Biochar Effects on Switchgrass Establishment and Water Quality

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INTRODUCTION

- The continuous depletion of fossil fuel resources and associated climate changes are major incentives for development of renewable, sustainable energy resources, including bioenergy.
- Thermochemical conversion is among the technologies available to generate liquid and gaseous fuels from plant biomass and other biological material.
- Pyrolysis of biomass feedstocks at relatively low temperatures (300-500 °C) in the absence of oxygen produces liquid fuel (termed bio-oil), combustible gases (termed synthesis gas), and a charcoal byproduct (termed biochar).
- The tropical soils of the Amazon, termed Terra Preta, are rich in black carbon or biochar as a result of historic burning of vegetation.
- Increased soil organic carbon and cation exchange capacity (CEC), resistance to microbial degradation (carbon sequestration), increased soil nitrogen retention, and enhanced soil fertility and crop productivity are among the benefits reported for these carbon-rich Terra Preta soils (Liang et al., 2006, Gaskin et al., 2008).
- Intensive biomass production in support of emerging bioenergy systems could deplete soil organic carbon and increase nonpoint-source sediment and nutrient losses from biomass production fields.
- Recycling biochars produced from pyrolysis may provide potential sources of mineral nutrients and organic carbon for sustaining biomass productivity and preserving soil and water quality.
- Yet, research is needed to evaluate biochar properties under varying pyrolysis conditions and verify that recycling pyrolysis biochars will have the same effects on soil properties as documented in the Terra Preta soils.

OBJECTIVES

- Evaluate the effects of biochar rate and supplemental fertilizer on soil physical, chemical, and biological properties and switchgrass seedling establishment and plant coverage of two contrasting soil types.
- Compare the runoff and leaching losses of water, sediment, and nutrients during switchgrass establishment with and without incorporation of biochar and supplemental fertilizer nutrients in two contrasting soil types.

MATERIALS AND METHODS

- Corn stover biomass was pyrolyzed at 550 °C through an auger-fed, fixed-bed pyrolyzer.
- Four rates of biochar (0, 4, 16, and 64 Mg ha^{-1}) with and without nitrogen (N), phosphorus (P), and potassium (K) fertilizer were incorporated in a Boonville fine sandy loam soil and a Burleson clay soil (soils studied in separate experiments under greenhouse conditions).
- N, P, and K fertilizer rates were 50, 100, and 200 kg ha^{-1}, respectively.
- Three replications of the eight treatments were installed in box lysimeters (45 x 33 x 15 cm).
- Alamo switchgrass was seeded at a rate of 1240 seeds m^{-2}.
- Prior to seeding, soil and biochar were sampled to quantify total and extractable forms of N, P, K, and organic C.
- Simulated rain from an oscillating, indoor multiple intensity rainfall simulator was applied at a rate of approximately 10 cm hr^{-1} at 50% and 100% switchgrass leaf coverage of the soil (Figure 1).
- Runoff was collected from flumes mounted on the front of each lysimeter box over a 24-minute period (Figure 2).

Table 1. Summary of the eight treatment packed into lysimeter boxes for both the Boonville fine sandy loam and Burleson clay experiments.

Treatment Abbreviation	Biochar Rate	N Rate	P Rate	K Rate
	Mg ha^{-1}	-------------- kg ha^{-1} --------------		
0 Char	0	0	0	0
4 Char	4	0	0	0
16 Char	16	0	0	0
64 Char	64	0	0	0
0 Char+NPK	0	50	100	200
4 Char+NPK	4	50	100	200
16 Char+NPK	16	50	100	200
64 Char+NPK	64	50	100	200

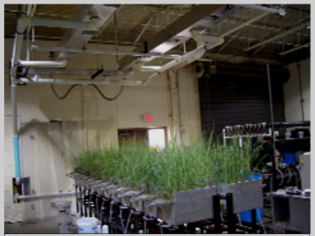

Figure 1. Box lysimeters mounted within a metal frame beneath the rainfall simulator.

Figure 2. Collection system for rainfall runoff.

MATERIALS AND METHODS (Continued)

- Runoff volumes were measured and sampled at 8-minute intervals and composited for sampling on each rainfall date.
- Runoff samples were filtered (<0.45 µm) and analyzed within 24 hours.
- Soluble reactive P (SRP) and inorganic N (NH_4 and NO_3) in runoff filtrate were determined colorimetrically.
- ICP analysis was used to measure total dissolved P (TDP) and K (DK) in runoff filtrate.
- Concentrations of total P and K in unfiltered composite samples of runoff were determined through a nitric acid digest followed by ICP analysis. A LiquiTOC analyzer measured total N and C.
- Following the second rain event (100% switchgrass coverage), leaf area and dry weight of above-ground switchgrass were measured and total N, P, and K in the biomass were analyzed.
- Two soil cores (6-cm diameter) were removed, separated into 0- to 5-cm and 5- to 15-cm depths, and dried for analysis of total C and N and total and extractable P and K.

RESULTS AND DISCUSSION

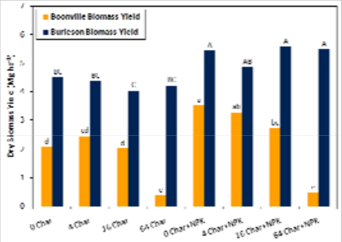

Figure 3. Switchgrass dry biomass yield of the 8 treatments for both the Boonville and Burleson soils.

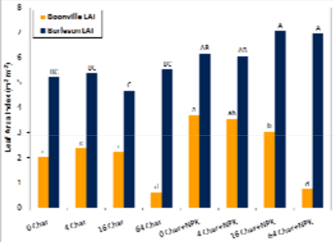

Figure 4. Switchgrass leaf area index (LAI) at harvest for the 8 treatments for both the Boonville and Burleson soils.

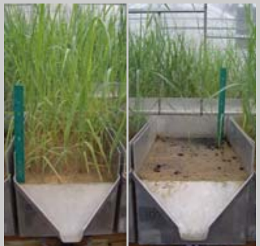

Figure 5. Switchgrass biomass with 0 Mg ha^{-1} char(left) and 64 Mg ha^{-1} char (right) after the 2nd rain event for the Boonville sandy loam.

Figure 6. Switchgrass biomass after the 2nd rain event for the Burleson clay soil.

- Switchgrass germination was very low (15%) in the Boonville soil amended with 64 Mg ha^{-1} char.
- Both dry biomass yield and leaf area index were greater in the Burleson soil than the Boonville.
- The addition of N, P, and K fertilizer significantly increased biomass yield and leaf area index except for the 64 Mg ha^{-1} biochar rate in the Boonville sandy loam soil (Figures 3 and 4).
- Contrary to previous studies showing increased crop productivity as a result of biochar application to degraded soils, the corn stover biochar in this experiment significantly inhibited the germination of switchgrass in the sandy loam soil.
- Inorganic fertilizer increased N,P, and K uptake in harvested switchgrass biomass (Table 2).
- Biochar rates > 4 Mg ha^{-1} increased soil pH, WEP, and SOC concentrations (Table 3).

Table 2. Total N, P, and K nutrient concentrations of switchgrass biomass collected following the 2nd rain event.

	Boonville			Burleson		
Treatment	Total N	Total P	Total K	Total N	Total P	Total K
	----------- g m^{-2} -----------			----------- g m^{-2} -----------		
0 Char	2.4 b	0.26 b	3.2 c	6.6 bcd	1.09 bc	9.5 b
4 Char	2.9 b	0.28 b	4.1 c	6.0 cd	0.97 cd	9.6 b
16 Char	2.9 b	0.28 b	3.7 c	5.5 d	0.89 de	8.9 b
64 Char	1.4 c	0.10 c	1.0 d	5.9 cd	0.76 e	9.6 b
0 Char+NPK	5.4 a	0.53 a	6.6 a	7.6 abc	1.18 ab	12.3 a
4 Char+NPK	5.2 a	0.47 a	6.2 ab	7.3 abcd	1.13 ab	11.9 a
16 Char+NPK	5.1 a	0.46 a	5.3 b	8.1 ab	1.28 a	13.9 a
64 Char+NPK	1.3 c	0.16 c	1.4 d	9.1 a	1.17 ab	13.8 a
P =	0.001	0.001	0.001	0.01	0.001	0.001

Table 3. Analysis of pH, water extractable P (WEP), and soil organic C (SOC) sampled at 0- to 5-cm after the 2nd rain event for each soil.

	Boonville Soil Test 0-5 cm			Burleson Soil Test 0-5 cm		
Treatment	pH	WEP	SOC	pH	WEP	SOC
		mg kg^{-1}	g kg^{-1}		mg kg^{-1}	g kg^{-1}
0 Char	7.7 bc	0.12 d	2.5 d	6.8 c	0.77 e	12.7 d
4 Char	7.9 b	0.08 d	3.8 d	7.0 bc	0.79 de	14.6 d
16 Char	8.0 b	0.22 d	6.0 c	7.0 bc	0.85 de	18.3 c
64 Char	8.6 a	0.78 b	15.8 b	7.4 a	1.93 a	39.5 a
0 Char+NPK	7.6 c	0.58 bc	2.6 d	6.9 c	0.89 de	13.1 d
4 Char+NPK	7.7 bc	0.56 c	3.2 d	7.0 bc	1.35 c	14.6 d
16 Char+NPK	7.9 b	0.68 bc	6.1 c	7.0 bc	0.92 d	19.8 c
64 Char+NPK	8.6 a	1.74 a	17.7 a	7.2 ab	1.72 b	27.6 b
P =	0.001	0.001	0.001	0.01	0.001	0.001

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RESULTS AND DISCUSSION (Continued)

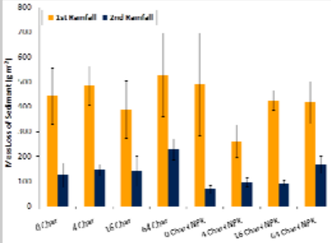

Figure 7. Mass loss of sediment during both rain events for the Boonville soil. Error bars indicate standard error of the mean.

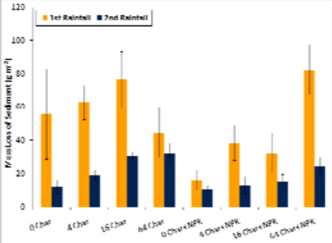

Figure 8. Mass loss of sediment during both rain events for the Burleson soil. Error bars indicate standard error of the mean.

- Sediment loss overall was much higher in the Boonville than the Burleson (Figures 8 and 9) even though there was no significant difference (P > 0.05) in the mass loss of sediment for either soil.
- In both soil types, the first rainfall event generated the most sediment loss due to less leaf coverage of the surface than when the second and final rain event occurred.
- Additions of biochar and fertilizer contributed to increased concentrations of TDP and SRP in runoff in both soils, but had no effect on soluble unreactive P (SUP) in runoff.
- In addition to reduced amounts of sediment loss, the clay soil generally had lower concentrations of TDP and SRP in runoff compared to the sandy loam, especially at the 64 Mg ha^{-1} biochar rate (Table 4). This is partially due to the physical properties of clay soils (i.e. high surface area).

Table 4. Analysis of total dissolved P (TDP), soluble reactive P (SRP), and soluble unreactive P (SUP) in runoff filtrate for each rain event for the Boonville and Burleson soils.

	Boonville Soil						Burleson Soil					
Treatment	TDP		SRP		SUP		TDP		SRP		SUP	
	1st Rain	2nd Rain	1st Rain	2nd Rain	1st Rain	2nd Rain	1st Rain	2nd Rain	1st Rain	2nd Rain	1st Rain	2nd Rain
	---------------------------- mg m^{-2} ----------------------------						---------------------------- mg m^{-2} ----------------------------					
0 Char	7.0 d	6.0 c	0.2 d	0.3 c	6.9 a	5.7 a	10.1 c	4.8 c	5.3 c	3.3 c	4.9 a	1.4 a
4 Char	7.5 d	6.8 c	0.6 cd	0.6 c	6.9 a	6.2 a	11.1 bc	9.3 abc	5.0 c	4.5 bc	6.0 a	4.8 a
16 Char	10.2 cd	6.7 c	1.9 cd	1.1 c	8.3 a	5.6 a	13.7 bc	6.2 bc	7.1 bc	5.2 bc	6.6 a	1.0 a
64 Char	21.0 b	12.1 b	11.5 b	6.9 b	9.4 a	5.2 a	17.5 ab	9.7 abc	10.9 ab	6.3 ab	6.6 a	3.3 a
0 Char+NPK	18.6 bc	8.4 bc	11.7 b	3.6 bc	7.0 a	4.8 a	12.7 bc	8.0 abc	7.0 bc	4.7 bc	5.7 a	3.3 a
4 Char+NPK	13.5 bcd	7.7 bc	7.3 bcd	2.6 bc	6.2 a	5.0 a	12.6 bc	6.9 bc	7.2 bc	5.3 bc	5.4 a	1.6 a
16 Char+NPK	17.4 bcd	10.0 bc	9.0 bc	3.9 bc	8.4 a	6.1 a	12.7 bc	11.3 ab	8.8 bc	6.2 b	3.9 a	5.1 a
64 Char+NPK	35.6 a	26.7 a	25.7 a	20.5 a	10.0 a	6.1 a	21.9 a	13.4 a	13.7 a	8.3 a	8.2 a	5.0 a
P =	0.001	0.001	0.001	0.001	n.s.	n.s.	0.07	0.09	0.02	0.005	n.s.	n.s.

- The highest rate of biochar increased the amount of WEP by 6.5-fold and 2.5-fold in the Boonville and Burleson soils, respectively (Table 3).
- Variation in runoff SRP concentration in both rainfall events was directly related to variation in WEP in the 0- to 5-cm depth, especially in the Boonville soil (Figures 9 and 10).

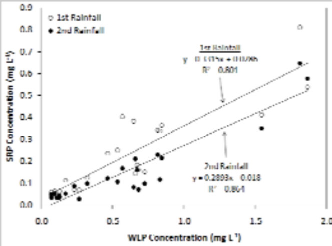

Figure 9. Regression analysis of WEP vs. SRP for each rain event for the Boonville soil.

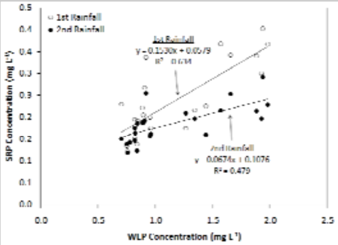

Figure 10. Regression analysis of WEP vs. SRP for each rain event for the Burleson soil.

CONCLUSION

- In this greenhouse experiment, high rates of biochar additions had a detrimental effect on switchgrass germination and establishment in the sandy loam soil, but not the clay.
- Increasing rates of biochar resulted in increases in soil pH, organic C, WEP, and runoff concentrations of SRP in both soil types.
- Concentrations of runoff SRP were directly related to soil WEP, especially in the sandy loam.
- Chemical and physical properties of the this biochar needs to be further examined.

REFERENCES

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