Effect of Augmented Fast-Pyrolysis Biochar on Soil Fertility

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Abstract

Reaction conditions and low-ash feedstock used in fast pyrolysis to maximize yield and quality of volatile organics result in co-product biochar of limited agronomic value. This study was aimed at improving agronomic value of yellow pine (Pinus taeda L.) fast pyrolysis biochar. Biochar was used to sorb extracts from anaerobically digested dairy manure solids and mixed with limestone quarry fines to produce $Biochar_G$, a co-product biochar of improved agronomic value. Selected extractions were used to assess $Biochar_G$ nutrient content and availability, and a greenhouse study conducted to evaluate $Biochar_G$ effects on foxtail millet (*Setaria italica* L.) growth in an acidic soil. $Biochar_G$ absorbed excess nutrients from the manure and improved soil fertility and millet growth.

Introduction

Pyrolysis, a thermochemical conversion of biomass to bio-fuel is one of the preferred process for converting feedstock of high lignin content into bio-oil. It also produces biochar, a carbonaceous material as a co-product. Biochar is considered a beneficial soil amendment, and its use is suggested to markedly reduces carbon emission, mitigating greenhouse gasses emission fluxes. Biochar contribution to soil fertility is heavily depends on feedstock source, pyrolysis time and peak temperature. As feedstock of low ash content are favorable in biomass to bio-oil conversion processes it result in biochar of low nutrients and liming content. In this study we used co-product biochar as sorbent for dairy manure solids extract and evaluated effect of resulting product ($Biochar_G$) on soil fertility and plant growth.

Materials and Methods

$Biochar_G$ production and characteristics: anaerobically digested dairy manure solids were extracted and yellow pine (Pinus Taeda L.) fast pyrolysis biochar used at different solid:solution ratios and filtering combinations to sorb the liquid extract. Loaded biochar slurry was unfiltered ('NoLeach') or filtered through 2.5µm filter paper ('Leach') before drying overnight at 45 °C. $Biochar_G$ water extracts were digested using EPA 3010A and analyzed for total Ca, Cu, Fe, K, Mg, Mn, P, S, and Zn in addition to pH and EC, and ionic composition determined using IC (Dionex ICS 1100), and ICP-OES (Perkin Elmer Optima 8300). $Biochar_G$ Mehlich-3 enrichment factor was calculated by the ratio of nutrient content in $Biochar_G$ to that in untreated biochar.

Greenhouse pot experiment: three biochar treatments were tested: a non-augmented biochar (as-is), '0.7-mm NoLeach' augmented biochar ($biochar_G$), and augmented biochar mixed with quarry granite fines at a 1:2 ratio ($Bichar_G$: Granite). All $biochar_G$ materials were agglomerated prior to crushing to a similar particle size as the untreated (non-augmented) biochar used in the 'as-is' treatment. Treatments for the pot experiment included: No lime + NPK; AgLime only; AgLime+NPK; AgLime+NPK (x2); Biochar (as is); $Biochar_G$; $Biochar_G$ + Granite. NPK application was based on soil lab test results recommendations and provided 65.4 mg N, 28 mg P_2O_4, and 31.1 mg K_2O per kg soil (in the 2X treatment these amounts were doubled). Biochars were mixed with Gilpin soil at three application rates (1, 2, and 5% by weight), and each rate was treated with or without limestone fines (applied at equivalent rate to that of AgLime). Foxtail millet (*Setaria italica* L.) was grown and biomass harvested and recorded after 30, 60, and 90 days. Soil was remixed and foxtail millet reseeded for a 2nd crop – harvest after 45d.

Results

Using fast pyrolysis biochar as sorbent for dairy solids manure extract improved biochar nutrient content (Table 1, Table 2) and plant growth (Fig. 1). Using no-leach approach during $Biochar_G$ production improved biochar nutrient retention while not elevating $Biochar_G$ EC to alarming values (soil EC elevated up to 200 µS cm^{-1} at highest $biochar_G$ application rate [5% by weight]). Total nitrogen increased upon biochar augmentation by more than 5.5 times, rising from 0.17% to 0.94% while NH_4-N increased from 165 to 393 mg kg^{-1} and NO_3-N decreased from 109 to 17 mg kg^{-1} (data not shown). Increased overall nitrogen content, coupled with reduced nitrate content likely improved biochar nitrogen retention in the root zone. $Biochar_G$ improved soil fertility and millet growth – more than doubling millet biomass (Fig. 1). Much of the plant treatment response can be associated with N application (in biochar or as mineral fertilizer; Fig. 2).

Sieve Size	Solid Extract	Solid Separation	Ca	Cu	Fe	K	Mg	Mn	S	Zn	P
	1st	NoLeach	4.3	36	0.9	2.1	6.8	1.2	4.0	3.6	5.5
1.7	1st	Leach	3.3	18	0.8	1.8	5.2	1.0	2.7	2.3	4.2
	Mix	NoLeach	3.1	24	0.9	1.5	4.7	1.2	2.5	2.7	4.0
	Mix	Leach	2.3	12	0.7	1.3	3.1	1.0	1.8	1.8	2.6
	1st	**NoLeach**	**4.3**	**20**	**1.1**	**2.3**	**6.3**	**1.2**	**5.3**	**3.2**	**5.3**
0.7	1st	Leach	3.0	8.3	0.8	1.9	4.6	1.0	3.7	2.1	3.9
	Mix	NoLeach	2.9	12	0.8	1.8	4.2	1.2	2.9	2.4	3.8
	Mix	Leach	2.2	5.9	0.8	1.5	2.9	1.1	2.3	1.8	2.6
Cheese-		NoLeach	3.2	18	0.7	2.6	4.4	1.2	3.5	3.0	3.2
Cloth		Leach	2.7	7.6	0.7	2.2	3.5	1.0	2.9	2.0	2.7
M-3 extractable nutrient in "as-is" biochar (mg kg^{-1})			523	0.3	83.2	603	108	71.7	36.8	6.6	126

Table 1. Enrichment Factor: eff solid-liquid separation and bioc element (M-3) in augmented bi

Parameter	Unit	Augmented Biochar	Non-augmented Biochar
pH		8.4	7.7
CCE	%	2.1 ± 0.2	1.3 ± 0.2
EC	µS cm^{-1}	429 ± 10	378 ± 4
NH_4^+	µg mg^{-1}	33 ± 18	21 ± 7
NO_3^-	µg mg^{-1}	ND†	ND
K^+	µg mg^{-1}	508 ± 36	179 ± 2
Ca^{2+}	µg mg^{-1}	232 ± 1	152 ± 3
Mg^{2+}	µg mg^{-1}	247 ± 32	230 ± 1
Na^+	µg mg^{-1}	140 ± 16	65 ± 5
PO_4^{3-}	µg mg^{-1}	218 ± 4	ND
SO_4^{2-}	µg mg^{-1}	518 ± 33	209 ± 10
Cl^-	µg mg^{-1}	508 ± 17	63 ± 2

Table 2. Selected properties and soluble ion composition (water extraction at 1: 10 ratio) of non-augmented and augmented biochar produced at 0.7mm sieve and NoLeach protocol.

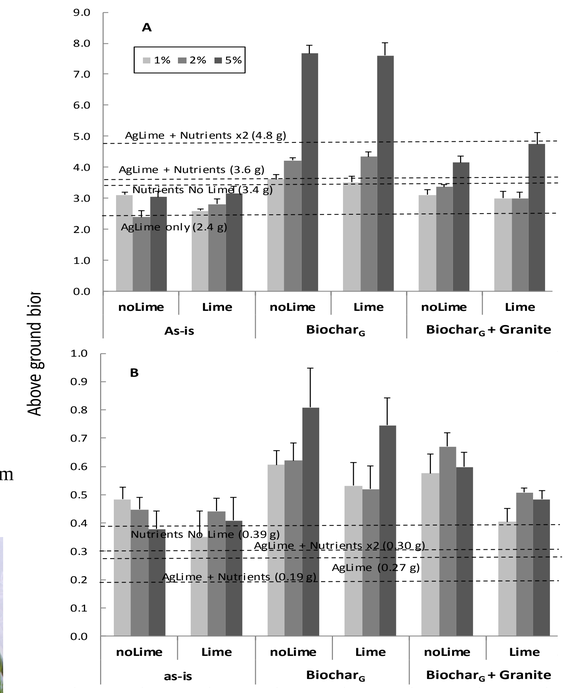

Figure 1. Foxtail millet aboveground biomass during 1st (sum of three harvests; A), and 2nd crop (B). Values of control treatments provided in dissected horizontal lines (i.e. Aglime only, Nutrients no lime, and Aglime + nutrients), vertical lines are one standard error.

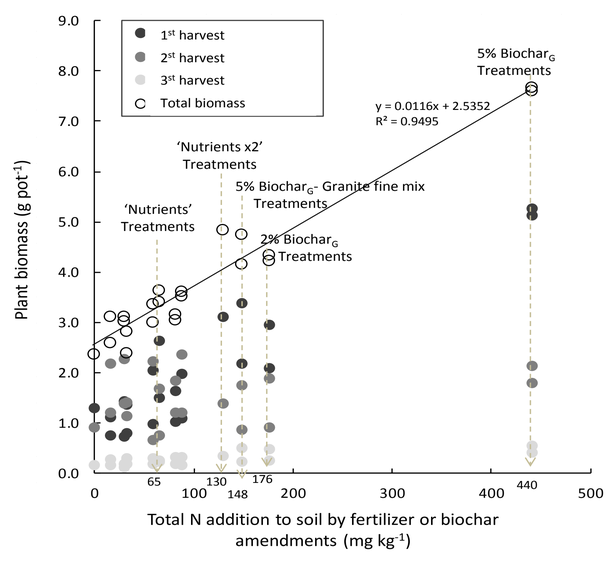

Figure 2. Biomass accumulation at different harvests of first millet crop as a function of total N added by fertilizer or biochar applications. Dissected vertical lines are used to illustrate selected treatment groups based on N source and application rates. The solid black line is a linear regression between total biomass and total N added in biochar treatments (R^2 = 0.9495)

Summary and Conclusions

Fast pyrolysis biochar used as sorbent to remove excess nutrients from solids of anaerobically digested dairy manure. Biochar augmentation increase nutrient content and plant biomass and favorably affected soil properties. Millet yield in $biochar_G$ treatments was higher than in non-loaded biochar. Yield with $biochar_G$ (at 1%) was similar to that of limed and fertilized control treatment while yield with $biochar_G$ (at 5%) more than doubled compared to limed, fertilized controls. Liming had no effect on millet yield in $biochar_G$ treatments.

The results of the study shows that augmenting biochar with manure solids extracts significantly improve biochar and soil fertility. Enhancing biochar P content and improving ratios of available nutrients (namely N/P/K) in the biochar will further improve plant response and nutrient use efficiency.