Biochar: Potential for climate change mitigation, improved yield and soil health

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Abstract. *There has been a significant increase in scientific, political and media attention on the use of biochar in agriculture and forestry (ABC Catalyst, 2007). The use of slow pyrolysis for generation of renewable energy from waste biomass is now becoming a commercial reality. The bi-product 'biochar' has significant potential for climate change mitigation through the sequestration of carbon in soil (Lehmann 2006), and can deliver improvements in crop yield and soil health. The process has recently been described as a win-win-win situation by Laird (2008) for the reasons mentioned above. This paper will provide a concise situation report on biochar, how it is made, and the results of some of the research conducted by New South Wales Department of Primary Industries in its application in agriculture.*

What is biochar and how is it made?

Biochar is a high carbon bi-product of slow-pyrolysis. Essentially, any biomass can be pyrolysed – that is, heated in the absence of oxygen. However, several key quality parameters of the biochar depend on feed-stock materials and pyrolysis conditions. Feed stocks suitable for biochar include; greenwaste, forestry waste, poultry litter, cattle feed-lot manure, paper mill waste, cane trash, mill mud and bagasse.

Commonly, biomass is heated in a kiln at controlled temperatures ranging from 400–700^{0}C. During this heating, syn gas (similar to town gas) is released from the biomass. A portion of this gas is then recycled to provide thermal energy for the process, with excess syn gas able to be re-directed into the production of renewable energy; either thermal or directly into electricity through a gas engine and generator. High calorific feed-stocks can produce around 1 MW/h electricity per tonne feedstock. Higher temperatures in the pyrolysis kiln generate more energy but the yield of biochar is lower. Typically, a yield of 40–50 per cent biochar is achieved.

Biochars have been produced for New South Wales Department of Primary Industries (NSW DPI) by BEST Energies Australia from a wide range of feed-stocks. What is evident is that biochars differ significantly in their chemical and physical characteristics with changing feed-stocks and processing conditions.

Improvements to soil health through biochar application

The health of soil affects both economic and environmental sustainability of farming systems. Concern about soil health is motivated by present and future interest, in both agricultural productivity and profitability (Sherwood and Uphoff 2000). To test the benefits of biochar on soil health, a number of glasshouse and field trials have been undertaken. NSW DPI currently manages 158 field plots with biochar applications in cropping, pasture and perennial tree crops.

Biochars have a wide range of both chemical and physical characteristics depending on their feedstock and processing conditions. A summary of chemical characteristics of two biochars is provided in Table 1. Generally, biochar alkalinity (measured both as pH and liming equivalents) increases with increasing pyrolysis temperatures, but available nutrients tend to decrease. Higher temperatures give lower total carbon biochars with higher ash contents. As expected, biochars made from manures have higher levels of total and available nutrients compared to woody feed-stocks.

In pot trials, two biochars (poultry litter biochar and green-waste biochar) were mixed into a Krasnozem at the rate of 10 t/ha (assuming incorporation into 0–100 mm profile) for a total of 47 days. Soils were then kept in a controlled temperature incubator at 23^{0}C. Table 2 shows results of the changes in soil properties following incubation with the biochars. Again, it is evident that these contrasting biochars gave very different responses in soil properties. For chemical fertility, it is clear that the poultry litter biochar provided greater benefit initially in terms of supplying higher amounts of available phosphorus (P) and nitrogen (N); and both biochars significantly increased the soil carbon

(C) content. The higher C content biochar resulted in higher soil C analysis. There was little difference in the microbial activity in the soil, measured by the hydrolysis of fluorescein diacetate method, described by Zelles *et al.* (1991).

In a field trial at Wollongbar Agricultural Institute, poultry litter biochar was applied at rates of 0, 5, 10, 20 and 50 t/ha. A sweet corn crop was planted and soil sampling conducted at day 50 of the cropping cycle. Table 3 demonstrates significant improvements in soil chemical properties with increasing biochar rates. Increasing biochar rates have resulted in increases in pH with concomitant increases in cation exchange capacity (CEC) and reductions in available aluminium (Al). Of the nutrients, a very significant increase in crop available P was measured.

In pot trials conducted by Chan *et al.* (2007), biochar derived from greenwaste was shown to significantly improve N fertiliser use efficiency in a hard setting Alfisol. This is particularly relevant as the cost of N fertiliser is likely to rise significantly over the next few years. The biochar also had the benefit of significantly reducing the tensile strength of the soil and increasing its water holding capacity.

Yield increases with biochar application

In December 2007, biochar derived from poultry litter was soil-incorporated at rates of 0, 5, 10, 20 and 50 t/ha and planted with sweet corn in replicated (n=4) plots. Changes in soil chemical characteristics are described in Table 3. The nil treatment plot yielded 16 t fresh weight (FW) cob/ha while the 10 and 50 t poultry litter biochar/ha produced 25 and 35 t cob FW/ha, respectively (Table 4). Plant biomass production also doubled with the highest rate of biochar application.

In another field trial with sweet corn, paper mill biochar and poultry litter biochar (both at 10 t/ha) were tested in triplicate in a randomised design with nil treatment control, lime (3 t/ha) and commercial compost at 25 t/ha. All treatments were repeated with and without luxury-rate fertiliser application. The highest yields were observed where biochars were added with fertiliser. However, poultry litter biochar alone out-performed luxury fertiliser treatment, lime amendment and compost amendment. These plots were sown to Faba bean in May 2008.

A pasture trial at Wollongbar has used biochars derived from cattle feedlot and municipal green-waste at 10 t/ha with 2 rates of lime (0, 5 t/ha). Amendments were incorporated into the soil in November 2006 and then sown with Amarillo pinto peanut (*Arachis pintoi*), a tropical legume. Six months later, annual ryegrass was over-sown with two rates of N fertiliser (0, 50 kg N/ha/month) throughout the ryegrass growing season. Over winter–spring the highest DM yields (6.7 t/ha) were harvested from the N fertiliser + cattle feedlot biochar plots. The addition of cattle feedlot biochar increased the yield response to N by 13 per cent. The green-waste biochar did not affect yield. Without N the cattle manure biochar increased N and P uptake by 23 per cent and 36 per cent, respectively.

Potential for climate change mitigation

Climate change caused by increase in the atmospheric concentration of greenhouse gases (GHGs) is predicted to cause catastrophic impacts on our planet (IPCC AR4 2006). This must therefore provide the impetus for action to reduce emissions and increase removal of GHGs from the atmosphere.

Table 1. Summary of characteristics of two contrasting biochars (produced by BEST Energies Australia)

	Poultry litter biochar	Green waste biochar
pH (1:5 $CaCl_2$)	13.0	8.1
Colwell Phosphorus (mg/kg)	1700	26
Phosphorus (%)	3.40	0.01
Nitrogen (%)	0.80	0.14
Carbon (%)	27	48
Cadmium (mg/kg)	<1	<1
Acid neutralising equivalent (% $CaCO_3$)	33.0	<0.5

Table 2. Summary of soil analysis following 47 days incubation with biochars (at 10 t/ha) in Krasnozem

	Control soil	Poultry litter biochar amended	Greenwaste biochar amended
pH (1:5 $CaCl_2$)	4.8	6.0	4.8
Carbon Dumas (%)	5.1	5.4	6.6
CEC (cmol(+)/kg)	11.3	21.7	13.3
Bray Phosphorus (mg/kg)	15	39	19
KCl extracted NO_3-N (mg/kg)	67	93	67
Microbial activity (mg fluorescein/g dry soil/min)	13.3	12.7	12.3

Table 3. Soil analysis in field rate trial using poultry litter biochar

Biochar rate (t/ha)	pH ($CaCl_2$)	Al (cmol(+)/kg)	CEC (cmol(+)/kg)	Organic C Walkley Black (%)	Total N (%)	Total C Dumas (%)	Bray P (mg/kg)	KCl NH_4-N (mg/kg)	KCl NO_3-N (mg/kg)
0	4.4	1.10	6.5	4.5	0.50	5.3	14.3	3.7	13.5
5	4.6	0.68	7.1	4.5	0.59	6.4	23.3	4.2	10.2
10	4.7	0.43	7.9	4.5	0.54	5.9	41.8	4.7	11.3
20	4.9	0.21	9.2	4.8	0.53	6.0	69.3	5.0	13.2
50	5.9	0.009	15.3	5.2	0.66	7.5	201.0	5.2	14.8

Table 4. Crop responses to increasing rates of biochar application

Biochar rate (t/ha)	Cob weight (t/ha ± std dev)	Plant dry weight (t/ha)
0	16.6 ±4.2	3.3 ±0.6
5	19.8 ±4.8	3.5 ±1.0
10	25.1 ±4.9	4.8 ±0.4
20	25.9 ±7.2	4.6 ±1.4
50	34.7 ±6.6	6.2 ±1.8

Biochar acts in several ways to aid in climate change mitigation. Firstly, the conversion of labile carbons from biological material to stable carbon (biochar) through slow pyrolysis can tie up C in the soil for many hundreds of years (Lehmann 2006). Secondly, biochar in soil has the potential to reduce emissions of non-CO_2 greenhouse gases. The soil is both a significant source and sink for greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Biochar application to soil has been shown to affect C and N transformation and retention processes in soil. These processes along with other mechanisms, as influenced by biochar can play a significant role in mitigating soil GHG emissions.

Recent studies have indicated that biochar reduces N_2O emissions (Yanai *et al.* 2007) and increases CH_4 uptake from soil (Rondon 2006). This could add substantially to the greenhouse mitigation benefit. However, there is currently very limited understanding of the mechanisms through which biochar impacts on fluxes of CH_4 and N_2O. NSW DPI is undertaking several studies to determine the mechanisms of reduced GHG emission from soil using both laboratory and field experimentation.

As biochar has been shown to increase biomass production by crop species, even more C is being taken out of the atmosphere and stored in plant tissue. Apart from obvious economic advantages of improved crop yields, this also increases the amount of waste biomass available for slow pyrolysis and bioenergy production, and increases the amount of biochar available to sequester carbon long-term.

Conclusions

This paper has summarised some of the key benefits of biochar in soil. It is clear that biochar has the ability to significantly: improve crop productivity; increase soil C and soil fertility; improve soil structure (and therefore soil physical properties); sequester C in soil long-term and reduce emissions of non CO_2 greenhouse gases from soil. NSW DPI and BEST Energies Australia are continuing to develop proposals for the commercial production of biochar, and continue to research the benefits of this product for Australian agriculture.

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