similar level of soil structural disturbance to all plots in the trial.

Canola was planted in 2010, wheat in 2011 and ryegrass in 2012.

Sampling

In 2010, groundcover measurements were performed three times over the first half of the season to determine any early vegetative plant response to treatments. A handheld, light sourced, plant reflectance sensor was used to measure normalised differential vegetation index (NDVI), a value related to the amount and vigour of measured plant matter. However, the results were inconclusive as the wet season adversely affected the data from the measurements in July and August (and probably June as well), due to the vigorous growth of weeds and soil surface moss.

Initial soil sampling data (2010) and plant data from 2010 season (canola crop) were collected but are unable to be analysed. Soils were sampled again in Jan 2011; plant data was collected at harvest in 2011 (wheat crop). Biomass cuts were taken from the ryegrass in late 2012, and soils were sampled again in November 2012. As the MAP was not applied to the trial in 2012, only those plots with 0 MAP applied in previous years were sampled that year (24 samples). Soils were analysed for Colwell P, pH, total C, and exchangeable cations (Ca, Mg, Na, K, Al).

Biochar Analysis

Element	Green Waste Biochar (%)	Poultry Manure Biochar (%)
C	75.45	51.85
O	20.93	30.68
N	0.53	1.58
P	0.1	2.85
S	0.11	0.47
Si	1.69	1.69
Ca	0.47	2.59
Al	0.48	0.98
Cl	0.23	0.31
Na		1.28
K		2.53
Mg		1.3

Table 1: Elemental measurement by XPS analysis of the two biochars used in Holbrook Field Trial

Both biochars used in the field trial were analysed by an X-ray photo-electron spectrometer (XPS) to determine elemental and functional group differences on the surface of the particles (**Error! Reference source not found.**). Analysis shows remarkable and significant differences in the percentages of most elements, including carbon (C), oxygen (O), and the major plant nutrients N, P, and S. Colwell phosphorous was also measured and whereas the GW biochar averaged 9 mg/kg, the PM biochar was approximately 3700 mg/kg. The pH also varied, with the GW biochar averaging approximately 6 (1:5 H_2O), and the PM biochar 7.9.

Results and Analysis

Each year was analysed independently, and only parameters that resulted in statistically significant differences due to treatments are included for discussion.

<u>2011:</u>

Influence of MAP addition

The addition of MAP did not produce statistically significant effects on measured parameters of the soil chemistry, with the exception of increasing concentrations of Colwell P, as would be expected. Similarly, MAP addition did not create any significant change in plant performance indicating an unresponsive soil to P addition.

Therefore MAP treatments were removed from statistical analysis allowing the same statistical comparisons of GW and PM biochars in both the 2011 and 2012 seasons.

2011 Soil chemistry.

Colwell P was greater in the PM biochar treated plots compared to the GW biochar plots, 48.5 and 32.2 ppm, respectively. Colwell P increased with increasing rate of application for either type of biochar (Table 2). Similar trends were apparent for increased soil carbon and

Biochar Rate (t/ha)	Colwell P (mg/kg)	C% (g C/100g soil)	Ex Al^{3+} (cmol+/kg)	Ex Na^{+} (cmol+/kg)	Al sat % (% of CEC)
0	27.1a	2.34a	0.47a	0.11a	8.54a
7.5	39.2a	2.82a	0.28b	0.11a	5.09b
15	54.6b	3.29b	0.27b	0.17b	4.46b
lsd	12.78	0.74	0.15	0.05	3.23

Table 2: Soil chemical parameters sampled from the 0-10 cm layer of soil at the end of the 2011 season. Data are means of the two biochar types as there were no significant differences between biochar types for the parameters shown. Means with different letters within each column are significantly different at p=0.05.

exchangeable sodium (Na^{+}) with increased addition of biochar regardless of the type. The exchangeable aluminium (Al^{3+}) concentration and the proportion of the cation exchange capacity (CEC) occupied by Al^{3+}, decreased with increasing biochar rate (Table 2) although soil pH was not significantly influenced by rate or type of biochar addition. This may be due to alkaline components of the biochar reacting with the exchangeable Al^{3+} converting it to unavailable forms, thereby decreasing the concentration of Al^{3+} and buffering the pH change that would otherwise have occurred.

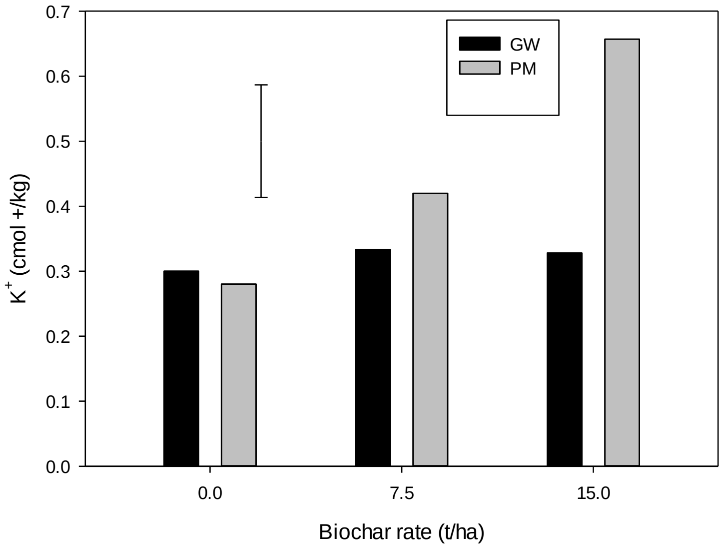

Figure 2. The exchangeable potassium (K^{+}) concentration (cmol +/kg) of soil in the 0-10 cm layer treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

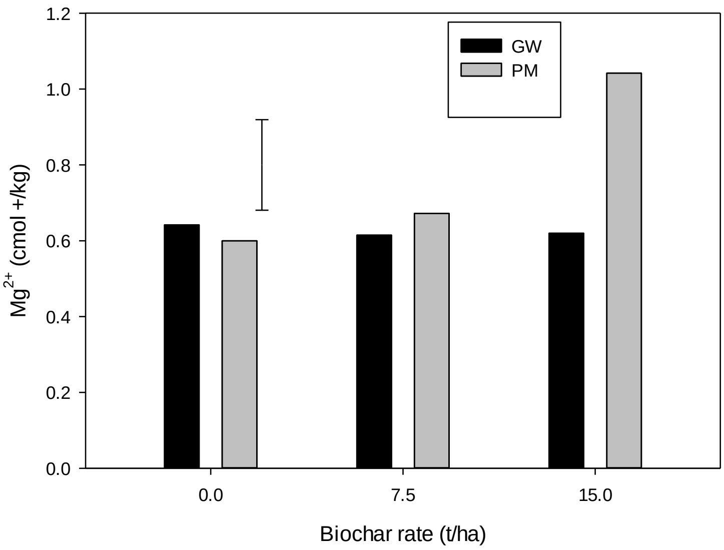

Figure 3. The exchangeable magnesium (Mg^{2+}) concentration (cmol +/kg) of soil in the 0-10 cm layer treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

The two biochars applied resulted in significant differences in Colwell P concentrations. The PM biochar had significantly higher Colwell P (48.5 mg/kg) than the GW biochar (32.2 mg/kg), possibly related to the available P present in the biochar added. Similarly, there was also a difference in the proportion of the CEC occupied by exchangeable K^+ in the soil treated with each biochar. The GM biochar treated soil had a significantly smaller proportion of the CEC (5.47 %) occupied by exchangeable K^+ than the PM biochar (7.32 %). Again, this is likely to be associated with the exchangeable K^+ content of the added biochar. The higher loading of potassium from the PM biochar resulted in increased concentrations of exchangeable K^+ being present at the highest application rate of PM biochar compared to other rates (Figure 2).

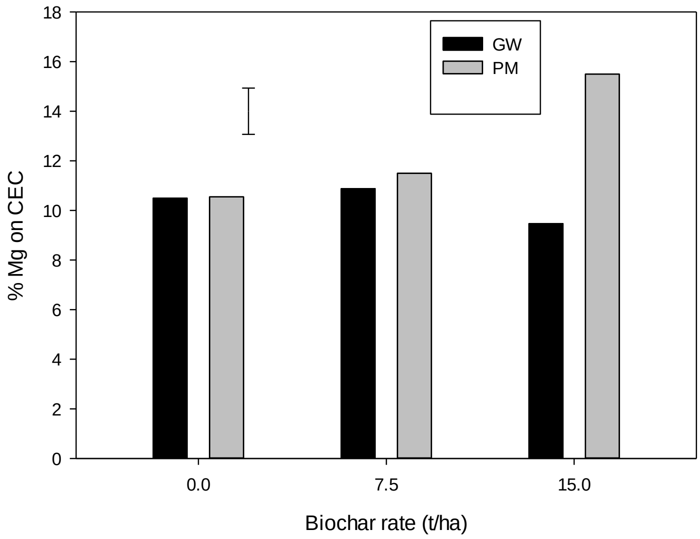

Figure 4. The proportion (%) of the cation exchange capacity (CEC) occupied by Mg^{2+} of soil in the 0-10 cm layer treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

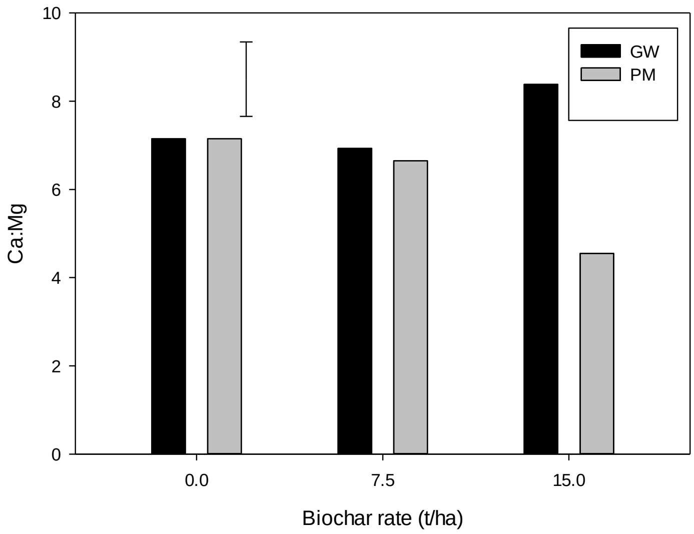

Figure 5. The ratio of exchangeable calcium to magnesium (Ca:Mg) of soil in the 0-10 cm layer treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

The greatest application rate of PM biochar resulted in significantly higher concentrations of exchangeable Mg^{2+} in the soil compared to other rates and the GW biochar (Figure 3). This caused the proportion of the CEC occupied by magnesium to increase (Figure 4) and decreased the Ca:Mg ratio (Figure 5). Whilst Ca:Mg was significantly influenced by the PM biochar addition the magnitude of that change did not result in the Ca:Mg moving to less than 2 (Figure 5) where problems associated with soil structure are known to occur.

2011 Agronomic performance.

The response to plant growth in 2011 of the biochar addition is shown in Figure 6. It can be seen that GW biochar applied at 15 t/ha resulted in significantly more dry matter production than all other application rates or any rate of the PM biochar. There was no significant effect of PM addition to dry matter production in the 2011 season.

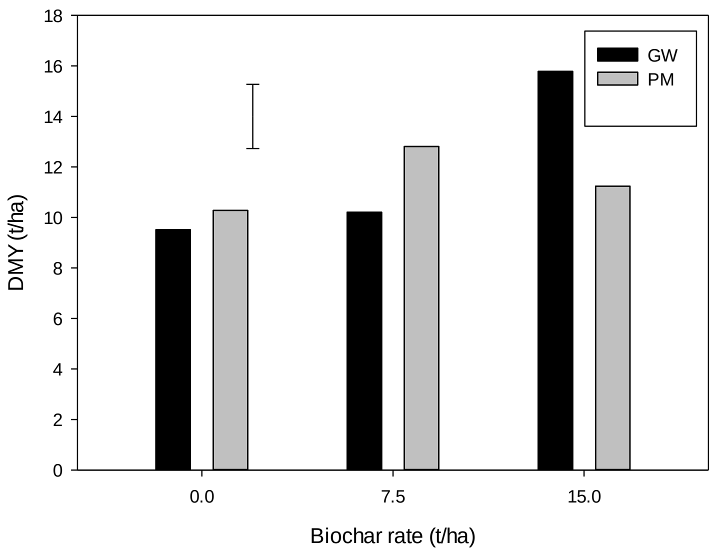

Figure 6. The Dry Matter Yield (DMY) (t/ha) in 2011 of plots treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

Similar effects observed in plant dry matter production were evident in the grain yield obtained in the 2011 season (Figure 7). Grain yield was significantly greater in plots where GW biochar had been applied at 15 t/ha. Where PM biochar was applied at 7.5 t/ha, the grain production significantly increased compared to the untreated control, however doubling the application rate did not increase grain yield any further. Therefore in terms of yield, PM biochar was optimised at 7.5 t/ha but it was not possible to determine if grain production had reached a plateau due to application of GW biochar (Figure 6).

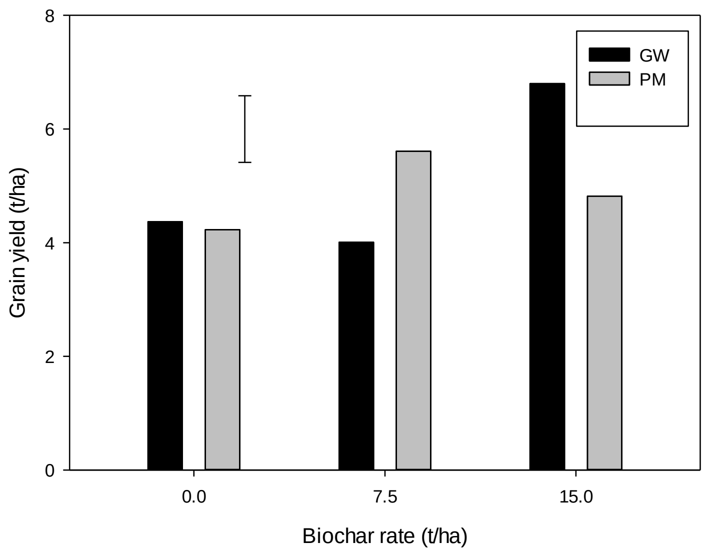

Figure 7. Grain yield (t/ha) in 2011 of plots treated with varying rates of PM and GW biochar as sampled in 2011. Line bar indicates least significant difference (lsd) at p=0.05.

2012:

2012 Soil chemistry.

The gain in exchangeable Mg, which was evident in the surface 0-10 in 2011 following PM biochar addition at 15 t/ha (Figure 3 and 4), remained present in 2012 soil analyses of the 0-10 and 10-20cm soil layers as increases in the proportion of the cation exchange capacity occupied by magnesium were evident at the highest rate of PM application (Figure 8). The only anomaly was a significantly greater magnesium % in the 10-20 cm layer due to GW biochar compared to PM biochar at application rates of 7.5 t/ha.

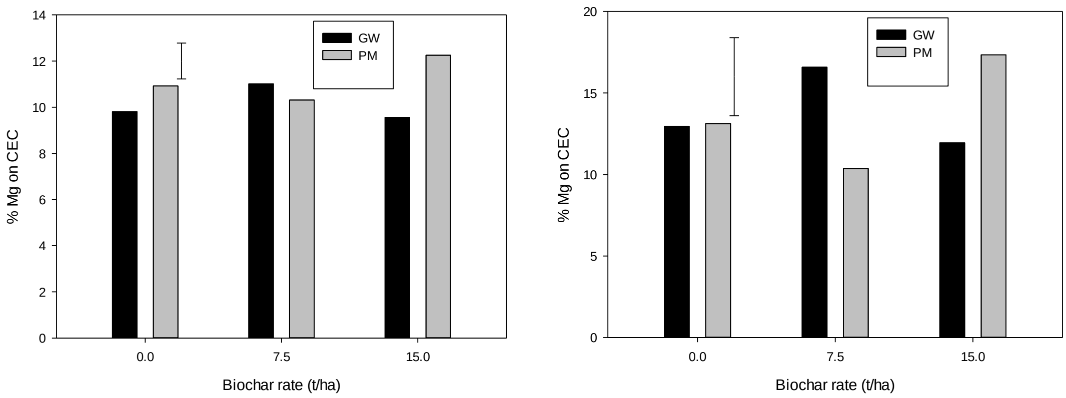

Figure 8. Proportion of the cation exchange capacity (CEC) occupied by magnesium (Mg^{2+}) in the 0-10cm (left) and 10-20 (right) in 2012. Line bar indicates least significant difference (lsd) at p=0.05.

As in 2011, the changes to the Ca:Mg, whilst significant in the 10-20cm layer (not significant in the 0-10cm) did not reach values of concern, that is, less than 2 (Figure 9).

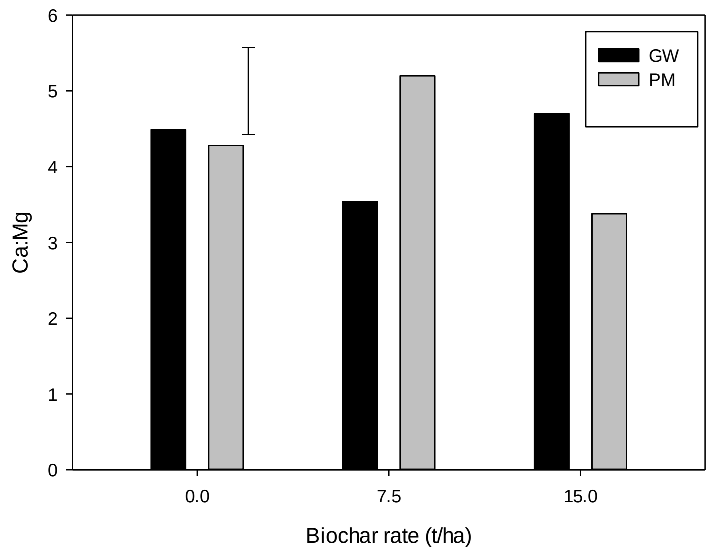

Figure 9. The ratio of exchangeable calcium to magnesium (Ca:Mg) in 2012 of soil from the 10-20 cm layer of plots treated with varying rates of PM and GW biochar. Line bar indicates least significant difference (lsd) at p=0.05.

2012 Agronomic performance.

The application of biochar resulted in a significant decrease in plant production in 2012 pasture when PM biochar was added at 15t/ha compared to the control, untreated soil (Figure 9). However it should be noted that a significant difference in the plant production occurred between the control treatments of the different biochar treatments; a result that is not able to be explained as no significant difference should exist between controls.

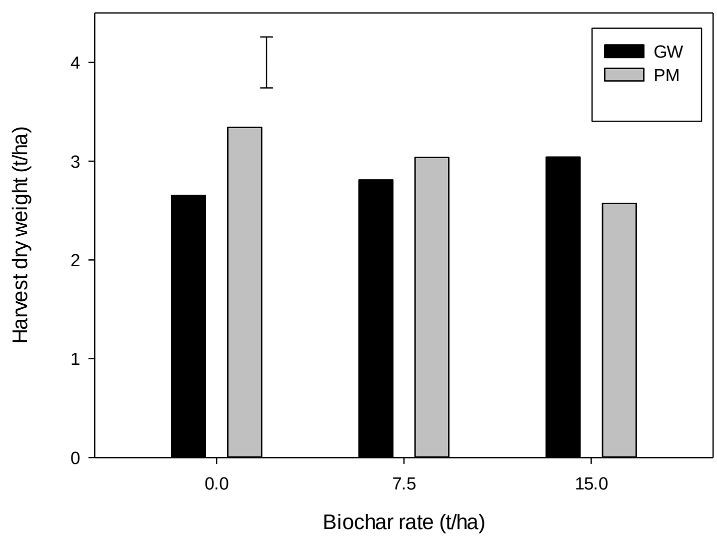

Figure 10. The Dry Matter Yield (DMY) (t/ha) of pasture in 2012 of plots treated with varying rates of PM and GW biochar. Line bar indicates least significant difference (lsd) at p=0.05.

Discussion

In 2011 the PM biochar resulted in increased plant growth compared to the control only at a rate of 7.5 t/ha and by 2012, growth decreased as PM biochar rate increased, compared to the untreated control. The PM biochar tended to increase exchangeable potassium (2011) and magnesium concentrations (2011 and 2012) in the topsoil and it is possible that poor plant performance was due to effects of cation antagonism or, more probably, osmotic effects associated with soluble ions. In the absence of electrical conductivity data or any other measure of salt concentrations it is not possible to be certain of the mechanisms of the deleterious properties on plant growth of PM biochar.

The GW biochar application at 15 t/ha significantly increased plant production in 2011 as measured by dry matter yield and grain yield. However no significant benefits were recorded in 2012 pasture production. The significant differences in positive soil properties, such as increased Colwell P and lower Al %, which were recorded in 2011 in response to GW biochar addition were not evident in 2012. Therefore long term effects of the biochar addition may be seasonally dependent or absent. Based on the analyses conducted, GW biochar would be the preferred biochar amendment of the two tested in this field trial however to assess long term influence of biochar addition annual production data would need to be recorded from plots on an ongoing basis.

Therefore, it is still not possible to make a general recommendation of biochar as a soil amendment for an agricultural business, as individual biochars vary in their chemical components and will react differently to different soil types and seasons. As seen here, they can either assist or limit plant growth, and these effects will vary with biochar type, biochar rate, soil type and season. Further research and monitoring of the trial is necessary.

Field Days

On 26th August 2009 a Carbon Myth Busters Field Day was held in Holbrook, with 60 people attending. The biochar project was introduced on this day. Another field day was held on 17th August 2010 at the biochar trial site, with David Waters (NSW DPI) giving the background to the trial.

Extension

The trial was launched with media articles in *The Southern News, The Rural*, the *Eastern Riverina Chronicle* and *Landcare In Focus* in 2010. It was updated in the *Holbrook Happenings* twice in 2012.

Funding

The Biochar trial was funded by Woolworths Sustainable Farming Fund through HLN, the Graham Centre and the Pastures Unit of I & I NSW.

Conclusion

The Holbrook biochar trial has found that biochar amendment does indeed have an effect on soil and plant properties. However, this field trial has underlined the variable nature of that effect. The two biochars chosen were very different in their chemical properties, ensuring quite different effects on soil chemistry and physical properties. The crop response to the added biochars was variable, with a lack of clarity about the effect of the biochar on plant production. Seasonal effects could not be ruled out. Given that the soil at the trial site was unresponsive to P, it is possible that clearer results could have been expected on a less fertile soil. In any case, insufficient data and analysis in this short term investigation have not yet shown consistent effects of adding biochar in this situation. However, monitoring the site over a longer term should continue to yield further information.

Acknowledgements

The following people are acknowledged for their contribution to the project:

Peter Trescowthick for providing the trial site; David Waters for initial trial set-up and field work; Mark Fraser and Raylene Brown for further field work and documentation; Jason Condon for data analysis and interpretation.