Effect of biochar on P uptake from two acid soils

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Abstract
Biochar may increase P availability in acid soils via direct P addition from biochar and indirect effects through soil processes. A pot trial was carried out to examine the effects of incubated and non-incubated poultry litter (Pl) and rice husk (Rh) biochars on maize (*Zea mays*) growth and P uptake from acid soils (Tenosol and Ferrosol). Biochar was mixed with soil at a rate of 10 ton/ha and P was applied at 0, 5, or 50 mg P kg^{-1} as superphosphate such that rates were part way up a pre-determined P response curve for maize. Appropriate, non-P limited controls were also established for each soil type. Compared to Rh biochar, Pl biochar treatments on both soils resulted in higher plant biomass and P uptake but lower P recovery as a proportion of P applied. Phosphorus uptake on non-incubated Pl-amended Ferrosol and Tenosol respectively was 9 and 7 times greater than on both Rh-amended soils. Incubation resulted in sorption of applied P and reduced bioavailability, and there was no indication that biochar reduced P sorption in Ferrosols. Interestingly, P uptake was greater from a combination of P and Rh biochar than when either was applied alone, providing evidence of synergistic benefits of biochar application. These benefits may have arisen due to the liming effect of biochar, to competitive inhibition of P sorption, and/or modification of the soil physical environment and further research is warranted.

Key Words
Biochar, P uptake, acid soil, Ferrosol, Tenosol, *Zea mays* L.

Introduction
Phosphorus (P) availability is low in many soils, particularly in acid soils with high P sorption capacity. Biochar may improve available P in soils; both directly through P addition from water-soluble P contained in biochar and/or indirectly through impact on soil chemical, physical and/or biological processes (DeLuca *et al*. 2009). Many biochars have a liming effect, so increased soil pH may increase negative charge which in turn reduces P sorption (DeLuca *et al*. 2009). The extent of this effect depends on the Acid Neutralizing Capacity (ANC) of biochar (Van Zwieten 2010 pers.l comm.). Biochar may also increase microorganism activities through application of C, especially aliphatic C compounds (Zimmermann 2010). The increase in microbial activities may affect microbial biomass phosphorus (MBP) (Liptzin and Silver 2009) and phosphatase activity (Trasar-Cepeda *et al*. 1990; Saa *et al.* 1993) resulting in increased plant available P.

Interactions between biochar and soil minerals may change the surface properties of soil minerals (Nguyen, *et al*. 2009; Singh and Kookana 2009), and impact P sorption and consequently P availability. This effect may increase as biochar “ages” in soil and develops more negative charge (Cheng and Lehmann 2009). In the laboratory, biochar aging can be stimulated by subjecting biochar-soil mixtures to wetting-drying cycles (Singh *et al*. 2010). However, such phenomena have not been studied intensively in relation to P uptake. The objective of this study was to examine the effects of fresh (non-incubated biochars) and aged (incubated) biochars on P uptake by plants.

Methods
The two soil types used in this study were Ferrosol from Wollongbar NSW Australia (high P sorption capacity) and Tenosol from Armidale (low P sorption capacity). The chemical composition of the biochars is presented in Table 1, Non-incubated samples of biochar-amended soil were prepared by mixing 1500 kg of air dry soil ($\leq$ 2 mm) mixed with poultry litter biochar (Pl) or rice husk biochar (Rh) at the rate 10 ton/ha. Incubated samples were subjected to weekly drying/wetting cycles for 4 months under warm, shaded, glasshouse conditions. Each mixture was placed in a 15cm diameter plastic pot. There were 20 treatments in total, each with 3 replications.

Two germinated maize seeds were planted in each pot. Before planting, phosphorus was applied as superphosphate. Ca-phosphate was first diluted with 200 g soil/biochar amended soil and then mixed evenly with the whole soil/biochar amended soil in the plastic bag and finally mixed by hand shaking at about 3 minutes at the rates of 0 and 50 mg P/kg for Ferrosol (denoted as PlP0, RhP0, PlP50, RhP50); and 0 and 5 mg P/kg for Tenosol (denoted as PlP0, RhP0, PlP5 and RhP5). The rates were part way up a pre-determined P response curve for maize, to ensure maize plants were P limited and responses to biochar application could be observed. In the non-P limiting controls biochar was mixed with 500 mg P/kg (P500) in the Ferrosol and with 50 mg P/kg (P50) in the Tenosol. Basal nutrients of 200 mg N/kg, 100 mg K/kg, 50 mg S/kg, 60 mg Ca/kg, 15 mg Mg/kg, 2 mg Cu/kg, 2.5 mg Zn/kg, 4 mg Mn/kg, 0.3 mg B/kg, and 0.2 mg Mo/kg were applied to all pots. The nutrients were applied as a solution that was mixed with the soil or biochar amended soils in a plastic bag that suited the pot size and evenly distributed by hand and then shaken for about 2 minutes.

The trial was conducted in a glasshouse with average day temperature of 30^{o}C, and night temperature of 25^{o}C. Pots were maintained at field water capacity (FWC) twice daily through weighing. The experiment was arranged as a completely randomized design. Four weeks after planting, shoots and roots were harvested separately and dried at 60^{o}C until reaching a constant weight, for determination of total plant biomass and chemical analysis. Samples were digested using the sealed chamber digestion method described by Anderson and Henderson (1986), and P determined by ICP. Phosphorus uptake was calculated using plant P content and the shoot dry weight. P recovery was determined using the balance method (Syers *et al*. 2008).

Results

Biochar Characteristics

Poultry litter biochar had higher pH (1:5 H_2O), EC, total N, total C and available P compared to rice husk biochar (Table 1). Based on available P in each biochar and application of 17.7 g/pot (10 ton/ha), theoretically Pl-biochar increased soil available P 127.4 mg P/kg while Rh gave 4.3 mg P/kg.

Table 1. Selected characteristics of poultry litter and rice husk biochars

	Poultry litter (Pl)	Rice husk (Rh)
pH (H_2O)	10.8(0.01)	9.90(0.02)
EC (dS/m)	0.08(0.01)	0.01(0.00)
Total N (%)	4.05(0.05)	0.44(0.02)
Total C (%)	48.4(0.90)	33.2(0.10)
Available P (mg/kg)	7200(420)	240 (7.00)

Note: average from 3 measurements with standard error in the parentheses

Total plant biomass, P uptake and P recovery on Ferrosol

Total biomass of maize in Pl-amended Ferrosol was significantly higher than that of Rh-amended treatments regardless of incubation and P addition (Table 2). Total biomass on the non-incubated Pl-amended Ferrosol was about five times higher than that of Rh-amended Ferrosol. Prior incubation of biochar in soil lowered total biomass on Pl-amended Ferrosol regardless of P addition but the effect was less when P was applied

Table 2. Total plant biomass, P uptake and P recovery by maize grown on Ferrosol amended by incubated and non-incubated Poultry litter (Pl) and Rice husk (Rh) biochar with P (P50) and without P (P0) application and a non P-limited control

Treatment	Total Plant Biomass (g/pot)		P uptake (mg/pot)		P Recovery (%)	
	Non-incubated	Incubated	Non-incubated	Incubated	Non-incubated	Incubated
RhP0	2.5 *a* *a*	1.7 *a* *a*	2.0 *a* *a*	1.4 *a* *a*	70.5 *b* *d*	44.7 *a* *c*
RhP50	3.3 *a* *a*	2.6 *a* *b*	3.4 *a* *a*	2.6 *a* *b*	6.4 *a* *a*	4.8 *a* *a*
PlP0	15.4 *b* *b*	8.2 *a* *c*	25.6 *b* *b*	14.0 *a* *c*	26.8 *b* *c*	14.9 *a* *b*
PlP50	14.3 *b* *b*	11.2 *a* *d*	25.2 *b* *b*	20.3 *a* *d*	16.3 *a* *b*	13.2 *a* *b*
Control	14.5 *a* *b*	16.6 *a* *e*	37.2 *a* *c*	36.9 *a* *e*	6.2 *a* *a*	6.03 *a* *a*

Note: Different letters indicate significant differences between treatments at the $p < 0.005$ level. Letters in column is the comparison between biochars and in rows is the comparison between non-incubated and incubated (biochar and soil were incubated for 4 months with wetting drying cycles) biochar amended soil.

Phosphorus uptake by maize grown on both incubated and non- incubated Pl-amended Ferrosol was significantly higher than that of both Rh-amended soils but lower than the control (Table 2). P uptake from the Rh-amended Ferrosol was less than 10% of the control. P addition on the Rh-amended Ferrosol increased P uptake slightly. Moreover, incubation reduced P uptake on the Pl-amended Ferrosol, but the effect was reduced with P addition. On the non-incubated Rh-amended Ferrosol, P recovery was higher than on the Ferrosol treated with Pl biochar. P addition and incubation reduced P recovery on both biochars.

Total plant biomass, P uptake and P Recovery on Tenosol

Total plant biomass of maize on Pl-amended Tenosol was significantly higher than that on Rh -amended soil but similar to control (Table 3). Regardless of P addition, total biomass on Pl-amended Tenosol was more than twice that of Rh-amended treatments. Moreover, incubation reduced total biomass on Rh-amended Tenosol but not on Pl-amended Tenosol and control.

Table 3. Total plant biomass, P uptake and P recovery by maize grown on Tenosol amended incubated and non-incubated Poultry litter (Pl) and Rice husk (Rh) biochar with P (P5) and without P (P0) application and a non P-limited control

Treatment	Total Plant Biomass (g/pot)		P uptake (mg/pot)		P Recovery (%)	
	Non-incubated	Incubated	Non-incubated	Incubated	Non-incubated	Incubated
RhP0	5.5 *b* *a*	2.7 *a* *a*	7.5 *b* *a*	2.3 *a* *a*	220.9 *b* *d*	68.8 *a* *a*
RhP5	6.5 *b* *a*	4.1 *a* *b*	9.8 *b* *a*	4.1 *a* *b*	106.7 *b* *c*	45.3 *a* *a*
PlP0	12.7 *a* *b*	15.8 *b* *cd*	56.8 *b* *c*	67.0 *a* *d*	55.1 *a* *ab*	69.0 *b* *a*
PlP5	16.1 *a* *c*	15.1 *a* *cd*	66.3 *a* *d*	69.4 *a* *d*	61.8 *a* *b*	65.7 *a* *a*
Control	16.6 *a* *c*	17.3 *a* *d*	25.2 *a* *b*	27.7 *a* *c*	42.8 *a* *a*	46.5 *b* *a*

Note: Different letters indicate significant differences between treatments at the $p < 0.005$ level, from 3 measurements. Letters in column is the comparison between biochars and in rows is the comparison between non-incubated and incubated (biochar and soil were incubated for 4 months with wetting drying cycles) biochar amended soil.

On Pl-amended Tenosol, both incubated and non-incubated, P uptake was significantly higher than on Rh-amended soil and control. Incubation increased P uptake by 20% on Pl-amended Tenosol but reduced it by 38% on Rh-amended soil. P uptake was over twice the control where Pl biochar was applied, but less than half the control for Rh biochar (Table 3). The P recovery from non-incubated Rh amended Tenosol was more twice than that of control and Pl amended soil but was unchanged when Rh biochar was incubated.

Discussion

Biomass production and P uptake by maize grown on both soils amended with Pl biochar was higher than that treated with Rh biochar due to the higher available P supplied by the Pl biochar (Table 1). High P supply from the Pl biochar resulted in higher P uptake than in the non P-limited control treatment in the Tenosol due to luxury uptake, however sorption reactions and higher basal P application resulted in lower P uptake in the Ferrosol than the non P-limited control. Part of the increased P uptake in Pl biochar amended soils may have been associated with increased pH as pH was increased by 0.5-0.6 on both soil types. This liming effect of biochar has also been observed by other researchers (DeLuca *et al*. 2009, Van Zwieten *et al*. 2010). In contrast, Rh biochar had minimal liming effects on soil, as pH was reduced by 0.1-0.2 units (Cheng and Lehmann 2009).

Although the influence of Rh biochar on biomass production and P uptake on both soils was not as great as Pl biochar, more P was recovered from Rh biochar amended systems (Table 3). This suggests a synergistic effect of Rh biochar that may increase the P when determined using the balance method (Syers *et al*. 2008). P recovery could be over 100% as the plant may be taking up P from the native P in soil (4.6 mgP/kg) as well asby direct addition from biochar. Our previous results (unpublished data) showed that after 4 weeks incubation, Rh biochar amended sand released 191.9 mg P/kg Rh biochar. Priming effects, competitive sorption processes or improvement of root growth may have contributed to the increased P recovery. Further research is needed to resolve this issue.

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Incubation of biochar in soil reduced total plant biomass and P uptake compared with fresh additions in most instances, most likely because of sorption of released P. The exception to this was the application of Pl biochar to the Tenosol (Table 3), where the high P release from this biochar apparently saturated the low sorption capacity maintaining high P availability following incubation. It is possible that the incubation of Rh biochar in the Tenosol resulted in reduced availability of P due to sorption of released P on the char itself, as observed by Beaton *et al*. (1960) in wood charcoals.

Conclusion

The majority of plant growth and P uptake improvements associated with Pl biochar addition can be accounted for by release of P supplied in the char, in conjunction with liming effects on soil microbial activity. In contrast recovery of applied P was higher in the lower P status Rh biochar, with possible synergistic interactions increasing the availability of native soil P resources. This warrants further investigation. There was little evidence that incubation of biochar in soils reduces P sorption reactions and increases P availability, but biological priming effects and positive effects on root growth and extension need to be investigated to account for the higher recovery of P in Rh amended soils.

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