INFLUENCE OF AMENDMENTS ON CHEMICAL AND BIOLOGICAL PROPERTIES OF SODIC SOILS

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Maria Christine Breker

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Thomas DeSutter
Chair

Amitava Chatterjee

Abbey Wick

Edward DeKeyser

Approved:

04/14/2016
Date

Francis Casey
Department Chair

ABSTRACT

Improving productivity of sodic soils has become a concern in North Dakota because of the desire for more land for producing crops. Field and incubation studies were conducted to determine the impacts of different amendments (flue-gas desulfurization gypsum, sugar beet processing by-product lime, and langbeinite) on the chemical and biological properties of two sodic soils. The field study evaluated the amendment effects on the chemical conditions of the soil and the impact on alfalfa yield and quality. Differences were not observed in percent sodium (%Na) in the first 17 months and alfalfa yield was not impacted by the treatments except for the high rate of langbeinite. The incubation study investigated the effects of amendments on both the chemical and biological properties of the soil. Spent lime increased the cumulative respiration but was not impacted by gypsum or langbeinite. Labile carbon (C) was negatively correlated with %Na and electrical conductivity (EC).

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DEDICATION

I would like to dedicate this to my parents, Joseph and Patricia Breker, for their love and support throughout this process. Your love for conservation and soils has positively impacted my life. Your constant efforts to improve the health of your soil pushed me to determine solutions to issues in your fields and in our region.

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GENERAL INTRODUCTION

Globally, 832.2 million ha of land is salt-affected and of those, 581 million ha are negatively impacted by sodium (Na; sodic) and have degrading chemical and physical properties that severely inhibit plant growth (Sumner et al., 1998). As the global world population continues to increase, it will be necessary for these unproductive soils to be ameliorated for world food production. In North Dakota there are 1.9 million ha of Na-affected soils. These soils are prone to swelling and dispersion due to excess Na relative to other cations in the soil (Shainberg and Letey, 1984). As a result, degradation and destabilization of structure occurs and consequently contributes to reduced saturated hydraulic conductivity (K_s), high bulk density, crusting, poor aeration, runoff, erosion, and ultimately poor plant productivity (Shainberg and Letey, 1984; Rengasamy and Olsson, 1991; Fitzpatrick et al., 1994; Levy et al., 1998; Nelson and Oades, 1998).

In order to improve the productivity of these soils, appropriate management strategies must be made that include: 1) addition of calcium (Ca) amendments, 2) leaching of salts with water, 3) proper subsoil drainage, and 4) establishment of plants. However, in semi-arid and arid climates, and in dryland farming conditions, water is a limiting factor because the potential evapotranspiration (PET) rates exceed the precipitation rates which limits amelioration time (Rengasamy, 2002). Therefore, site specific sodic soil management in semi-arid and arid climates is needed to provide producers with economically sustainable management options to improve health and productivity of sodic soils.

This thesis is divided into five parts that include the literature review and two research papers that will be submitted for publication to appropriate scientific journals, a general conclusion, and an appendix. The literature review discusses the genesis and identification of sodic soils, their management, and how amendments impact soil biology. The first paper investigates in-field management with amendments, drainage, and alfalfa to evaluate the impacts they have on soil metrics and yield and quality. The second paper investigates how amendments impact the soil biological production of carbon dioxide (CO_2) and consumption of labile C. The general conclusion section provides an overview of significant results from both papers and provides information on strategies for improving the productivity of sodic soils and direction for further research.

LITERATURE REVIEW

Global Sodicity and Genesis

Globally, there are 832.2 million ha of salt-affected soils that are negatively impacting plant growth, and of those soils, 581 million ha are degraded by Na-containing salts (Sumner et al., 1998). Sodium-affected soils are commonly referred to as sodic soils and have poor chemical and physical conditions due to the excess amount of Na relative to other cations on exchange sites and/or in the soil solution (Shainberg and Letey, 1984; Valzano et al., 2001; DeSutter et al., 2015). These soils are found in many areas of the world, most commonly in arid and semi-arid climates such as Australia, North/Central Asia, and parts of North America (Shainberg and Letey, 1984; Sumner et al., 1998). These climates are prone to salt-accumulation in the soil profile due to PET rates exceeding precipitation, consequently accentuating the severity of the problem.

Formation of Salt-Affected Soils

The formation of sodic soils occurs in a three phase process: 1) salinization, 2) solonization, and 3) solodization (Kellogg, 1934; Bui et al., 1998; Schaetzl and Anderson, 2005). Canadian taxonomy includes four groups of solonetzic soils and these are recognized in order as alkali solonetz, solonetz, solodized solonetz, and solod (Bowser et al., 1962). The variation of different phases across a landscape can be found in order of solod, solodized solonetz, and solonetz from the hillcrest to the footslope (Munn and Boehm, 1983; Miller and Pawluk, 1994) or in reverse order (Anderson, 1987). The high variability of sodic soils is influenced by landscape position and water regime, and found on the landscape where there is a high evaporative demand (Seelig, 1989).

The first phase, salinization, also termed as solonchak or alkali solonetz, is the accumulation of soluble salts at or near the surface of the soil. Salinization can occur by many different processes which include contribution from inherently salt-rich parent materials, groundwater discharge and capillary rise of saline water tables, and secondary sources such as saline seeps, salinization along road ditches, lagoon margins, wetland drainage, and irrigation (Henry et al., 1985; Skarie et al., 1986; Fullerton and Pawluk, 1987). When salts accumulate from capillary rise, calcite followed by gypsum precipitate first lower in the profile and the salts more soluble than gypsum, such as Na-sulfate salts, precipitate at or near the soil surface (Reid et al., 1993). When Na-containing salts are present, monovalent (Na) cations begin to replace divalent cations (Ca or Mg); however, the soil remains flocculated and maintains water movement because of the elevated electrolyte concentration (often measured as electrical conductivity; EC) (Kellogg, 1934; Miller and Brierley, 2011). As a result of osmotic stress from high EC, these areas may become devoid of vegetation and are then prone to wind and water erosion, further exacerbating the surface evaporation and deposition of Na-salts in the upper soil horizons (Reid et al., 1993). These areas have been referred to as "physiologic deserts" (Hopkins et al., 1991).

A transition from salinization to solonization occurs when the soil solution's EC is lowered (desalinization) due to leaching, and Na ions remain on the exchange sites of clay particles, initiating alkalization (Kellogg, 1934; Miller and Brierley, 2011). In this stage, soil colloids are deflocculated (dispersed) and become mobile in the soil and form a solonetz soil (Kellogg, 1934). The mobile clay particles then clog soil pores which severely restrict downward water movement (Sumner, 1993). The mobilization of clay also results in a sharp textural change between the A and B horizons (Bui et al., 1998) and when soluble salts and gypsum crystals are visible within 40 cm of the mineral soil surface, the subgroup is defined as “leptic” (Soil Survey Staff, 1999).

The third phase is solodization. In this phase, solodized solonetz have very slow water permeability, and eluviation continues to move dispersed colloids lower in the soil profile creating hard columnar structures, thus creating an E horizon (eluvial zone) just above the columns (Kellogg, 1934; Bui et al., 1998). In the E horizon, the exchange capacity of the soil is lessened, and because of an increase in exchangeable hydrogen, the pH decreases (Schaetzl and Anderson, 2005). At the end of the final phase of sodic soil formation, Na is no longer replenished in the Btn horizon by capillary rise, and with vigorous vegetation growth and replenishing of Ca, the columns begin to weather and breakdown, in which the soil is then referred to as a solod (Miller and Brierley, 2011). The subgroup “glossic” is a result of the degradation of an argillic and natric horizon, and the “interfingering” of albic materials into the natric and argillic horizon (Soil Survey Staff, 1999). Consequently, deeper eluviation occurs, further reducing the pH and developing a more productive soil, such as a chernozem (mollisol) (Anderson, 1987).

Sodic Soil Identification and Properties

The United States identifies and characterizes salt-affected soils with four different classes 1) normal, 2) saline, 3) sodic, and 4) saline-sodic. The criteria are dependent upon EC of a saturated paste extract (ECe), exchangeable sodium percentage (ESP), sodium adsorption ratio of a saturated paste extract (SARe), and pH. Sodic soils have an ECe <4 dS m^{-1}, ESP >15%, SARe >12, and pH >8.5 and saline-sodic soils have an ECe >4 dS m^{-1}, ESP >15%, SARe >12, and pH >8.5 (USDA, 1954). Australia utilizes a lower ESP value of greater than 5 to characterize sodic soils (McIntyre, 1979). Recent research conducted in the northern Great Plains (NGP) of the United States has discovered that degrading effects of Na and EC occur at a SARe >5 when the ECe is <2 (He et al., 2015). Similar to Suarez et al. (2008), where saturated hydraulic conductivity (K_s) decreased with applications of low SAR (4) irrigation water with EC values less than 2 dS m^{-1}.

A new Na measurement (%Na) has been adopted in the NGP that is highly correlated with SAR (DeSutter et al., 2015). The main reason for finding a new method was because %Na test takes less time to complete than SAR and the cost is much more reasonable (DeSutter et al., 2015). Sodium adsorption ratio only takes into account the cations in solution (U.S. Salinity Laboratory Staff, 1954), where %Na is both solution and exchanger phase (DeSutter et al, 2015). Percent Na is analyzed by extracting Ca, Mg, K, and Na using either a 1:10 or 1:20 ratio of Soil to 1M ammonium acetate at a pH = 7, and is expressed as:

$$\%Na = \frac{100Na}{Ca+Mg+Na+K} \qquad [1]$$

Where cations are in units of cmol(+) kg^{-1} (DeSutter et al., 2015).

The United States Department of Agriculture – Natural Resources Conservation Service uses taxonomy to classify soils (Soil Survey Staff, 2014). Sodic soils are classified by a Natric horizon or in the field, identified by a Btn horizon. In order to identify and classify a Natric horizon, characteristics must include an argillic horizon accelerated by the dispersive properties of Na (Soil Survey Staff, 2014). To classify as a Natric horizon, it must 1) meet a thickness requirement, 2) have evidence of clay illuviation, and 3) contain more clay in the illuvial horizon than in the eluvial horizon (Soil Survey Staff, 2014). The horizon must also have structural columns or prisms; or both blocky structure and eluvial materials (Soil Survey Staff, 2014). The chemical properties of the horizon must have a SAR $\geq$ 13 within 40 cm of its upper boundary; or more Mg plus Na than Ca plus exchange acidity (pH 8.2) within 40 cm of its upper boundary if

SAR $\geq$ 13 within 200 cm of the mineral soil surface (Soil Survey Staff, 2014). If the lower values mentioned above are used for assessing sodic soils (i.e. SARe >5), the land area affected by sodic soils in the United States would greatly increase, especially in regions in the NGP where Na-salts are common.

The existence of Na on the exchange sites of clay and organic matter can result in swelling and dispersion at low values of EC. Swelling occurs upon wetting of the soil when the repulsion forces are greater than the attraction forces expanding the diffuse-double layer of clay particles (Essington, 2004). Dispersion will occur if hydration continues and the equilibrium state of the two forces is broken (Rengasamy and Sumner, 1998). As a result, degradation and destabilization of soil structure occurs and consequently contributes to reduced K_s, high bulk density, crusting, poor aeration, runoff, erosion, and ultimately poor plant productivity (Shainberg and Letey, 1984; Rengasamy and Olsson, 1991; Fitzpatrick et al., 1994; Levy et al., 1998; Nelson and Oades, 1998). Therefore, Na-affected soils require high levels of management to improve their productivity.

Sodic Soil Management

The goal of sodic soil management is to improve productivity and reduce swelling and dispersion by the removal of Na from the soil profile while still maintaining an EC that will keep the soil flocculated (Qadir et al., 2001). Amelioration methods include physical, biological, chemical, and hydrotechnical approaches (FAO, 1973). Physical methods include deep plowing, subsoiling, and profile inversion. These methods are most successful with breaking up compaction layers and utilizing gypsum or lime that may be present in the subsoil, such as those found in Leptic soils. In southeastern Oregon, a saline-sodic soil was reclaimed in a 4-year period by deep plowing and irrigation, and wheat (*Triticum aesativum*) and barley (*Hordeum* *vulgare*) yields were increased by 330% in the first year and the alfalfa (*Medicago sativa*) yield was increased by 380% in the second year (Rasmussen et al., 1972). Additionally, water intake was increased by 230% and at the end of the third cropping year the ESP was at the same level as the deep plowing plus gypsum treatment. Another long term study was conducted in Alberta, Canada, that used deep plowing to ameliorate sodic soils and after 11, 12, and 20 years crop yields were significantly improved by 44, 43, and 16%, respectively, compared to the untreated control (McAndrew and Malhi, 1990). The Rhoades and Wade series in western North Dakota are both formed on saline parent materials and have high ESP; however, management using deep tillage (30-60 cm) would suffice for the Rhoades series, but deep tillage and drainage would need to be used to improve the Wade series (Sandoval and Reichman, 1971).

Biological methods include bioremediation or phytoremediation, which use plant root respiration and microbial respiration to increase CO_2 partial pressure to improve lime dissolution, and improve the soil structure due to root growth (Qadir and Oster, 2002). A field experiment conducted on a saline-sodic soil with flood irrigation in California had a crop rotation of two years barley, one year sweet-clover (*Melilotus indicus*), one year white sweet-clover (*Melilotus albus*), followed by five years of alfalfa (Kelley and Brown, 1934). After the alfalfa, cotton (*Gossypium hirsutum*) was grown and yielded 2.1 Mg ha^{-1} on the bioremediated soils as compared to the gypsum treatment that yielded 1.82 Mg ha^{-1}. The ESP in the upper 30 cm also decreased from 65 to 6 in the bioremediated plots and decreased from 70 to 5 in the gypsum-treated plots. This study indicates the effectiveness of plants to help improve soil function and productivity compared to gypsum, albeit under irrigated conditions.

Another way to improve biological activity in the soil includes the addition of manure or other sources high in organic matter to increase CO_2 respiration by introducing substrates (FAO, 1973). A lysimeter study was conducted on a calcareous sodic soil with both cropped and non-cropped treatments, where treatments included 50 Mg ha^{-1} of chopped alfalfa and fresh manure added into the top 20 cm of the soil and alfalfa, cotton, and sudan grass hybrid (*Sorghum sudanese*) planted as crops (Robbins, 1986). In result, the non-cropped Na-removal efficiency order was chopped alfalfa > manure > check, and for cropped treatments; sudan grass hybrid > alfalfa > cotton. Biological amelioration may not be as effective in the short-term as chemical amendments, but in the long-term may be more economical and have better biological and physical health benefits than chemically-ameliorated soils (Qadir and Oster, 2002).

The most common method for sodic soil production improvement is by the addition of chemical amendments which are used to reduce the poor chemical and physical conditions by increasing the EC and exchanging divalent cations for Na (Qadir and Oster, 2004). However, this method can become costly for farmers (Ahmad et al., 1990) as gypsum costs approximately $220 Mg^{-1} (A. Hoiberg, Personal Communication, 2016). Chemical ameliorants can be separated into three categories 1) soluble Ca salts, 2) slowly soluble Ca compounds, and 3) acidifying materials (FAO, 1973). The acidifying materials can either be acid or have acid-forming properties that improve the dissolution of natural lime for Ca to become available to exchange with Na (Abrol et al., 1988). Table 1 shows common chemical amendments used in sodic soil amelioration, their chemical composition, and the reaction that takes place in the soil after application. Factors to consider when choosing amendments are their solubility, surface areas, cost, and how much time and money are needed to improve soils to provide an economic gain in five or ten years (FAO, 1973; Abrol et al., 1988).

Table 1. Sodic soil amendments and chemical reaction in the soil. Adapted from (Abrol et al., 1988) and amended.

Amendment	Chemical	Reaction in Soil
Calcium Carbonate	$CaCO_3$	$Na,H - X + CaCO_3 \leftrightarrow CaX_2 + NaHCO_3$
Calcium Chloride	$CaCl_2 \cdot 2H_2O$	$Na_2CO_3 + CaCl_2 \leftrightarrow CaCO_3 + 2NaCl\ (leachable)$ $2NaX + CaCl_2 \leftrightarrow CaX_2 + 2NaCl\ (leachable)$
Gypsum	$CaSO_4 \cdot 2H_2O$	$Na_2CO_3 + CaSO_4 \leftrightarrow CaCO_3 + NaSO_4\ (leachable)$ $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4\ (leachable)$
Iron or Aluminum Sulfate	$FeSO_4 \cdot 7H_2O$ or $Al_2(SO_4)_3 \cdot 18H_2O$	$FeSO_4 + 2H_2O \leftrightarrow H_2SO_4 + Fe(OH)_2$ $CaCO_3 + H_2SO_4 \leftrightarrow CaSO_4 + H_2O + CO_2$ $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4\ (leachable)$
Langbeinite	$K_2SO_4 \cdot 2MgSO_4$	$2NaX + K_2SO_4 \leftrightarrow 2KX + Na_2SO_4\ (leachable)$ $4NaX + 2MgSO_4 \leftrightarrow 2MgX_2 + 2Na_2SO_4\ (leachable)$
Sulfur	S	$2S + 3O_2 \rightarrow 2SO_3\ (Microbial\ oxidation)$ $SO_3 + H_2O = H_2SO_4$ $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + H_2O + CO_2$ $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4\ (leachable)$
Sulphuric Acid	H_2SO_4	$Na_2CO_3 + H_2SO_4 \leftrightarrow CO_2 + H_2O + NaSO_4\ (leachable)$ $CaCO_3 + H_2SO_4 \leftrightarrow CaSO_4 + H_2O + CO_2$ $2NaX + CaSO_4 \leftrightarrow CaX_2 + Na_2SO_4\ (leachable)$

Hydrotechnical amelioration involves leaching and drainage for removal of soluble salts and Na (FAO, 1973). Downward moving water is important for leaching Na and soluble salts lower into the soil profile, commonly assisted by the application of irrigation water (FAO, 1973). If soil drainage is poor, subsurface drainage may be necessary to remove salts and Na from the soil profile (Rengasamy and Olsson, 1993). A 3-year saline-sodic soil field experiment was conducted in Pakistan utilizing low-quality irrigation water (EC 2.7 dS m^{-1} and SAR 8.0) and tile drainage for salt leaching, finding that the most effective treatment was the 100% gypsum requirement (GR) + *Sesbania aculeata* with a wheat and rice (*Oryza sativa*) rotation (Ghafoor et al., 2012). The treatment improved the infiltration rate which improved the salt removal efficiency by reducing both EC (24 to 4.6 dS m^{-1}) and SAR (120 to 19). This study worked very well for amelioration, however, in many cases, irrigation may not be available. Therefore, sodic soil amelioration in arid and semi-arid climates where the PET rate exceeds the precipitation rate may take much longer for meaningful results to appear.

For the best results, sodic soil amelioration studies that use a combination of various amelioration methods tend to be the most successful. Therefore, four criteria that are important for sodic soil management are: 1) a source of Ca, 2) a source of downward moving high quality water, 3) proper subsoil drainage, and 4) establishment of plants. Although these criteria aid in the amelioration process, there are many other soil properties and aspects to consider, such as depth of soil to be ameliorated, presence of compacted layers, type and amount of salts present, presence of gypsum or lime in the soil, clay minerology, amendment availability and cost, type of crop grown, climate, and time for amelioration (Qadir et al., 2001). Determining the efficiency of different amendments and amelioration methods in a semi-arid climate under dryland conditions will help producers determine which methods would be economically feasible for land improvement.

Gypsum

Gypsum ($CaSO_4 \cdot 2H_2O$) is the most commonly used amendment for sodic soil amelioration (Shainberg et al., 1989). In addition, gypsum increases the soil water EC which is important for reducing swelling and dispersion. The increase of EC is dependent on the amount of gypsum applied, the soil water content, Ca-Na exchange efficiency, and leaching (Gupta and Abrol, 1990). However, the extent of the increase of EC is not likely to be detrimental to plant health because a saturated solution of gypsum only reaches approximately 2.2 dS m^{-1} (Bernstein, 1975). Another factor to consider is the dissolution rate which is dependent on the surface area of the gypsum, purity of the gypsum, and solution flow velocity (Keren and Shainberg, 1981; Keren and O'Connor, 1982; Gupta and Abrol, 1990). Laboratory grade gypsum has a solubility in water of 2.1 g L^{-1} at 20 C whereas, flue-gas desulfurization gypsum (FGDG) has a slightly higher solubility of 2.6 g L^{-1} (Bolan et al., 1991). Flue-gas desulfurization gypsum is produced from electrical coal power plants as a means to reduce sulfur emissions (Punshon et al., 1999).

Many laboratory and field studies have reported improvements in both physical and chemical properties after gypsum use. Benefits include improved water and air permeability (Carter et al., 1978; Keren and Shainberg, 1981; Ilyas et al., 1993; Yu et al., 2014b), reduced surface crusting (Keren and Shainberg, 1981; Gal et al., 1984), improved flocculation (Chartres et al, 1985) and aggregate stability (Chi et al., 2012), and decreased SAR or ESP (Khosla et al., 1979; Ahmad et al., 1990; Qadir et al., 1996; Ilyas et al., 1997; Valzano et al., 2001; Hanay et al., 2004; Clark et al., 2007; Chi et al., 2012). Improvements in soil properties depend on the severity of the situation, the amount of gypsum applied, and the time needed for change to occur.

In many ways, laboratory studies help in aiding the selection of amelioration methods for use in the field. However, field conditions cannot be controlled as easily as in the laboratory, and, for example, permeability studies may not be as easily repeatable in field conditions, although their chemical theories would hold true. Because the effect of plant roots, plant cover, manure, mechanical treatments and soil variability cannot be replicated easily in the laboratory, field studies are required to evaluate the effectiveness of laboratory treatments and observations (FAO, 1973).

Reported in Table 2 are results from dryland field studies where gypsum has been applied to sodic soils. Although many studies exist, of these, many are laboratory experiments or field irrigation studies that are not necessarily indicative of dryland field studies. Calcium carbonate and langbeinite are also included in the table which are less commonly used than gypsum. Most studies have been done outside of the USA and the gypsum rates have ranged from 0.9 to 71.4 Mg ha^{-1}. The greatest decreases in Na metrics (SAR or ESP) were observed in the studies using the highest gypsum rates and over the longest time periods. Smaller, or no observed changes occurred when the rate of gypsum was low and the study periods short. Overall, gypsum efficiency is dependent on the rate of application, the duration of study, and the amount of water available to solubilize gypsum and provide mobility of Na to lower horizons.

Table 2. Field experiment results of applications of gypsum, calcium carbonate and langbeinite on semi-arid and arid dry-land sodic soils.

Amendment†	Rate	Crop	Time‡	Depth§	Na¶	EC#	pH††	Country	Reference
	---Mg ha^{-1}---			---cm---	---% I or D---		± pH units		
G	9.1	Wheat-safflower-canola	2.5 y	7.5	48.6‡‡	-87.8	-0.3§§	Australia	Valzano et al., 2001a
G	0.9	Wheat	12 m	5.0	9.1	-347	-0.3	Australia	Valzano et al., 2001b
G	2.3	Wheat	12 m	5.0	32.5	-317	-0.4	Australia	Valzano et al., 2001b
G	4.5	Wheat	12 m	5.0	37.7	-1466	-0.5	Australia	Valzano et al., 2001b
CC	0.9	Wheat	12 m	5.0	-7.8	-83.5	+0.6	Australia	Valzano et al., 2001b
CC	2.3	Wheat	12 m	5.0	6.5	-134	+0.9	Australia	Valzano et al., 2001b
CC	4.5	Wheat	12 m	5.0	33.8	-276	+1.3	Australia	Valzano et al., 2001b
G	4.5	Rangeland	12 y	5.0	-7.7	26.9	+0.1	Australia	Bennett et al., 2014
CC	4.5	Rangeland	12 y	5.0	30.8	0.0	+0.1	Australia	Bennett et al., 2014
G	10.2 – ann. ¶¶	Bromegrass	7 y	Ap	94.1	NA	-0.4	Canada	Carter et al., 1978
G	10.2 – ann.	Bromegrass	7 y	Ap	90.5	NA	-0.7	Canada	Carter et al., 1978
G	71.4 - total	Bromegrass	11 y	Ap	90.5	-31.6	-1.1	Canada	Carter, 1986
G	11.9 and 5.8	8-way grass mix	1 y	15.0	0.0##	-20.8	NA	USA	Day, 2014†††
G	11.9 and 5.8	8-way grass mix	2 y	15.0	0.0	-31.6	0.0	USA	Day, 2014
L	32.5 and11.0	8-way grass mix	1 y	15.0	0.0	-95.8	NA	USA	Day, 2014
L	32.5 and11.0	8-way grass mix	2 y	15.0	0.0	-138.7	-0.3	USA	Day, 2014

† G = gypsum; L = langbeinite; CC = calcium carbonate
‡ y = year; m = month
§ Ap = Ap soil horizon with no designated depth
¶ ESP or SAR
# ECe, EC1:1
†† pHe, pH1:1, pH1:5
‡‡ For both Na and EC % increase (I) or decrease (D) is calculated as i = initial, f = final: ((i – f) / i) x 100 where negative values indicate an increase and positive values indicate and decrease
§§ pH is ± unit values
¶¶ Rate of amendment applied annually
Values were not significantly different from the control and not reported
††† Values estimated from bar graph

Langbeinite

Langbeinite is less commonly researched than gypsum as a sodic soil amendment and has had positive results regarding the exchange and removal of Na. The cost of langbeinite is $510 Mg^{-1} (S. Koch, Personal Communication, Mosaic, 2016), which is two times the price of gypsum. However, langbeinite is highly soluble (280 g L^{-1}) (Aydemir and Najjar, 2005) and therefore requires less water than gypsum or lime for dissolution, which makes this amendment attractive for sodic soil amelioration in arid and semi-arid climates. The main constituents of langbeinite include 21.5% K_2O, 10.5% Mg, and 22% S ($K_2SO_4 \cdot 2MgSO_4$). Most studies that have used langbeinite as a potential amendment have been within columns in the laboratory (Heluf, 1995; Alsharari, 1999; Artiola et al., 2000; Aydemir and Najjar, 2005). For instance, langbeinite applied at 18.1 Mg ha^{-1} lowered ESP from 24.9 to 4.5%, but overall, gypsum applied at 16.3 Mg ha^{-1} increased the infiltration rate more than langbeinite while only decreasing ESP from 24.9 to 14.5% (Heluf, 1995). These results indicate the high flocculating potential of Ca and the potential swelling or dispersive properties of K and Mg. However, He et al. (2013) found that Mg had the same flocculating abilities as Ca in soils dominated with montmorillonite, illite, and kaolinite. Langbeinite and gypsum have also been found to comparably reduce sodic conditions and increase K_s (Aydemir and Najjar, 2005). Improved short-term movement of water using langbeinite compared to gypsum was attributed to its high solubility and thus less water and time needed for Na replacement from exchange sites.

Few field studies have been conducted but Day (2014) reported from Wyoming that after two years there were no differences in ESP between langbeinite treatments and the control (Table 2). However, langbeinite significantly increased $EC_{1:1}$ (soil:water ratio) from 4 to 9 dS m^{-1} and provided an improvement in soil structure. Day concluded that not enough precipitation occurred for the amendment to improve soil conditions which points to the limitations of many studies located in arid and semi-arid environments, even with highly soluble amendments.

Calcium Carbonate

Calcium carbonate is very insoluble (0.06 g L^{-1}) (FAO, 1973) but, given its natural accumulation in soil, strategies have been used to capitalize on its Ca-providing potential. There are two ways to improve the dissolution of *in situ* lime: 1) increasing the CO_2 partial pressure of the soil by either plant root respiration or adding C amendments that increase microbial respiration and thus decreasing pH and solubilizing lime (Gupta and Karan, 1985; Gupta et al., 1989; Qadir et al., 2003b), or 2) adding a chemical amendment that acidifies the soil (Abrol et al., 1988). Deliberate application of lime for sodic soil improvement has also been done, with and without the additional strategies listed above. The low solubility of calcium carbonate does not allow for improved efficiency compared to gypsum but cost and availability may be overriding variables. However, lime has been shown to provide longer-term results than gypsum, but at a soil pH of 6.1 (Bennett et al., 2014). At higher pH, calcium carbonate may not be as effective as its dissolution threshold is 8.3 (Bennett et al., 2014).

A readily available by-product lime source in the Red River Valley (RRV) of North Dakota and Minnesota is sugar beet spent lime, and is being produced at a total of approximately 453,000 Mg annually at seven processing facilities (Sims et al., 2006). The cost of spent lime is \$2.20 Mg^{-1} or is free at some facilities (A. Sawatzky, Personal communication, American Crystal Sugar Co., 2016). In the process of sugar refining, lime and heat are used to coagulate and flocculate suspended solids and impurities to form macrofloc particles that are not reused in the process and become waste (McDill, 1947; Doherty and Edye, 1999). The by-product is high in organics (McDill, 1947) and plant nutrients such as N, P, and K, with concentrations as high as

5,100, 7,200, and 4,307 mg kg^{-1}, respectively (Sims et al., 2006). Not only does spent lime contain essential crop nutrients, but it also reduces root rot disease pressure from *Aphanomyces cochlioides* (Windels et al., 2008) and can aid in increasing soil pH (DeSutter and Godsey, 2010).

Alfalfa

Alfalfa is a deep rooted perennial forage crop that has been suggested for improving infiltration rates in soils with poor structure (Meek et al., 1989, 1990; Ilyas et al., 1993; Mitchell et al., 1995) and has been used in many sodic and saline-sodic soil experiments (Kelley and Brown, 1934; Robbins, 1986; Qadir et al., 1992, 2003a; b; Ilyas et al., 1993, 1997; Ahmad et al., 2006; Zia et al., 2007; Chatterjee et al., 2014). Alfalfa is a forage crop and guidelines are used to report its quality based on crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), relative feed value (RFV), and total digestible nutrients (TDN) (Table 3) (Putnam et al., 2008).

Table 3. USDA alfalfa quality guidelines (Putnam et al., 2008).

Category	**CP**	**ADF**	**NDF**	**RFV†**	**TDN‡**
	----------	----------	%	----------	----------
Supreme	>22	<27	<34	>185	>55.9
Premium	20-22	27-29	34-36	170-185	54.5-55.9
Good	18-20	29-32	36-40	150-170	52.5-54.5
Fair	16-18	32-35	40-44	130-150	50.5-52.5
Utility	<16	>35	>44	<100	<50.5

†RFV is calculated as: RFV = [88.9-(.779 x %ADF)] x [120/ %NDF)/1.29]
‡TDN (90% DM) = TDN x 0.09

Due to its moderate tolerance to salinity, alfalfa can withstand an ECe of 2 to 3.5 dS m^{-1} with no yield decline but higher soil ECe (8-9 dS m^{-1}) can decrease yields by 50% (Bernstein, 1975). In a sodic soil-Na removal experiment that included treatments of alfalfa, alfalfa fertilized with NH_4NO_3, and application of sulfuric acid or gypsum resulted in Na removal in this order: sulfuric acid > gypsum ≈ alfalfa > NH_4NO_3-fed alfalfa > control (Qadir et al., 2003a). Therefore, coupling amendments with a perennial crop such as alfalfa may provide improved soil conditions by accumulation of organic matter into the soil, improved drainage, and translocation of natural Ca from lower soil horizons which may ultimately aid in sodic soil productivity improvement.

Amendment Impacts on Soil Biology

Soil biology plays many important roles in soil that range from organic matter decomposition to soil structural stabilization (Lee and Pankhurst, 1992). A commonly used method for determining soil biological health has been to quantify CO_2 evolution from microbial and root respiration (Stotzky, 1965). The impact of the application of amendments on sodic soil biology is a much less studied topic and results have been mixed, although most studies have concluded no significant differences and only a few have reported positive impacts (Table 4) (Carter, 1986; Clark et al., 2007; Wong et al., 2009; Celis et al., 2013; Yazdanpanah et al., 2013).

Table 4. Initial soil chemical properties for studies involving gypsum additions to naturally sodic and saline-sodic soils and the resultant microbial respiration.

Gypsum Rate	Respiration†	EC	pH	SAR	ESP	Country	Publication
Mg ha^{-1}	% I or D	dS m^{-1}			%		
5.4	17	1.0	6.1	0.8		Canada	Carter, 1986‡
10.9	19	1.0	6.1	0.8		Canada	Carter, 1986‡
5.4	-9.2	1.9	6.1	13.7		Canada	Carter, 1986‡
10.9	16	1.9	6.1	13.7		Canada	Carter, 1986‡
5.4	45	2.0	5.9	3.8		Canada	Carter, 1986‡
10.9	53	2.0	5.9	3.8		Canada	Carter, 1986‡
6.4§	-30	102.6	8.4		75.5	Chile	Celis et al., 2013¶
6.4#	5.0	102.6	8.4		75.5	Chile	Celis et al., 2013¶
9.1	82	1.6	10.2	13.0	50.0	Australia	Wong et al., 2009††
9.1	25	1.7	4.7	1.7	61.0	Australia	Wong et al., 2009††
16.2	44	32.9	6.0		21.4	Australia	Clark et al., 2007‡‡

† the % increase (I) or decrease (D) is calculated as i = initial, f = final: ((i – f) / i) x 100 where negative values indicate an increase and positive values indicate and decrease
‡ ECe, $pH_{1:2.5,}$ SARe
§ Synthetic gypsum
¶ ECe, pHe
# Mined gypsum
†† $EC_{1:5}$, $pH_{1:5}$, $SAR_{1:5}$.Values have been estimated from graphs.
‡‡ $EC_{1:5}$, $pH_{1:5}$

For example, when 9.1 Mg ha^{-1} of gypsum was added to a sodic soil with an $EC_{1:5}$ of 1.7 dS m^{-1} and an ESP of 61, the cumulative respiration of the gypsum treatment and control over a 12 week period were 600 and 800 µg CO_2-C g^{-1} soil, respectively (Wong et al., 2009). Other treatments in this study using gypsum with kangaroo grass (*Themeda australis*) compared to just kangaroo grass had cumulative respirations of 3,300 and 2,000 µg CO_2-C g^{-1} soil, respectively. Gypsum alone can improve soil chemical and physical properties but with the addition of high C containing amendments the soil biological activity can be improved. For example, the addition of high organic C amendments including manure, plant material, and compost has increased microbial respiration of sodic soils (Nelson et al., 1996; Pathak and Rao, 1998; Clark et al., 2007; Deshpande et al., 2012; Celis et al., 2013; Yazdanpanah et al., 2013; Yu et al., 2014a; Oo et al., 2015). Organic amendments can ultimately increase organic matter and improve soil physical properties, thereby improving conditions for microbial activity. For example, gypsum and municipal solid waste compost applied to a saline-sodic soil increased the soils function by decreasing ESP, improving water movement, and increasing the cumulative CO_2 production (Hanay et al., 2004). Further determination of the impact that amendments have on soil biology will help producers better understand the impacts that these amendments have on overall soil health.

Summary

Sodic soils are, in general, difficult to manage in arid and semi-arid regions. Limitations to improvement often revolve around the lack of precipitation for downward movement of salts and amendments, which is exacerbated by PET rates exceeding annual precipitation. The following two studies focus on the impact different amendments (FGDG, spent lime, and langbeinite) have on sodic soils. The field study specifically looks at chemical changes and how the treatments impact alfalfa yield and quality after 17 months. The incubation study evaluates the impacts that the amendments have on microbial respiration. This research will provide a better understanding of potential amendments for the use of ameliorating sodic soils in a semi-arid climate without irrigation and how amendment choice may impact soil microbiology.

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PAPER 1. FIELD STUDY: PERCENT SODIUM, ELECTRICAL CONDUCTIVITY, AND ALFALFA YIELD EFFECTED BY APPLICATION OF SODIC SOIL AMENDMENTS

Abstract

In the NGP of the United States, 10 million ha of land are negatively impacted by sodic soils. Sodic soils typically have poor chemical and physical conditions due to the excess amount of monovalent Na relative to other cations on exchange sites and in the soil solution (high Na, low EC). The existence of Na on exchange sites of clay and organic matter may result in swelling and/or dispersion, which is often controlled with the addition of amendments. A two-year field study with a random complete block design (RCBD) replicated four times on surface (non-tiled) and subsurface (tile) drained sites was conducted. Flue-gas desulfurization gypsum (FGDG) and sugar beet processing by-product lime (spent lime) were applied at rates of 11.2, 33.6, 67.2 Mg ha^{-1}, and langbeinite was applied at rates of 2.2, 5.6, and 11.2 Mg ha^{-1}. The objective was to evaluate movement of Na and EC and impacts on alfalfa yield and quality. No significant differences were observed across the treatments at either site after 17 months of treatment applications, but both high rates of FGDG and spent lime had the lowest %Na in the 0-15cm depth. Alfalfa yields did not show any statistical differences on the tiled site, but the yields were significantly reduced for the two high rates of langbeinite at the non-tiled site. Forage quality was not significantly impacted by the treatments and was within prime quality feed criteria. Although significant changes were not seen across treatments for %Na, both the gypsum and spent lime treatments had the most positive impact on the %Na and did not reduce the alfalfa yield or quality.

Introduction

Throughout the world, farmers are faced with many challenges to consistently produce crops. These challenges relate to production costs, crop revenue, weather, transportation, weeds, and soil health. Within the NGP of the USA, farmers are specifically faced with challenges when cropping sodic soils. These soils typically have poor chemical and physical conditions contributing to poor soil structure and aeration, reduced water infiltration, low organic matter and nutrient availability, surface crusting, erosion, and ultimately poor productivity (Shainberg and Letey, 1984; Rengasamy and Olsson, 1991; Fitzpatrick et al., 1994; Nelson and Oades, 1998). The main cause of poor physical condition is due to excess amounts of Na relative to other cations on the exchange sites of soil clays and low soil solution EC which in turn causes swelling and dispersion (Shainberg and Letey, 1984; He et al., 2013; DeSutter et al., 2015). Plant growth in both saline-sodic and sodic soils is negatively impacted by ion toxicity and deficiency, and alone, osmotic stress and structural degradation, respectively (Naidu and Rengasamy, 1993). Sodic soil environments are not conducive for biological activity, nutrient cycling, organic matter accumulation and mineralization (Naidu and Rengasamy, 1993).

Sodic soils can have high spatial variability across the landscape, as well as with depth, and can be interspersed among highly productive soils (Kelley, 1922; Kellogg, 1934; He, 2014). Management becomes difficult for farmers when trying to maneuver large farm equipment across fields where sodic soil patches are present. The sodic soil areas are generally referred to as "slickspots" (Kellogg, 1934), "burn-outs", or "blow-outs" (MacGregor and Wyatt, 1945). When the soil is dry, it oftentimes becomes crusted and/or hard-set (Sumner, 1993). Alleviating the chemistry and degraded physical properties of these soils can be expensive depending on the amount of Na present and the choice of amendment. Evaluating amelioration strategies for sodic soils in the NGP will be important for increasing productivity and production efficiency, as well as determining economic feasibility of improvement in semi-arid climates.

Traditional methods to improve the productivity of sodic soils have included 1) application of Ca, 2) a source of downward moving high quality water, 3) proper subsoil drainage, and the use of 4) deep rooted perennial crops. Gypsum ($CaSO_4 \cdot 2H_2O$) is a very common amendment used for ameliorating sodic soils (Oster, 1982) and costs \$220 Mg^{-1} (A. Hoiberg, Personal Communication, 2016). The gypsum by-product FGDG has the potential to be available for agricultural uses and used for ameliorating sodic soils (Punshon et al., 1999). The solubility of FGDG is 2.6 g L^{-1} and mined gypsum is 2.1 g L^{-1} (Bolan et al., 1991). Another Ca source that is much less soluble than gypsum is sugar beet by-product spent lime ($CaCO_3$; solubility of 0.06 g L^{-1} (FAO, 1973)) and costs \$2.20 Mg^{-1} or is free at some facilities (A. Sawatzky, Personal Communication, American Crystal Sugar Co., 2016). Spent lime is widely available in regions that produce beet and cane sugar and is the end-product from the removal of impurities in the sugar juice by processes of coagulation and flocculation (Doherty and Edye, 1999).

An alternative amelioration strategy is the use of langbeinite ($K_2SO_4 \cdot 2MgSO_4$), which is a commercial fertilizer (K-Mag; Mosaic Crop Nutrition, LLC, Riverview, Florida) used to provide Mg, K, and SO_4^{2-} to plants in an easily soluble form. The cost of langbeinite is \$510 Mg^{-1} (S. Koch, Personal Communication, Mosaic, 2016), which is twice the cost of gypsum but the solubility of langbeinite is 280 g L^{-1} (Aydemir and Najjar, 2005) and therefore requires significantly less water than gypsum to displace and leach Na from the soil (Heluf, 1995; Alsharari, 1999) potentially reducing the time it takes to ameliorate. Many studies using langbeinite as an ameliorant for sodic soils were done using leaching columns (Heluf, 1995;

Alsharari, 1999; Artiola et al., 2000; Aydemir and Najjar, 2005). However, a field study has been conducted in an arid dryland condition where langbeinite was included as a treatment and was the most successful at reducing Na, but was the least economical because of the price and the amount needed for amelioration (Day, 2014).

The introduction of plant species tolerant to salinity and sodicity have also shown to be effective at bioremediation in calcareous soils by two processes: 1) increasing the CO_2 partial pressure in response to plant roots and microbial respiration for enhanced dissolution of *in situ* lime in the rooting zone, and 2) soil structure improvement by roots for improved infiltration (Qadir and Oster, 2002). The introduction of perennial crops can be problematic as the root-zone salts may be unfavorable for establishment and long-term growth. However, alfalfa (*Medicago sativa L.*) has been used in many studies as a phytoremediation treatment for saline-sodic and sodic soils (Kelley and Brown, 1934; Goertzen and Bower, 1958; Robbins, 1986a; b; Qadir et al., 1992, 2003b; Ilyas et al., 1993, 1997). The coupling of amendments and cropping has shown to further improve Na removal efficiency and K_s, thus reducing the time for amelioration (Ilyas et al., 1993, 1997). Additionally, the use of subsurface drainage is essential for the removal of soluble salts including Na-containing salts (FAO, 1973).

The combinations of amendments, perennial cropping to alfalfa, and drainage, have yet to be investigated in the NGP for the purpose of improving the productivity of sodic soils. Therefore, the objectives of this field study were to: 1) determine how FGDG, spent lime, and langbeinite impact sodic soils at different rates of application under subsurface and surface drained systems, and 2) determine how the treatments impact the alfalfa yield and quality.

Material and Methods

Location and Field Design

The two sites selected for this study were located near the town of Delamere in southeastern North Dakota, USA (Figure 1).

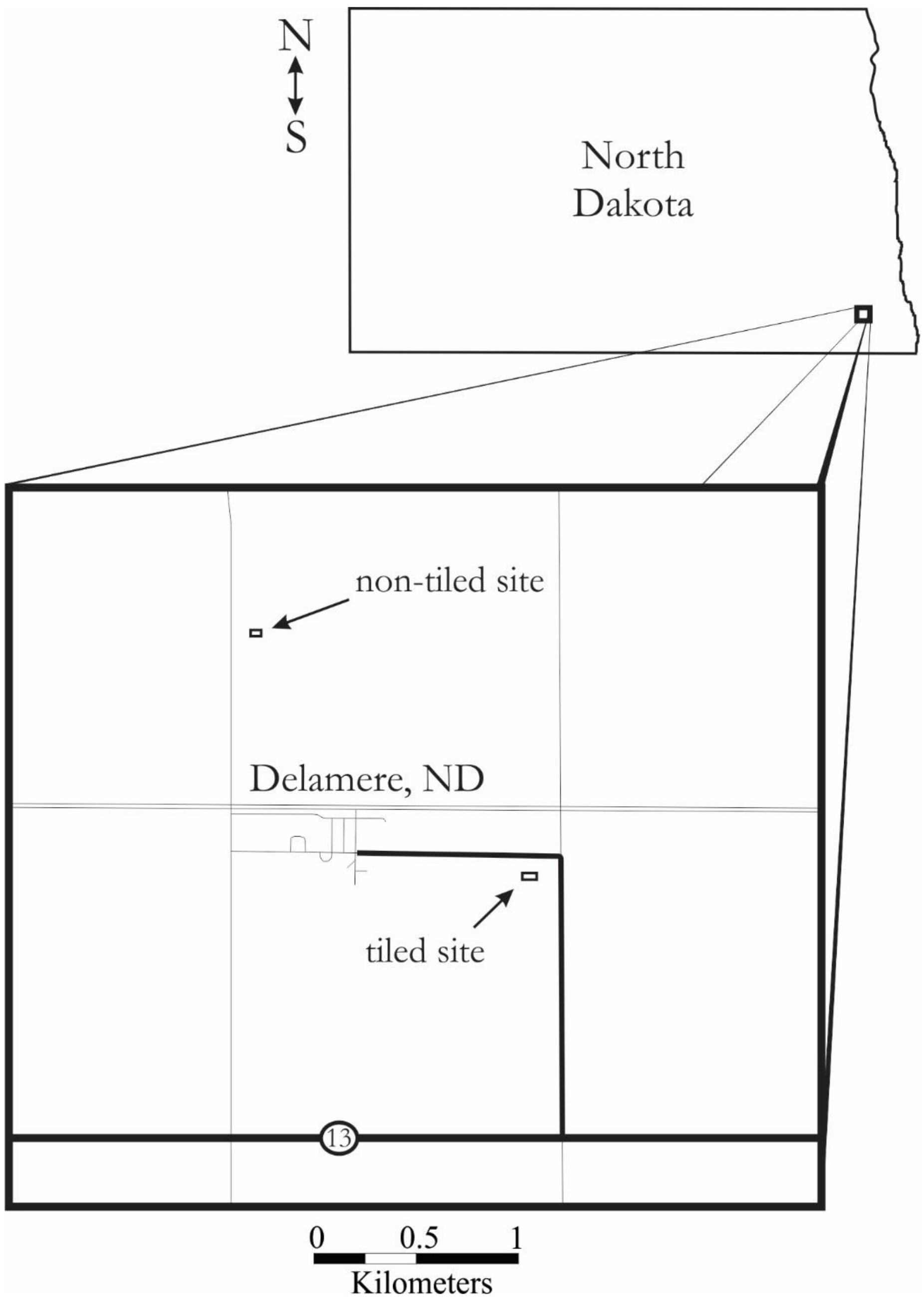

Figure 1. Diagram depicting site locations near Delamere, ND.

Subsurface drainage was installed at the tiled site (46º15’52.27N, 97º19’28.29W) in the fall of 2013 with 18.3 m spacings that were approximately 1.2 m deep. The non-tiled site was surface drained only (46°16’31.92N, 97°20’29.07W). A RCBD was used, replicated four times with nine treatments and a control (no amendments added). Each plot spanned 6.1 m by 6.1 m and was located at least 3 m from any tile line. The treatments included FGDG and spent lime applied at 11.2, 33.6, and 67.2 Mg ha^{-1}, respectively, and langbeinite applied at 2.2, 5.6, and 11.2 Mg ha^{-1}. The lower rates of langbeinite were chosen due to its high solubility. The FGDG is composed of 22.6% Ca and was obtained from Great River Energy coal power plant, located near Falkirk, ND. The spent lime had a purity of 70.5% and an effective calcium carbonate of 14.4%, and was obtained from Minn-Dak Farmers Cooperative sugar beet plant (Wahpeton, ND). The spent lime used in this study also contained 4.2 kg Mg^{-1} and 9.0 kg Mg^{-1}, of total nitrogen and phosphate (P_2O_5) respectively (Agvise Laboratories, Northwood, ND). The langbeinite is 21.5% K_2O and 10.5% Mg and was obtained from Mosaic Crop Nutrition, LLC (Riverview, FL). The treatments were incorporated into the soil immediately after hand-application to a 10 cm depth using a rototiller. The climate in the study region is semi-arid. The respective total precipitation in 2014 and 2015 was 350 and 436 mm obtained from manual rain gauges, and the respective total PET rates were 1048 and 1320 mm (NDAWN, 2014-2015).

Soil Properties

The sites are both located on the same soil map unit, an Aberdeen-Ryan silty clay loam, sandy substratum, 0 to 2 percent slopes (Soil Survey Staff, 2014). In-field soil characterization determined that the tiled site is more representative of the Aberdeen series (fine, smectitic, frigid Glossic Natrudolls) (USDA-NRCS, 2014) and the non-tiled site is more representative of the Ryan series (fine, smectitic, frigid Typic Natraquerts) (USDA-NRCS, 1997) (Appendix A).

Texture of the soil in the 0 to 15 cm depth at the tiled site was a sandy clay loam (sand 46%, silt 25%, clay 29%) and a sandy loam (sand 59%, silt 23%, clay 18%) at the non-tiled site. Both of these soil are very different from one another and therefore will not be compared and will be treated separately.

Soil Sampling, Prep, and Analysis

Soil samples were taken from the plots with a hydraulic probe (6 cm diameter) in the fall of 2014 and 2015 to a depth of 120 cm. The 120 cm cores were dissected into increments of 0 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 120 cm. Two more samples were taken by hand using 3.4 cm diameter stainless steel probes in each plot from the 0 to 15 and 15 to 30 cm depths, mixed and homogenized with core samples to acquire an evenly distributed sample for the top two depths. The samples where then air-dried and ground to pass through a 2 mm sieve.

The $EC_{1:1}$ and $pH_{1:1}$ were determined using the same 10 g soil and 10 mL deionized (DI) water slurry (Rhoades, 1996; Whitney, 1998). The EC was determined using a sensION378 meter (Hach, Loveland, CO) and pH was determined using an AB15 meter (Fisher Scientific, Pittsburgh, PA). Percent $CaCO_3$ was analyzed using the Williams (1948) method where 2N HCl was used to dissolve the carbonates from a 1 g sample and the head pressure measured using a pressure transducer. Samples were also sent to Agvise Laboratories (Northwood, ND) to analyze %Na by:

$$\%Na = \frac{100Na}{Ca+Mg+Na+K} \qquad [2]$$

where cations are in units of cmol(+) kg^{-1} (DeSutter et al., 2015). The 2015 samples were sent to Agvise Laboratories for Olsen-P and NO_3-N determination.

Alfalfa

Alfalfa (Pioneer 55V50) was planted in May of 2014 at both sites. The tiled site was planted on the 17th and the non-tiled site was planted on the 27th. In preparation for planting, 112 kg ha^{-1} of MAP (11-52-0) was applied by the cooperator and harrowed into the soil. The non-tiled site was reseeded into the existing stand the fall of 2014 to ensure establishment in areas that had poor stands due to wet conditions. Alfalfa was hand harvested once in the fall of 2014 and four times in 2015. Hand clippers were used to collect 1.1 m^2 of alfalfa from each plot, dried at 60 ^oC for 48 hr, and then weighed for biomass yield. The 2014 and first 2015 harvested samples were prepared for forage quality analysis by grinding to pass through a 2 mm sieve. Samples were analyzed by the Animal Nutrition Laboratory at North Dakota State University for (1) dry matter (DM), (2) ash, (3) crude protein (CP), (4) neutral detergent fiber (NDF), (5) acid detergent fiber (ADF), (6) Ca, and (7) P.

Statistics

Statistical differences were determined using an analysis of variance (ANOVA) and Tukey's HSD at an alpha level of 0.05 (JMP 12, Cary, NC). Tests were performed on %Na, EC, pH, %$CaCO_3$, Olsen-P, NO_3-N, alfalfa yield and each parameter of forage quality.

Results and Discussion

In the first 17 months of the field experiment, changes in the soil were only observed in the 0 to 15 cm depth. Metrics for depths below 15 cm depth were not significantly different and therefore results will not be further discussed, but tables reporting this information can be found in Appendix B. Despite the two sites being located on the same soil map unit, the surface soil variability and drainage played a very important role in treatment response.

Electrical Conductivity (1:1), 0-15 cm

Overall, the $EC_{1:1}$ values of the controls at the non-tiled site in 2014 and 2015 (2.6 and 2.7 dS m^{-1}, respectively) were much higher than the tiled site (1.4 and 0.4 dS m^{-1}, respectively) (Figure 2 and 3).

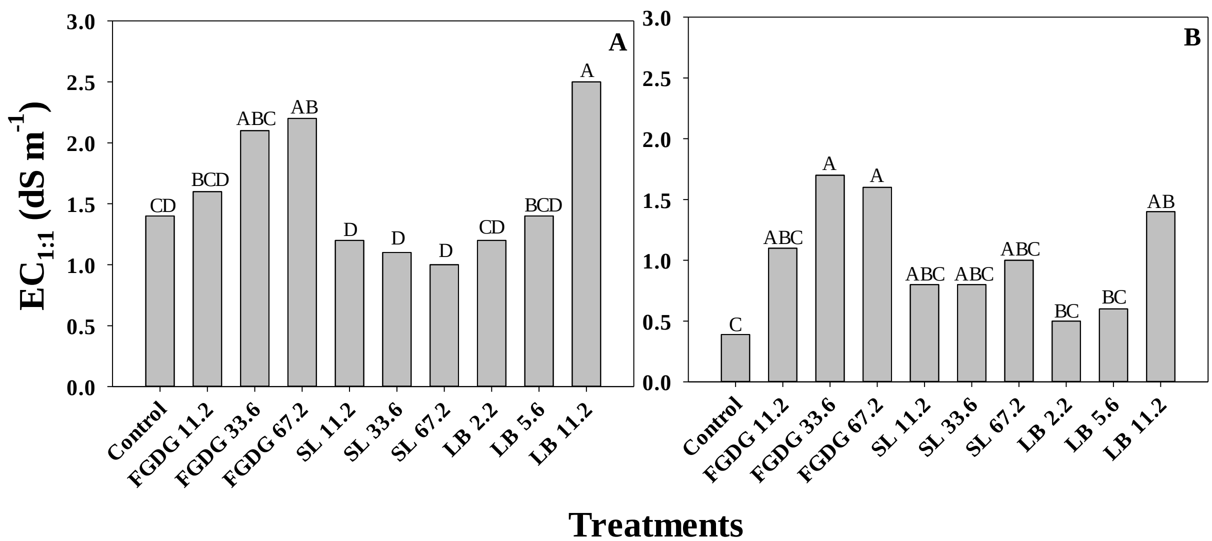

Figure 2. Electrical conductivity of the 0 to 15 cm depth samples in both 2014 and 2015 for the tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015.

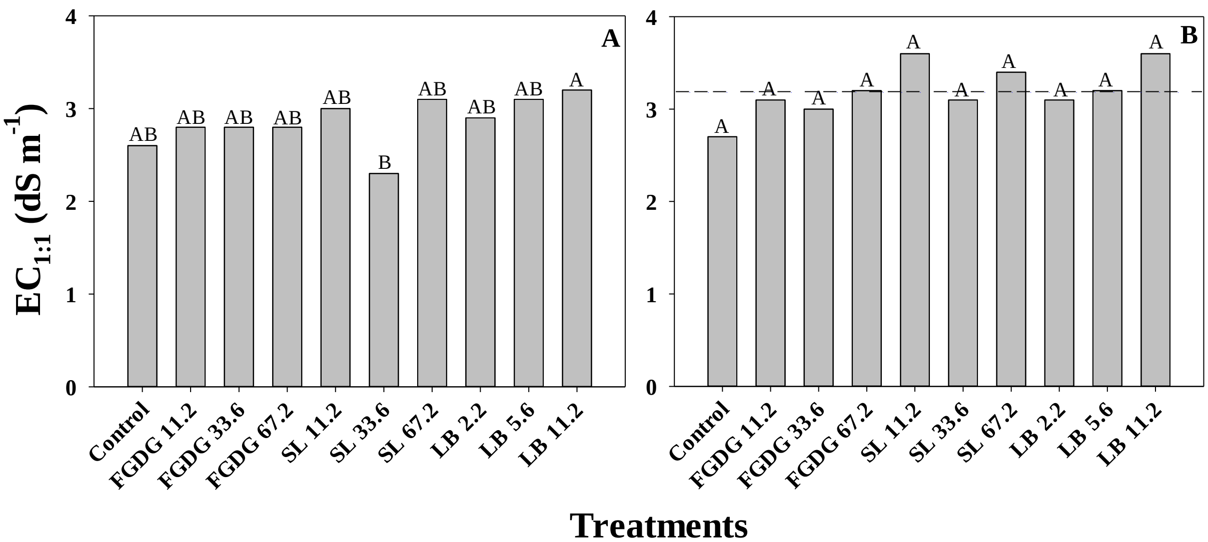

Figure 3. Electrical conductivity of the 0 to 15 cm depth samples in both 2014 and 2015 for the non-tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015. The dotted line in B is the average EC across all treatments.

Because of the much lower $EC_{1:1}$ at the tiled site, a greater increase was observed in $EC_{1:1}$ after application of amendments in both years as shown in 2014 where the high rate of FGDG and langbeinite (2.2 and 2.5 dS m^{-1}, respectively) had significantly higher values than the control. Similarly in 2015, the $EC_{1:1}$ values of the 33.6 and 67.2 Mg ha^{-1} rates of FGDG plots and highest rate of langbeinite plots were significantly higher than the control. In contrast, the non-tiled $EC_{1:1}$ values from the different treatments were not significantly different than the control in either year. However, in 2014 the $EC_{1:1}$ of the high rate of langbeinite was significantly greater than the medium rate of spent lime and in 2015 no significant differences were observed across treatments and averaged 3.2 dS m^{-1}. As the rates of both the FGDG and langbeinite increased the $EC_{1:1}$ also increased but not for spent lime treatments.

Many studies have shown that the equilibrium between the EC and the level of exchangeable Na in a soil is important for maintaining adequate physical conditions (Quirk and

Schofield, 1955; McNeal and Coleman, 1966; Frenkel et al., 1978; Shainberg et al., 1981; He et al., 2013). However, the extent of soil degradation is also dependent on the type of clay minerals present (McNeal and Coleman, 1966; Frenkel et al., 1978; Sumner et al., 1998; He et al., 2013). In the NGP where montmorillonite is the dominant clay, in order to maintain water movement when the %Na is five or greater the EC must be two or greater (He et al., 2015).

In 2014, the langbeinite plots had the highest EC but in 2015 values were slightly lower than the two high rates of FGDG. In a study where langbeinite was applied at 10.0 and 29.5 Mg ha^{-1} EC was significantly increased at a sodic soil reclamation site in Wyoming compared to the control, but lower rates of gypsum (5.3 and 10.8 Mg ha^{-1}) than those reported in Figure 2 did not increase EC (Day, 2014). However, 12 yr after 4.5 Mg ha^{-1} application of gypsum, $EC_{1:5}$ was moderated back to the original pre-application value of 0.05 dS m^{-1} in a semi-arid environment (Valzano et al., 2001; Bennett et al., 2014). The spent lime had very little impact on the EC of the soil, likely due to its very low solubility. Even though the solubility of lime is low, 0.5 and 2.0% $CaCO_3$ has been shown to maintain a high enough electrolyte concentration to prevent dispersion at an SAR of 10 and 20, but not 30 (Shainberg and Gal, 1982). The tiled-site EC across all treatments decreased from 2014 to 2015, likely due to gravitational water transporting ions. Because of the semi-arid climate (PET exceeding rainfall), the high evaporative demand was likely causing upward movement of water and soluble salts into the 0-15 cm depth causing an increase in EC at the tiled site from 2014 to 2015.

% Sodium (0-15 cm)

Similar to EC, the %Na values of the controls at the non-tiled site in 2014 and 2015 (12.3 and 14.2%, respectively) were much higher than the tiled site (6.2 and 2.9%, respectively) (Figure 4 and 5). Although there were no significant differences observed for %Na in both years and sites between the treatments and the control, a decreasing %Na pattern was observed for both FGDG and spent lime as application rates increased. The 2015 tiled site showed no significant differences across all treatments averaging 3.1% Na. However, the tiled site in 2014 and the non-tiled site in 2014 and 2015 had significantly lower %Na in the high rate of FGDG than the low rate of spent lime, which was expected given the solubilities of these amendments. Again, the tiled site %Na decreased from year 2014 to 2015, likely due to dissolution of amendments thus diluting Na and/or the leaching of Na from the 0 to 15 cm depth. The increase in %Na at the non-tiled site is most likely due to the PET exceeding precipitation causing further upward migration of Na from the parent material salts with the water table.

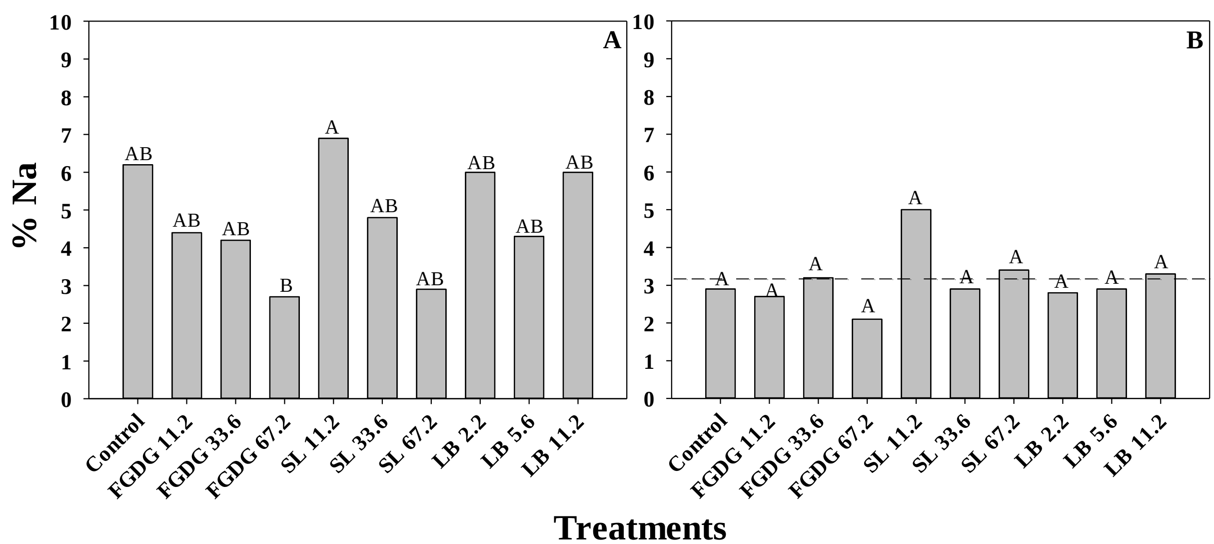

Figure 4. Percent sodium of the 0 to 15 cm depth samples in both 2014 and 2015 at the tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015. The dotted line in B is the average %Na across all treatments.

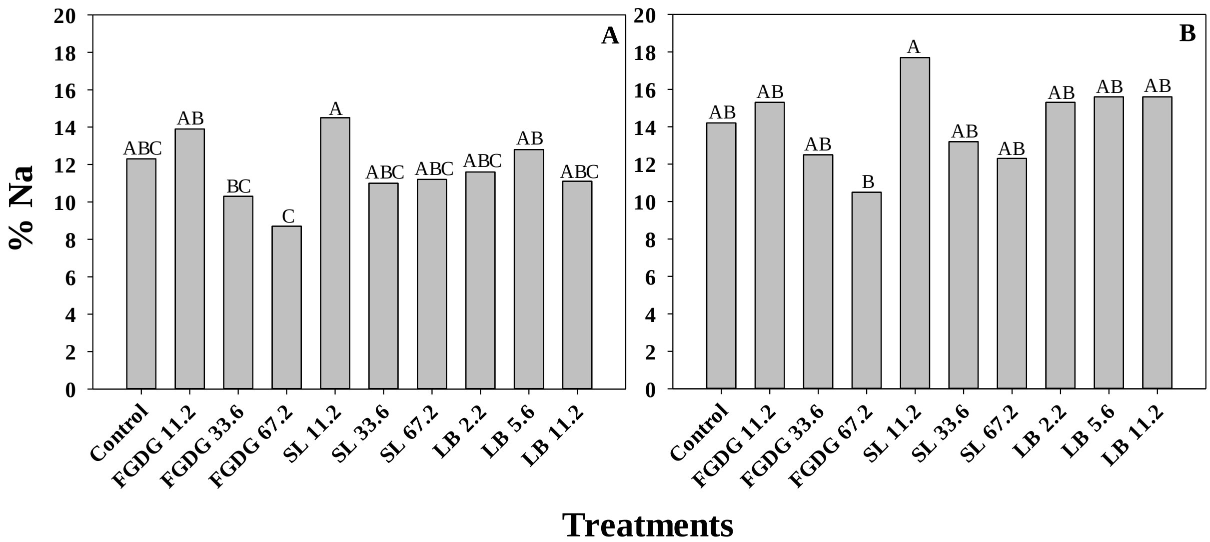

Figure 5. Percent sodium of the 0 to 15 cm depth samples in both 2014 and 2015 at the non-tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015.

pH and %$CaCO_3$ (0-15 cm)

The pH values of the controls at the non-tiled site in 2014 and 2015 (8.1 and 8.1, respectively) were higher than the tiled site (7.6 and 7.8, respectively) (Figure 6 and 7). The application of spent lime was anticipated to increase the pH, however, this only occurred at the tiled site where the pH was lower. Of the treatments and application rates, only the high rate of spent lime (8.2) was significantly higher, and the high rate of langbeinite (7.3) was significantly lower compared to the tiled site control in 2015. In regards to the non-tiled site, in 2015 there were no significant differences and averaged 8.2.

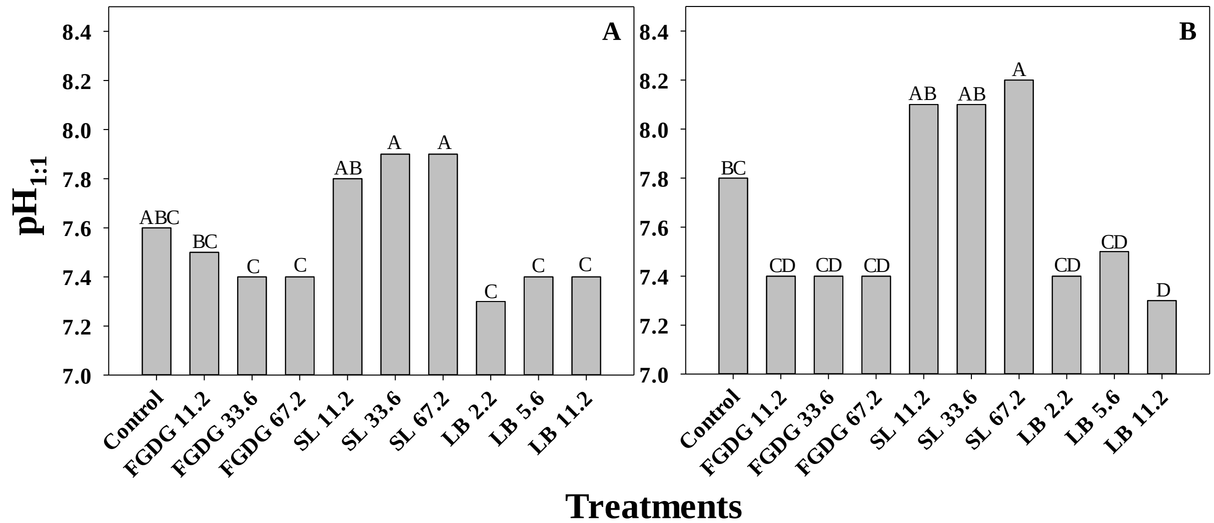

Figure 6. pH of the 0 to 15 cm depth samples in both 2014 and 2015 at the tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015.

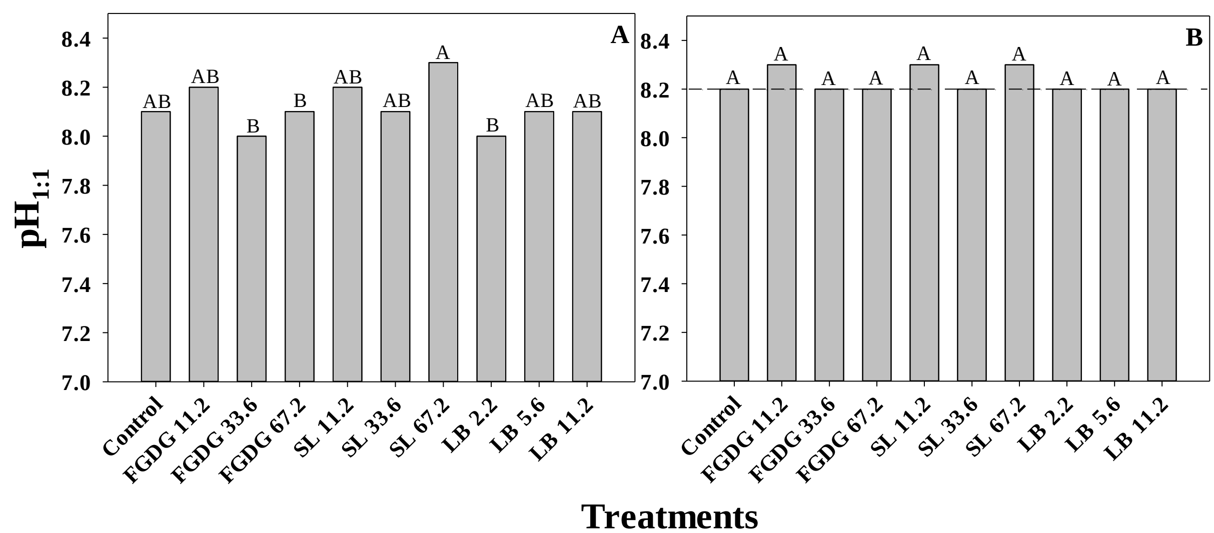

Figure 7. pH of the 0 to 15 cm depth samples in both 2014 and 2015 at the non-tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015. The dotted line on B represents the average across all of the treatments.

Application of spent lime is expected to increase pH in low-pH soils (DeSutter and Godsey, 2010), and this was observed in the soil at the tiled site. However, soil pH was near 8.1

at the non-tiled site and therefore the addition of spent lime did not further increase pH. The reduction in pH from the langbeinite may be influenced more by the variability across the plots than the treatment reducing the pH.

In 2014 and 2015, the %$CaCO_3$ values at the non-tiled site were not different across treatments and had averages of 1.5 and 1.3%, respectively (Figure 8 and 9). However, at the tiled site, the high rate of spent lime in 2014 and 2015 expectably produced a significant increase in %$CaCO_3$ compared to the controls. Increasing the $CaCO_3$, and subsequently the soil pH, could increase the risk of iron deficiency chlorosis in soybean (*Glycine max*) which is a commonly grown crop in the NGP (NASS, 2014). In addition, increases in soil pH and %$CaCO_3$ provide further support that spent lime can be used as a liming agent for variable pH soils.

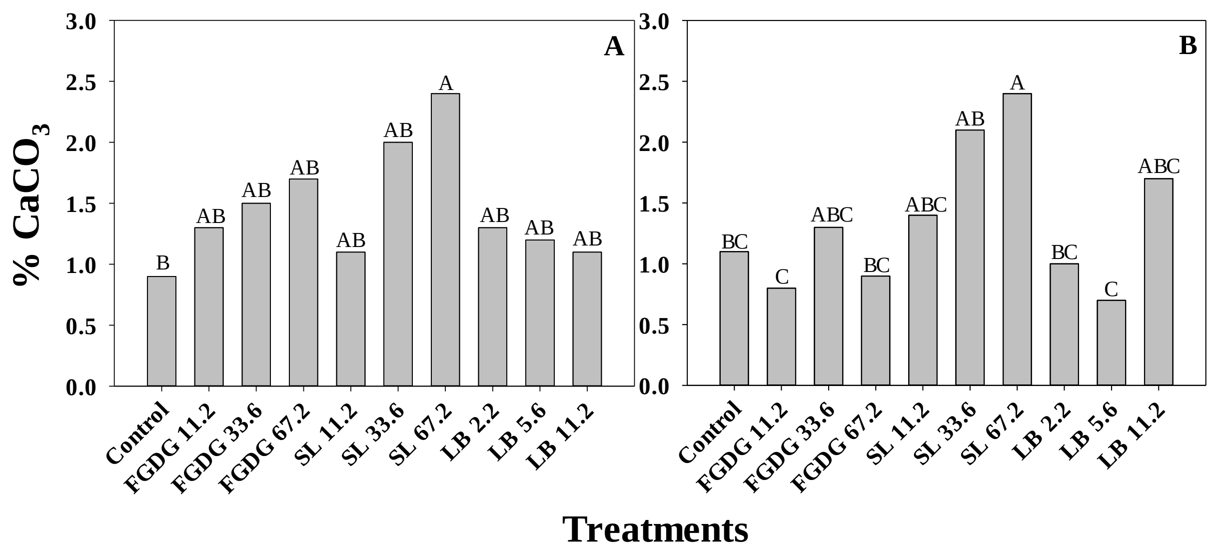

Figure 8. Percent calcium carbonate ($CaCO_3$) of the 0 to 15 cm depth samples in 2014 and 2015 at the tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015.

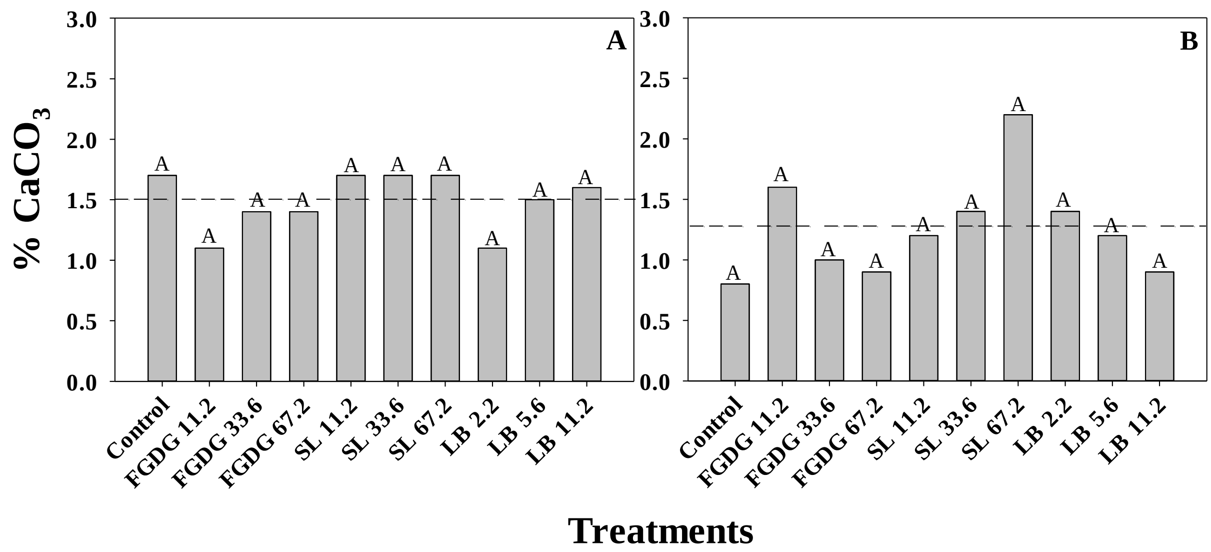

Figure 9. Percent calcium carbonate ($CaCO_3$) of the 0 to 15 cm depth samples in both 2014 and 2015 at the non-tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p <0.05$). The letters in each corner are denoted by: (A) 2014, and (B) 2015. The dotted lines on C and D represent the average across all of the treatments.

Phosphorus and Nitrogen (0-15 cm)

In 2015 concentrations of Olsen-P (Figure 10 and 11) only had significant differences at the tiled site where it was significantly greater in the high rate of spent lime treatment (44 mg kg^{-1}) compared to the control (16.3 mg kg^{-1}). The non-tiled site averaged 18.9 mg P kg^{-1}. The spent lime contains high amounts of P, which has been reported up to 7,000 mg P kg^{-1} (Sims et al, 2006) and thus has been used in the region as a P fertilizer source. The NO_3-N however was not significantly different at the tiled and non-tiled sites in 2015 and averaged 11.1 and 10.8 mg kg^{-1}, respectively.

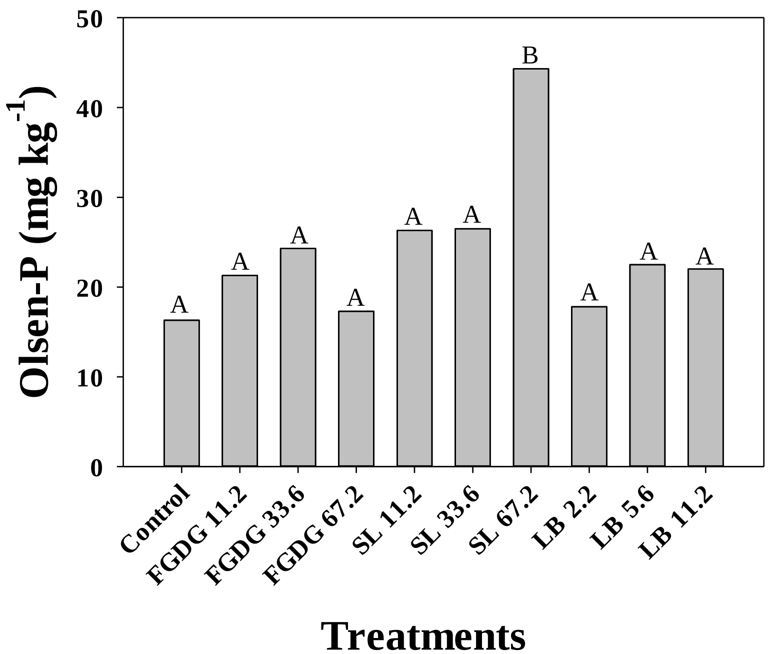

Figure 10. Olsen-P in the 0 to 15 cm depth samples in 2015 at the tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$).

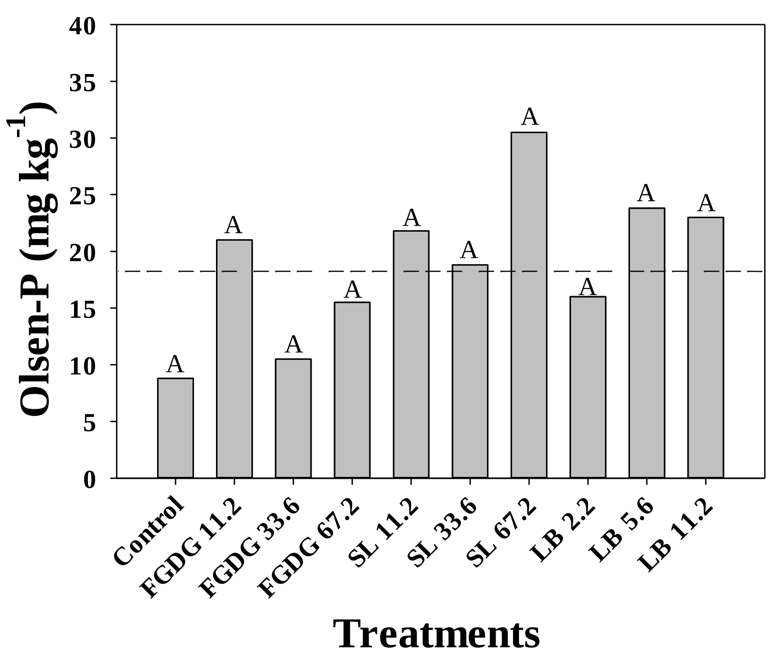

Figure 11. Olsen-P in the 0 to 15 cm depth samples in 2015 at the non-tiled site. The treatments are flue-gas desulfurization gypsum (FGDG), spent lime (SL), and langbeinite (LB) at the rates applied in Mg ha^{-1}. Significant differences between the treatments are represented by different letters ($p < 0.05$). The dotted line represents the average across all treatments.

Alfalfa Yield and Quality

There were no significant differences in alfalfa yield at the tiled site across treatments in both 2014 and 2015 and averaged 1.8 and 9.9 Mg ha^{-1}, respectively (Table 5). However, at the non-tiled site in 2014 the high rate of langbeinite significantly decreased yield compared to the control (0.40 vs 1.96 Mg ha^{-1}, respectively) and in 2015 the 5.6 and 11.2 Mg ha^{-1} rates significantly lowered yields compared to the control (3.6, 6.3, and 8.7 Mg ha^{-1}, respectively). The decrease in yield was likely due to the increase in EC which led to poor establishment and growth at the onset of the experiment where the $EC_{1:1}$ of the langbeinite treatments were above 3 dS m^{-1} (approximately ECe = 6.3 dS m^{-1}) where a 50% yield reduction is reported for alfalfa when ECe is 8 to 9 dS m^{-1}, therefore some yield loss would be expected at the tiled site (Bernstein, 1975). Overall, the amendments did not impact yield at the tiled site and only the two high rates of langbeinite negatively impacted yield at the non-tiled site, suggesting that using langbeinite at the rates used in our study when soil $EC_{1:1}$ is greater than 2.5 dS m^{-1} may inhibit establishment and yields of alfalfa.

Table 5. Alfalfa yield from tiled and non-tiled locations in 2014 and 2015.

Site†	Treatment‡	2014	2015 Yield				2015
		Total§	**Jun. 1¶**	**Jun. 29#**	**Jul. 29**	**Aug. 20**	**Total††**
	Mg ha^{-1}	---Mg ha^{-1}---	-----------------------Mg ha^{-1}-----------------------				--Mg ha^{-1}--
T	Control	2.4(0.3)a§§	3.6(0.2)a	3.4(0.3)a	1.7(0.1)a	1.0(0.1)b	9.8(0.3)a
	FGDG 11.2	2.4(0.4)a	3.8(0.5)a	3.7(0.2)a	1.4(0.6)a	1.2(0.1)ab	10.1(1.0)a
	FGDG 33.6	1.4(0.3)a	3.2(0.4)a	3.5(0.5)a	2.0(0.3)a	1.1(0.2)b	9.8(1.1)a
	FGDG 67.2	2.1(0.2)a	3.5(0.2)a	3.7(0.3)a	1.9(0.2)a	1.2(0.0)ab‡‡	10.3(0.5)a
	SL 11.2	1.5(0.3)a	3.0(0.3)a	3.3(0.3)a	1.7(0.2)a	1.1(0.1)ab	9.1(0.6)a
	SL 33.6	1.4(0.9)a	3.2(0.5)a	3.3(0.3)a	2.1(0.6)a	1.1(0.2)ab	9.7(0.4)a
	SL 67.2	1.5(0.6)a	3.2(0.7)a	3.1(0.8)a	1.8(0.5)a	1.1(0.2)ab	9.2(2.0)a
	LB 2.2	1.9(0.6)a	3.0(0.3)a	3.9(0.1)a	1.9(0.2)a	1.2(0.1)ab	10.0(0.5)a
	LB 5.6	1.8(0.7)a	3.4(0.3)a	3.8(0.1)a	1.9(0.2)a	1.4(0.1)a	10.5(0.3)a
	LB 11.2	1.6(0.3)a	3.6(0.5)a	3.7(0.4)a	2.0(0.1)a	1.3(0.2)ab	10.6(0.3)a
	Average¶¶	1.80	3.35	3.53	1.85	1.17	9.91
NT	Control	2.0(0.5)a	2.8(0.8)ab	2.8(0.7)ab	1.8(0.3)a	1.3(0.2)ab	8.7(1.7)a
	FGDG 11.2	1.1(0.3)ab	2.0(0.2)abc	2.7(0.3)ab	1.6(0.2)a	1.2(0.1)abc	7.5(0.4)ab
	FGDG 33.6	2.0(0.8)a	2.9(0.3)ab	3.0(0.6)a	1.8(0.4)a	1.1(0.1)abcd	8.7(0.8)a
	FGDG 67.2	2.1(0.3)a	3.1(0.3)a	3.0(0.2)ab	1.6(0.2)a	1.3(0.1)abc	9.0(0.2)a
	SL 11.2	1.1(0.6)ab	1.8(0.4)bc	2.5(0.7)ab	1.6(0.1)a	1.0(0.1)bcd	6.9(0.9)ab
	SL 33.6	1.6(0.8)ab	2.5(0.7)ab	2.7(0.5)ab	1.7(0.1)a	1.1(0.1)abcd	8.0(1.0)ab
	SL 67.2	1.0(1.0)ab	2.1(0.5)abc	2.4(0.3)ab	1.7(0.2)a	1.0(0.2)cd	7.2(0.7)ab
	LB 2.2	1.8(0.2)a	2.9(0.3)a	2.6(0.3)ab	1.8(0.3)a	1.4(0.1)a	8.8(0.6)a
	LB 5.6	1.3(0.2)ab	1.2(0.3)cd	2.2(0.8)ab	1.7(0.1)a	1.2(0.2)abc	6.3(1.2)b
	LB 11.2	0.4(0.6)b	0.6(0.3)d	1.6(0.8)b	0.7(0.3)b	0.8(0.2)d	3.6(1.0)c
	Average	1.43	2.19	2.54	1.59	1.14	7.46

† Tile site (T), non-tile site (NT)
‡ Flue-gas desulfurization gypsum (FGDG), spent lime (SL), langbeinite (LB)
§ One harvest on August 25, 2014
¶ Date alfalfa was harvested
# The NT site was harvested on July 7
†† Sum of four harvestings in 2015
‡‡ Numbers in parenthesis indicate the standard deviation and the different letters in each column indicate significant differences ($p < 0.05$) among treatments for each site within each year
§§ Standard deviation than 0.05
¶¶ This row indicates the average over all treatments for each harvest

Despite the fact that alfalfa yield after treatment applications was generally unchanged, alfalfa has beneficial effects on leaching soluble salts and Na with the application of gypsum, indicated by an increase in soil porosity and infiltration rates (Meek et al., 1990; Ilyas et al., 1997). Alfalfa alone was comparable to gypsum on the Na removal efficiency in sodic soils used in a column study (Qadir et al., 2003a) and flood irrigation with 5 years of alfalfa resulted in better cotton yields than the gypsum treatment and decreased ESP from 65 to 6 vs the gypsum treatment that reduced ESP from 70 to 5 (Kelley and Brown, 1934). When gypsum and alfalfa were used in unison in the Indus Plain of Pakistan, where annual precipitation is about 600 mm, the gypsum provided a better soil environment for the alfalfa, allowing for deeper root penetration and improved water permeability down to 80 cm deep (Ilyas, 1993). Although not directly supported by soil chemical data reported in the above tables, alfalfa, or other perennial crops can aid in sodic soil improvement, with or without chemical amendments, and may reduce time for improvement as well (Goertzen and Bower, 1958; Robbins, 1986a; b; Qadir et al., 1992, 2003b; Ilyas et al., 1997).

Generally, forage quality was not impacted by the treatments compared to the control (Table 6 & 7), and fell within the supreme to fair category for forage quality (Putnam et al., 2008). The alfalfa quality at the tiled site in 2014 was supreme and in 2015 was good to fair. The alfalfa quality at the non-tiled site in 2014 was supreme and in 2015 was good to fair. The decrease in quality was from an increase in NDF and ADF, which is from later harvest timing in the early bloom stage and causes the forage to become less palatable to livestock (Schroeder, 2012).

Table 6. Forage quality analysis for the tiled site in 2014 and 2015.

Year	Treatment†	Forage Quality Analysis‡						
		DM	Ash	CP	NDF	ADF	Ca	P
	Mg ha^{-1}	--	--------------------	-----------------	%	--------------------	--------------------	----------------------
2014§	Control	96.7(1.1)a¶	10.4(0.3)a	23.7(2.0)a	35.4(3.0)a	26.6(1.6)a	1.5(0.2)a	0.38(0.04)a
	FGDG 11.2	97.2(0.4)a	10.7(0.2)a	24.2(1.0)a	34.2(0.7)a	24.0(0.4)a	1.8(0.0)a#	0.38(0.02)a
	FGDG 33.6	97.9(0.2)a	10.7(0.6)a	25.4(1.5)a	33.7(2.7)a	24.2(1.6)a	1.7(0.2)a	0.39(0.02)a
	FGDG 67.2	97.1(0.3)a	10.4(0.3)a	25.3(1.2)a	33.7(3.1)a	22.8(2.6)a	1.5(0.1)a	0.35(0.02)a
	SL 11.2	96.4(0.9)a	10.5(0.6)a	25.1(1.0)a	34.4(1.7)a	24.7(0.7)a	1.6(0.1)a	0.41(0.04)a
	SL 33.6	96.6(2.0)a	10.5(0.7)a	24.7(1.6)a	33.6(1.9)a	24.1(1.5)a	1.7(0.2)a	0.38(0.02)a
	SL 67.2	96.6(1.9)a	10.3(0.4)a	25.2(1.7)a	34.1(3.1)a	24.7(2.6)a	1.7(0.1)a	0.39(0.00)a
	LB 2.2	96.7(1.0)a	11.2(0.8)a	24.2(1.2)a	32.0(1.0)a	23.0(0.4)a	1.8(0.3)a	0.39(0.01)a
	LB 5.6	96.9(0.5)a	11.2(0.5)a	25.4(0.7)a	33.5(0.4)a	23.6(0.8)a	1.6(0.3)a	0.39(0.03)a
	LB 11.2	95.9(0.7)a	11.3(0.5)a	24.8(2.1)a	32.4(2.5)a	23.3(2.1)a	1.6(0.3)a	0.38(0.03)a
	Average	96.8	10.7	24.8	33.7	24.1	1.6	0.38
2015††	Control	92.2(0.6)a	9.5(0.4)d	23.7(1.5)ab	45.5(2.1)a	31.5(1.3)a	1.1(0.1)ab	0.45(0.01)a
	FGDG 11.2	91.2(0.7)a	10.3(0.5)cd	24.8(1.3)ab	41.5(2.3)abc	29.1(2.3)a	1.2(0.1)ab	0.43(0.02)a
	FGDG 33.6	92.0(0.7)a	10.7(0.5)bcd	24.7(1.2)ab	42.6(1.6)abc	29.0(1.3)a	1.2(0.2)ab	0.45(0.03)a
	FGDG 67.2	91.8(0.3)a	10.9(0.5)abc	25.8(0.5)a	39.6(1.1)c	28.5(1.5)a	1.3(0.1)a	0.44(0.01)a
	SL 11.2	91.9(0.6)a	10.3(0.3)cd	21.9(1.9)b	43.7(1.1)abc	31.0(0.7)a	1.2(0.2)a	0.45(0.04)a
	SL 33.6	91.6(0.8)a	10.1(0.4)cd	23.2(1.8)ab	42.0(0.5)abc	30.4(0.9)a	1.1(0.2)ab	0.44(0.02)a
	SL 67.2	92.5(0.4)a	10.5(0.3)bcd	22.3(2.0)ab	44.4(2.6)ab	31.2(2.3)a	1.2(0.1)ab	0.44(0.03)a
	LB 2.2	90.9(0.9)a	11.0(0.7)abc	25.7(1.4)ab	40.7(2.2)bc	29.4(1.8)a	1.1(0.1)ab	0.45(0.02)a
	LB 5.6	92.3(0.8)a	11.6(0.5)ab	23.5(1.6)ab	42.0(2.1)abc	29.1(1.8)a	1.0(0.2)ab	0.42(0.04)a
	LB 11.2	91.8(0.6)a	11.9(0.5)a	23.8(1.5)ab	41.8(1.1)abc	29.3(2.4)a	0.9(0.2)b	0.44(0.01)a
	Average	91.8	10.7	23.9	42.4	29.9	1.1	0.44

† Flue-gas desulfurization gypsum (FGDG), spent lime (SL), langbeinite (LB)
‡ Dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P)
§ Alfalfa was harvested on August 25, 2014
¶ Numbers in parenthesis indicate the standard deviation and the different letters in each column indicate significant differences ($p < 0.05$) among treatments for each year
# Standard deviation less than 0.05
†† This row indicates the average over all treatments
‡‡ Alfalfa was harvested on June 1, 2015

Table 7. Forage quality analysis for the non-tiled site in 2014 and 2015.

Year	Treatment†	Forage Quality Analysis‡						
		DM	Ash	CP	NDF	ADF	Ca	P
	Mg ha^{-1}	------------------%						------------------
2014§	Control	95.7(0.9)a¶	10.8(0.4)a	23.7(0.6)a	35.6(1.8)a	25.8(1.9)a	1.2(0.1)a	0.34(0.02)a
	FGDG 11.2	96.2(0.8)a	10.3(0.8)a	24.3(1.8)a	32.6(1.8)ab	24.1(1.7)a	1.2(0.0)a#	0.32(0.02)a
	FGDG 33.6	97.3(0.4)a	11.3(2.3)a	22.6(0.4)a	33.8(1.7)ab	25.1(1.7)a	1.2(0.1)a	0.32(0.01)a
	FGDG 67.2	96.2(1.4)a	10.3(0.9)a	23.7(0.5)a	34.0(2.1)ab	24.7(1.7)a	1.2(0.1)a	0.32(0.02)a
	SL 11.2	96.0(1.0)a	10.5(0.4)a	25.2(0.8)a	30.0(3.0)b	21.7(2.6)a	1.3(0.1)a	0.34(0.01)a
	SL 33.6	97.6(0.6)a	10.0(0.7)a	23.7(1.6)a	32.9(0.5)ab	23.8(0.4)a	1.3(0.1)a	0.32(0.01)a
	SL 67.2	96.8(1.3)a	10.5(0.3)a	24.1(1.2)a	32.9(1.7)ab	23.9(1.2)a	1.3(0.1)a	0.33(0.01)a
	LB 2.2	96.8(0.8)a	10.6(0.7)a	24.1(1.7)a	32.9(1.5)ab	24.1(0.8)a	1.2(0.1)a	0.33(0.02)a
	LB 5.6	96.5(0.6)a	10.3(0.4)a	22.9(1.3)a	32.9(0.3)ab	24.2(1.0)a	1.2(0.1)a	0.32(0.02)a
	LB 11.2	96.9(0.8)a	10.5(0.6)a	22.6(0.8)a	32.9(2.7)ab	23.7(2.1)a	1.2(0.2)a	0.33(0.02)a
	Average††	96.6	10.5	23.7	33.1	24.1	1.2	0.32
2015‡‡	Control	93.2(0.5)ab	11.5(0.1)a	19.9(1.5)a	41.6(2.1)ab	29.1(1.6)ab	1.1(0.1)a	0.39(0.02)a
	FGDG 11.2	92.8(0.3)ab	11.2(0.3)a	18.5(1.6)ab	40.1(1.6)ab	28.0(2.1)ab	1.2(0.2)a	0.36(0.03)a
	FGDG 33.6	92.4(0.8)b	11.3(0.2)a	19.9(1.3)a	45.0(2.0)a	31.7(1.4)a	1.2(0.2)a	0.35(0.03)a
	FGDG 67.2	93.0(0.6)a	11.3(0.3)a	19.0(0.7)ab	44.6(2.7)a	30.4(1.7)ab	1.2(0.1)a	0.36(0.03)a
	SL 11.2	92.5(0.4)ab	11.6(0.3)a	20.4(1.0)a	42.0(4.3)ab	28.7(2.2)ab	1.3(0.0)a	0.37(0.04)a
	SL 33.6	92.7(0.9)ab	11.3(0.1)a	20.0(2.7)a	44.2(1.6)a	30.5(2.2)ab	1.3(0.1)a	0.37(0.02)a
	SL 67.2	93.0(0.5)ab	11.9(0.7)a	19.3(0.9)ab	42.2(2.5)ab	29.3(1.2)ab	1.3(0.0)a	0.35(0.03)a
	LB 2.2	92.6(0.8)ab	11.6(0.4)a	18.8(0.9)ab	43.3(1.2)ab	30.4(1.4)ab	1.1(0.1)a	0.36(0.04)a
	LB 5.6	92.3(0.4)b	11.3(0.1)a	18.9(1.8)ab	40.8(1.5)ab	28.3(2.5)ab	1.2(0.1)a	0.36(0.00)a
	LB 11.2	92.2(0.5)b	11.2(0.3)a	15.9(1.3)b	37.7(2.7)b	26.7(1.7)b	1.0(0.1)a	0.36(0.04)a
	Average	92.8	11.4	19.1	42.2	29.3	1.2	0.36

† Flue-gas desulfurization gypsum (FGDG), spent lime (SL), langbeinite (LB)
‡ Dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P)
§ Alfalfa was harvested on August 25, 2014
¶ Numbers in parenthesis indicate the standard deviation and the different letters in each column indicate significant differences ($p < 0.05$) among treatments for each year
# Standard deviation less than 0.05
†† This row indicates the average over all treatments
‡‡ Alfalfa was harvested on June 1, 2015

Conclusions

In the first 17 months, changes were only seen in the 0 to 15 cm depth at both sites which was likely due to high PET compared to precipitation, as well as, high variation within the soil. No significant declines in %Na in the surface soil compared to the controls were observed but reductions in %Na did occur in the following order: FGDG > spent lime > langbeinite. Alfalfa yield was not impacted by the amendments at the tiled site, however, at the non-tiled site, the high rate of langbeinite decreased the yield significantly because of the increased EC. The alfalfa quality was not impacted by the amendments, but timing of harvest in the pre-bloom stage provides prime forage quality.

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PAPER 2. MICROBIAL RESPONSE TO SODIC SOILS AMENDED WITH FLUE-GAS DESULFURIZATION GYPSUM, SUGAR BEET PROCESSING BY-PRODUCT LIME, AND LANGBEINITE

Abstract

In attempts to improve production of sodic soils, amendments are commonly used to alleviate the poor physical and chemical conditions related to the presence of Na. However, information on how microbial activity responds to amendments can vary depending on the severity of sodicity and the types and rates of amendments applied. The objective of this incubation study was to compare the microbial response as influenced by three chemical amendments (FGDG, spent lime, and langbeinite) applied at three rates to two sodic soils (0-15 cm). At rates of 33.6 and 67.2 Mg ha^{-1}, spent lime had the greatest influence on microbial activity, and at the highest rate of application (67.2 Mg ha^{-1}), cumulative respiration was three and two times greater than the control for both soils. High rates of langbeinite had the lowest respiration but were not significantly different than the control and the FGDG had no significant influence on the respiration. The amendments and their rates were not detrimental to microbial activity, and in the case of spent lime, may enhance soil health through its increased activity.

Introduction

Approximately ten million hectares of land in the NGP of the USA and 1.9 million ha alone in North Dakota are mapped as being sodic (J. Brennan, personal communication, NRCS North Dakota, 2008). Sodic soils have excess amounts of Na ions relative to Ca, magnesium (Mg), and potassium (K) on soil particle exchange sites, in the soil solution, or both (Valzano et al., 2001; DeSutter et al., 2015). When soil is wetted when high concentrations of Na are present, degradation of structure occurs due to swelling and dispersion of clay and organic matter particles. Swelling causes a reduction in pore size, making transfer and movement of water and air through the soil function slower (Essington, 2004). Dispersion is a more destructive mechanism that forces clay particles away from one another resulting in clogged soil pores that form a restrictive barrier (Rengasamy and Sumner, 1998). Many of the negative impacts include: low water infiltration, poor aeration, low organic matter, high bulk density, surface crusting, runoff, erosion, and ultimately poor productivity (Shainberg and Letey, 1984; Rengasamy and Olsson, 1991; Fitzpatrick et al., 1994; Nelson and Oades, 1998). Although sodic soil conditions are harsh, amendments are commonly used to reduce swelling and dispersion and therefore improve chemical and physical properties.

A common management strategy for improving sodic soil includes addition of Ca, or other non-dispersive base cation-containing amendments. Adding amendments results in increased EC and promotion of the exchange and removal of Na off of the exchange sites (Rengasamy and Olsson, 1991). Although the increase in EC is an undesired consequence for plant growth, it is required to keep the soil flocculated and to promote better drainage (Muneer and Oades, 1989). However, Na removal is commonly restricted in arid and semi-arid climates where evaporation rates exceed precipitation. Therefore, dryland agriculture with a semi-arid climate common to that found in the NGP will increase the time it takes to improve soil conditions.

Gypsum ($CaSO_4 \cdot 2H_2O$) is a commonly used amendment for the amelioration of sodic soils all around the world. Other ameliorants that are not as commonly studied include lime ($CaCO_3$) (Carter, 1986; Roth and Pavan, 1991; Valzano et al., 2001; Bennett et al., 2014) and langbeinite ($K_2SO_4 \cdot 2MgSO_4$) (Artolia et al., 2000; Aydemir and Najjar, 2005). One form of gypsum, FGDG, has a solubility of 2.6 g L^{-1} (Bolan et al., 1991) and since it is in powder form has an advantage over pelletized gypsum due to its higher surface area per volume. For example, FGDG has a surface area that ranges from 6 and 185 $m^2\ g^{-1}$ (Bolan et al., 1991; Punshon et al., 1999) and pellet gypsum is about 7.6 x $10^{-4}\ m^2\ g^{-1}$ (adapted from Frenkel et al., 1989). Although surface area does not increase solubility, it does increase the distribution of product within the soil after incorporation, thus increasing the efficiency of rate of dissolution and thus exchange of Na for Ca.

A common Ca by-product that is regionally produced in the RRV of North Dakota and Minnesota is sugar beet processing by-product lime or spent lime (DeSutter and Godsey, 2010), whose foundation is calcium carbonate (0.06 g L^{-1}) (FAO, 1973). Spent lime also contains many important plant nutrients, such as P, N, Ca, Mg, and K (Sims et al., 2006). Twelve years after the application of 4.5 Mg lime ha^{-1} on a sodic soil with a pH of 6.1, the ESP decreased by 30.8% and the microbial respiration was increased by 108% from the control, which was attributed to increased vegetation growth and total organic C, whereas the application of 4.5 Mg gypsum ha^{-1} did not observe any benefits (Bennett et al., 2014). Spent lime's use for improving the productivity of sodic soils has not been studied.

The commercial fertilizer langbeinite (K-Mag, Mosaic) ($K_2SO_4 \cdot 2MgSO_4$) is another potential ameliorant to displace Na in sodic soils. Studies have shown K_s improvements when using langbeinite as a sodic soil ameliorant (Artiola et al., 2000; Aydemir and Najjar, 2005). Although Mg has induced soil-structure degradation (Curtin et al., 1994), He et al. (2013) determined that Mg does not induce dispersion in pure montmorillonite, illite, and kaolinite minerals. Langbeinite has a solubility of 280 g L^{-1} (Aydemir and Najjar, 2005) and has a much higher potential for increasing the EC of the soil, which may be detrimental to microbial activity due to osmotic stress (Marschner, 1995; Pathak and Rao, 1998; Mavi and Marschner, 2011; Setia et al., 2011b) but also help maintain the EC needed for flocculation. Similar to plants, microorganisms are sensitive to salt stress. Adaptations have been made by bacteria in saline soils that allow them to accumulate solutes or develop a special membrane to tolerate low water potentials (Alexander, 1998). Soil microbes can adjust to small increases in EC, however, when amendments are added it can be an abrupt change that induces shock to the soil system.

Soil biology is important for many soil health forming processes (Chen et al., 2003), however, the negative impacts of Na on microorganisms is less known throughout literature. A few important soil processes performed by microorganisms include C mineralization and nutrient cycling (Pathak and Rao, 1998). Measuring C mineralization or microbial respiration in saline and saline-sodic soils have been a way to identify correlations between how microbes respond to different soil properties. For example, many studies have concluded that increasing EC (natural or induced) decreases microbial respiration (Pathak and Rao, 1998; Yuan et al., 2007; Setia et al., 2011b; Mavi et al., 2012) and is most likely due to osmotic shock (Pathak and Rao, 1998; Wong et al., 2008; Chowhurdy et al., 2011; Setia et al., 2011a; Mavi et al., 2012).

Mixed results regarding sodicity have been observed regarding microbial respiration. Although sodic soils tend to contain low organic matter resulting in low microbial respiration (Setia et al., 2011a), it is important to consider the effects of dispersion of organic matter on microbial respiration. An increase in microbial respiration due to dispersion of soil aggregates, thus releasing organic matter and making it accessible to microorganisms can occur (Nelson et al., 1996). However, microbial activity may not be affected at high sodicity due to solubilization of substrates which reduces microbe stress (Pathak and Rao, 1998). Given the lack of understanding on how amendments impact overall microbial activity, the aim of this study was to evaluate the microbial response after addition of amendments: 1) FGDG, 2) spent lime, and 3) langbeinite to two sodic soils. The study's hypothesis was that after additions of amendments the microbial respiration would decrease in the short-term due to the increase in EC that could contribute to osmotic shock, as well as increased flocculation and reduced availability of C substrates.

Material and Methods

Sodic Soils

Two locations were sampled near Delamere in Sargent County, North Dakota. The soil at both locations was mapped as an Aberdeen-Ryan silty clay loam, sandy substratum, with 0 to 2 percent slopes (Soil Survey Staff, 2014). Soil 1 (S1; 46°15'52.27N, 97°19'28.29W) resembled the Aberdeen series which is a fine, smectitic, frigid Glossic Natrudolls (USDA-NRCS, 2014). Soil 2 (S2; 46°16'31.92N, 97°20'29.07W) resembled the Ryan series which is a fine, smectitic, frigid Typic Natraquerts (USDA-NRCS, 1997).

The soil samples were taken from the 0 to 15 cm depth, air dried, and ground to pass through a 2 mm sieve. The texture, % Na, and $EC_{1:1}$ were different at each site. Texture of S1 was a sandy clay loam (sand 46%, silt 25%, clay 29%) with a 4.6% Na and an $EC_{1:1}$ of 0.99 dS m^{-1}. Texture of S2 was a sandy loam (sand 59%, silt 23%, clay 18%) with 19% Na and an $EC_{1:1}$ of 3.4 dS m^{-1}. The ground samples were used to create microcosms.

Soil Treatments and Preparation

Due to space constraints two separate incubations were done for S1 and S2 including nine treatments and a control, replicated four times with each treatment containing 1-kg of soil. The treatments included three additions of FGDG (9, 27 and 54 g, equivalent to rates of 11.2, 33.6, and 67.2 Mg ha^{-1}, respectively), three additions of spent lime (9, 27 and 54 g, equivalent to rates of 11.2, 33.6, and 67.2 Mg ha^{-1}, respectively), and three additions of langbeinite (2, 4.5, 9 g, equivalent to rates of 2.2, 5.6, and 11.2 Mg ha^{-1}, respectively). The controls for this experiment were microcosms that did not include a soil amendment. The FGDG was obtained from the Great River Energy coal power plant, located near Falkirk, ND, and is composed of 22.6% Ca. The spent lime was obtained from Minn-Dak Farmers Cooperative sugar beet plant near Wahpeton, ND, and has a purity of 70.5% and ECC of 14.4%. The spent lime also contains 3.3% organic carbon (OC) (SKALAR Primacs^{SLC}, Breda, The Netherlands). The langbeinite was obtained from Mosaic Crop Nutrition, LLC (Riverview, FL) and is 21.5% K_2O and 10.5% Mg. The FGDG and spent lime were air dried and ground to pass through a 2 mm sieve and the langbeinite (K-Mag, Mosaic) was ground to pass through a 1.1 mm sieve. Upon visual evaluation, all amendments were less than their sieved sizes after homogenization. The soil and treatments were combined into a plastic bag that was brought to 20 percent gravimetric water content using deionized (DI) water, and mixed until homogenized. The soil was then transferred to a microcosm having a thin plastic bag to contain the soil and maintain soil moisture. Each microcosm was manufactured from 10 cm diameter PVC and cut 15 cm tall. The tops of the microcosms were constructed with a rubber gasket to ensure an air-tight seal with the CO_2 closed system chamber (SCR-1, PPSystems, Amesbury, MA) and was closed on the bottom using a hose clamp and wire mesh.

Microbial Respiration

The microcosms were incubated in the dark at 20 °C and maintained at 20 percent gravimetric water content for 76 days. The CO_2 respiration rate (g CO_2 m^{-2} hr^{-1}) was measured using an EGM-4 Environmental Gas Monitor for CO_2 and the SRC-1 (PPSystems). S1 was measured on day 4, 9 and then consistently measured every 7 days until the end of the experiment and S2 was measured on day 6 and consistently measured every 7 days until the end of the experiment. The head space volume between the top of the soil and where the SCR-1 sits was accounted for by:

$$A_a = A_i \times \left(\frac{HS+V}{V}\right) \quad [3]$$

where, A_a is the reading after accounting for headspace volume (g CO_2-C m^{-2} hr^{-1}), A_i is the initial EGM-4 reading (g CO_2-C m^{-2} hr^{-1}), *HS* is the headspace volume (cm^3), and *V* is the volume of the SCR-1 (1171 cm^3). The cumulative efflux (g CO_2-C m^{-2}) was calculated by:

$$Cumulative\ efflux = \sum\left(\frac{A_a \times AW_C \times 24 \times n}{AW_{CO_2}}\right) \quad [4]$$

where, AW_C is the atomic weight of C (12.0 g mol^{-1}), 24 is to convert hours to days, *n* is the number of days before each reading, and AW_{CO2} is the atomic weight of CO_2 (44.0 g mol^{-1}).

Soil Analysis

After the incubation, using moist soil, a 1:5 soil to DI water (6 grams soil:30 mL of DI water) sample was used to extract dissolved organic carbon (DOC) (Jones and Willett, 2006) by shaking for 1 hr, centrifuge for 20 min, and analyzing the supernatant. The DOC was analyzed using a TOC-V_{CPH} total organic carbon analyzer (Shimadzu, Tokyo, Japan). The remaining sample was ground to pass through a 2mm sieve. Percent Na was determined by Agvise laboratories as:

$$\%Na = \frac{100Na}{Ca+Mg+Na+K} \quad [5]$$

where cations are in units of $cmol_{(+)}$ kg^{-1} (DeSutter et al., 2015). The EC was determined on a 1:1 soil to water ratio (10 g soil:10 mL DI water) using a sensION378 meter (Hach, Loveland, CO). The pH was determined from the same $EC_{1:1}$ slurry using an AB15 meter (Fisher Scientific, Pittsburgh, PA). The Williams (1948) method was used to analyze Inorganic Carbon (IC). Total carbon (TC) was analyzed using high temperature combustion (SKALAR Primacs^{SLC}, Breda, The Netherlands) and total organic carbon (OC) was the difference between TC and IC. Field capacity water (FCW) was determined by applying -1/3 bar pressure using pressure plates (Klute, 1986).

Statistical Analysis

The decay rate and labile C were determined using a single pool non-exponential first-order decay model (La Scala et al., 2008):

$$F(t) = C_o k e^{-kt} \quad [6]$$

where, F(t) is the CO_2-C flux at time t, C_o is the initial amount of labile C in the soil and should decay exponentially in time controlled by the decay constant (k), and t is the days of incubation. This model was performed using the PROC NLIN Marquardt method (SAS 9.3, Cary, NC). Analysis of variance (ANOVA) was used to analyze the cumulative efflux, decay rate, and labile C. Additional ANOVAs were performed on DOC, %Na, EC, pH, IC, TC, TOC and FCW for each treatment to determine potential explanations for any significant differences observed in cumulative efflux, decay rate, and labile C. Significant differences at an alpha level of 0.05 were assessed using Tukey's HSD (JMP 12, Cary, NC).

Results

Soil Microcosm Analysis

Addition of amendments and their application rates had significant effects on soil properties and microbial respiration for both soils. Within both soils, the highest values of EC was observed with the application of langbeinite, in some cases, significantly increased EC compared to all other treatments (Table 8 and 9) which indicates its high solubility compared to the other amendments. The spent lime treatments, in general, significantly increased pH and IC compared to the other treatments and treatment differences in pH also occurred. The %Na across all treatments, within both soils, were significantly different than the control with the greatest reductions from the highest application rates within amendments. The highest application rate of spent lime also yielded the greatest concentrations of OC, although not generally different from other treatments. No differences were observed for FCW and the tiled and non-tiled site averaged 0.33 and 0.32 g g^{-1} (data not shown; Appendix C) indicating that soil swelling was not occurring (He et al., 2015).

Table 8. Soil 1 (S1) respiration and soil analysis after 76 days of incubation.

Treatment	Microbial Respiration			Microcosm Analysis						
	Cumulative Efflux	Labile C	Decay Rate	$EC_{1:1}$	$pH_{1:1}$	Na	IC†	OC‡	TC§	DOC¶
Mg ha^{-1}	------------g CO_2-C m^{-2}-------------		day^{-1}	dS m^{-1}		-----------------%------------------				mg L^{-1}
Control	76.9(6.0)cd#	120(28)cd	0.057(0.019)ab	0.986i	7.55d	4.63a	0.023c	1.72b	1.74c	140a
FGDG 11.2	65.2(7.2)cd	102(25)d	0.068(0.038)ab	2.22e	7.35ef	4.00d	0.043c	1.69b	1.73c	25.9bc
FGDG 33.6	68.2(5.8)cd	138(24)b	0.029(0.007)b	2.53d	7.41ef	3.43e	0.013c	1.70b	1.71c	27.3bc
FGDG 67.2	84.8(11.3)cd	111(6)d	0.063(0.014)ab	2.74c	7.52d	2.88f	0.020c	1.65b	1.67c	24.3c
Spent Lime 11.2	119(13)bc	206(13)bc	0.032(0.007)b	1.05hi	7.91c	3.40e	0.083c	1.90a	1.98b	53.7bc
Spent Lime 33.6	161(19)bc	213(15)b	0.038(0.006)ab	1.10gh	8.00b	2.78f	0.225b	1.92a	2.14b	57.8b
Spent Lime 67.2	223(20)a	346(20)a	0.041(0.008)ab	1.19g	8.08a	2.75f	0.480a	1.91a	2.39a	55.1bc
Langbeinite 2.2	57.7(7.1)d	93.9(20.9)d	0.044(0.006)ab	1.89f	7.42e	4.40b	0.008c	1.80ab	1.80c	31.9bc
Langbeinite 5.6	64.3(6.8)cd	86.0(11.6)d	0.067(0.011)ab	2.87b	7.34f	4.40b	0.008c	1.78ab	1.78c	22.4c
Langbeinite 11.2	59.3(5.5)d	68.0(7.4)d	0.121(0.028)a	3.72a	7.37ef	4.23c	0.030c	1.71b	1.74c	30.6bc

† IC – Inorganic carbon
‡ OC – Organic carbon
§ TC – Total carbon
¶ DOC – Dissolved organic carbon
# In the parenthesis is the square error of the mean and the different letters in each column indicate significant differences ($p < 0.05$) among treatments for each soil

Table 9. Soil 2 (S2) respiration and soil analysis after 76 days of incubation.

Treatment	Microbial Respiration			Microcosm Analysis						
	Cumulative Efflux	Labile C	Decay Rate	$EC_{1:1}$	$pH_{1:1}$	Na	IC†	OC‡	TC§	DOC¶
Mg ha^{-1}	-----------g CO_2-C m^{-2}------------		day^{-1}	dS m^{-1}		-------------------%-------------------				mg L^{-1}
Control	219(24)c#	261(28)b	0.036(0.005)a	3.37ef	8.14d	19.0a	0.005d	1.35bc	1.36cd	40.2ab
FGDG 11.2	239(21)bc	249(45)b	0.053(0.012)a	3.59ed	8.14d	15.9d	0.000d	1.35bc	1.35cd	32.6cd
FGDG 33.6	240(29)bc	285(55)b	0.036(0.006)a	3.84cd	8.20cd	11.7fg	0.000d	1.30bc	1.30d	31.5cd
FGDG 67.2	329(32)bc	383(45)b	0.031(0.002)a	3.89c	8.23cd	9.4h	0.000d	1.29c	1.29d	31.0d
Spent Lime 11.2	296(45)bc	326(50)b	0.041(0.004)a	3.28ef	8.37b	15.0e	0.078d	1.34bc	1.42c	36.3bc
Spent Lime 33.6	365(34)b	416(51)ab	0.039(0.005)a	3.26f	8.48a	12.2f	0.170b	1.41ab	1.58b	35.8bcd
Spent Lime 67.2	510(49)a	573(34)a	0.040(0.004)a	3.35ef	8.57a	11.2g	0.365a	1.48a	1.85a	36.0bcd
Langbeinite 2.2	273(9)bc	263(26)b	0.065(0.021)a	3.74cd	8.18cd	17.8b	0.005d	1.36bc	1.37cd	42.0a
Langbeinite 5.6	228(12)bc	268(14)b	0.036(0.004)a	4.44b	8.20cd	16.7c	0.010d	1.34bc	1.35cd	43.1a
Langbeinite 11.2	204(13)c	231(20)b	0.046(0.015)a	5.57a	8.29bc	15.0e	0.000d	1.34bc	1.34cd	43.7a

† IC – Inorganic carbon
‡ OC – Organic carbon
§ TC – Total carbon
¶ DOC – Dissolved organic carbon
# In the parenthesis is the square error of the mean and the different letters in each column indicate significant differences ($p < 0.05$) among treatments for each soil

Cumulative Respiration

Cumulative respiration ranged from 57.7 to 510 g CO_2-C m^{-2} across both soils with S2 values being greater for all respective treatments and rates (Table 8 and 9). Applications of spent lime had the highest cumulative respirations in both soils and were significantly different than all other treatments. The lowest cumulative respiration was observed from the low and high rates of langbeinite for both soils. However, these rates were not significantly lower than the other treatments with the exception of spent lime. An example of cumulative respiration rates for spent lime are shown in Figure 12. A complimentary study determined that the dissolution of $CaCO_3$ from the spent lime was not contributing to the increase in CO_2 efflux (data not shown).

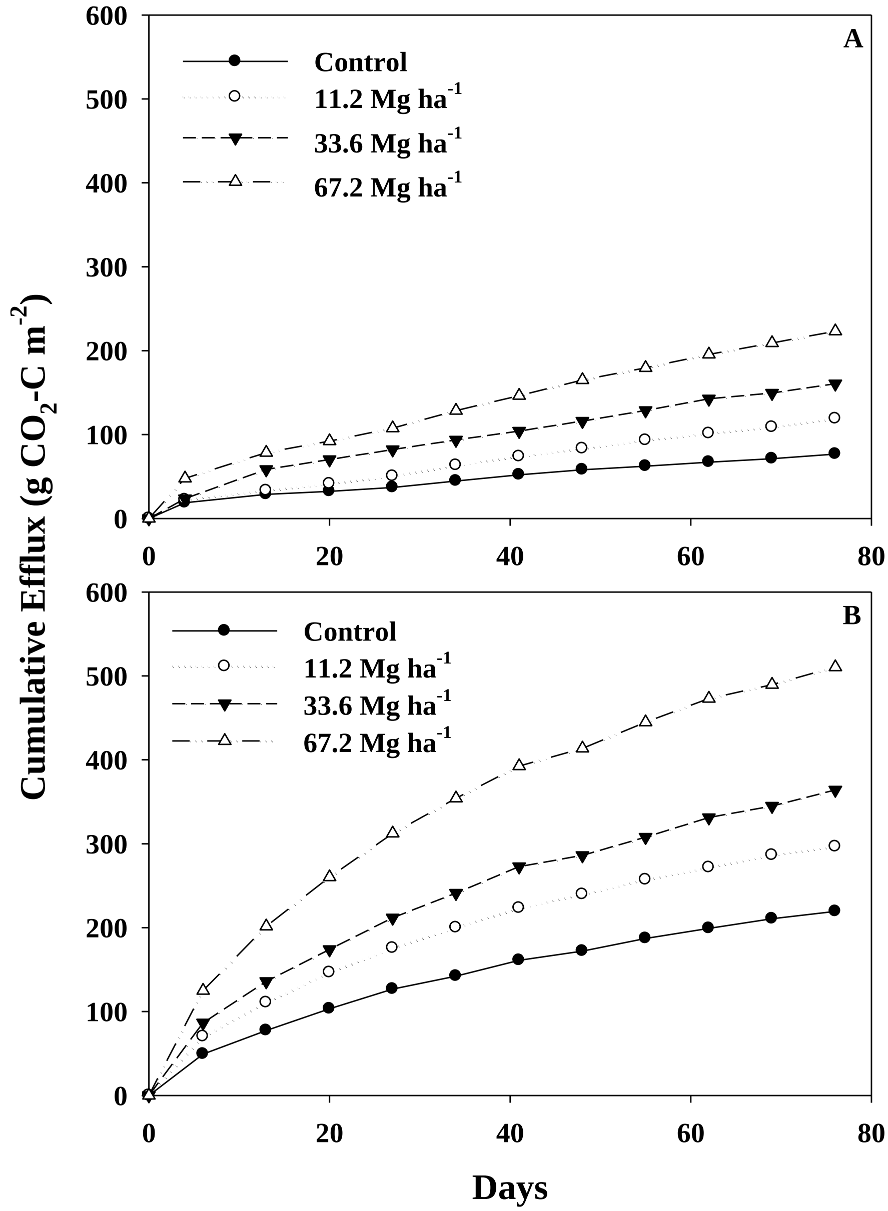

Figure 12. Cumulative efflux of the spent lime treatments and the control from S1 (A) and S2 (B).

Labile Carbon, Correlations, & Decay Rate

The labile C ranged from 68.0 to 573 g CO_2-C m^{-2} across both soils (Table 8 and 9). Similar patterns were observed for the labile C as for the cumulative respiration where the high rates of spent lime and langbeinite exhibited the highest and lowest labile C, respectively. The medium rate of FGDG and the two highest rates of spent lime were the only treatments significantly higher than the control from S1. However, the only treatment that was significantly higher from S2 was the high rate of spent lime. Across soils labile C was significantly correlated to all variables except DOC and FCW and negatively correlated with %Na and EC (Table 10).

Table 10. Labile carbon correlations with soil metrics.

Correlations†	Labile Carbon	
	Location 1‡	Location 2
Cumulative Efflux	0.9097**	0.9311**
TC	0.8309**	0.7088**
pH	0.8276**	0.6177**
IC	0.8028**	0.7569**
OC	0.6180**	0.4504*
%Na	-0.6452**	-0.5723*
EC	-0.6111**	-0.4072*
DOC	0.2238	-0.1906
FCW	0.1116	0.2750

† TC = total carbon, IC = inorganic carbon, OC = orgainic carbon, EC = electrical conductivity, DOC = dissolved organic carbon, FCW = field capacity water
‡ p-value < 0.01* and p-value < 0.0001**

The decay rate function represents the rate (0.029 to 0.121 day^{-1}) at which labile C is being mineralized and respired (Table 7 and 8). S1 had the most variation among treatments with the highest decay rate from the high rate of langbeinite. However, no differences in decay rate occurred across treatments in S2.

Discussion

Soil Microcosm Analysis

Differences observed in the soil chemical properties are due to amendments' chemical composition, and their solubilities play an important role in the EC of the soil. Langbeinite had the highest EC, likely due to its high solubility (280 g L^{-1}), compared to the other amendments.

Previous studies have demonstrated negative correlations between EC and microbial respiration, but many of these studies caused a shock effect when saline water was applied to non-saline soils (Pathak and Rao, 1998; Wong et al., 2008; Chowhurdy et al., 2011; Setia et al., 2011a; Mavi et al., 2012). Consequently, microbial populations in these studies were not given time to acclimate to saline conditions. In naturally saline soils it is possible that the microbial populations can adapt to excess salts in the soil (Wichern et al., 2006; Schimel et al., 2007; Allison and Martiny, 2008; Rath and Rousk, 2015). For example, some strains of bacteria have become more salt tolerant and could potentially help promote the cultivation of leguminous plants in saline soils (Trabelsi et al., 2010). Not surprising, minimal EC changes were observed after application of spent lime because, due to its low solubility, a saturated water/lime sample only has an EC of 0.4 dS m^{-1}. The increase in EC from applications of FGDG was also expected and has been reported by numerous authors (Carter, 1986; Ilyas et al., 1997; Mace et al., 1999; Valzano et al., 2001; Ahmad et al., 2006; Clark et al., 2007; Wong et al., 2009) but was not observed in this study.

Spent lime has been shown to increase soil pH, both in Paper 1 and from DeSutter and Godsey (2010). High pH soils have been shown to have positive influences on bacterial communities where low pH soils are more conducive for fungal communities (Rousk et al., 2009). The amendments were effective at reducing Na which has been shown by many studies (Artiola et al., 2000; Valzano et al., 2001; Wong et al., 2009; Bennett et al., 2014). Although this study only lasted for 76 days, the greatest changes noted in soil-Na metrics field studies (ESP or SAR) have been when the application rates of amendments have been high and the time from application has been long (Table 2) (Carter, 1986; Bennett et al., 2014). Since %Na includes both exchanger and solution phase Na in relation to the total cations (Na, Ca, Mg, K), one may assume that the increase in cations (Ca, Mg, K) from the amendments, diluted Na and thus decreased %Na. Equilibrium between exchanger and solution phases from amendment cations would eventually occur but during the 76 days of incubation these cations are most likely from the dissolution of the amendments and not from exchange sites.

Microbial Respiration

The most notable results from this experiment were that the amendments did not decrease microbial activity more than the control and that spent lime contributed OC which likely contributed to high values of cumulative respiration and labile C (Table 7 and 8). Addition of OC amendments is a common way to improve soil activity and microbial respiration (Wong et al., 2009; Deshpande et al., 2012; Yazdanpanah et al., 2013; Celis et al., 2013). Moreover, it has been observed in field conditions that increasing partial pressure of CO_2, whether it be from microbial respiration, plant root respiration (Nakayama, 1969) or exudates, will lower the pH of the soil solution, resulting in *in situ* lime dissolution (Robbins, 1986a; 1986b). The addition of the OC with the spent lime may help promote lime dissolution that would allow Ca to become available to replace Na on the exchanger phase.

The lack of reduced microbial activity due to applications of langbeinite and FGDG should be seen as another positive result from this study, as well as the fact that both amendments reduced %Na. Oftentimes, when salts are added to soil for salinity studies, microbial respiration rapidly declines (Pathak and Rao, 1998; Wong et al., 2008; Chowdhury et al., 2011; Setia et al., 2011a; Mavi et al., 2012) but microbes may be able to adapt to natural salinity increases (Wichern et al., 2006; Schimel et al., 2007; Allison and Martiny, 2008; Rath and Rousk, 2015). Since this study applied moderately or fairly insoluble salts, a shock effect did not reduce microbial activity. Higher rates of langbeinite than what was used in this study have the potential to decrease microbial activity since the treatments reported in Tables 6 and 7 show the highest langbeinite rates have the numerically lowest respiration metrics, and highest decay rate in S1. The hypothesis from this study was rejected because the microbial respiration did not decrease due to osmotic shock after the amendments where applied.

Conclusion

Amelioration of sodic soils oftentimes requires the use of chemical amendments. However, these amendments may influence soil microbial activity thereby decreasing the ability to improve soil health. The use of spent lime was shown to positively increase microbial respiration while also decreasing %Na, which are both indicative of soil health improvement. Although FGDG and langbeinite did not increase microbial activity like the spent lime did, the amendments decreased %Na and did not decrease activity compared to the control. The amendments and their rates of application used in this incubation experiment were not harmful to microbial activity, based on respiration, or the soil environment and therefore can be used for sodic soil improvement.

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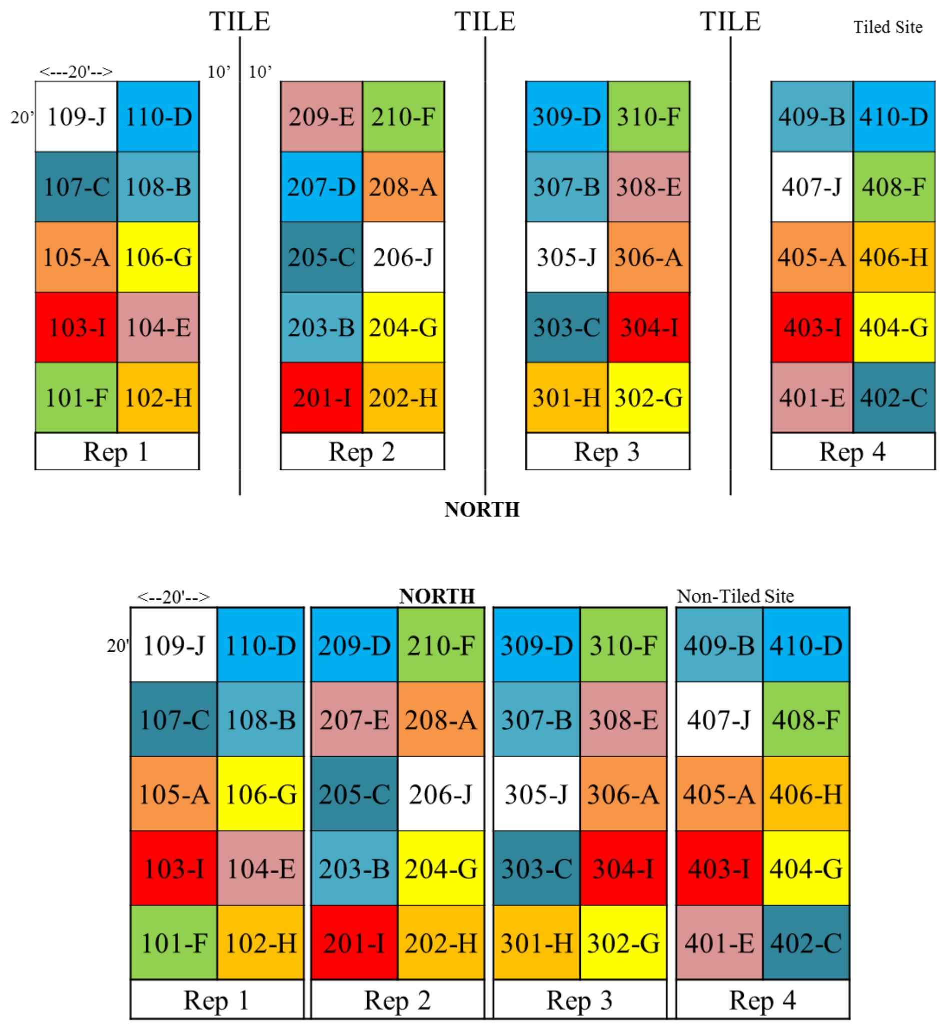
GENERAL CONCLUSION

The improvement of sodic soils for the purpose of growing agricultural crops is challenging, especially in arid and semi-arid regions that are not irrigated. Considerations must include “how long will improvement take?”, “how much will improvement cost?”, and “are amendments more harmful than good?” To help answer some of these questions both field and laboratory experiments were conducted using two sodic soils from southeastern North Dakota. The field study showed no significant declines in %Na in the surface soil compared to the controls but reductions in %Na did occur in the following order: FGDG > spent lime > langbeinite. Although some impact on alfalfa and its quality was expected, no impacts were observed at the tiled site and only using the high rates of langbeinite at the non-tiled site was the alfalfa negatively impacted by high EC. Because of natural, in-field variability and its influence on defining subtle treatment changes an incubation study was conducted which resulted in some interesting results. The spent lime treatments increased microbial respiration and decreased %Na while FGDG and langbeinite also decreased %Na but not microbial respiration. Correlations showed that labile C is negatively related to Na and EC and that ideal remedial strategies should simultaneously remove Na and provide a C source for increasing microbial activity. Overall, the results from this thesis support the studies that have concluded that in dryland conditions the amelioration of sodic soils may take many years, but during this amelioration phase, microbial activity should not be negatively impacted and may actually improve depending on the choice of amendment.

APPENDIX A. FIELD DESIGN AND PEDON DESCRIPTIONS FOR PAPER 1



Treatments	$Mg\ ha^{-1}$	
FDGD	11.2	A
	33.6	B
	67.2	C
Lime	11.2	D
	33.6	E
	67.2	F
LB	2.2	G
	5.6	H
	11.2	I
Control	0	J

Figure A1. Tiled and Non-Tiled Site Field Design

Aberdeen-like Series: Tiled Site

Evaluated by Breker, M. and Anderson, K.

Colors are for moist soil unless otherwise stated.

Ap— 0 to 6 cm; black (2.5Y 2.5/1) loam, very dark gray (2.5Y 3/2) dry; strong medium cloddy structure parting to strong fine granular; hard, friable; common medium roots; abrupt smooth boundary.

BE—6 to 13 cm; black (2.5Y 2.5/1) clay loam, very dark gray (2.5Y 3/1) dry; strong coarse columnar structure parting to strong medium angular blocky; hard, friable; grayish brown (2.5Y 5/2) silt coatings on faces of peds; common fine and few medium roots, common fine nests of salts; abrupt smooth boundary.

Btnz—13 to 28 cm; black (2.5Y 2.5/1) clay, very dark gray (2.5Y 3/1) dry; strong coarse prismatic structure parting to strong medium subangular blocky; hard, friable; common thin clay films on faces of peds; common fine and few medium roots; common fine threads and masses of salts; clear smooth boundary.

Btnkz—28 to 49 cm; 80% dark grayish brown (2.5Y 4/2) and 20% very dark gray (2.5Y 3/1) clay; moderate medium prismatic structure parting to moderate fine subangular blocky; slightly hard, friable; many thick clay films on faces of peds; few fine roots; common fine threads and masses of salt; many coarse accumulations of carbonates; violent effervescence; clear smooth boundary.

Bkyz—49 to 69 cm; light olive brown (2.5Y 5/3) clay loam; weak medium prismatic structure parting to moderate medium subangular blocky; friable; few fine prominent yellowish brown (10YR 5/8) redoximorphic concentrations and common medium distinct gray (2.5Y 5/1) depletions; very few fine roots; common fine prominent black (10YR 2/1) soft masses of manganese; common fine threads and masses of salt; few fine nests of gypsum; common medium accumulations of carbonates; violent effervescence; clear smooth boundary.

2C1—69 to 80 cm; light olive brown (2.5Y 5/4) fine sand; single grained; loose; many coarse prominent yellowish brown (10YR 5/8) redoximorphic concentrations and many coarse distinct grayish brown (2.5Y 5/2) depletions; very few fine roots; common fine threads and masses of salt; common fine prominent black (10YR 2/1) soft masses of manganese; violent effervescence; gradual smooth boundary.

2C2—80 to 89 cm; light olive brown (2.5Y 5/3) loam; massive; friable; many coarse distinct light olive brown (2.5Y 5/6) redoximorphic concentrations and common medium distinct light brownish gray (2.5Y 6/2) depletions; common fine prominent black (10YR 2/1) soft masses of manganese; few fine nests of gypsum; violent effervescence; gradual smooth boundary.

2C3—89 to 150 cm; olive brown (2.5Y 4/4) sand; single grained; loose; common coarse prominent dark brown (10YR 3/4) and brownish yellow (10YR 6/8) redoximorphic concentrations.

Notes: 7/23/2015
Latitude: 46° 15'52.3"N   Longitude: 97° 19'25.8"W
Saturated at 150 cm
Sandy substratum is out the of range in characteristics
Description site is south of plots 209 & 210
Vegetation: Alfalfa

Ryan-like Series: Non-tiled Site

Evaluated by Breker, M. and Anderson, K.

Colors are for moist soil unless otherwise stated.

Apz—0 to 6 cm; black (2.5Y 2.5/1) clay loam, very dark gray (2.5Y 3/1) dry; strong medium cloddy structure parting to moderate fine granular; friable; common medium and many fine roots; common fine masses of salts; slight effervescence; abrupt smooth boundary.

Btnz—6 to 21 cm; black (2.5Y 2.5/1) clay, very dark gray (2.5Y 3/1) dry; strong coarse prismatic structure parting to strong medium angular blocky; firm; common thin clay films on faces of peds; common medium and many fine roots; common fine masses and threads of salts; slight effervescence; clear smooth boundary.

Btnkyz—21 to 39 cm; very dark gray (2.5Y 3/1) clay loam; moderate coarse prismatic structure parting to moderate fine angular blocky; friable; common medium clay films on faces and peds; common medium and few fine roots; common fine masses and threads of salts; few fine nests of gypsum; many coarse accumulations of carbonates; violent effervescence; clear smooth boundary.

Bky—39 to 48 cm; light brownish gray (2.5Y 6/2) loam; moderate coarse subangular blocky; friable; few fine prominent yellow (10YR 7/6) redoximorphic concentrations; common medium roots; few fine nests of gypsum; many coarse accumulations of carbonates; violent effervescence; abrupt smooth boundary.

2Bk—40 to 59 cm; light yellowish brown (2.5Y 6/3) loamy very fine sand; moderate medium subangular blocky structure; very friable; many coarse prominent brownish yellow (10YR 6/6) redoximorphic concentrations and common fine faint light gray (2.5Y 7/1) depletions; common medium roots; violent effervescence, clear smooth boundary.

2C1—59 to 77 cm; light olive brown (2.5Y 5/4) loamy fine sand; massive; very friable; common fine distinct light olive brown (2.5Y 5/6) redoximorphic concentrations and common fine distinct light gray (2.5Y 7/1) depletions; few fine prominent black (10YR 2/1) soft masses of manganese; very few fine roots; strong effervescence; clear smooth boundary.

2C2—77 to 88 cm; light olive brown (2.5Y 5/4) very fine sandy loam; massive; very friable; common fine prominent dark yellowish brown (10YR 4/6) redoximorphic concentrations and common fine distinct light gray (2.5Y 7/1) depletions; few fine prominent black (10YR 2/1) soft masses of manganese; very few fine roots; strong effervescence; clear smooth boundary.

2C3—88 to 130 cm; gray (5Y 5/1) loamy very fine sand; massive; very friable; many coarse prominent dark yellowish brown (10YR 4/6) redoximorphic concentrations; common fine prominent black (10YR 2/1) soft masses of manganese; very few fine roots; slight effervescence; clear smooth boundary.

2C4—130 to 150 cm; brown (10YR 4/3) sand; single grained; loose; many coarse distinct brown (10YR 4/6) redoximorphic concentrations and few fine distinct gray (10YR 5/1) depletions; few fine distinct black (10YR 2/1) soft masses of manganese; slight effervescence.

Notes: 7/23/2015
Latitude: 46° 16’31.6”N   Longitude: 97° 20’28.4”W
Saturated at 70 cm
Water at 120 cm
Sandy substratum is out the of range in characteristics
Description site is north of plot 210
Vegetation: Alfalfa

APPENDIX B. FIELD STUDY DATA

Table B1. 2014 Soil Data

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	Control	1	1	9.4	2.3	7.6	0.7	1.3
Tile	Control	1	2	12.6	4.1	7.8	2.7	1.5
Tile	Control	1	3	7.4	4.1	8.0	18.7	1.4
Tile	Control	1	4	11.9	2.5	8.3	16.4	1.8
Tile	Control	1	5	13.1	0.2	9.1	5.9	1.5
Tile	Control	2	1	4.3	0.8	7.8	1.6	1.5
Tile	Control	2	2	7.8	2.8	7.8	0.9	1.7
Tile	Control	2	3	9.5	3.8	8.0	28.6	1.4
Tile	Control	2	4	10.5	1.6	8.5	17.4	1.7
Tile	Control	2	5	10.6	0.4	9.1	7.8	1.7
Tile	Control	3	1	5.3	1.1	7.5	0.9	1.6
Tile	Control	3	2	10.9	3.0	7.8	1.5	1.7
Tile	Control	3	3	5.1	3.8	8.1	22.2	1.4
Tile	Control	3	4	10.7	1.3	8.8	19.4	1.7
Tile	Control	3	5	11.5	1.0	8.9	11.2	1.8
Tile	Control	4	1	5.8	1.1	7.5	0.5	1.6
Tile	Control	4	2	8.5	3.4	7.8	2.3	1.7
Tile	Control	4	3	3.0	3.1	8.1	24.2	1.6
Tile	Control	4	4	12.1	1.7	8.7	13.6	1.8
Tile	Control	4	5	12.8	0.7	8.8	6.2	1.9
Tile	FGDG 11.2	1	1	4.4	1.6	7.4	0.6	1.5
Tile	FGDG 11.2	1	2	7.1	2.1	7.8	4.8	1.6
Tile	FGDG 11.2	1	3	7.1	3.6	7.8	27.5	1.5
Tile	FGDG 11.2	1	4	11.4	2.8	8.3	19.8	1.6
Tile	FGDG 11.2	1	5	14.0	0.9	8.9	8.2	1.8
Tile	FGDG 11.2	2	1	3.0	1.4	7.5	1.3	1.5
Tile	FGDG 11.2	2	2	6.4	2.4	7.7	1.9	1.6
Tile	FGDG 11.2	2	3	10.1	3.5	8.0	2.3	1.6
Tile	FGDG 11.2	2	4	12.3	2.9	8.4	10.7	1.7
Tile	FGDG 11.2	2	5	12.3	0.5	8.9	8.0	1.8
Tile	FGDG 11.2	3	1	4.8	1.8	7.6	1.5	1.6
Tile	FGDG 11.2	3	2	9.4	2.7	7.8	1.9	1.6
Tile	FGDG 11.2	3	3	5.7	3.8	8.2	23.4	1.5
Tile	FGDG 11.2	3	4	9.8	1.5	8.7	18.9	1.7
Tile	FGDG 11.2	3	5	10.0	0.5	9.0	6.8	1.8

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	FGDG 11.2	4	1	5.3	1.6	7.4	1.9	1.6
Tile	FGDG 11.2	4	2	8.2	3.2	7.8	6.0	1.7
Tile	FGDG 11.2	4	3	5.6	2.9	8.1	22.3	1.6
Tile	FGDG 11.2	4	4	3.7	3.3	8.1	10.8	1.6
Tile	FGDG 11.2	4	5	14.4	1.2	8.6	8.2	1.9
Tile	FGDG 33.6	1	1	2.7	2.2	7.4	2.3	1.5
Tile	FGDG 33.6	1	2	8.1	2.5	7.8	4.6	1.6
Tile	FGDG 33.6	1	3	7.8	3.7	7.9	13.6	1.4
Tile	FGDG 33.6	1	4	15.5	2.3	8.6	16.7	1.7
Tile	FGDG 33.6	1	5	15.5	0.4	8.9	8.1	1.8
Tile	FGDG 33.6	2	1	2.9	2.1	7.2	1.1	1.5
Tile	FGDG 33.6	2	2	6.5	1.8	7.9	5.1	1.4
Tile	FGDG 33.6	2	3	5.8	3.4	8.0	18.1	1.4
Tile	FGDG 33.6	2	4	12.0	2.2	8.5	21.3	1.6
Tile	FGDG 33.6	2	5	13.6	1.4	8.8	12.1	1.8
Tile	FGDG 33.6	3	1	4.4	1.6	7.5	1.7	1.6
Tile	FGDG 33.6	3	2	10.2	2.4	7.9	2.7	1.6
Tile	FGDG 33.6	3	3	6.2	4.0	8.2	14.7	1.5
Tile	FGDG 33.6	3	4	12.6	2.1	8.7	18.2	1.7
Tile	FGDG 33.6	3	5	13.0	1.5	8.8	10.8	1.8
Tile	FGDG 33.6	4	1	6.8	2.4	7.4	0.9	1.6
Tile	FGDG 33.6	4	2	12.1	3.3	7.8	1.3	1.6
Tile	FGDG 33.6	4	3	10.3	2.5	8.2	18.0	1.7
Tile	FGDG 33.6	4	4	11.1	1.2	8.8	11.1	1.7
Tile	FGDG 33.6	4	5	11.6	1.1	8.8	8.7	1.3
Tile	FGDG 67.2	1	1	2.9	2.4	7.5	1.5	1.5
Tile	FGDG 67.2	1	2	8.3	2.5	7.7	2.7	1.7
Tile	FGDG 67.2	1	3	9.2	4.1	8.0	10.9	1.4
Tile	FGDG 67.2	1	4	15.8	2.1	8.7	15.6	1.7
Tile	FGDG 67.2	1	5	13.0	1.0	8.9	11.8	1.7
Tile	FGDG 67.2	2	1	3.1	2.2	7.3	1.7	1.5
Tile	FGDG 67.2	2	2	8.4	2.9	7.7	4.3	1.6
Tile	FGDG 67.2	2	3	9.2	3.6	8.0	12.8	1.5
Tile	FGDG 67.2	2	4	13.5	2.2	8.6	18.5	1.6
Tile	FGDG 67.2	2	5	15.6	0.8	8.9	8.4	1.8
Tile	FGDG 67.2	3	1	2.2	2.1	7.5	2.1	1.6
Tile	FGDG 67.2	3	2	10.3	1.8	7.8	1.9	1.6
Tile	FGDG 67.2	3	3	5.7	3.7	8.1	16.7	1.5
Tile	FGDG 67.2	3	4	11.1	1.5	8.9	15.7	1.7

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	FGDG 67.2	3	5	12.3	1.4	8.8	13.2	1.7
Tile	FGDG 67.2	4	1	2.6	2.1	7.2	1.6	1.5
Tile	FGDG 67.2	4	2	9.9	1.7	7.7	1.7	1.5
Tile	FGDG 67.2	4	3	8.3	2.5	8.0	24.1	1.5
Tile	FGDG 67.2	4	4	10.1	1.3	8.7	19.2	1.7
Tile	FGDG 67.2	4	5	11.6	1.2	8.7	9.3	1.8
Tile	SL 11.2	1	1	3.5	0.7	7.8	0.9	1.4
Tile	SL 11.2	1	2	8.1	1.6	7.8	1.4	1.6
Tile	SL 11.2	1	3	4.9	3.2	7.8	16.7	1.5
Tile	SL 11.2	1	4	12.0	1.7	8.5	14.4	1.7
Tile	SL 11.2	1	5	17.4	0.8	8.7	4.5	1.7
Tile	SL 11.2	2	1	9.0	1.0	7.8	1.3	1.4
Tile	SL 11.2	2	2	3.8	1.8	7.8	1.6	1.4
Tile	SL 11.2	2	3	6.0	3.6	8.1	10.4	1.5
Tile	SL 11.2	2	4	13.9	2.0	8.8	13.0	1.7
Tile	SL 11.2	2	5	12.3	0.6	8.9	8.7	1.8
Tile	SL 11.2	3	1	9.0	1.6	7.8	1.2	1.6
Tile	SL 11.2	3	2	13.0	3.5	7.9	1.7	1.7
Tile	SL 11.2	3	3	6.1	4.1	8.2	21.8	1.5
Tile	SL 11.2	3	4	11.5	1.9	8.6	14.0	1.7
Tile	SL 11.2	3	5	13.0	0.6	9.0	7.5	1.7
Tile	SL 11.2	4	1	6.0	1.4	7.8	1.1	1.6
Tile	SL 11.2	4	2	9.3	2.5	7.6	1.0	1.7
Tile	SL 11.2	4	3	7.5	1.9	8.1	25.4	1.5
Tile	SL 11.2	4	4	8.8	1.4	8.4	14.5	1.7
Tile	SL 11.2	4	5	10.3	1.1	8.5	7.1	1.7
Tile	SL 33.6	1	1	5.7	1.3	7.8	1.5	1.5
Tile	SL 33.6	1	2	9.5	3.1	7.7	4.6	1.5
Tile	SL 33.6	1	3	11.0	3.7	7.9	34.2	1.4
Tile	SL 33.6	1	4	14.2	1.9	8.6	18.9	1.7
Tile	SL 33.6	1	5	18.0	0.6	8.8	7.9	1.8
Tile	SL 33.6	2	1	2.7	0.7	7.9	2.1	1.4
Tile	SL 33.6	2	2	6.2	1.4	7.9	6.0	1.7
Tile	SL 33.6	2	3	8.9	3.1	8.0	3.6	1.6
Tile	SL 33.6	2	4	12.0	2.1	8.6	15.0	1.7
Tile	SL 33.6	2	5	12.6	1.0	8.9	9.8	1.9
Tile	SL 33.6	3	1	6.5	1.4	7.9	2.1	1.5
Tile	SL 33.6	3	2	12.0	3.3	7.8	2.2	1.6
Tile	SL 33.6	3	3	9.9	4.2	8.2	30.8	1.5

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	SL 33.6	3	4	12.2	2.0	8.8	23.4	1.8
Tile	SL 33.6	3	5	12.7	1.2	8.8	13.2	1.8
Tile	SL 33.6	4	1	4.3	0.8	7.9	2.3	1.5
Tile	SL 33.6	4	2	11.2	1.4	7.8	3.9	1.6
Tile	SL 33.6	4	3	4.6	3.1	7.9	10.6	1.5
Tile	SL 33.6	4	4	7.3	2.8	8.2	12.8	1.7
Tile	SL 33.6	4	5	14.4	1.5	8.4	9.6	1.8
Tile	SL 67.2	1	1	3.6	1.2	7.8	3.9	1.2
Tile	SL 67.2	1	2	8.0	2.8	7.6	5.4	1.5
Tile	SL 67.2	1	3	6.6	3.5	7.7	33.0	1.4
Tile	SL 67.2	1	4	12.2	1.3	8.7	11.0	1.7
Tile	SL 67.2	1	5	15.9	1.0	8.7	10.2	1.8
Tile	SL 67.2	2	1	2.6	0.8	7.9	2.5	1.5
Tile	SL 67.2	2	2	7.2	1.8	7.9	2.2	1.7
Tile	SL 67.2	2	3	5.0	3.5	8.1	13.7	1.5
Tile	SL 67.2	2	4	11.0	1.5	8.6	14.3	1.7
Tile	SL 67.2	2	5	11.8	0.6	9.0	8.6	1.8
Tile	SL 67.2	3	1	3.0	0.9	8.1	2.3	1.4
Tile	SL 67.2	3	2	9.7	1.9	7.9	1.1	1.6
Tile	SL 67.2	3	3	8.6	2.9	8.1	20.4	1.6
Tile	SL 67.2	3	4	9.6	1.1	8.8	12.6	1.6
Tile	SL 67.2	3	5	12.3	0.5	9.1	6.6	1.3
Tile	SL 67.2	4	1	2.4	0.9	7.8	0.9	1.6
Tile	SL 67.2	4	2	6.8	1.8	7.7	0.5	1.7
Tile	SL 67.2	4	3	5.3	1.4	8.0	15.4	1.6
Tile	SL 67.2	4	4	6.2	1.0	8.4	13.2	1.7
Tile	SL 67.2	4	5	11.2	0.7	8.5	5.4	1.8
Tile	Kmag 2.2	1	1	4.0	1.1	7.6	1.3	1.2
Tile	Kmag 2.2	1	2	8.6	3.3	7.7	10.7	1.5
Tile	Kmag 2.2	1	3	7.7	3.8	7.9	31.3	1.4
Tile	Kmag 2.2	1	4	15.5	2.6	8.5	20.5	1.7
Tile	Kmag 2.2	1	5	13.7	0.9	8.8	10.8	1.8
Tile	Kmag 2.2	2	1	8.1	1.5	7.6	1.1	1.4
Tile	Kmag 2.2	2	2	13.2	3.5	7.9	3.0	1.6
Tile	Kmag 2.2	2	3	12.9	4.8	8.2	38.1	1.4
Tile	Kmag 2.2	2	4	11.7	0.9	9.0	13.3	1.7
Tile	Kmag 2.2	2	5	15.0	0.3	9.1	6.2	1.7
Tile	Kmag 2.2	3	1	6.8	1.2	7.5	1.0	1.5

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	Kmag 2.2	3	2	12.5	2.3	7.6	1.3	1.6
Tile	Kmag 2.2	3	5	12.6	0.7	9.0	5.6	1.7
Tile	Kmag 2.2	4	1	5.1	1.1	6.7	1.6	1.6
Tile	Kmag 2.2	4	2	8.1	1.4	7.7	1.3	1.1
Tile	Kmag 2.2	4	3	3.1	3.3	8.0	23.4	1.3
Tile	Kmag 2.2	4	4	6.1	2.8	8.2	18.3	1.8
Tile	Kmag 2.2	4	5	10.3	0.7	8.8	7.7	1.6
Tile	Kmag 5.6	1	1	5.1	2.0	7.4	1.8	1.4
Tile	Kmag 5.6	1	2	10.4	2.3	7.8	3.2	1.6
Tile	Kmag 5.6	1	3	10.7	2.9	7.7	3.0	1.5
Tile	Kmag 5.6	1	4	13.1	1.7	8.5	16.5	1.7
Tile	Kmag 5.6	1	5	13.7	0.3	8.9	6.6	1.8
Tile	Kmag 5.6	2	1	5.3	1.5	7.6	1.0	1.4
Tile	Kmag 5.6	2	2	8.5	3.4	7.8	5.8	1.6
Tile	Kmag 5.6	2	3	8.0	4.1	8.1	9.9	1.5
Tile	Kmag 5.6	2	4	13.7	1.7	8.7	16.4	1.7
Tile	Kmag 5.6	2	5	10.5	0.6	9.1	8.4	1.8
Tile	Kmag 5.6	3	1	4.3	1.0	7.4	0.9	1.6
Tile	Kmag 5.6	3	2	8.2	1.9	7.8	2.1	1.5
Tile	Kmag 5.6	3	3	11.1	2.7	8.1	19.9	1.5
Tile	Kmag 5.6	3	4	10.6	1.1	8.7	11.3	1.7
Tile	Kmag 5.6	3	5	11.7	1.3	8.8	10.6	1.8
Tile	Kmag 5.6	4	1	2.5	1.0	7.1	0.9	1.5
Tile	Kmag 5.6	4	2	5.4	1.5	7.3	0.9	1.6
Tile	Kmag 5.6	4	3	5.0	2.6	7.9	28.6	1.5
Tile	Kmag 5.6	4	4	8.5	1.3	8.5	13.8	1.7
Tile	Kmag 5.6	4	5	10.9	0.7	8.7	6.8	1.8
Tile	Kmag 11.2	1	1	4.3	2.7	7.4	1.5	1.6
Tile	Kmag 11.2	1	2	8.3	2.4	7.7	3.2	1.5
Tile	Kmag 11.2	1	3	9.1	3.4	7.8	21.3	1.5
Tile	Kmag 11.2	1	4	12.4	2.1	8.4	16.4	1.7
Tile	Kmag 11.2	1	5	12.0	0.8	8.8	11.2	1.8
Tile	Kmag 11.2	2	1	7.4	2.6	7.4	1.1	1.4
Tile	Kmag 11.2	2	2	11.5	3.8	7.8	3.5	1.5
Tile	Kmag 11.2	2	3	12.4	4.2	8.0	38.6	1.4
Tile	Kmag 11.2	2	4	12.1	1.1	8.8	13.5	1.7
Tile	Kmag 11.2	2	5	18.3	0.8	8.8	6.7	1.7
Tile	Kmag 11.2	3	1	5.8	2.3	7.3	1.9	1.6
Tile	Kmag 11.2	3	2	10.9	2.9	7.7	2.3	1.7

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Tile	Kmag 11.2	3	3	6.5	3.9	8.1	23.3	1.5
Tile	Kmag 11.2	3	4	10.0	1.4	8.7	17.1	1.7
Tile	Kmag 11.2	3	5	12.0	0.8	8.9	8.2	1.8
Tile	Kmag 11.2	4	1	6.6	2.3	7.4	0.1	1.7
Tile	Kmag 11.2	4	2	11.5	3.5	7.8	2.7	1.7
Tile	Kmag 11.2	4	3	5.0	3.5	8.2	24.3	1.5
Tile	Kmag 11.2	4	4	3.6	2.9	8.1	10.3	1.7
Tile	Kmag 11.2	4	5	7.9	2.7	8.5	7.6	1.7
Non-Tile	Control	1	1	12.7	2.3	8.1	1.3	1.5
Non-Tile	Control	1	2	11.7	2.5	8.0	5.0	1.6
Non-Tile	Control	1	3	10.8	2.0	8.3	24.7	1.5
Non-Tile	Control	1	4	10.8	1.1	8.8	21.5	1.7
Non-Tile	Control	1	5	8.4	0.5	8.7	10.1	1.8
Non-Tile	Control	2	1	14.0	2.5	8.1	2.2	1.5
Non-Tile	Control	2	2	11.7	3.1	8.1	3.3	1.7
Non-Tile	Control	2	3	10.9	2.3	8.3	10.0	1.6
Non-Tile	Control	2	4	7.7	1.0	8.7	32.1	1.7
Non-Tile	Control	2	5	6.5	0.6	8.8	14.0	1.5
Non-Tile	Control	3	1	12.4	3.0	8.0	2.3	1.7
Non-Tile	Control	3	2	11.2	2.7	8.0	2.2	1.6
Non-Tile	Control	3	3	8.7	1.9	8.2	21.6	1.5
Non-Tile	Control	3	4	7.7	1.0	8.7	23.3	1.7
Non-Tile	Control	3	5	6.4	0.7	8.6	16.1	1.6
Non-Tile	Control	4	1	10.2	2.5	8.0	1.0	1.6
Non-Tile	Control	4	2	14.1	3.1	8.0	0.9	1.7
Non-Tile	Control	4	3	11.6	2.3	8.3	14.7	1.6
Non-Tile	Control	4	4	9.2	1.2	8.7	24.4	1.7
Non-Tile	Control	4	5	9.2	0.8	8.7	9.0	1.7
Non-Tile	FGDG 11.2	1	1	14.1	2.2	8.1	0.5	1.7
Non-Tile	FGDG 11.2	1	2	20.2	2.2	8.1	0.5	1.7
Non-Tile	FGDG 11.2	1	3	12.3	1.9	8.5	14.8	1.6
Non-Tile	FGDG 11.2	1	4	8.7	0.8	9.0	22.8	1.8
Non-Tile	FGDG 11.2	1	5	5.4	0.4	8.8	15.0	1.7
Non-Tile	FGDG 11.2	2	1	13.0	2.6	8.3	1.3	1.6
Non-Tile	FGDG 11.2	2	2	15.8	2.8	8.1	1.0	1.7
Non-Tile	FGDG 11.2	2	3	12.4	1.9	8.6	19.7	1.5
Non-Tile	FGDG 11.2	2	4	8.2	0.9	8.9	32.3	1.7
Non-Tile	FGDG 11.2	2	5	6.1	0.5	8.9	9.8	1.8

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			**%**	**dS m^{-1}**		**%**	**g cm^{-2}**
Non-Tile	FGDG 11.2	3	1	13.3	3.2	8.1	0.9	1.8
Non-Tile	FGDG 11.2	3	2	14.6	2.6	8.2	0.9	1.8
Non-Tile	FGDG 11.2	3	3	10.2	1.1	8.7	9.3	1.7
Non-Tile	FGDG 11.2	3	4	6.0	0.8	8.6	18.5	1.7
Non-Tile	FGDG 11.2	3	5	5.9	0.6	8.6	12.0	1.5
Non-Tile	FGDG 11.2	4	1	15.0	3.2	8.2	1.5	1.6
Non-Tile	FGDG 11.2	4	2	15.0	3.4	7.9	2.0	1.8
Non-Tile	FGDG 11.2	4	3	10.5	3.0	8.2	13.8	1.6
Non-Tile	FGDG 11.2	4	4	9.6	1.3	8.7	25.4	1.8
Non-Tile	FGDG 11.2	4	5	11.2	1.4	8.5	16.1	1.8
Non-Tile	FGDG 33.6	1	1	8.4	2.5	8.0	1.1	1.5
Non-Tile	FGDG 33.6	1	2	16.9	1.8	8.2	1.3	1.7
Non-Tile	FGDG 33.6	1	3	11.0	1.6	8.6	29.7	1.6
Non-Tile	FGDG 33.6	1	4	10.1	1.0	8.9	23.6	1.8
Non-Tile	FGDG 33.6	1	5	7.7	0.6	8.8	19.5	1.6
Non-Tile	FGDG 33.6	2	1	10.4	2.7	8.0	1.1	1.5
Non-Tile	FGDG 33.6	2	2	12.5	2.3	8.1	2.5	1.7
Non-Tile	FGDG 33.6	2	3	12.0	2.3	8.3	21.2	1.5
Non-Tile	FGDG 33.6	2	4	11.1	1.5	8.7	30.9	1.7
Non-Tile	FGDG 33.6	2	5	11.0	0.7	8.8	12.4	1.8
Non-Tile	FGDG 33.6	3	1	13.6	3.7	8.2	1.3	1.7
Non-Tile	FGDG 33.6	3	2	14.5	3.7	8.1	2.0	1.7
Non-Tile	FGDG 33.6	3	3	7.4	3.3	8.2	10.0	1.5
Non-Tile	FGDG 33.6	3	4	9.8	1.2	8.8	26.2	1.7
Non-Tile	FGDG 33.6	3	5	11.9	0.9	8.9	6.8	1.5
Non-Tile	FGDG 33.6	4	1	8.7	2.4	8.0	2.0	1.6
Non-Tile	FGDG 33.6	4	2	11.5	2.5	7.9	1.8	1.7
Non-Tile	FGDG 33.6	4	3	9.0	1.9	8.2	19.5	1.6
Non-Tile	FGDG 33.6	4	4	10.4	1.4	8.7	27.7	1.7
Non-Tile	FGDG 33.6	4	5	10.0	1.0	8.7	13.5	1.9
Non-Tile	FGDG 67.2	1	1	7.8	3.2	8.0	1.1	1.6
Non-Tile	FGDG 67.2	1	2	17.1	3.1	7.9	1.6	1.8
Non-Tile	FGDG 67.2	1	3	12.9	2.0	8.5	28.0	1.6
Non-Tile	FGDG 67.2	1	4	12.0	1.4	8.7	22.3	1.7
Non-Tile	FGDG 67.2	1	5	9.6	1.0	8.7	15.8	1.5
Non-Tile	FGDG 67.2	2	1	7.8	2.4	8.0	1.8	1.4
Non-Tile	FGDG 67.2	2	2	13.9	3.2	8.0	2.3	1.8
Non-Tile	FGDG 67.2	2	3	10.8	2.7	8.1	7.4	1.5

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			**%**	**dS m^{-1}**		**%**	**g cm^{-2}**
Non-Tile	FGDG 67.2	2	4	7.4	0.8	8.8	25.9	1.7
Non-Tile	FGDG 67.2	2	5	5.7	0.6	8.6	12.9	1.7
Non-Tile	FGDG 67.2	3	1	9.8	2.9	8.1	1.1	1.6
Non-Tile	FGDG 67.2	3	2	15.7	3.4	8.0	1.2	1.7
Non-Tile	FGDG 67.2	3	3	11.8	2.4	8.2	6.6	1.6
Non-Tile	FGDG 67.2	3	4	10.3	1.2	8.7	21.6	1.7
Non-Tile	FGDG 67.2	3	5	8.9	0.9	8.8	16.0	1.8
Non-Tile	FGDG 67.2	4	1	9.5	2.7	8.1	1.3	1.8
Non-Tile	FGDG 67.2	4	2	13.6	2.7	8.1	2.6	1.8
Non-Tile	FGDG 67.2	4	3	12.2	2.8	8.3	20.5	1.6
Non-Tile	FGDG 67.2	4	4	12.6	1.6	8.8	22.0	1.7
Non-Tile	FGDG 67.2	4	5	13.2	1.4	8.8	10.7	1.7
Non-Tile	SL 11.2	1	1	13.0	2.7	8.1	2.1	1.7
Non-Tile	SL 11.2	1	2	13.0	3.2	8.0	4.0	1.7
Non-Tile	SL 11.2	1	3	6.4	2.9	8.1	25.9	1.5
Non-Tile	SL 11.2	1	4	10.7	0.9	8.9	22.6	1.7
Non-Tile	SL 11.2	1	5	8.9	0.5	8.9	10.4	1.8
Non-Tile	SL 11.2	2	1	13.9	2.9	8.1	1.0	1.7
Non-Tile	SL 11.2	2	2	12.0	3.8	8.2	6.1	1.6
Non-Tile	SL 11.2	2	3	4.0	2.9	8.3	20.2	1.5
Non-Tile	SL 11.2	2	4	12.3	1.7	8.8	25.2	2.4
Non-Tile	SL 11.2	2	5	12.0	1.3	8.7	15.3	1.8
Non-Tile	SL 11.2	3	1	16.0	3.3	8.2	2.1	1.6
Non-Tile	SL 11.2	3	2	14.5	3.9	8.0	1.5	1.7
Non-Tile	SL 11.2	3	3	12.3	3.4	8.3	11.6	1.5
Non-Tile	SL 11.2	3	4	11.8	1.7	8.8	15.2	1.7
Non-Tile	SL 11.2	3	5	12.9	1.3	8.8	13.0	1.9
Non-Tile	SL 11.2	4	1	15.1	2.9	8.2	1.7	1.7
Non-Tile	SL 11.2	4	2	12.3	3.6	8.1	4.8	1.6
Non-Tile	SL 11.2	4	3	11.1	1.9	8.5	24.2	1.8
Non-Tile	SL 11.2	4	4	10.4	1.2	8.7	22.5	1.9
Non-Tile	SL 11.2	4	5	10.2	0.8	8.6	10.1	1.4
Non-Tile	SL 33.6	1	1	9.8	1.9	8.2	2.1	1.6
Non-Tile	SL 33.6	1	2	11.0	1.9	8.3	4.0	1.7
Non-Tile	SL 33.6	1	3	11.2	1.7	8.6	25.9	1.5
Non-Tile	SL 33.6	1	4	12.1	1.3	8.7	22.6	1.7
Non-Tile	SL 33.6	1	5	12.9	1.3	8.7	10.4	1.1
Non-Tile	SL 33.6	2	1	11.4	2.0	8.2	1.0	1.5

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			**%**	**dS m^{-1}**		**%**	**g cm^{-2}**
Non-Tile	SL 33.6	2	2	13.5	2.4	8.2	6.1	1.8
Non-Tile	SL 33.6	2	3	12.3	1.6	8.6	20.2	1.5
Non-Tile	SL 33.6	2	4	8.1	0.8	9.0	25.2	1.8
Non-Tile	SL 33.6	2	5	5.7	0.4	9.0	15.3	1.9
Non-Tile	SL 33.6	3	1	10.3	3.0	8.2	2.1	1.6
Non-Tile	SL 33.6	3	2	13.2	3.2	8.0	1.5	1.8
Non-Tile	SL 33.6	3	3	7.5	2.9	8.1	11.6	1.5
Non-Tile	SL 33.6	3	4	8.1	1.0	8.7	15.2	1.7
Non-Tile	SL 33.6	3	5	7.2	0.9	8.7	13.0	2.3
Non-Tile	SL 33.6	4	1	12.4	2.1	8.0	1.7	1.7
Non-Tile	SL 33.6	4	2	12.7	3.0	8.0	4.8	1.7
Non-Tile	SL 33.6	4	3	9.0	2.5	8.2	24.2	1.6
Non-Tile	SL 33.6	4	4	12.2	1.6	8.6	22.5	1.7
Non-Tile	SL 33.6	4	5	11.4	1.3	8.6	10.1	1.8
Non-Tile	SL 67.2	1	1	12.2	3.0	8.3	1.9	1.7
Non-Tile	SL 67.2	1	2	14.0	3.2	8.2	4.1	1.6
Non-Tile	SL 67.2	1	3	12.2	1.9	8.6	21.2	1.6
Non-Tile	SL 67.2	1	4	11.1	1.0	8.8	24.9	1.7
Non-Tile	SL 67.2	1	5	10.5	1.0	8.8	19.1	1.4
Non-Tile	SL 67.2	2	1	11.8	3.2	8.3	2.4	1.7
Non-Tile	SL 67.2	2	2	14.4	3.7	8.1	2.9	1.7
Non-Tile	SL 67.2	2	3	4.3	3.2	8.3	20.4	1.5
Non-Tile	SL 67.2	2	4	4.3	2.8	8.4	19.9	1.7
Non-Tile	SL 67.2	2	5	14.3	1.6	8.7	16.4	1.7
Non-Tile	SL 67.2	3	1	11.5	3.1	8.2	0.7	1.5
Non-Tile	SL 67.2	3	2	14.4	3.9	8.1	0.6	1.7
Non-Tile	SL 67.2	3	3	9.4	3.1	8.2	3.2	1.6
Non-Tile	SL 67.2	3	4	12.7	2.0	8.7	24.4	1.8
Non-Tile	SL 67.2	3	5	12.7	1.7	8.6	15.9	1.2
Non-Tile	SL 67.2	4	1	9.3	3.0	8.2	1.9	1.6
Non-Tile	SL 67.2	4	2	12.5	3.6	8.1	1.5	1.8
Non-Tile	SL 67.2	4	3	7.9	2.8	8.2	9.8	1.6
Non-Tile	SL 67.2	4	4	8.5	1.1	8.7	25.6	1.6
Non-Tile	SL 67.2	4	5	9.7	1.0	8.6	12.1	1.8
Non-Tile	Kmag 2.2	1	1	9.9	2.3	7.9	1.0	1.5
Non-Tile	Kmag 2.2	1	2	15.0	2.4	7.9	1.1	1.7
Non-Tile	Kmag 2.2	1	3	14.4	2.1	8.4	5.7	1.6
Non-Tile	Kmag 2.2	1	4	10.9	1.4	8.8	27.5	1.7

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			%	dS m^{-1}		%	g cm^{-2}
Non-Tile	Kmag 2.2	1	5	9.5	0.6	8.9	14.8	1.6
Non-Tile	Kmag 2.2	2	1	9.7	3.0	8.1	1.5	1.5
Non-Tile	Kmag 2.2	2	2	10.4	2.9	8.0	3.5	1.7
Non-Tile	Kmag 2.2	2	3	6.8	2.4	8.1	19.8	1.5
Non-Tile	Kmag 2.2	2	4	8.5	0.9	8.7	25.6	1.7
Non-Tile	Kmag 2.2	2	5	6.5	0.6	8.6	16.5	1.5
Non-Tile	Kmag 2.2	3	1	12.4	3.0	8.1	0.9	1.7
Non-Tile	Kmag 2.2	3	2	13.4	3.4	8.0	2.3	1.8
Non-Tile	Kmag 2.2	3	3	6.6	2.8	8.2	17.7	1.5
Non-Tile	Kmag 2.2	3	4	11.0	1.0	8.8	22.4	1.7
Non-Tile	Kmag 2.2	3	5	10.8	0.5	8.7	6.2	1.8
Non-Tile	Kmag 2.2	4	1	14.4	3.4	8.1	0.9	1.7
Non-Tile	Kmag 2.2	4	2	15.8	3.1	8.2	2.1	1.8
Non-Tile	Kmag 2.2	4	3	8.4	3.1	8.2	8.0	1.6
Non-Tile	Kmag 2.2	4	4	5.3	2.1	8.1	19.5	1.6
Non-Tile	Kmag 2.2	4	5	8.0	1.1	8.4	12.2	1.8
Non-Tile	Kmag 5.6	1	1	11.5	3.0	8.0	2.0	1.7
Non-Tile	Kmag 5.6	1	2	11.3	3.4	8.0	13.2	1.7
Non-Tile	Kmag 5.6	1	3	8.5	2.1	8.2	24.4	1.7
Non-Tile	Kmag 5.6	1	4	7.9	0.7	8.9	23.8	1.8
Non-Tile	Kmag 5.6	1	5	6.6	0.5	8.8	12.7	1.3
Non-Tile	Kmag 5.6	2	1	10.9	2.8	8.1	1.5	1.8
Non-Tile	Kmag 5.6	2	2	12.9	3.0	8.0	3.2	1.6
Non-Tile	Kmag 5.6	2	3	9.0	2.4	8.1	2.3	1.6
Non-Tile	Kmag 5.6	2	4	9.9	1.0	8.7	8.0	1.7
Non-Tile	Kmag 5.6	2	5	5.8	0.6	8.7	13.4	1.8
Non-Tile	Kmag 5.6	3	1	13.9	2.6	8.0	1.5	1.5
Non-Tile	Kmag 5.6	3	2	14.1	2.8	7.8	2.0	1.7
Non-Tile	Kmag 5.6	3	3	10.1	3.0	8.0	4.5	1.5
Non-Tile	Kmag 5.6	3	4	12.0	1.6	8.6	26.4	1.6
Non-Tile	Kmag 5.6	3	5	10.1	1.0	8.6	8.2	1.9
Non-Tile	Kmag 5.6	4	1	15.0	3.8	8.3	1.1	1.7
Non-Tile	Kmag 5.6	4	2	11.9	3.3	8.0	3.9	1.8
Non-Tile	Kmag 5.6	4	3	4.4	2.6	8.1	12.6	1.5
Non-Tile	Kmag 5.6	4	4	3.5	2.0	8.1	23.8	1.7
Non-Tile	Kmag 5.6	4	5	8.5	1.2	8.5	15.9	1.7
Non-Tile	Kmag 11.2	1	1	12.3	3.5	8.1	1.3	1.3
Non-Tile	Kmag 11.2	1	2	11.9	2.6	8.1	6.3	1.7

Table B1. 2014 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	EC	pH	CCE	BD
	Mg ha^{-1}			**%**	**dS m^{-1}**		**%**	**g cm^{-2}**
Non-Tile	Kmag 11.2	1	3	12.7	2.1	8.5	22.8	1.5
Non-Tile	Kmag 11.2	1	4	11.0	1.2	8.7	25.4	1.8
Non-Tile	Kmag 11.2	1	5	9.1	0.6	8.9	2.7	1.7
Non-Tile	Kmag 11.2	2	1	10.5	3.4	8.2	1.9	1.7
Non-Tile	Kmag 11.2	2	2	12.1	3.0	8.1	3.9	1.8
Non-Tile	Kmag 11.2	2	3	13.1	1.8	8.6	15.9	1.6
Non-Tile	Kmag 11.2	2	4	10.3	1.3	8.7	17.5	1.7
Non-Tile	Kmag 11.2	2	5	8.1	1.0	8.5	17.4	1.8
Non-Tile	Kmag 11.2	3	1	11.5	3.0	8.1	1.5	1.8
Non-Tile	Kmag 11.2	3	2	13.7	2.6	7.9	2.3	1.7
Non-Tile	Kmag 11.2	3	3	7.0	2.2	8.1	10.3	1.6
Non-Tile	Kmag 11.2	3	4	8.2	1.2	8.7	23.0	1.7
Non-Tile	Kmag 11.2	3	5	8.7	1.5	8.4	17.3	1.8
Non-Tile	Kmag 11.2	4	1	10.0	3.0	8.0	1.7	1.7
Non-Tile	Kmag 11.2	4	2	12.0	3.1	8.1	4.5	1.7
Non-Tile	Kmag 11.2	4	3	5.7	2.7	8.2	16.5	1.5
Non-Tile	Kmag 11.2	4	4	12.1	1.5	8.7	22.6	1.7
Non-Tile	Kmag 11.2	4	5	12.0	1.2	8.7	18.1	1.8

Table B2. 2015 Soil Data

Site	**Treatment**	**Replication**	**Depth**	**Na**	**CEC**	**Nitrate-N**	**P-olsen**	**EC**	**pH**	**CCE**
				%	**meq 100g^{-1}**	**ppm**	**ppm**	**dS/m**		**%**
Tile	Control	1	1	2.6	22.1	11.5	17.0	0.4	7.9	1.5
Tile	Control	1	2	8.6	29.5	3.5	2.0	1.5	7.9	1.5
Tile	Control	1	3	8.9	66.7	.	.	3.3	8.1	2.7
Tile	Control	1	4	17.2	32.5	.	.	3.0	8.6	8.0
Tile	Control	1	5	18.6	14.0	.	.	1.2	9.0	6.1
Tile	Control	2	1	4.0	22.2	8.0	9.0	0.4	8.0	0.8
Tile	Control	2	2	6.1	36.6	3.0	2.0	1.6	8.0	2.5
Tile	Control	2	3	8.1	58.8	.	.	2.9	8.3	24.1
Tile	Control	2	4	14.0	29.9	.	.	1.7	8.9	12.9
Tile	Control	2	5	15.4	18.3	.	.	1.1	8.6	7.0
Tile	Control	3	1	1.5	20.3	15.0	15.0	0.4	7.6	0.9
Tile	Control	3	2	5.6	33.4	5.0	8.0	1.1	8.1	2.9
Tile	Control	3	3	11.5	46.3	.	.	3.4	8.3	8.6
Tile	Control	3	4	14.3	29.3	.	.	2.2	8.9	12.8
Tile	Control	3	5	14.4	16.0	.	.	0.7	9.0	7.4
Tile	Control	4	1	3.5	20.8	7.5	24.0	0.4	7.5	1.0
Tile	Control	4	2	10.4	24.7	7.5	2.0	1.4	7.7	0.9
Tile	Control	4	3	17.8	34.7	.	.	4.1	8.1	1.3
Tile	Control	4	4	15.7	31.6	.	.	2.2	8.8	9.5
Tile	Control	4	5	16.9	23.1	.	.	1.6	9.0	7.0
Tile	FGDG 11.2	1	1	1.9	25.3	11.0	19.0	1.2	7.6	1.6
Tile	FGDG 11.2	1	2	5.6	40.1	3.5	3.0	1.6	8.1	4.2
Tile	FGDG 11.2	1	3	7.4	69.1	.	.	3.7	8.1	12.4
Tile	FGDG 11.2	1	4	14.7	36.5	.	.	2.6	8.7	15.5
Tile	FGDG 11.2	1	5	13.1	18.1	.	.	1.0	8.9	7.3

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	**meq 100g^{-1}**	**ppm**	**ppm**	**dS/m**		**%**
Tile	FGDG 11.2	2	1	1.3	21.3	11.5	19.0	0.5	7.5	0.4
Tile	FGDG 11.2	2	2	4.0	25.3	7.5	12.0	1.1	7.6	1.5
Tile	FGDG 11.2	2	3	7.3	63.9	.	.	3.0	8.2	9.8
Tile	FGDG 11.2	2	4	13.6	33.5	.	.	1.8	8.9	16.1
Tile	FGDG 11.2	2	5	10.3	14.6	.	.	0.8	8.8	7.2
Tile	FGDG 11.2	3	1	2.5	21.7	16.0	22.0	1.3	7.3	0.7
Tile	FGDG 11.2	3	2	7.9	35.7	4.5	2.0	2.3	7.8	2.6
Tile	FGDG 11.2	3	3	8.2	51.3	.	.	3.6	8.4	42.0
Tile	FGDG 11.2	3	4	14.3	31.8	.	.	2.4	9.0	20.8
Tile	FGDG 11.2	3	5	12.5	29.8	.	.	0.9	8.8	11.7
Tile	FGDG 11.2	4	1	5.2	22.5	15.0	25.0	1.5	7.3	0.3
Tile	FGDG 11.2	4	2	9.6	43.6	3.5	2.0	3.2	8.0	4.4
Tile	FGDG 11.2	4	3	4.6	94.6	.	.	2.9	8.5	24.5
Tile	FGDG 11.2	4	4	8.4	59.8	.	.	3.6	8.6	11.1
Tile	FGDG 11.2	4	5	16.0	19.7	.	.	1.2	9.0	5.7
Tile	FGDG 33.6	1	1	2.0	24.5	16.5	19.0	1.3	7.4	1.4
Tile	FGDG 33.6	1	2	4.7	44.7	3.5	6.0	2.3	7.8	3.1
Tile	FGDG 33.6	1	3	9.7	61.9	.	.	3.7	8.3	21.1
Tile	FGDG 33.6	1	4	17.4	33.5	.	.	2.8	9.0	14.7
Tile	FGDG 33.6	1	5	15.3	13.4	.	.	1.1	9.0	7.0
Tile	FGDG 33.6	2	1	3.3	32.3	16.5	27.0	1.7	7.2	1.6
Tile	FGDG 33.6	2	2	6.2	44.5	4.5	2.0	1.8	7.9	5.9
Tile	FGDG 33.6	2	3	7.2	56.6	.	.	1.9	8.2	16.2
Tile	FGDG 33.6	2	4	11.9	40.9	.	.	2.5	8.6	23.8
Tile	FGDG 33.6	2	5	11.8	26.2	.	.	1.0	8.9	9.4
Tile	FGDG 33.6	3	1	5.1	29.6	8.5	24.0	1.9	7.7	1.9

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	**meq 100g^{-1}**	**ppm**	**ppm**	**dS/m**		**%**
Tile	FGDG 33.6	3	2	14.0	36.7	5.0	8.0	3.5	8.1	1.9
Tile	FGDG 33.6	3	3	7.3	84.8	.	.	4.1	8.4	24.1
Tile	FGDG 33.6	3	4	15.2	36.1	.	.	3.0	8.9	20.8
Tile	FGDG 33.6	3	5	13.7	27.6	.	.	1.3	9.0	10.8
Tile	FGDG 33.6	4	1	2.4	31.9	6.5	27.0	1.8	7.3	0.3
Tile	FGDG 33.6	4	2	10.1	27.9	2.5	5.0	2.6	7.5	0.3
Tile	FGDG 33.6	4	3	7.2	67.9	.	.	3.5	8.3	20.7
Tile	FGDG 33.6	4	4	12.9	30.2	.	.	1.7	8.9	13.9
Tile	FGDG 33.6	4	5	13.6	24.5	.	.	1.3	8.9	7.3
Tile	FGDG 67.2	1	1	1.4	43.6	7.0	10.0	2.0	7.6	0.7
Tile	FGDG 67.2	1	2	7.1	31.2	3.0	2.0	2.8	7.8	1.1
Tile	FGDG 67.2	1	3	10.2	61.8	.	.	3.6	8.1	3.2
Tile	FGDG 67.2	1	4	16.2	38.2	.	.	2.7	8.7	13.0
Tile	FGDG 67.2	1	5	17.2	17.4	.	.	1.3	8.9	7.6
Tile	FGDG 67.2	2	1	0.8	31.3	12.5	17.0	1.6	7.3	0.6
Tile	FGDG 67.2	2	2	5.0	32.5	2.5	2.0	1.8	7.7	1.3
Tile	FGDG 67.2	2	3	6.0	74.9	.	.	3.1	8.2	10.5
Tile	FGDG 67.2	2	4	12.7	43.6	.	.	2.4	8.6	24.1
Tile	FGDG 67.2	2	5	13.9	18.3	.	.	1.1	9.0	7.6
Tile	FGDG 67.2	3	1	1.2	36.2	0.5	21.0	1.7	7.6	1.7
Tile	FGDG 67.2	3	2	8.1	34.5	0.5	3.0	2.2	7.8	2.0
Tile	FGDG 67.2	3	3	7.4	72.0	.	.	4.1	8.3	21.2
Tile	FGDG 67.2	3	4	14.8	32.5	.	.	2.7	8.9	16.9
Tile	FGDG 67.2	3	5	10.6	21.9	.	.	0.6	9.0	7.1
Tile	FGDG 67.2	4	1	4.9	24.0	8.0	21.0	1.3	7.2	0.7
Tile	FGDG 67.2	4	2	11.9	45.3	2.5	2.0	1.3	7.8	0.9

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Tile	FGDG 67.2	4	3	7.0	81.1	.	.	2.8	8.4	16.5
Tile	FGDG 67.2	4	4	14.7	34.8	.	.	1.7	9.0	19.4
Tile	FGDG 67.2	4	5	19.0	30.8	.	.	1.4	9.0	9.0
Tile	SL 11.2	1	1	4.2	21.6	16.0	35.0	0.5	8.0	2.7
Tile	SL 11.2	1	2	12.6	28.8	5.0	15.0	2.0	7.9	1.9
Tile	SL 11.2	1	3	10.1	66.4	.	.	4.0	8.3	15.9
Tile	SL 11.2	1	4	13.7	35.3	.	.	3.1	8.7	18.3
Tile	SL 11.2	1	5	17.5	11.3	.	.	1.1	9.1	6.0
Tile	SL 11.2	2	1	4.0	21.9	6.5	20.0	0.5	8.1	0.7
Tile	SL 11.2	2	2	9.8	29.6	4.5	3.0	2.0	7.8	1.3
Tile	SL 11.2	2	3	10.4	60.0	.	.	3.7	8.4	24.8
Tile	SL 11.2	2	4	15.3	35.2	.	.	2.4	8.9	16.3
Tile	SL 11.2	2	5	15.1	21.4	.	.	1.5	9.0	7.4
Tile	SL 11.2	3	1	4.5	21.1	2.0	33.0	0.6	8.1	1.5
Tile	SL 11.2	3	2	10.9	33.7	0.5	9.0	2.8	8.1	1.5
Tile	SL 11.2	3	3	8.1	55.7	.	.	3.3	8.3	19.3
Tile	SL 11.2	3	4	12.2	30.7	.	.	1.5	9.0	15.6
Tile	SL 11.2	3	5	13.0	15.9	.	.	1.3	9.0	6.6
Tile	SL 11.2	4	1	7.1	23.9	6.0	17.0	1.6	8.1	0.7
Tile	SL 11.2	4	2	10.1	23.7	3.0	3.0	2.1	8.0	0.4
Tile	SL 11.2	4	3	7.1	33.0	.	.	1.5	8.5	13.4
Tile	SL 11.2	4	4	6.4	24.0	.	.	0.7	8.8	9.7
Tile	SL 11.2	4	5	11.1	15.4	.	.	0.6	8.8	5.0
Tile	SL 33.6	1	1	1.2	35.5	8.0	20.0	0.5	8.2	2.3
Tile	SL 33.6	1	2	5.6	27.6	3.0	3.0	0.7	8.2	1.7
Tile	SL 33.6	1	3	8.9	46.9	.	.	2.9	8.1	34.5

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Tile	SL 33.6	1	4	13.1	39.9	.	.	2.9	8.7	20.0
Tile	SL 33.6	1	5	18.5	20.1	.	.	1.4	8.9	8.7
Tile	SL 33.6	2	1	3.4	26.0	14.5	29.0	0.5	8.1	1.9
Tile	SL 33.6	2	2	8.8	34.7	3.0	2.0	2.1	7.8	1.6
Tile	SL 33.6	2	3	7.3	75.8	.	.	3.1	8.3	18.7
Tile	SL 33.6	2	4	11.2	38.8	.	.	2.1	8.7	16.4
Tile	SL 33.6	2	5	11.5	24.7	.	.	1.1	8.9	7.7
Tile	SL 33.6	3	1	5.0	32.6	15.5	28.0	1.7	8.0	3.1
Tile	SL 33.6	3	2	14.3	27.9	3.5	3.0	3.2	7.9	1.6
Tile	SL 33.6	3	3	13.7	48.2	.	.	4.3	8.4	5.0
Tile	SL 33.6	3	4	15.5	32.4	.	.	2.7	9.0	15.8
Tile	SL 33.6	3	5	16.2	31.4	.	.	2.5	8.9	16.7
Tile	SL 33.6	4	1	2.0	28.5	11.5	29.0	0.4	8.2	1.1
Tile	SL 33.6	4	2	8.7	23.7	3.5	4.0	0.5	8.4	0.5
Tile	SL 33.6	4	3	6.0	85.4	.	.	3.8	8.4	29.2
Tile	SL 33.6	4	4	3.8	121.1	.	.	3.4	8.8	8.6
Tile	SL 33.6	4	5	17.3	41.7	.	.	3.9	8.7	8.8
Tile	SL 67.2	1	1	2.4	41.5	19.0	51.0	0.6	8.3	2.6
Tile	SL 67.2	1	2	7.7	40.3	4.0	6.0	1.9	8.1	4.2
Tile	SL 67.2	1	3	9.1	56.7	.	.	3.3	8.2	28.4
Tile	SL 67.2	1	4	15.3	35.8	.	.	2.6	8.8	24.4
Tile	SL 67.2	1	5	14.0	19.5	.	.	1.0	9.1	8.0
Tile	SL 67.2	2	1	1.9	32.4	10.5	41.0	0.4	8.3	2.9
Tile	SL 67.2	2	2	6.5	26.4	4.0	4.0	1.3	7.9	1.3
Tile	SL 67.2	2	3	4.5	71.2	.	.	2.6	8.1	11.6
Tile	SL 67.2	2	4	9.7	30.3	.	.	1.5	8.6	13.6

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq $100g^{-1}$	ppm	ppm	dS/m		%
Tile	SL 67.2	2	5	9.6	14.4	.	.	0.8	9.0	7.0
Tile	SL 67.2	3	1	3.2	37.1	10.0	46.0	1.2	8.2	2.2
Tile	SL 67.2	3	2	9.7	29.5	3.5	7.0	2.4	8.1	1.0
Tile	SL 67.2	3	3	6.5	57.4	.	.	3.3	8.3	13.2
Tile	SL 67.2	3	4	10.3	30.4	.	.	1.5	8.9	15.6
Tile	SL 67.2	3	5	13.1	9.9	.	.	0.4	9.3	5.3
Tile	SL 67.2	4	1	6.0	29.0	7.5	39.0	1.6	8.2	1.7
Tile	SL 67.2	4	2	11.5	26.6	2.5	5.0	2.3	8.2	0.8
Tile	SL 67.2	4	3	7.2	33.2	.	.	1.9	8.4	27.2
Tile	SL 67.2	4	4	6.7	26.5	.	.	0.9	8.8	14.3
Tile	SL 67.2	4	5	12.8	13.2	.	.	0.7	8.9	4.5
Tile	Kmag 2.2	1	1	2.0	23.4	16.0	15.0	0.4	7.7	1.1
Tile	Kmag 2.2	1	2	5.0	37.2	3.0	2.0	1.4	7.9	2.8
Tile	Kmag 2.2	1	3	10.8	43.3	.	.	2.5	8.4	33.7
Tile	Kmag 2.2	1	4	16.2	38.5	.	.	2.4	8.7	27.0
Tile	Kmag 2.2	1	5	13.3	23.1	.	.	1.4	8.9	7.1
Tile	Kmag 2.2	2	1	4.3	24.1	8.5	8.0	0.9	7.7	0.9
Tile	Kmag 2.2	2	2	7.5	44.0	3.5	2.0	2.5	8.0	4.5
Tile	Kmag 2.2	2	3	8.2	72.8	.	.	3.4	8.4	26.3
Tile	Kmag 2.2	2	4	17.8	21.9	.	.	1.4	9.0	8.0
Tile	Kmag 2.2	2	5	12.8	11.2	.	.	0.8	8.8	5.4
Tile	Kmag 2.2	3	1	2.0	18.8	11.5	24.0	0.4	7.3	1.1
Tile	Kmag 2.2	3	2	6.7	21.4	2.5	3.0	0.7	7.8	0.7
Tile	Kmag 2.2	3	3	4.9	60.8	.	.	2.9	8.0	20.3
Tile	Kmag 2.2	3	4	10.4	31.5	.	.	1.5	8.7	18.5
Tile	Kmag 2.2	3	5	9.9	26.7	.	.	0.8	9.0	11.3

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Tile	Kmag 2.2	4	1	2.7	16.5	10.0	24.0	0.3	6.9	0.9
Tile	Kmag 2.2	4	2	9.4	23.7	2.5	2.0	1.0	7.7	1.2
Tile	Kmag 2.2	4	3	4.4	86.5	.	.	3.2	8.3	21.9
Tile	Kmag 2.2	4	4	10.9	30.7	.	.	1.6	8.9	14.0
Tile	Kmag 2.2	4	5	12.3	25.4	.	.	1.4	8.9	7.8
Tile	Kmag 5.6	1	1	1.9	23.9	15.5	20.0	0.5	7.5	0.9
Tile	Kmag 5.6	1	2	6.6	37.9	3.5	2.0	2.4	7.9	3.7
Tile	Kmag 5.6	1	3	10.2	57.5	.	.	3.8	8.3	30.0
Tile	Kmag 5.6	1	4	15.3	34.4	.	.	2.5	8.8	20.4
Tile	Kmag 5.6	1	5	19.8	13.2	.	.	1.0	9.0	5.3
Tile	Kmag 5.6	2	1	2.6	22.1	20.0	22.0	0.5	7.8	0.9
Tile	Kmag 5.6	2	2	5.6	42.4	3.0	4.0	1.9	7.9	4.5
Tile	Kmag 5.6	2	3	8.4	53.9	.	.	3.0	8.3	41.8
Tile	Kmag 5.6	2	4	13.0	28.0	.	.	1.4	9.0	16.3
Tile	Kmag 5.6	2	5	11.4	24.4	.	.	0.9	8.9	8.2
Tile	Kmag 5.6	3	1	3.7	21.1	7.5	26.0	0.6	7.4	0.9
Tile	Kmag 5.6	3	2	11.8	23.9	4.5	5.0	1.7	7.7	0.9
Tile	Kmag 5.6	3	3	10.6	55.8	.	.	3.8	8.1	18.0
Tile	Kmag 5.6	3	4	11.0	29.1	.	.	1.5	8.8	16.1
Tile	Kmag 5.6	3	5	15.7	15.2	.	.	0.6	8.8	5.2
Tile	Kmag 5.6	4	1	3.3	19.2	12.0	22.0	0.9	7.4	0.0
Tile	Kmag 5.6	4	2	12.8	23.8	5.0	2.0	2.1	7.7	0.0
Tile	Kmag 5.6	4	3	10.0	37.5	.	.	2.3	8.4	13.2
Tile	Kmag 5.6	4	4	8.6	27.8	.	.	0.9	8.8	14.0
Tile	Kmag 5.6	4	5	10.6	27.1	.	.	1.3	8.8	8.0
Tile	Kmag 11.2	1	1	2.0	28.0	16.0	21.0	1.7	7.4	0.9

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq $100g^{-1}$	ppm	ppm	dS/m		%
Tile	Kmag 11.2	1	2	7.0	45.3	3.5	4.0	2.8	7.8	2.4
Tile	Kmag 11.2	1	3	8.1	78.4	.	.	3.8	8.2	18.7
Tile	Kmag 11.2	1	4	13.4	40.9	.	.	3.5	8.7	16.0
Tile	Kmag 11.2	1	5	14.3	19.8	.	.	1.3	8.8	8.0
Tile	Kmag 11.2	2	1	2.7	21.9	6.0	24.0	0.7	7.3	2.5
Tile	Kmag 11.2	2	2	9.9	38.2	3.0	2.0	2.3	7.8	2.5
Tile	Kmag 11.2	2	3	11.1	54.7	.	.	3.4	8.3	37.9
Tile	Kmag 11.2	2	4	12.0	39.9	.	.	2.5	8.7	19.5
Tile	Kmag 11.2	2	5	20.9	16.5	.	.	1.2	8.9	6.4
Tile	Kmag 11.2	3	1	3.6	21.0	15.5	22.0	1.2	6.9	2.0
Tile	Kmag 11.2	3	2	12.0	26.1	4.0	3.0	2.3	7.6	1.0
Tile	Kmag 11.2	3	3	9.2	60.1	.	.	3.9	8.1	10.2
Tile	Kmag 11.2	3	4	12.2	33.2	.	.	2.2	8.8	18.3
Tile	Kmag 11.2	3	5	13.7	15.6	.	.	0.6	8.9	6.2
Tile	Kmag 11.2	4	1	4.9	24.0	8.0	21.0	1.9	7.4	1.3
Tile	Kmag 11.2	4	2	11.9	45.3	2.5	2.0	3.9	8.0	1.1
Tile	Kmag 11.2	4	3	7.0	81.1	.	.	3.8	8.4	16.9
Tile	Kmag 11.2	4	4	14.7	34.8	.	.	2.6	8.8	12.9
Tile	Kmag 11.2	4	5	19.0	30.8	.	.	2.3	8.8	8.6
Non-Tile	Control	1	1	11.7	31.5	10.0	11.0	2.3	8.2	1.2
Non-Tile	Control	1	2	10.5	41.5	2.5	2.0	3.2	8.1	7.5
Non-Tile	Control	1	3	4.6	78.9	.	.	2.8	8.3	29.4
Non-Tile	Control	1	4	12.0	29.4	.	.	1.7	8.8	16.5
Non-Tile	Control	1	5	10.3	21.8	.	.	0.6	8.8	7.2
Non-Tile	Control	2	1	17.3	31.2	15.0	8.0	3.1	8.3	0.5
Non-Tile	Control	2	2	12.4	45.2	2.5	2.0	3.2	8.3	1.3

Table B2. 2015 Soil Data (continued)

Site	**Treatment**	**Replication**	**Depth**	**Na**	**CEC**	**Nitrate-N**	**P-olsen**	**EC**	**pH**	**CCE**
				%	**meq 100g^{-1}**	**ppm**	**ppm**	**dS/m**		**%**
Non-Tile	Control	2	3	11.0	47.6	.	.	3.1	8.4	9.4
Non-Tile	Control	2	4	11.5	31.9	.	.	2.1	8.9	21.5
Non-Tile	Control	2	5	9.7	25.8	.	.	0.9	9.0	9.5
Non-Tile	Control	3	1	10.9	28.3	4.0	9.0	3.0	8.0	1.1
Non-Tile	Control	3	2	8.8	39.8	1.5	2.0	3.6	8.0	1.5
Non-Tile	Control	3	3	5.3	57.9	.	.	2.7	8.3	24.6
Non-Tile	Control	3	4	8.0	31.1	.	.	1.3	8.8	28.0
Non-Tile	Control	3	5	5.6	25.5	.	.	0.9	8.7	14.2
Non-Tile	Control	4	1	16.7	29.0	14.0	7.0	2.6	8.2	0.5
Non-Tile	Control	4	2	16.0	28.8	3.0	2.0	2.8	8.1	0.5
Non-Tile	Control	4	3	11.1	32.7	.	.	1.5	8.6	6.4
Non-Tile	Control	4	4	8.1	29.7	.	.	1.0	8.9	21.8
Non-Tile	Control	4	5	8.5	18.3	.	.	0.8	8.8	8.3
Non-Tile	FGDG 11.2	1	1	14.3	24.4	9.0	17.0	2.4	8.1	1.8
Non-Tile	FGDG 11.2	1	2	21.2	20.5	2.0	2.0	1.8	8.4	1.8
Non-Tile	FGDG 11.2	1	3	11.7	33.1	.	.	1.7	8.9	18.4
Non-Tile	FGDG 11.2	1	4	7.6	28.2	.	.	0.8	9.1	26.6
Non-Tile	FGDG 11.2	1	5	4.8	26.7	.	.	0.4	8.8	20.3
Non-Tile	FGDG 11.2	2	1	11.2	43.8	12.5	21.0	2.4	8.4	2.7
Non-Tile	FGDG 11.2	2	2	16.6	31.2	2.0	2.0	3.5	8.2	0.7
Non-Tile	FGDG 11.2	2	3	12.4	34.1	.	.	1.7	8.9	6.4
Non-Tile	FGDG 11.2	2	4	8.2	30.1	.	.	1.1	9.0	25.6
Non-Tile	FGDG 11.2	2	5	8.2	14.1	.	.	0.5	9.0	6.2
Non-Tile	FGDG 11.2	3	1	14.8	31.9	5.5	30.0	3.8	8.4	0.8
Non-Tile	FGDG 11.2	3	2	11.9	36.7	1.0	3.0	2.9	8.2	0.7
Non-Tile	FGDG 11.2	3	3	8.6	35.3	.	.	2.0	8.4	6.7

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	FGDG 11.2	3	4	5.6	29.1	.	.	1.0	8.7	23.9
Non-Tile	FGDG 11.2	3	5	5.7	24.1	.	.	0.8	8.7	10.9
Non-Tile	FGDG 11.2	4	1	20.8	34.0	2.5	16.0	3.8	8.3	1.0
Non-Tile	FGDG 11.2	4	2	19.4	35.2	1.0	4.0	3.6	8.2	0.5
Non-Tile	FGDG 11.2	4	3	12.9	38.4	.	.	2.4	8.4	6.1
Non-Tile	FGDG 11.2	4	4	10.5	30.9	.	.	1.5	8.8	24.0
Non-Tile	FGDG 11.2	4	5	11.6	32.5	.	.	1.1	8.6	14.4
Non-Tile	FGDG 33.6	1	1	8.0	28.5	13.5	5.0	2.4	8.0	0.6
Non-Tile	FGDG 33.6	1	2	13.4	24.3	5.5	2.0	2.1	8.1	0.9
Non-Tile	FGDG 33.6	1	3	9.7	32.0	.	.	1.7	8.6	22.4
Non-Tile	FGDG 33.6	1	4	10.8	30.4	.	.	1.6	8.9	25.2
Non-Tile	FGDG 33.6	1	5	8.4	29.0	.	.	1.0	8.8	24.5
Non-Tile	FGDG 33.6	2	1	12.8	37.7	2.0	22.0	2.7	8.4	1.3
Non-Tile	FGDG 33.6	2	2	10.3	44.8	1.0	2.0	2.5	8.2	4.8
Non-Tile	FGDG 33.6	2	3	10.9	33.5	.	.	1.4	8.7	22.8
Non-Tile	FGDG 33.6	2	4	9.6	29.9	.	.	1.0	9.1	32.6
Non-Tile	FGDG 33.6	2	5	7.7	29.1	.	.	0.7	8.9	17.9
Non-Tile	FGDG 33.6	3	1	15.9	34.6	16.5	7.0	4.2	8.2	0.9
Non-Tile	FGDG 33.6	3	2	14.8	33.3	3.0	2.0	3.9	8.1	1.0
Non-Tile	FGDG 33.6	3	3	10.6	36.2	.	.	1.9	8.6	17.0
Non-Tile	FGDG 33.6	3	4	8.0	29.2	.	.	1.2	8.9	19.5
Non-Tile	FGDG 33.6	3	5	13.6	12.8	.	.	1.0	8.8	4.4
Non-Tile	FGDG 33.6	4	1	13.2	33.3	6.5	8.0	2.9	8.1	1.3
Non-Tile	FGDG 33.6	4	2	11.0	39.6	3.0	2.0	3.0	8.0	1.5
Non-Tile	FGDG 33.6	4	3	7.5	47.4	.	.	2.6	8.2	17.7
Non-Tile	FGDG 33.6	4	4	9.8	31.2	.	.	1.1	8.8	26.8

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	FGDG 33.6	4	5	9.2	26.5	.	.	1.1	8.7	13.6
Non-Tile	FGDG 67.2	1	1	7.6	57.1	6.0	14.0	3.4	8.0	0.5
Non-Tile	FGDG 67.2	1	2	18.6	26.2	1.0	3.0	3.3	8.0	0.7
Non-Tile	FGDG 67.2	1	3	11.7	33.3	.	.	0.2	8.6	27.2
Non-Tile	FGDG 67.2	1	4	10.9	29.2	.	.	1.4	8.9	28.0
Non-Tile	FGDG 67.2	1	5	7.2	27.1	.	.	0.8	8.8	15.7
Non-Tile	FGDG 67.2	2	1	12.0	40.7	13.5	16.0	3.2	8.2	0.5
Non-Tile	FGDG 67.2	2	2	11.7	39.5	3.0	2.0	3.1	8.1	1.3
Non-Tile	FGDG 67.2	2	3	10.1	38.7	.	.	2.4	8.4	11.2
Non-Tile	FGDG 67.2	2	4	7.6	31.2	.	.	1.4	8.7	28.7
Non-Tile	FGDG 67.2	2	5	6.6	24.8	.	.	1.0	8.7	9.5
Non-Tile	FGDG 67.2	3	1	13.0	35.5	15.5	16.0	3.7	8.2	1.0
Non-Tile	FGDG 67.2	3	2	12.6	39.5	4.0	2.0	4.0	8.1	1.5
Non-Tile	FGDG 67.2	3	3	11.6	38.9	.	.	3.4	8.3	2.5
Non-Tile	FGDG 67.2	3	4	10.5	30.9	.	.	1.6	8.8	19.1
Non-Tile	FGDG 67.2	3	5	9.8	28.2	.	.	1.1	9.0	12.4
Non-Tile	FGDG 67.2	4	1	9.5	50.1	21.0	16.0	2.5	8.3	1.7
Non-Tile	FGDG 67.2	4	2	13.2	37.9	3.5	2.0	2.4	8.1	3.7
Non-Tile	FGDG 67.2	4	3	12.0	33.8	.	.	1.7	8.7	21.6
Non-Tile	FGDG 67.2	4	4	10.6	32.5	.	.	1.3	8.8	24.3
Non-Tile	FGDG 67.2	4	5	8.9	24.9	.	.	1.0	8.8	11.7
Non-Tile	SL 11.2	1	1	15.6	35.6	8.5	9.0	3.8	8.2	1.9
Non-Tile	SL 11.2	1	2	13.1	45.5	2.0	2.0	3.7	8.2	4.0
Non-Tile	SL 11.2	1	3	6.0	69.5	.	.	3.3	8.3	23.1
Non-Tile	SL 11.2	1	4	10.5	31.0	.	.	1.6	8.8	19.6
Non-Tile	SL 11.2	1	5	9.5	25.1	.	.	1.1	8.7	11.4

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	SL 11.2	2	1	19.1	33.2	6.0	37.0	3.2	8.4	0.5
Non-Tile	SL 11.2	2	2	13.1	47.1	3.0	2.0	3.1	8.2	0.7
Non-Tile	SL 11.2	2	3	3.4	94.0	.	.	2.8	8.3	15.4
Non-Tile	SL 11.2	2	4	4.0	66.7	.	.	2.7	8.3	28.7
Non-Tile	SL 11.2	2	5	8.0	25.3	.	.	0.8	8.9	8.6
Non-Tile	SL 11.2	3	1	19.8	32.0	7.5	26.0	4.3	8.4	1.1
Non-Tile	SL 11.2	3	2	15.0	43.5	2.0	3.0	4.4	8.3	2.9
Non-Tile	SL 11.2	3	3	11.0	51.5	.	.	4.5	8.5	11.8
Non-Tile	SL 11.2	3	4	11.7	32.0	.	.	1.8	9.0	24.3
Non-Tile	SL 11.2	3	5	11.9	28.0	.	.	1.2	8.8	14.4
Non-Tile	SL 11.2	4	1	16.4	34.8	6.0	15.0	3.1	8.3	1.4
Non-Tile	SL 11.2	4	2	12.7	45.5	2.0	2.0	3.8	8.2	5.8
Non-Tile	SL 11.2	4	3	11.8	34.5	.	.	1.9	8.6	22.6
Non-Tile	SL 11.2	4	4	10.4	31.7	.	.	0.9	8.8	25.8
Non-Tile	SL 11.2	4	5	9.1	22.5	.	.	0.9	8.8	12.0
Non-Tile	SL 33.6	1	1	9.8	31.7	10.5	19.0	2.6	8.2	1.7
Non-Tile	SL 33.6	1	2	11.2	39.5	1.5	2.0	3.3	8.2	3.5
Non-Tile	SL 33.6	1	3	11.4	34.1	.	.	1.8	8.7	16.6
Non-Tile	SL 33.6	1	4	12.0	31.9	.	.	1.7	8.8	26.0
Non-Tile	SL 33.6	1	5	14.6	34.2	.	.	1.8	8.8	26.0
Non-Tile	SL 33.6	2	1	15.0	30.4	2.0	9.0	3.5	8.2	0.7
Non-Tile	SL 33.6	2	2	17.0	28.8	1.5	2.0	3.1	8.2	4.4
Non-Tile	SL 33.6	2	3	11.9	34.9	.	.	1.7	8.8	20.2
Non-Tile	SL 33.6	2	4	10.3	31.6	.	.	1.4	9.0	23.8
Non-Tile	SL 33.6	2	5	6.7	17.2	.	.	0.6	9.2	14.4
Non-Tile	SL 33.6	3	1	12.1	30.7	12.0	7.0	3.6	8.2	0.8

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	SL 33.6	3	2	10.7	35.7	2.5	6.0	3.4	8.1	0.3
Non-Tile	SL 33.6	3	3	10.3	37.4	.	.	2.8	8.4	5.1
Non-Tile	SL 33.6	3	4	7.2	30.6	.	.	1.1	8.8	17.9
Non-Tile	SL 33.6	3	5	5.8	22.8	.	.	0.8	8.8	8.1
Non-Tile	SL 33.6	4	1	16.0	37.0	8.5	40.0	2.7	8.2	2.4
Non-Tile	SL 33.6	4	2	11.9	43.1	2.0	3.0	3.1	8.1	4.6
Non-Tile	SL 33.6	4	3	9.3	39.3	.	.	2.1	8.3	18.3
Non-Tile	SL 33.6	4	4	9.5	31.1	.	.	1.3	8.8	21.3
Non-Tile	SL 33.6	4	5	7.6	21.6	.	.	0.8	8.9	9.7
Non-Tile	SL 67.2	1	1	15.7	39.2	14.0	49.0	4.2	8.4	3.7
Non-Tile	SL 67.2	1	2	13.1	41.0	2.5	3.0	3.6	8.3	14.4
Non-Tile	SL 67.2	1	3	12.4	36.2	.	.	2.2	8.7	21.3
Non-Tile	SL 67.2	1	4	11.7	33.0	.	.	1.8	8.7	25.4
Non-Tile	SL 67.2	1	5	9.8	30.1	.	.	0.9	8.8	18.1
Non-Tile	SL 67.2	2	1	8.3	37.1	14.5	22.0	2.5	8.3	1.9
Non-Tile	SL 67.2	2	2	12.8	34.2	2.5	2.0	0.3	8.2	0.7
Non-Tile	SL 67.2	2	3	6.7	56.8	.	.	2.7	8.4	22.7
Non-Tile	SL 67.2	2	4	6.2	54.9	.	.	3.1	8.5	25.0
Non-Tile	SL 67.2	2	5	11.4	29.2	.	.	1.0	8.9	15.9
Non-Tile	SL 67.2	3	1	13.2	41.5	11.5	38.0	3.7	8.4	1.8
Non-Tile	SL 67.2	3	2	15.9	32.9	5.0	4.0	3.7	8.2	1.7
Non-Tile	SL 67.2	3	3	7.0	50.1	.	.	3.1	8.4	18.0
Non-Tile	SL 67.2	3	4	9.4	31.4	.	.	1.3	8.8	28.9
Non-Tile	SL 67.2	3	5	9.4	28.2	.	.	1.5	8.6	13.5
Non-Tile	SL 67.2	4	1	12.0	37.9	12.0	13.0	3.1	8.3	1.4
Non-Tile	SL 67.2	4	2	11.8	42.0	2.5	2.0	3.6	8.2	1.5

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	SL 67.2	4	3	12.1	36.4	.	.	2.3	8.5	10.4
Non-Tile	SL 67.2	4	4	9.8	30.8	.	.	1.6	8.9	17.5
Non-Tile	SL 67.2	4	5	13.1	34.1	.	.	1.8	8.6	9.9
Non-Tile	Kmag 2.2	1	1	15.4	25.3	15.5	10.0	2.9	8.0	1.8
Non-Tile	Kmag 2.2	1	2	21.4	21.0	3.5	2.0	2.3	8.1	1.6
Non-Tile	Kmag 2.2	1	3	13.0	34.9	.	.	2.3	6.6	10.4
Non-Tile	Kmag 2.2	1	4	10.3	30.5	.	.	1.5	8.9	27.3
Non-Tile	Kmag 2.2	1	5	7.1	21.2	.	.	0.6	8.9	10.3
Non-Tile	Kmag 2.2	2	1	16.1	30.4	14.0	18.0	3.3	8.2	1.5
Non-Tile	Kmag 2.2	2	2	11.7	39.5	3.0	2.0	3.4	8.2	2.5
Non-Tile	Kmag 2.2	2	3	7.5	43.2	.	.	2.5	8.3	15.6
Non-Tile	Kmag 2.2	2	4	7.6	30.7	.	.	0.8	9.0	31.3
Non-Tile	Kmag 2.2	2	5	5.5	27.0	.	.	0.7	8.8	14.1
Non-Tile	Kmag 2.2	3	1	16.3	31.4	8.0	23.0	3.8	8.3	1.1
Non-Tile	Kmag 2.2	3	2	14.2	36.0	2.5	4.0	3.6	8.1	2.4
Non-Tile	Kmag 2.2	3	3	12.5	34.0	.	.	2.3	8.7	19.1
Non-Tile	Kmag 2.2	3	4	11.3	30.2	.	.	1.6	8.8	20.4
Non-Tile	Kmag 2.2	3	5	11.8	17.4	.	.	0.8	9.0	6.4
Non-Tile	Kmag 2.2	4	1	13.3	28.2	10.5	13.0	2.4	8.2	1.0
Non-Tile	Kmag 2.2	4	2	14.4	39.8	2.0	3.0	2.8	8.2	2.3
Non-Tile	Kmag 2.2	4	3	9.9	46.1	.	.	2.4	8.4	16.9
Non-Tile	Kmag 2.2	4	4	10.3	34.9	.	.	1.8	8.6	26.0
Non-Tile	Kmag 2.2	4	5	8.4	27.8	.	.	0.9	8.6	10.8
Non-Tile	Kmag 5.6	1	1	10.1	33.0	10.5	18.0	2.6	8.1	2.1
Non-Tile	Kmag 5.6	1	2	11.6	43.7	3.0	3.0	3.7	8.2	11.0
Non-Tile	Kmag 5.6	1	3	12.8	34.6	.	.	2.0	8.8	30.3

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	meq 100g^{-1}	ppm	ppm	dS/m		%
Non-Tile	Kmag 5.6	1	4	11.6	30.9	.	.	1.4	9.0	27.1
Non-Tile	Kmag 5.6	1	5	10.2	24.9	.	.	0.9	8.9	11.0
Non-Tile	Kmag 5.6	2	1	18.6	30.1	11.0	37.0	3.7	8.4	0.8
Non-Tile	Kmag 5.6	2	2	14.0	34.2	4.0	3.0	2.8	8.1	1.1
Non-Tile	Kmag 5.6	2	3	12.6	28.4	.	.	1.6	8.4	2.6
Non-Tile	Kmag 5.6	2	4	8.1	28.2	.	.	1.1	8.6	4.9
Non-Tile	Kmag 5.6	2	5	6.3	24.7	.	.	0.8	8.8	11.6
Non-Tile	Kmag 5.6	3	1	15.9	29.9	13.5	11.0	3.7	8.1	0.9
Non-Tile	Kmag 5.6	3	2	18.7	29.1	2.5	2.0	3.9	7.9	0.7
Non-Tile	Kmag 5.6	3	3	8.5	52.0	.	.	3.7	8.1	3.9
Non-Tile	Kmag 5.6	3	4	9.4	32.2	.	.	1.8	8.5	18.5
Non-Tile	Kmag 5.6	3	5	10.5	18.0	.	.	1.1	8.6	7.0
Non-Tile	Kmag 5.6	4	1	17.7	33.8	21.0	29.0	2.6	8.2	1.1
Non-Tile	Kmag 5.6	4	2	9.4	41.2	5.0	4.0	2.5	8.0	3.9
Non-Tile	Kmag 5.6	4	3	2.4	84.7	.	.	2.5	8.1	15.8
Non-Tile	Kmag 5.6	4	4	5.3	32.9	.	.	1.4	8.3	26.6
Non-Tile	Kmag 5.6	4	5	5.6	26.5	.	.	0.8	8.5	16.4
Non-Tile	Kmag 11.2	1	1	14.8	30.2	15.0	21.0	3.4	8.1	1.3
Non-Tile	Kmag 11.2	1	2	10.1	36.0	1.5	3.0	2.0	8.6	20.8
Non-Tile	Kmag 11.2	1	3	8.6	32.5	.	.	1.1	9.0	25.0
Non-Tile	Kmag 11.2	1	4	7.3	29.6	.	.	0.7	9.1	26.2
Non-Tile	Kmag 11.2	1	5	6.9	26.3	.	.	0.6	8.8	10.2
Non-Tile	Kmag 11.2	2	1	18.4	35.8	18.0	23.0	3.2	8.3	0.8
Non-Tile	Kmag 11.2	2	2	21.2	27.5	3.5	4.0	2.2	8.2	0.9
Non-Tile	Kmag 11.2	2	3	12.8	36.0	.	.	1.3	8.7	13.6
Non-Tile	Kmag 11.2	2	4	9.6	31.5	.	.	0.8	9.0	11.2

Table B2. 2015 Soil Data (continued)

Site	Treatment	Replication	Depth	Na	CEC	Nitrate-N	P-olsen	EC	pH	CCE
				%	**meq $100g^{-1}$**	**ppm**	**ppm**	**dS/m**		**%**
Non-Tile	Kmag 11.2	2	5	7.5	27.1	.	.	0.8	9.0	13.0
Non-Tile	Kmag 11.2	3	1	13.8	31.3	8.0	22.0	4.3	8.2	0.7
Non-Tile	Kmag 11.2	3	2	10.9	40.7	3.0	3.0	3.8	8.1	1.1
Non-Tile	Kmag 11.2	3	3	4.9	72.4	.	.	3.0	8.2	13.9
Non-Tile	Kmag 11.2	3	4	9.1	30.9	.	.	1.2	8.8	24.0
Non-Tile	Kmag 11.2	3	5	7.4	27.9	.	.	1.0	8.5	12.4
Non-Tile	Kmag 11.2	4	1	15.3	33.9	8.5	26.0	3.4	8.3	0.6
Non-Tile	Kmag 11.2	4	2	9.8	51.2	2.5	4.0	3.1	8.2	4.8
Non-Tile	Kmag 11.2	4	3	6.1	69.7	.	.	3.1	8.3	15.3
Non-Tile	Kmag 11.2	4	4	11.1	32.5	.	.	1.4	8.8	21.2
Non-Tile	Kmag 11.2	4	5	9.6	31.7	.	.	0.9	8.6	21.2

Table B3. 2014 and 2015 Alfalfa Yield

Site	Treatment	Replication	Yield				
	Mg ha^{-1}		----------------------------Mg ha^{-1}--------------------------				
			8/25/14	6/1/15	6/29/15 & 7/7/15	7/29/15	8/20/15
Tile	Control	1	1.69	3.40	3.19	1.86	1.24
Tile	Control	2	3.07	3.53	3.61	1.68	1.02
Tile	Control	3	2.20	3.79	3.60	1.52	0.89
Tile	Control	4	2.42	3.76	3.14	1.81	0.99
Tile	FGDG 11.2	1	1.78	4.17	4.05	1.62	1.13
Tile	FGDG 11.2	2	2.81	3.66	3.64	0.64	1.20
Tile	FGDG 11.2	3	2.38	4.04	3.72	1.95	1.22
Tile	FGDG 11.2	4	2.69	3.19	3.56	1.50	1.21
Tile	FGDG 33.6	1	1.34	3.15	3.08	1.66	1.09
Tile	FGDG 33.6	2	1.96	3.49	3.97	1.96	1.15
Tile	FGDG 33.6	3	1.85	3.48	3.72	2.10	1.17
Tile	FGDG 33.6	4	0.50	2.80	3.33	2.19	0.78
Tile	FGDG 67.2	1	1.66	3.52	3.72	2.20	1.32
Tile	FGDG 67.2	2	2.57	3.24	3.33	1.77	1.19
Tile	FGDG 67.2	3	2.08	3.33	3.78	1.84	1.16
Tile	FGDG 67.2	4	2.17	3.70	4.06	1.86	1.18
Tile	SL 11.2	1	1.41	2.87	3.20	2.04	1.18
Tile	SL 11.2	2	2.37	3.09	3.71	1.71	1.17
Tile	SL 11.2	3	0.99	2.66	3.01	1.59	0.91
Tile	SL 11.2	4	1.14	3.35	3.26	1.63	1.18
Tile	SL 33.6	1	1.66	3.32	3.68	1.78	1.29
Tile	SL 33.6	2	0.38	2.51	2.88	3.07	0.77
Tile	SL 33.6	3	1.44	3.84	3.12	1.91	1.11
Tile	SL 33.6	4	2.25	3.16	3.33	1.78	1.20
Tile	SL 67.2	1	1.49	3.31	3.64	1.70	1.29
Tile	SL 67.2	2	1.03	3.67	2.83	2.14	1.02
Tile	SL 67.2	3	0.53	2.27	1.97	1.00	0.78
Tile	SL 67.2	4	2.94	3.64	3.90	2.16	1.34
Tile	Kmag 2.2	1	1.56	3.23	3.87	1.68	1.20
Tile	Kmag 2.2	2	2.29	2.77	3.72	1.95	1.27
Tile	Kmag 2.2	3	1.52	3.39	3.85	2.11	1.13
Tile	Kmag 2.2	4	2.20	2.71	4.01	1.76	1.31
Tile	Kmag 5.6	1	1.92	3.57	3.77	2.17	1.51
Tile	Kmag 5.6	2	1.83	3.64	3.71	1.91	1.42

Table B3. 2014 and 2015 Alfalfa Yield (continued)

Site	**Treatment**	**Replication**	**Yield**				
	Mg ha^{-1}		---------------------------**Mg ha^{-1}**--------------------------				
			8/25/14	6/1/15	6/29/15 & 7/7/15	7/29/15	8/20/15
Tile	Kmag 5.6	3	1.54	3.04	3.86	1.92	1.30
Tile	Kmag 5.6	4	1.96	3.36	3.78	1.66	1.50
Tile	Kmag 11.2	1	1.81	3.16	4.21	2.23	1.62
Tile	Kmag 11.2	2	1.06	3.36	3.49	2.09	1.27
Tile	Kmag 11.2	3	2.07	3.68	3.61	2.04	1.09
Tile	Kmag 11.2	4	1.41	4.26	3.29	1.81	1.15
Non-Tile	Control	1	2.13	2.46	2.86	1.60	1.17
Non-Tile	Control	2	1.38	2.09	1.96	1.52	1.40
Non-Tile	Control	3	2.06	2.85	3.11	2.05	1.52
Non-Tile	Control	4	2.25	3.61	3.43	1.88	1.27
Non-Tile	FGDG 11.2	1	1.37	2.50	3.28	1.82	1.17
Non-Tile	FGDG 11.2	2	0.77	2.16	2.70	1.36	1.10
Non-Tile	FGDG 11.2	3	1.36	1.85	2.21	1.70	1.48
Non-Tile	FGDG 11.2	4	0.87	1.66	2.53	1.44	1.17
Non-Tile	FGDG 33.6	1	2.00	3.73	3.55	1.98	1.19
Non-Tile	FGDG 33.6	2	2.07	2.77	2.45	1.45	0.93
Non-Tile	FGDG 33.6	3	1.92	2.64	3.63	1.50	1.17
Non-Tile	FGDG 33.6	4	1.81	2.39	2.26	2.11	0.93
Non-Tile	FGDG 67.2	1	1.78	3.21	3.18	1.88	1.28
Non-Tile	FGDG 67.2	2	2.12	3.08	2.82	1.59	1.27
Non-Tile	FGDG 67.2	3	1.93	3.26	3.17	1.47	1.33
Non-Tile	FGDG 67.2	4	2.53	2.81	2.69	1.55	1.36
Non-Tile	SL 11.2	1	0.95	1.68	2.56	1.54	1.17
Non-Tile	SL 11.2	2	1.47	1.98	3.36	1.68	0.86
Non-Tile	SL 11.2	3	0.95	1.69	1.87	1.75	1.07
Non-Tile	SL 11.2	4	1.15	1.87	2.02	1.37	0.96
Non-Tile	SL 33.6	1	1.47	3.64	2.51	1.69	1.02
Non-Tile	SL 33.6	2	1.38	2.62	3.09	1.73	1.24
Non-Tile	SL 33.6	3	0.57	1.54	2.28	1.73	1.09
Non-Tile	SL 33.6	4	2.99	2.23	2.91	1.51	1.13
Non-Tile	SL 67.2	1	1.39	2.84	2.81	1.59	1.00
Non-Tile	SL 67.2	2	0.22	1.41	2.00	1.50	0.98
Non-Tile	SL 67.2	3	0.53	2.36	2.31	2.10	0.77
Non-Tile	SL 67.2	4	1.84	1.83	2.60	1.58	1.14
Non-Tile	Kmag 2.2	1	0.88	3.52	3.18	2.20	1.35

Table B3. 2014 and 2015 Alfalfa Yield (continued)

Site	Treatment	Replication	Yield				
	Mg ha^{-1}		**----------------------------Mg ha^{-1}--------------------------**				
			8/25/14	6/1/15	6/29/15 & 7/7/15	7/29/15	8/20/15
Non-Tile	Kmag 2.2	2	1.63	2.83	2.45	1.90	1.33
Non-Tile	Kmag 2.2	3	2.10	2.97	2.62	1.57	1.43
Non-Tile	Kmag 2.2	4	2.64	2.41	2.17	1.62	1.44
Non-Tile	Kmag 5.6	1	1.33	1.58	2.61	1.81	1.51
Non-Tile	Kmag 5.6	2	1.74	1.37	2.49	1.77	1.15
Non-Tile	Kmag 5.6	3	1.60	1.09	2.78	1.63	1.20
Non-Tile	Kmag 5.6	4	0.47	0.73	0.99	1.51	0.90
Non-Tile	Kmag 11.2	1	0.07	0.77	1.63	0.43	0.77
Non-Tile	Kmag 11.2	2	0.43	0.32	1.15	0.94	0.50
Non-Tile	Kmag 11.2	3	0.68	0.37	0.98	1.02	1.00
Non-Tile	Kmag 11.2	4	0.42	0.83	2.57	0.44	0.81

Table B4. 2014 and 2015 Forage Quality Analysis

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}				--%--					
Tile	Control	2014	1	96.27	10.85	25.60	33.22	24.72	1.34	0.35
Tile	Control	2014	2	95.76	9.96	20.94	39.47	29.32	1.47	0.32
Tile	Control	2014	3	96.90	10.72	26.18	32.10	25.07	1.66	0.47
Tile	Control	2014	4	98.04	10.16	22.06	36.70	27.27	1.52	0.38
Tile	FGDG 11.2	2014	1	97.57	11.07	25.98	30.54	21.40	1.79	0.35
Tile	FGDG 11.2	2014	2	96.33	10.54	23.70	34.69	24.79	1.69	0.34
Tile	FGDG 11.2	2014	3	97.45	10.74	23.90	35.72	24.17	1.78	0.41
Tile	FGDG 11.2	2014	4	97.37	10.59	23.23	35.75	25.73	1.72	0.40
Tile	FGDG 33.6	2014	1	98.22	11.34	26.46	29.78	21.11	1.87	0.35
Tile	FGDG 33.6	2014	2	97.91	10.55	25.11	33.37	24.80	1.83	0.33
Tile	FGDG 33.6	2014	3	97.94	11.12	23.89	38.33	26.76	1.55	0.43
Tile	FGDG 33.6	2014	4	97.50	9.66	25.93	33.16	24.19	1.37	0.43
Tile	FGDG 67.2	2014	1	97.64	10.73	26.00	30.04	20.47	1.55	0.27
Tile	FGDG 67.2	2014	2	96.67	10.04	23.21	38.68	26.44	1.27	0.33
Tile	FGDG 67.2	2014	3	96.96	10.37	25.93	33.88	23.40	1.63	0.43
Tile	FGDG 67.2	2014	4	96.99	10.39	26.05	32.16	20.72	1.50	0.40
Tile	SL 11.2	2014	1	95.78	10.49	26.83	29.26	21.64	1.68	0.38
Tile	SL 11.2	2014	2	95.41	10.84	23.61	35.21	25.26	1.72	0.35
Tile	SL 11.2	2014	3	97.50	9.95	25.35	36.92	25.73	1.53	0.43
Tile	SL 11.2	2014	4	96.84	10.79	24.80	36.24	26.23	1.54	0.47
Tile	SL 33.6	2014	1	97.98	10.13	22.85	33.32	23.80	1.44	0.31
Tile	SL 33.6	2014	2	97.26	10.05	25.33	33.00	23.66	1.67	0.37
Tile	SL 33.6	2014	3	97.58	10.61	26.57	33.05	23.35	1.68	0.45
Tile	SL 33.6	2014	4	93.41	11.37	24.21	35.04	25.58	1.84	0.41
Tile	SL 67.2	2014	1	96.44	10.90	25.97	30.30	21.46	1.79	0.33

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}				-------------	-------------	%	-------------	-------------	
Tile	SL 67.2	2014	2	97.68	9.85	25.66	33.89	24.75	1.79	0.36
Tile	SL 67.2	2014	3	94.44	10.26	27.29	31.89	22.90	1.53	0.44
Tile	SL 67.2	2014	4	98.03	10.11	21.84	40.10	29.69	1.50	0.42
Tile	Kmag 2.2	2014	1	97.94	10.23	22.95	29.63	20.62	1.48	0.33
Tile	Kmag 2.2	2014	2	95.36	10.89	23.51	32.18	23.55	1.72	0.36
Tile	Kmag 2.2	2014	3	97.46	12.15	25.61	31.47	23.03	2.06	0.43
Tile	Kmag 2.2	2014	4	95.97	11.36	24.66	34.51	24.87	1.73	0.43
Tile	Kmag 5.6	2014	1	97.12	11.34	25.57	30.75	21.38	2.02	0.33
Tile	Kmag 5.6	2014	2	97.34	11.36	25.30	33.69	24.03	1.22	0.38
Tile	Kmag 5.6	2014	3	96.91	11.79	26.75	34.16	23.12	1.54	0.48
Tile	Kmag 5.6	2014	4	96.22	10.46	23.99	35.38	25.89	1.54	0.39
Tile	Kmag 11.2	2014	1	95.50	10.78	23.86	30.53	21.92	1.99	0.29
Tile	Kmag 11.2	2014	2	95.78	11.81	26.89	30.00	21.84	1.61	0.39
Tile	Kmag 11.2	2014	3	97.00	11.35	23.35	35.80	26.05	1.37	0.44
Tile	Kmag 11.2	2014	4	95.28	11.09	25.00	33.44	23.29	1.36	0.42
Non-Tile	Control	2014	1	95.19	9.99	23.68	34.50	25.98	1.36	0.31
Non-Tile	Control	2014	2	98.05	11.27	24.51	33.37	24.11	1.11	0.34
Non-Tile	Control	2014	3	96.38	10.62	23.57	35.87	25.59	1.23	0.33
Non-Tile	Control	2014	4	93.18	11.30	23.01	38.49	27.70	1.27	0.36
Non-Tile	FGDG 11.2	2014	1	95.83	10.76	27.37	30.32	22.97	1.24	0.34
Non-Tile	FGDG 11.2	2014	2	98.29	9.50	23.16	34.84	25.52	1.25	0.30
Non-Tile	FGDG 11.2	2014	3	95.77	9.78	22.62	33.10	24.78	1.18	0.31
Non-Tile	FGDG 11.2	2014	4	94.86	11.33	24.23	32.29	23.07	1.20	0.34
Non-Tile	FGDG 33.6	2014	1	97.49	9.35	23.03	31.93	23.42	1.20	0.29
Non-Tile	FGDG 33.6	2014	2	98.11	10.41	22.27	31.56	23.33	1.24	0.31
Non-Tile	FGDG 33.6	2014	3	97.70	9.79	22.74	34.73	25.03	1.16	0.32

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}						%			
Non-Tile	FGDG 33.6	2014	4	96.01	15.52	22.41	37.04	28.52	1.25	0.34
Non-Tile	FGDG 67.2	2014	1	95.45	9.44	24.77	31.53	22.54	1.28	0.30
Non-Tile	FGDG 67.2	2014	2	96.16	11.10	22.99	34.51	25.53	1.05	0.33
Non-Tile	FGDG 67.2	2014	3	96.47	10.80	23.56	36.67	26.93	1.23	0.34
Non-Tile	FGDG 67.2	2014	4	96.73	9.99	23.34	33.08	23.94	1.17	0.30
Non-Tile	SL 11.2	2014	1	95.74	10.14	25.01	26.21	18.92	1.33	0.32
Non-Tile	SL 11.2	2014	2	98.24	10.46	24.87	33.67	24.55	1.23	0.33
Non-Tile	SL 11.2	2014	3	96.60	10.63	26.10	26.96	18.72	1.31	0.36
Non-Tile	SL 11.2	2014	4	93.28	10.82	24.66	33.20	24.71	1.17	0.34
Non-Tile	SL 33.6	2014	1	97.62	9.48	23.38	30.15	21.06	1.23	0.31
Non-Tile	SL 33.6	2014	2	97.92	10.41	25.94	32.60	24.28	1.43	0.32
Non-Tile	SL 33.6	2014	3	98.23	10.26	23.89	34.16	24.49	1.30	0.33
Non-Tile	SL 33.6	2014	4	96.52	9.77	21.68	34.82	25.55	1.15	0.31
Non-Tile	SL 67.2	2014	1	94.89	9.95	23.11	31.03	22.23	1.50	0.30
Non-Tile	SL 67.2	2014	2	98.45	10.53	24.56	34.61	25.13	1.23	0.34
Non-Tile	SL 67.2	2014	3	98.75	10.52	24.79	31.15	22.52	1.27	0.35
Non-Tile	SL 67.2	2014	4	95.27	10.81	24.11	34.87	25.58	1.23	0.34
Non-Tile	Kmag 2.2	2014	1	97.78	10.75	27.36	28.95	21.50	1.24	0.35
Non-Tile	Kmag 2.2	2014	2	97.38	10.66	22.91	31.83	23.65	1.26	0.31
Non-Tile	Kmag 2.2	2014	3	96.89	10.49	23.05	34.22	24.54	1.22	0.32
Non-Tile	Kmag 2.2	2014	4	95.29	10.34	23.24	36.72	26.63	1.05	0.34
Non-Tile	Kmag 5.6	2014	1	96.17	9.13	21.75	30.23	21.12	1.21	0.28
Non-Tile	Kmag 5.6	2014	2	97.46	10.52	23.84	33.32	24.79	1.23	0.33
Non-Tile	Kmag 5.6	2014	3	96.43	10.18	23.46	33.10	25.82	1.20	0.33
Non-Tile	Kmag 5.6	2014	4	95.91	11.20	22.41	34.79	24.92	1.03	0.32
Non-Tile	Kmag 11.2	2014	1	97.04	10.31	24.28	26.79	19.37	1.07	0.32

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}				-----	-----	-----%-----	-----	-----	
Non-Tile	Kmag 11.2	2014	2	97.59	9.76	22.50	32.51	23.81	1.18	0.31
Non-Tile	Kmag 11.2	2014	3	98.46	10.09	21.49	36.69	27.05	1.06	0.32
Non-Tile	Kmag 11.2	2014	4	94.68	11.87	22.11	35.62	24.74	1.34	0.36
Tile	Control	2015	1	91.30	9.26	22.33	46.08	32.20	0.91	0.45
Tile	Control	2015	2	92.83	9.34	24.37	41.93	31.85	1.05	0.48
Tile	Control	2015	3	92.39	9.31	24.23	47.96	30.57	1.02	0.44
Tile	Control	2015	4	92.28	10.24	23.68	46.16	31.26	1.23	0.44
Tile	FGDG 11.2	2015	1	89.96	9.86	23.78	43.58	31.34	1.03	0.41
Tile	FGDG 11.2	2015	2	91.12	10.13	25.85	38.47	27.79	1.11	0.43
Tile	FGDG 11.2	2015	3	92.00	10.32	24.78	43.07	28.51	1.09	0.44
Tile	FGDG 11.2	2015	4	91.76	10.99	24.91	40.87	28.82	1.40	0.45
Tile	FGDG 33.6	2015	1	92.62	11.44	26.92	39.85	26.93	1.28	0.46
Tile	FGDG 33.6	2015	2	92.06	10.67	24.48	42.41	28.67	1.27	0.42
Tile	FGDG 33.6	2015	3	91.85	9.90	24.26	43.33	30.22	0.92	0.45
Tile	FGDG 33.6	2015	4	91.37	10.64	23.00	44.89	30.33	1.21	0.45
Tile	FGDG 67.2	2015	1	91.67	11.84	25.89	38.25	26.41	1.37	0.41
Tile	FGDG 67.2	2015	2	91.59	10.64	26.62	40.47	31.20	1.21	0.47
Tile	FGDG 67.2	2015	3	91.65	9.94	25.09	39.39	29.15	1.18	0.46
Tile	FGDG 67.2	2015	4	92.43	11.29	25.63	40.10	27.37	1.47	0.43
Tile	SL 11.2	2015	1	92.29	10.81	23.40	44.25	30.61	1.20	0.48
Tile	SL 11.2	2015	2	91.09	9.66	24.27	42.97	30.72	1.03	0.46
Tile	SL 11.2	2015	3	92.08	9.90	18.84	44.79	32.33	1.25	0.42
Tile	SL 11.2	2015	4	92.18	10.85	21.16	42.83	30.34	1.45	0.44
Tile	SL 33.6	2015	1	91.07	10.92	25.17	40.66	30.62	1.18	0.42
Tile	SL 33.6	2015	2	92.16	9.97	20.78	41.44	30.09	1.28	0.43
Tile	SL 33.6	2015	3	90.63	9.43	23.02	43.29	30.76	0.88	0.46

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}				----------	----------	----------%----------	----------	----------	
Tile	SL 33.6	2015	4	92.53	10.16	23.85	42.57	30.04	1.23	0.43
Tile	SL 67.2	2015	1	92.78	11.10	24.84	40.92	27.25	1.14	0.41
Tile	SL 67.2	2015	2	92.12	10.02	23.10	42.57	32.09	1.08	0.49
Tile	SL 67.2	2015	3	92.43	9.84	18.64	48.19	34.58	1.02	0.43
Tile	SL 67.2	2015	4	92.47	11.12	22.52	45.93	30.80	1.46	0.45
Tile	Kmag 2.2	2015	1	89.48	11.03	24.53	41.68	30.72	0.94	0.41
Tile	Kmag 2.2	2015	2	91.75	9.97	26.89	41.94	30.60	0.97	0.47
Tile	Kmag 2.2	2015	3	91.12	11.47	25.48	38.66	28.73	0.91	0.47
Tile	Kmag 2.2	2015	4	91.16	11.64	26.03	40.67	27.67	1.38	0.44
Tile	Kmag 5.6	2015	1	92.49	11.13	23.90	40.25	26.96	0.96	0.40
Tile	Kmag 5.6	2015	2	91.11	11.74	21.88	44.52	32.19	0.81	0.46
Tile	Kmag 5.6	2015	3	92.32	11.54	24.83	41.10	29.80	0.90	0.45
Tile	Kmag 5.6	2015	4	93.19	11.83	23.31	41.97	27.48	1.45	0.35
Tile	Kmag 11.2	2015	1	91.90	12.31	26.64	41.33	25.90	1.07	0.42
Tile	Kmag 11.2	2015	2	91.59	12.23	23.54	41.38	28.50	0.82	0.46
Tile	Kmag 11.2	2015	3	92.57	11.19	22.96	41.08	30.77	0.76	0.46
Tile	Kmag 11.2	2015	4	91.25	11.86	22.01	43.52	32.02	0.91	0.42
Non-Tile	Control	2015	1	92.38	11.61	18.64	42.72	30.64	1.14	0.42
Non-Tile	Control	2015	2	93.03	11.53	18.87	40.82	26.48	1.22	0.37
Non-Tile	Control	2015	3	93.34	11.43	21.22	38.62	29.08	1.01	0.38
Non-Tile	Control	2015	4	93.90	11.52	20.73	44.32	30.27	0.99	0.37
Non-Tile	FGDG 11.2	2015	1	92.42	11.20	20.14	44.41	30.66	1.05	0.38
Non-Tile	FGDG 11.2	2015	2	93.12	10.92	19.62	36.75	27.04	1.42	0.33
Non-Tile	FGDG 11.2	2015	3	92.98	11.11	17.53	39.82	29.80	1.04	0.37
Non-Tile	FGDG 11.2	2015	4	92.50	11.66	16.66	39.58	24.53	1.31	0.38
Non-Tile	FGDG 33.6	2015	1	92.85	11.35	22.15	49.55	31.23	1.35	0.38

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}			-------------------	-------------------	-------------------	%	-------------------	-------------------	-------------------
Non-Tile	FGDG 33.6	2015	2	92.59	11.52	18.91	45.18	32.39	1.08	0.38
Non-Tile	FGDG 33.6	2015	3	92.92	11.19	19.09	41.75	31.77	1.30	0.32
Non-Tile	FGDG 33.6	2015	4	91.38	11.22	19.31	43.60	31.38	1.23	0.30
Non-Tile	FGDG 67.2	2015	1	93.15	10.87	19.96	49.38	33.20	1.09	0.35
Non-Tile	FGDG 67.2	2015	2	94.40	11.45	18.07	42.76	29.60	1.13	0.38
Non-Tile	FGDG 67.2	2015	3	94.86	11.37	19.38	39.80	27.79	1.17	0.39
Non-Tile	FGDG 67.2	2015	4	93.35	11.33	18.60	46.49	31.08	1.36	0.32
Non-Tile	SL 11.2	2015	1	92.10	11.66	20.00	38.47	27.20	1.26	0.43
Non-Tile	SL 11.2	2015	2	93.01	11.34	19.26	41.90	28.75	1.26	0.34
Non-Tile	SL 11.2	2015	3	92.95	11.99	21.39	44.62	30.31	1.18	0.37
Non-Tile	SL 11.2	2015	4	92.05	11.21	20.99	42.84	28.54	1.29	0.36
Non-Tile	SL 33.6	2015	1	92.82	11.22	19.34	47.02	32.88	1.09	0.38
Non-Tile	SL 33.6	2015	2	93.03	11.09	23.69	41.10	27.04	1.29	0.39
Non-Tile	SL 33.6	2015	3	91.77	11.44	18.86	42.47	29.76	1.39	0.35
Non-Tile	SL 33.6	2015	4	93.21	11.23	18.20	46.15	32.10	1.36	0.34
Non-Tile	SL 67.2	2015	1	92.56	12.89	19.99	45.42	32.71	1.21	0.37
Non-Tile	SL 67.2	2015	2	93.03	11.36	17.77	38.68	28.00	1.34	0.32
Non-Tile	SL 67.2	2015	3	94.05	11.23	19.44	44.24	28.66	1.24	0.34
Non-Tile	SL 67.2	2015	4	92.49	12.02	20.09	40.56	27.86	1.31	0.36
Non-Tile	Kmag 2.2	2015	1	91.38	11.54	20.03	45.99	31.59	1.12	0.31
Non-Tile	Kmag 2.2	2015	2	92.05	11.56	17.58	43.36	30.84	1.05	0.39
Non-Tile	Kmag 2.2	2015	3	93.56	12.16	19.26	42.25	31.41	1.11	0.36
Non-Tile	Kmag 2.2	2015	4	93.31	11.31	18.17	41.70	27.81	1.14	0.38
Non-Tile	Kmag 5.6	2015	1	92.35	11.49	18.24	41.60	28.35	1.22	0.37
Non-Tile	Kmag 5.6	2015	2	92.02	11.15	17.90	41.29	31.31	1.16	0.37
Non-Tile	Kmag 5.6	2015	3	92.31	11.24	17.80	39.49	26.00	1.09	0.35

Table B4. 2014 and 2015 Forage Quality Analysis (continued)

Site	Treatment	Year	Replication	DM	Ash	CP	NDF	ADF	Ca	Phos
	Mg ha^{-1}				------------	------------	%	------------	------------	
Non-Tile	Kmag 5.6	2015	4	92.48	11.35	21.69	40.74	27.54	1.11	0.34
Non-Tile	Kmag 11.2	2015	1	91.35	11.03	16.20	43.95	30.65	0.99	0.32
Non-Tile	Kmag 11.2	2015	2	91.89	10.97	16.21	35.94	26.11	1.22	0.42
Non-Tile	Kmag 11.2	2015	3	92.78	11.09	13.88	36.22	25.57	0.99	0.35
Non-Tile	Kmag 11.2	2015	4	92.81	11.55	17.39	34.72	24.47	0.94	0.34

APPENDIX C. INCUBATION STUDY DATA

Table C1. Soil Analysis, Cumulative Respiration, Labile C, and Decay Rate Data

Site	Treatment	Rep	EC	pH	Na	OC	IC	TC	DOC	.33 bar	Cumulative respiration	Labile C	Decay Rate
			dS m^{-1}		**---------------%---------------**				**mg L^{-1}**	**g g^{-1}**	**g CO2-C m^{-2}**	**g CO2-C**	
Tile	Control	1	0.993	7.54	4.7	1.70	0.00	1.7	189.0	33.09	94.92	197.00	0.0413
Tile	Control	2	0.961	7.55	4.6	1.72	0.00	1.72	124.5	34.46	69.23	99.28	0.0543
Tile	Control	3	0.99	7.55	4.6	1.72	0.02	1.74	95.7	31.53	72.09	118.00	0.0207
Tile	Control	4	0.998	7.56	4.6	1.72	0.07	1.79	150.7	34.16	71.31	63.86	0.111
Tile	FGDG 11.2	1	2.2	7.28	4.1	1.70	0.01	1.71	26.2	32.82	85.01	157.00	0.0218
Tile	FGDG 11.2	2	2.23	7.37	4	1.69	0.00	1.69	23.9	33.25	66.65	124.30	0.0223
Tile	FGDG 11.2	3	2.17	7.36	4	1.63	0.09	1.72	26.1	30.62	56.08	43.31	0.1805
Tile	FGDG 11.2	4	2.29	7.38	3.9	1.74	0.07	1.81	27.4	33.40	53.19	82.61	0.0484
Tile	FGDG 33.6	1	2.58	7.34	3.4	1.69	0.00	1.69	29.7	32.38	81.79	203.30	0.0114
Tile	FGDG 33.6	2	2.55	7.41	3.4	1.67	0.00	1.67	24.0	32.68	73.59	139.90	0.0433
Tile	FGDG 33.6	3	2.51	7.43	3.5	1.69	0.02	1.71	24.7	30.35	56.03	92.12	0.0315
Tile	FGDG 33.6	4	2.47	7.45	3.4	1.73	0.03	1.76	30.6	33.97	61.56	114.90	0.0302
Tile	FGDG 67.2	1	2.74	7.47	2.9	1.68	0.00	1.68	28.1	32.13	117.28	108.30	0.0967
Tile	FGDG 67.2	2	2.73	7.51	2.9	1.65	0.00	1.65	24.5	33.12	82.53	97.62	0.0404
Tile	FGDG 67.2	3	2.73	7.53	2.9	1.64	0.02	1.66	23.4	31.02	71.76	126.20	0.0413
Tile	FGDG 67.2	4	2.74	7.55	2.8	1.63	0.06	1.69	21.3	33.65	67.43	110.10	0.0719
Tile	SL 11.2	1	1.043	7.85	3.5	1.91	0.04	1.95	59.1	32.54	120.99	232.80	0.013
Tile	SL 11.2	2	1.036	7.91	3.4	2.14	0.03	2.17	55.0	33.41	135.86	180.10	0.0314
Tile	SL 11.2	3	1.05	7.93	3.4	1.74	0.09	1.83	52.7	31.69	135.61	224.20	0.0409
Tile	SL 11.2	4	1.051	7.94	3.3	1.81	0.17	1.98	48.1	33.35	82.86	187.50	0.0409
Tile	SL 33.6	1	1.122	7.94	2.8	1.91	0.21	2.12	60.4	31.39	212.35	257.60	0.051
Tile	SL 33.6	2	1.103	8	2.8	1.92	0.21	2.13	52.9	32.94	161.70	192.70	0.0268
Tile	SL 33.6	3	1.091	8.01	2.7	1.93	0.20	2.13	55.5	31.97	140.45	195.00	0.0476

Table C1. Soil Analysis, Cumulative Respiration, Labile C, and Decay Rate Data (continued)

Site	Treatment	Rep	EC	pH	Na	OC	IC	TC	DOC	.33 bar	Cumulative respiration	Labile C	Decay Rate
			dS m^{-1}		---------------%---------------				mg L^{-1}	g g^{-1}	g CO2-C m^{-2}	g CO2-C	
Tile	SL 33.6	4	1.101	8.03	2.8	1.90	0.28	2.18	62.4	32.90	127.95	204.60	0.0284
Tile	SL 67.2	1	1.194	8.04	2.8	1.91	0.44	2.35	55.5	32.31	274.80	360.40	0.045
Tile	SL 67.2	2	1.198	8.08	2.8	1.89	0.49	2.38	55.6	33.46	228.72	316.90	0.062
Tile	SL 67.2	3	1.154	8.09	2.7	1.82	0.55	2.37	54.2	31.95	177.77	310.00	0.0244
Tile	SL 67.2	4	1.195	8.1	2.7	2.02	0.44	2.46	54.9	34.22	210.84	396.90	0.0318
Tile	Kmag 2.2	1	1.856	7.4	4.5	1.92	0.00	1.92	34.6	34.44	78.30	153.50	0.0318
Tile	Kmag 2.2	2	1.93	7.4	4.4	1.74	0.00	1.74	34.0	31.60	54.77	61.64	0.0492
Tile	Kmag 2.2	3	1.889	7.43	4.3	1.76	0.00	1.76	32.9	35.25	46.73	91.33	0.0385
Tile	Kmag 2.2	4	1.891	7.43	4.4	1.76	0.03	1.79	26.0	33.02	51.04	68.96	0.0581
Tile	Kmag 5.6	1	2.86	7.32	4.5	1.76	0.00	1.76	29.1	33.76	81.26	117.70	0.0592
Tile	Kmag 5.6	2	2.92	7.34	4.3	1.72	0.00	1.72	33.0	30.93	66.01	75.93	0.0926
Tile	Kmag 5.6	3	2.8	7.34	4.4	1.72	0.00	1.72	27.3	30.26	48.46	63.52	0.0401
Tile	Kmag 5.6	4	2.89	7.35	4.4	1.90	0.03	1.93	-6.7	33.35	61.40	86.89	0.0771
Tile	Kmag 11.2	1	3.79	7.34	4.3	1.73	0.00	1.73	34.3	33.42	75.80	88.20	0.1124
Tile	Kmag 11.2	2	3.69	7.37	4.2	1.69	0.01	1.7	32.7	31.30	55.42	66.80	0.1244
Tile	Kmag 11.2	3	3.68	7.37	4.2	1.78	0.00	1.78	30.9	32.22	53.39	64.64	0.0557
Tile	Kmag 11.2	4	3.72	7.38	4.2	1.64	0.11	1.75	24.3	33.08	52.70	52.48	0.1905
Non-Tile	Control	1	3.52	8.01	18.6	1.39	0.00	1.39	43.298	33.08	235.34	306.5	0.0249
Non-Tile	Control	2	3.09	8.16	19	1.34	0.02	1.36	38.608	33.43	255.92	297.6	0.0277
Non-Tile	Control	3	3.41	8.18	19.4	1.36	0.00	1.36	39.216	30.68	236.05	255.2	0.0422
Non-Tile	Control	4	3.45	8.19	19.1	1.32	0.00	1.32	39.641	32.64	149.80	182.5	0.0472
Non-Tile	FGDG 11.2	1	3.65	8.07	15.6	1.37	0.00	1.37	29.467	32.53	253.19	181.3	0.0853
Non-Tile	FGDG 11.2	2	3.56	8.15	15.3	1.34	0.00	1.34	35.715	32.12	268.33	370.9	0.0259
Non-Tile	FGDG 11.2	3	3.68	8.17	16.2	1.37	0.00	1.37	33.782	31.99	259.89	257.6	0.0481
Non-Tile	FGDG 11.2	4	3.45	8.17	16.3	1.32	0.00	1.32	31.425	32.50	176.05	184	0.0507
Non-Tile	FGDG 33.6	1	3.8	8.13	11.5	1.32	0.00	1.32	33.765	33.61	290.91	426.9	0.0212

Table C1. Soil Analysis, Cumulative Respiration, Labile C, and Decay Rate Data (continued)

Site	Treatment	Rep	EC	pH	Na	OC	IC	TC	DOC	.33 bar	Cumulative respiration	Labile C	Decay Rate
			dS m^{-1}		---------------	%	---------------		mg L^{-1}	g g^{-1}	g CO2-C m^{-2}	g CO2-C	
Non-Tile	FGDG 33.6	2	3.83	8.2	11.5	1.30	0.00	1.3	32.005	32.11	263.80	297.5	0.0316
Non-Tile	FGDG 33.6	3	3.89	8.22	11.9	1.33	0.00	1.33	28.265	29.87	249.85	250.5	0.0413
Non-Tile	FGDG 33.6	4	3.85	8.23	12	1.23	0.00	1.23	31.970	32.87	155.87	163.5	0.0512
Non-Tile	FGDG 67.2	1	3.48	8.22	9.2	1.28	0.00	1.28	32.841	34.19	374.94	469.8	0.0293
Non-Tile	FGDG 67.2	2	4.05	8.26	9.2	1.31	0.00	1.31	30.764	32.35	360.62	407.7	0.0331
Non-Tile	FGDG 67.2	3	3.97	8.17	9.6	1.27	0.00	1.27	31.259	30.36	346.57	399.2	0.0278
Non-Tile	FGDG 67.2	4	4.07	8.28	9.7	1.29	0.00	1.29	29.158	31.45	235.63	255.2	0.0354
Non-Tile	SL 11.2	1	3.16	8.32	15	1.40	0.04	1.44	36.565	33.53	391.72	434.3	0.0354
Non-Tile	SL 11.2	2	3.3	8.37	15	1.24	0.17	1.41	38.365	31.41	285.49	294.3	0.0539
Non-Tile	SL 11.2	3	3.36	8.39	14.9	1.31	0.07	1.38	34.530	30.41	331.67	371.7	0.0363
Non-Tile	SL 11.2	4	3.31	8.38	15.1	1.40	0.03	1.43	35.590	31.26	177.32	201.8	0.0377
Non-Tile	SL 33.6	1	3.18	8.43	12.1	1.38	0.17	1.55	38.544	32.63	454.68	535.8	0.0364
Non-Tile	SL 33.6	2	3.25	8.48	12.2	1.39	0.19	1.58	34.804	31.41	367.48	458.4	0.0276
Non-Tile	SL 33.6	3	3.32	8.5	12.1	1.39	0.20	1.59	35.533		349.02	367.2	0.0391
Non-Tile	SL 33.6	4	3.3	8.52	12.3	1.46	0.12	1.58	34.492	32.31	289.71	303.2	0.0531
Non-Tile	SL 67.2	1	3.27	8.52	11.2	1.43	0.34	1.77	35.394	33.46	497.78	579.6	0.0457
Non-Tile	SL 67.2	2	3.36	8.55	11	1.43	0.37	1.8	35.772	31.95	446.18	536.4	0.032
Non-Tile	SL 67.2	3	3.42	8.58	11.5	1.62	0.36	1.98	34.489	32.74	444.27	509.6	0.0361
Non-Tile	SL 67.2	4	3.35	8.62	11.1	1.44	0.39	1.83	38.496	32.33	652.43	666.4	0.0478
Non-Tile	Kmag 2.2	1	3.75	8.13	17.8	1.36	0.00	1.36	41.974	33.88	269.21	332.4	0.031
Non-Tile	Kmag 2.2	2	3.63	8.17	17.8	1.39	0.00	1.39	41.799	31.10	293.38	246.5	0.0619
Non-Tile	Kmag 2.2	3	3.86	8.2	17.5	1.37	0.00	1.37	40.068	32.07	249.45	262.3	0.0422
Non-Tile	Kmag 2.2	4	3.73	8.23	18.2	1.33	0.02	1.35	43.990	31.63	280.38	209.6	0.1259
Non-Tile	Kmag 5.6	1	4.43	8.17	16.5	1.33	0.00	1.33	43.291	33.11	213.45	257.5	0.0302
Non-Tile	Kmag 5.6	2	4.49	8.2	16.6	1.34	0.00	1.34	43.398	30.29	202.70	255.9	0.0279
Non-Tile	Kmag 5.6	3	4.35	8.21	16.8	1.32	0.04	1.36	40.755	31.90	239.96	248.7	0.0461

Table C1. Soil Analysis, Cumulative Respiration, Labile C, and Decay Rate Data (continued)

Site	**Treatment**	**Rep**	**EC**	**pH**	**Na**	**OC**	**IC**	**TC**	**DOC**	**.33 bar**	**Cumulative respiration**	**Labile C**	**Decay Rate**
			dS m^{-1}		**---------------%---------------**				**mg L^{-1}**	**g g^{-1}**	**g CO2-C m^{-2}**	**g CO2-C**	
Non-Tile	Kmag 5.6	4	4.5	8.23	16.7	1.36	0.00	1.36	45.020	31.31	255.16	310.3	0.0413
Non-Tile	Kmag 11.2	1	5.59	8.27	14.9	1.34	0.00	1.34	45.326	33.00	216.22	218.4	0.0427
Non-Tile	Kmag 11.2	2	5.48	8.28	15	1.34	0.00	1.34	43.546	30.07	187.13	230.5	0.0313
Non-Tile	Kmag 11.2	3	5.58	8.3	15.2	1.33	0.00	1.33	46.475	31.81	236.01	190.3	0.0882
Non-Tile	Kmag 11.2	4	5.63	8.32	15	1.35	0.00	1.35	39.252	31.42	177.35	283.6	0.0214

Table C2. EGM-4 CO_2 Weekly Readings

Site	Day	Rep	EGM-4 Reading									
			Control	**FGDG 11.2**	**FGDG 33.6**	**FGDG 67.2**	**SL 11.2**	**SL 33.6**	**SL 67.2**	**Kmag 2.2**	**Kmag 5.6**	**Kmag 11.2**
			----------g CO_2-C m^{-2} hr^{-1}----------									
Tile	4	1	1.06	0.47	0.33	1.12	0.41	0.77	2.08	0.66	0.84	0.98
Tile	4	2	0.71	0.38	0.78	0.50	0.77	0.75	2.42	0.39	0.76	0.78
Tile	4	3	0.38	0.58	0.39	0.67	1.22	1.29	1.07	0.46	0.37	0.49
Tile	4	4	0.71	0.51	0.48	0.91	1.01	0.79	1.72	0.48	0.76	0.71
Tile	13	1	0.00	0.08	0.13	0.34	0.14	1.08	1.36	0.13	0.14	0.30
Tile	13	2	0.30	0.11	0.06	0.40	0.24	0.51	0.30	0.24	0.27	0.23
Tile	13	3	0.23	0.11	0.09	0.14	0.27	0.55	0.19	0.09	0.15	0.16
Tile	13	4	0.18	0.13	0.07	0.09	0.08	0.22	0.23	0.06	0.15	0.10
Tile	20	1	0.07	0.06	0.08	0.09	0.17	0.12	0.15	0.09	0.06	0.05
Tile	20	2	0.03	0.10	0.06	0.07	0.26	0.47	0.53	0.14	0.08	0.10
Tile	20	3	0.08	0.06	0.24	0.11	0.18	0.20	0.21	0.04	0.06	0.09
Tile	20	4	0.14	0.21	0.09	0.06	0.09	0.24	0.29	0.19	0.16	0.09
Tile	27	1	0.07	0.28	0.27	0.12	0.11	0.37	0.40	0.20	0.21	0.05
Tile	27	2	0.09	0.05	0.12	0.15	0.26	0.36	0.33	0.06	0.14	0.05
Tile	27	3	0.13	0.01	0.07	0.07	0.31	0.05	0.21	0.04	0.06	0.12
Tile	27	4	0.12	0.01	0.13	0.05	0.10	0.26	0.41	0.04	0.09	0.10
Tile	34	1	0.27	0.27	0.17	0.27	0.40	0.33	0.45	0.24	0.13	0.14
Tile	34	2	0.09	0.21	0.19	0.14	0.27	0.16	0.42	0.10	0.03	0.09
Tile	34	3	0.13	0.06	0.08	0.20	0.25	0.20	0.43	0.15	0.12	0.13
Tile	34	4	0.14	0.12	0.14	0.10	0.22	0.32	0.52	0.10	0.11	0.07
Tile	41	1	0.22	0.25	0.03	0.18	0.28	0.28	0.45	0.18	0.09	0.01
Tile	41	2	0.14	0.01	0.11	0.10	0.24	0.24	0.39	0.05	0.03	0.00
Tile	41	3	0.08	0.10	0.04	0.19	0.20	0.20	0.36	0.11	0.09	0.03
Tile	41	4	0.08	0.03	0.09	0.06	0.18	0.18	0.36	0.03	0.09	0.07

Table C2. EGM-4 CO_2 Weekly Readings (continued)

Site	**Day**	**Rep**	**EGM-4 Reading**									
			Control	**FGDG 11.2**	**FGDG 33.6**	**FGDG 67.2**	**SL 11.2**	**SL 33.6**	**SL 67.2**	**Kmag 2.2**	**Kmag 5.6**	**Kmag 11.2**
			g CO_2-C m^{-2} hr^{-1}									
Tile	48	1	0.19	0.07	0.17	0.08	0.15	0.26	0.40	0.06	0.13	0.13
Tile	48	2	0.16	0.17	0.12	0.12	0.26	0.26	0.36	0.06	0.06	0.04
Tile	48	3	0.15	0.16	0.09	0.11	0.27	0.23	0.43	0.08	0.08	0.12
Tile	48	4	0.13	0.08	0.16	0.15	0.13	0.30	0.44	0.13	0.13	0.07
Tile	55	1	0.13	0.19	0.20	0.23	0.33	0.43	0.15	0.03	0.17	0.03
Tile	55	2	0.02	0.18	0.13	0.14	0.28	0.29	0.37	0.03	0.08	0.00
Tile	55	3	0.13	0.10	0.09	0.03	0.25	0.21	0.39	0.10	0.09	0.09
Tile	55	4	0.08	0.08	0.10	0.12	0.01	0.17	0.34	0.03	0.06	0.01
Tile	62	1	0.15	0.09	0.21	0.28	0.25	0.48	0.45	0.15	0.11	0.12
Tile	62	2	0.13	0.19	0.14	0.06	0.15	0.31	0.27	0.09	0.09	0.05
Tile	62	3	0.09	0.09	0.13	0.13	0.12	0.12	0.35	0.04	0.03	0.03
Tile	62	4	0.05	0.10	0.11	0.14	0.17	0.31	0.35	0.10	0.00	0.02
Tile	69	1	0.11	0.08	0.18	0.12	0.28	0.18	0.29	0.09	0.07	0.09
Tile	69	2	0.06	0.05	0.08	0.08	0.23	0.17	0.26	0.02	0.05	0.04
Tile	69	3	0.11	0.08	0.11	0.02	0.10	0.17	0.27	0.07	0.05	0.02
Tile	69	4	0.07	0.02	0.09	0.04	0.04	0.08	0.36	0.11	0.02	0.12
Tile	76	1	0.25	0.19	0.11	0.11	0.24	0.35	0.31	0.13	0.12	0.09
Tile	76	2	0.00	0.13	0.12	0.14	0.25	0.17	0.29	0.09	0.08	0.08
Tile	76	3	0.13	0.08	0.03	0.13	0.21	0.25	0.36	0.00	0.06	0.03
Tile	76	4	0.08	0.03	0.06	0.10	0.16	0.20	0.25	0.01	0.04	0.05
Non-tile	4	1	1.2	1.5	1.28	2.23	2.22	2.68	3.45	1.51	1.29	1.35
Non-tile	4	2	1.31	1.49	1.25	1.90	1.97	2.04	2.57	1.75	1.12	1.04
Non-tile	4	3	1.51	1.58	1.45	1.56	1.89	2.07	2.73	1.63	1.37	1.59
Non-tile	4	4	0.99	1.21	1.07	1.23	1.07	2.02	3.95	1.94	1.65	1.01
Non-tile	13	1	0.7	0.6	0.61	1.15	1.13	1.47	1.74	0.84	0.51	0.51

Table C2. EGM-4 CO_2 Weekly Readings (continued)

Site	Day	Rep	EGM-4 Reading									
			Control	**FGDG 11.2**	**FGDG 33.6**	**FGDG 67.2**	**SL 11.2**	**SL 33.6**	**SL 67.2**	**Kmag 2.2**	**Kmag 5.6**	**Kmag 11.2**
			------------------------------g CO_2-C m^{-2} hr^{-1}------------------------------									
Non-tile	13	2	0.68	0.74	0.94	1.05	0.87	1.05	1.35	0.74	0.53	0.58
Non-tile	13	3	0.61	0.82	0.73	1.06	0.99	0.91	1.28	0.63	0.60	0.59
Non-tile	13	4	0.47	0.5	0.45	0.83	0.54	0.88	2.32	0.62	0.35	0.54
Non-tile	20	1	0.52	0.39	0.77	0.78	0.98	1.01	1.31	0.77	0.48	0.47
Non-tile	20	2	0.6	0.6	0.71	0.70	0.76	0.78	1.09	0.76	0.63	0.52
Non-tile	20	3	0.63	0.61	0.46	0.97	0.92	0.84	1.10	0.55	0.61	0.49
Non-tile	20	4	0.51	0.47	0.41	0.48	0.47	0.68	1.60	0.84	0.60	0.46
Non-tile	27	1	0.62	0.61	0.77	0.74	0.84	1.11	1.25	0.82	0.47	0.41
Non-tile	27	2	0.6	0.74	0.59	0.86	0.56	0.82	1.09	0.42	0.45	0.48
Non-tile	27	3	0.44	0.49	0.49	0.68	0.73	0.72	1.05	0.41	0.41	0.38
Non-tile	27	4	0.38	0.3	0.35	0.48	0.41	0.64	1.16	0.40	0.58	0.38
Non-tile	34	1	0.33	0.34	0.46	0.61	0.75	0.71	1.05	0.47	0.22	0.41
Non-tile	34	2	0.34	0.53	0.37	0.59	0.40	0.68	0.84	0.75	0.35	0.40
Non-tile	34	3	0.4	0.38	0.38	0.72	0.61	0.57	0.77	0.41	0.44	0.48
Non-tile	34	4	0.28	0.31	0.25	0.47	0.36	0.61	0.99	0.57	0.49	0.45
Non-tile	41	1	0.45	0.46	0.69	0.71	0.81	1.01	0.86	0.51	0.36	0.43
Non-tile	41	2	0.5	0.52	0.44	0.85	0.45	0.71	0.74	0.68	0.40	0.47
Non-tile	41	3	0.5	0.54	0.45	0.75	0.52	0.65	0.79	0.39	0.41	0.62
Non-tile	41	4	0.19	0.31	0.22	0.45	0.25	0.38	0.95	0.58	0.57	0.44
Non-tile	48	1	0.2	0.27	0.49	0.35	0.51	0.11	0.48	0.07	0.36	0.35
Non-tile	48	2	0.34	0.15	0.39	0.49	0.36	0.43	0.35	0.38	0.34	0.30
Non-tile	48	3	0.35	0.33	0.37	0.47	0.42	0.35	0.25	0.38	0.25	0.25
Non-tile	48	4	0.08	0.1	0.13	0.22	0.14	0.28	0.77	0.22	0.23	0.16
Non-tile	55	1	0.38	0.4	0.42	0.54	0.52	0.65	0.60	0.41	0.29	0.24
Non-tile	55	2	0.34	0.41	0.43	0.37	0.41	0.58	0.69	0.47	0.28	0.14

Table C2. EGM-4 CO_2 Weekly Readings (continued)

Site	Day	Rep	EGM-4 Reading									
			Control	**FGDG 11.2**	**FGDG 33.6**	**FGDG 67.2**	**SL 11.2**	**SL 33.6**	**SL 67.2**	**Kmag 2.2**	**Kmag 5.6**	**Kmag 11.2**
			----------	----------	----------	----------	g CO_2-C m^{-2} hr^{-1}	----------	----------	----------	----------	----------
Non-tile	55	3	0.34	0.39	0.34	0.50	0.39	0.38	0.56	0.33	0.46	0.28
Non-tile	55	4	0.25	0.19	0.21	0.42	0.20	0.30	0.87	0.30	0.36	0.02
Non-tile	62	1	0.36	0.45	0.42	0.49	0.52	0.47	0.32	0.10	0.27	0.32
Non-tile	62	2	0.41	0.33	0.30	0.58	0.27	0.52	0.52	0.50	0.28	0.29
Non-tile	62	3	0.17	0.36	0.44	0.46	0.29	0.58	0.63	0.45	0.47	0.36
Non-tile	62	4	0.10	0.17	0.12	0.38	0.18	0.48	0.98	0.34	0.44	0.06
Non-tile	69	1	0.41	0.46	0.27	0.46	0.56	0.32	0.00	0.25	0.25	0.20
Non-tile	69	2	0.33	0.32	0.21	0.40	0.25	0.40	0.42	-0.10	-0.10	-0.26
Non-tile	69	3	0.12	0.10	0.23	0.24	0.33	0.48	0.46	0.30	-0.26	0.00
Non-tile	69	4	0.16	0.21	0.14	0.17	0.15	-0.01	0.57	0.23	0.33	0.29
Non-tile	76	1	0.13	0.26	0.35	0.44	0.02	0.67	0.29	0.33	0.34	0.22
Non-tile	76	2	0.33	0.23	0.30	0.35	0.20	0.30	0.45	0.20	0.20	0.01
Non-tile	76	3	0.30	0.30	0.32	0.37	0.41	0.36	0.46	0.19	0.41	0.33
Non-tile	76	4	0.00	0.23	0.20	0.18	0.25	0.34	0.63	0.34	0.20	0.20

APPENDIX D. SAS CODE USED FOR SINGLE POOL NON-EXPONENTIAL FIRST-ORDER DECAY MODEL

```
Title Control;
data;
Input plot day CO2;
datalines;
1      4      6.93
1      34     1.80
1      41     1.45
1      48     1.23
1      55     0.87
1      69     0.72
;
Proc sort;
by plot;
proc nlin method=marquardt;
by plot;
parameters ka=0.0001 ca=100 to 1000 by 100;
model CO2= (ca*ka*exp(-ka*day));
der.ca=ka*exp(-ka*day);
der.ka=exp(-ka*day)*(ca-(ca*ka*day));
output out=fitexp p=fluxfit r=resid;
proc print;
run;
proc gplot data=fitexp;
by plot;
plot CO2*day fluxfit*day/overlay;
symbol1 v=circle c=black I=none;
symbol2 v=none c=black I=spline;
run;
```