Sodic Soil Reclamation Potential of Flue Gas Desulfurization Gypsum and Biochar Additions

Eric Schultz, Amitava Chatterjee, Tom DeSutter, and Dave Franzen

Department of Soil Science, North Dakota State University, Fargo, North Dakota

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Abstract

Reclamation of sodic soils is proving increasingly vital as greater land area becomes salt-affected in the northern Great Plains of the USA. Along with flue gas desulfurization gypsum (FGDG), organic amendments have been considered, but not extensively studied, for reclamation purposes. In this study, a laboratory incubation experiment was used to assess the potential of FGDG and of biochar, an organic amendment formed through decomposition of organic material, in reclaiming sodic soils through observed soil chemical properties, water retention, and soil respiration changes. A control treatment of sodic soil was compared to sodic soil with addition of FGDG at treatment rates of 33.6 and 67.2 Mg ha^{-1} and biochar at treatment rates of 16.8 and 33.6 Mg ha^{-1}, as well as a combination treatment of FGDG + biochar at a treatment rate of 33.6 Mg ha^{-1} each. Overall, FGDG improved chemical properties while biochar increased soil respiration, and the FGDG + biochar treatment positively influenced almost all observed soil characteristics.

Introduction

- In the northern Great Plains of the USA alone there are 1.9 million ha of Na-affected lands (He, et al., 2015).
- Sodic soils are defined in the United States by a SAR of 13 or greater, an exchangeable sodium percentage (ESP) greater than 15, EC of less than 4 dS m^{-1}, and pH of 8.5 or greater (Richards, 1954).
- There has been recent focus on FGDG, a by-product of wet and semi-dry desulfurization processes of flue gas using limestone in coal-fired power stations, having similar agricultural amendment benefits as mined gypsum (DeSutter and Cihacek, 2009)
- Biochar has improved soil properties of total available water, nutrient availability, total C, and microbial community (Joseph et al., 2010; Lehmann et al., 2011; Rogovska et al., 2014).

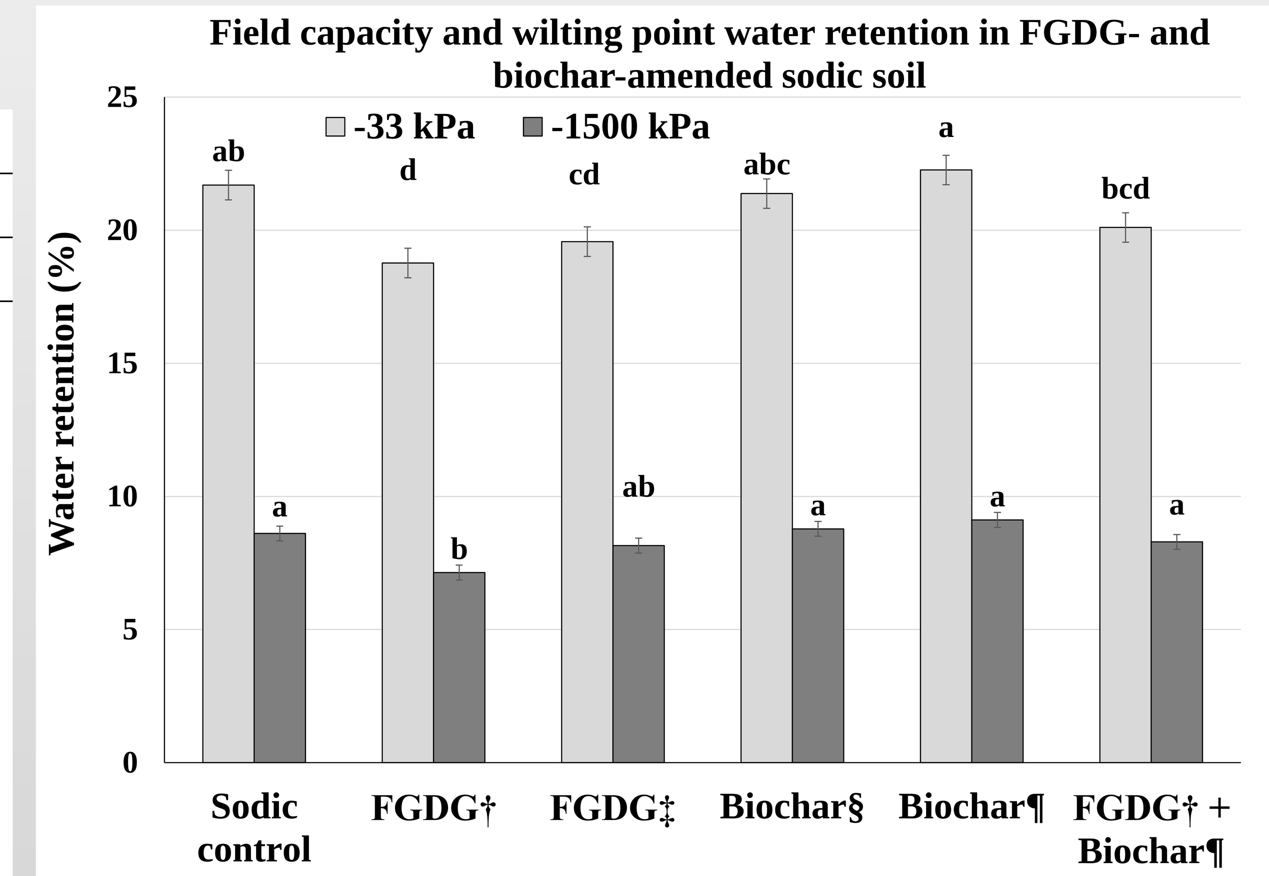
Objectives

1. Evaluate reclamation potential of FGDG and biochar additions to a northern Great Plains (USA) Na-affected soil.
2. Compare FGDG and biochar additions reclamation potential and effects on Na present.

Results

Table 1. Respiration rates (mean ± standard deviation, N=5) of treatments, treatment rate accompanies treatment type(s). Significance shown (*P* <0.05) is within columns for days after incubation.

Treatment	Days after incubation						
	12	19	23	28	32	43	52
	Respiration rate (mg C kg^{-1} soil day^{-1})						
Sodic control	0.16 ± 0.10b	0.25 ± 0.03b	0.11 ± 0.10b	0.17 ± 0.14cd	0.11 ± 0.06d	0.24 ± 0.10bcd	0.13 ± 0.09c
FGDG (33.6 Mg ha^{-1})	0.12 ± 0.11b	0.12 ± 0.09b	0.12 ± 0.12b	0.20 ± 0.11cd	0.12 ± 0.16cd	0.11 ± 0.04d	0.08 ± 0.03c
FGDG (67.2 Mg ha^{-1})	0.16 ± 0.28b	0.18 ± 0.09b	0.14 ± 0.09b	0.04 ± 0.04d	0.09 ± 0.10d	0.13 ± 0.07cd	0.11 ± 0.06c
Biochar (16.8 Mg ha^{-1})	0.58 ± 0.31a	0.54 ± 0.17a	0.46 ± 0.20a	0.33 ± 0.13bc	0.47 ± 0.24ab	0.31 ± 0.20bc	0.35 ± 0.16b
Biochar (33.6 Mg ha^{-1})	0.66 ± 0.43a	0.48 ± 0.25a	0.48 ± 0.14a	0.68 ± 0.18a	0.59 ± 0.21a	0.66 ± 0.26a	0.52 ± 0.10a
FGDG + Biochar (33.6 Mg ha^{-1} ea.)	0.59 ± 0.30a	0.55 ± 0.12a	0.45 ± 0.09a	0.51 ± 0.21ab	0.33 ± 0.15bc	0.38 ± 0.14b	0.37 ± 0.08b
	$P = 0.0078$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$



† Flue gas desulfurization gypsum treatment rate of 33.6 Mg ha^{-1}.
‡ Flue gas desulfurization gypsum treatment rate of 67.2 Mg ha^{-1}.
§ Biochar treatment rate of 16.8 Mg ha^{-1}.
¶ Biochar treatment rate of 33.6 Mg ha^{-1}.

Table 2. Chemical properties (mean ± standard deviation, N=5) for seven treatments.

Treatment	pH	EC_e	SAR_e	TOC
		dS m^{-1}		µg g^{-1}
Sodic control	8.3 ± 0.1b	3.5 ± 0.60b	16 ± 2a	62.2 ± 1.73cd
FGDG (33.6 Mg ha^{-1})	8.0 ± 0.1c	8.4 ± 0.78a	9 ± 3c	50.2 ± 3.57d
FGDG (67.2 Mg ha^{-1})	8.0 ± 0.0c	8.2 ± 0.84a	8 ± 2c	51.2 ± 3.54d
Biochar (16.8 Mg ha^{-1})	8.3 ± 0.1ab	3.4 ± 0.41b	13 ± 2b	81.4 ± 13.9b
Biochar (33.6 Mg ha^{-1})	8.4 ± 0.1a	3.4 ± 0.29b	14 ± 2b	99.5 ± 9.35a
FGDG + Biochar (33.6 Mg ha^{-1} ea.)	8.1 ± 0.0c	7.7 ± 0.56a	9 ± 1c	68.9 ± 15.9bc

Table 3. Cation concentrations (µg g^{-1}) obtained 52 days after incubation (mean ± standard deviation, N=5). Significance shown (*P* <0.05) is within columns.

Treatment	Ca^{2+}	Mg^{2+}	K^+	Na^+
Sodic control	355 ± 23c	247 ± 28a	3.12 ± 0.96c	93.0 ± 21.6a
FGDG (33.6 Mg ha^{-1})	404 ± 50abc	215 ± 21abc	2.45 ± 0.50c	63.0 ± 10.5c
FGDG (67.2 Mg ha^{-1})	436 ± 68a	238 ± 30ab	2.31 ± 0.49c	69.7 ± 18.8bc
Biochar (16.8 Mg ha^{-1})	376 ± 24bc	224 ± 13abc	5.23 ± 0.46b	88.2 ± 14.1ab
Biochar (33.6 Mg ha^{-1})	360 ± 32c	208 ± 14bc	7.64 ± 2.47a	77.7 ± 16.0abc
FGDG + Biochar (33.6 Mg ha^{-1} ea.)	418 ± 49ab	201 ± 40c	5.58 ± 0.83b	57.0 ± 21.6c
	$P = 0.0396$	$P = 0.0762$	$P < 0.0001$	$P = 0.0221$

Materials and Methods

- Soil series: Wyndmere (Coarse-loamy, mixed, superactive, frigid Aeric Calciaquolls).
- Seven treatments: sodic control soil, FGDG treatment rates of 33.6 and 67.2 Mg ha^{-1}, biochar treatment rates of 16.8 and 33.6 Mg ha^{-1}, and FGDG + biochar at 33.6 Mg ha^{-1} each. Completely random design, five replications.
- Soil (< 2mm), amendment (< 1mm), and water (20 percent gravimetric water content) mixed and added to microcosms.
- Cation exchange resin strips placed into 5 cm deep slits in each microcosm (replaced after 28 days).
- Microcosms incubated in the dark at 25 °C.
- PP Systems EGM-4 infra-red gas analyzer equipped with a SRC-1 Soil Respiration Chamber (PP Systems, Amesbury, Ma, USA) used to quantify headspace CO_2 concentration (soil respiration measurements).
- CO_2 efflux measured seven times over duration of the incubation experiment, converted to mg C respired per kg of soil per day.
- Cation concentrations from cation exchange resin strips obtained from 28 days after incubation and 52 days after incubation.
- pH, EC, SAR, TOC, and water retention determined at the conclusion of the 52 day incubation period.

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Summary

- FGDG-treated sodic soil had significant improvements in chemical properties of SAR_e, pH, and EC_e. Biochar significantly reduced the SAR_e and increased the TOC. The FGDG + biochar treatment positively influenced all chemical properties.
- The addition of biochar at both rates substantially increased the soil respiration rate, while the FGDG-treated sodic soils were not significantly different than the sodic control soil throughout the duration of the incubation.
- Treatment rate of FGDG or biochar did not consistently influence any of the measured parameters.
- FGDG + biochar treatment significantly improved chemical properties, Na cation concentration, and soil respiration.

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