**Improving Soil Health and Productivity of Sodic Soils**

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**Situation Statement:**

Approximately 10 percent (4.7 million acres) of agricultural land in North Dakota is considered to be sodic (J. Brennan, personal communication, NRCS North Dakota, 2008) and proves challenging for soybean producers all across the state. Sodicity is caused by an excess amount of sodium (Na) on the soil exchange sites, in the soil solution, or both, and creates unfavorable chemical and physical soil conditions (Shainberg and Letey, 1984; Valzano et al., 2001; DeSutter et al., 2015). As sodic soils are wetted and Na ions become hydrated, swelling causes a reduction in pore size making transfer and movement of water and air through the soil function slower (Essington, 2004). Dispersion can also occur forcing clay particles away from one another resulting in clogged soil pores that forms a restrictive barrier or seal (Seelig, 2000). 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; Levy et al., 1998; Nelson and Oades, 1998).

A typical sodic soil has a “Natric” horizon, meaning accumulation of clay and Na, which can be located at various depths within a soil profile. These soils are also variable across the landscape making them difficult to manage. Recent NDSU research has found that dispersion can occur at an %Na as low as 5 in northern Great Plains soils (He et al., 2015). There are three main requirements for management of sodic soils that include: (1) addition of calcium (Ca) or other flocculating cations, (2) downward moving high quality water, and (3) proper subsoil drainage. Calcium or potentially magnesium (Mg) is needed to replace Na on the soil exchange sites. Water is needed to dissolve the Ca source and to leach the Na, and lastly drainage is needed to remove the Na from the profile.

Another important step in sodic soil remediation is appropriate crop selection. Selecting a crop like alfalfa can provide benefits like increased macropores in both “shrink-swell” and compacted soils to allow for downward water flow and improved infiltration (Mitchell et al., 1995). The vigorous deep tap root of alfalfa will help penetrate the Natric horizon, providing a path for water and amendments to move downward making remediation more efficient. Alfalfa is also a perennial high water use crop that will lower the water table and reduce evaporation at the soil surface. This will prevent the upward movement and deposition of salts in the rooting zone caused by high water tables.

**Objectives:**

In this field study, the objectives were to:

1. Determine how flue-gas desulfurization gypsum (FGDG), sugar beet processing lime (spent lime), and potassium-magnesium sulfate (K-Mag) impact sodic soils at different rates of application under subsurface and surface drained systems, and
2. Determine how these treatments impact alfalfa yield and quality.
3. Determine how these treatments impact soil microbial activity.

These objectives are important to soybean producers because sodic soils often have low productivities, can often times be seen in patches, and are difficult to maneuver around with farm machinery and equipment. Therefore, a better understanding of (1) the effectiveness of amendments applied, (2) the removal or reduction of Na and root-zone salts by tile drainage and surface-only drainage, and (3) the ability for alfalfa to be grown as a cash crop in harsh soil conditions, all for the improvement of soil health and productivity of sodic soils is needed, and that (4) how these amendments influence soil microbial respiration has yet to be determined. This research will also provide valuable information for Extension programs to help educate farmers about management options for saline and sodic soils.

**Research Conducted:**

Field plots were established at two sites near Delamere, North Dakota in the spring of 2014. Subsurface drainage was installed at one site in the fall of 2013 and the other site is surface drained only. Both sites share the same soil map unit, an Aberdeen-Ryan silty clay loam, sandy substratum. When the soils were field characterized, the tiled site resembled the Aberdeen series and the non-tiled site resembled the Ryan series. Both of the soils have a “Natric” horizon but are located at different depths in the profile. The depth to the Na at the tiled site is deeper in the soil profile and is generally found in the 15-30 cm depth. The Na in the non-tiled site is high throughout the profile. The EC at the tiled site is very low at the surface but drastically increases with depth. The non-tiled site is high at the surface. The low EC at the tiled site could cause some dispersion issues if amendments are not applied to increase flocculation.

A random complete block design (RCBD) was used at each site. The sites were divided into four replications that consisted of 10, 20 x 20 ft plots. Each replication contained a control and nine treatments that included three amendments at three different rates. FGDG and spent lime were applied at 11.2, 33.6 and 67.2 Mg ha‑1 and K-Mag was applied at 2.2, 5.6, and 11.2 Mg ha‑1. Alfalfa was hand harvested once in August of 2014 (year of establishment), twice after June 30th 2015 and twice before June 30th 2016. Harvestings occurred at approximately pre- to early-bloom stage. 2016 data is still be computed and will not be reported in this Technical Summary. Soil cores were taken in the fall of 2014 and 2015 from each plot to a depth of four feet. Cores were dissected into 0-15, 15-30, 30-60, 60-91, and 91-122 cm samples, air dried, ground, and analyzed for %Na, EC, pH, and %calcium carbonate (CaCO3). For brevity, only the EC and Na results from the 0-15cm will be discussed.

A laboratory study was also conducted using soils from each site (0-15cm; tiled and non tiled) and each of the above-stated treatments. Soils were incubated for 76 days at 20% gravimetric water and microbial respiration determined approximately every seven days from which cumulative respiration, labile carbon (C), and labile C decay rates were calculated.

**Findings:**

*EC and %Na*

Overall, the EC1:1 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 1 and 2). Because of the much lower EC1:1 at the tiled site, a greater increase was observed in EC1:1 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 EC1:1 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 EC1:1 values from the different treatments were not significantly different than the control in either year. However, in 2014 the EC1:1 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 EC1:1 also increased but not for spent lime treatments.

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 3 and 4). 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 potential evapotranspiration exceeding precipitation causing further upward migration of Na from the parent material salts with the water table.

*Alfalfa*

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 1). 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 EC1:1 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 EC1:1 is greater than 2.5 dS m-1 may inhibit establishment and yields of alfalfa. Alfalfa quality was largely unaffected by the treatments and treatment differences (not shown) are likely the result of the time of harvest and the plant’s growth stage.

*Laboratory Study*

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 (Tables 2 and 3). 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.

**Summary:**

Many factors must be considered when the objective is to improve the productivity of sodic soils. First and foremost, there must be an understanding of the %Na and EC within the soil profile so that the amount of Ca needed can be calculated to replace the Na in the soil. Again the target values to reach for %Na and EC1:1 are 5 and 1.5 dS m‑1, respectively. The amendments and their rates of application did not impact yields and quality at the tiled site and only the high K-Mag significantly decreased yield at the non-tiled site compared to the control. In general, variability of soil across the treatments did not allow for detection of differences in %Na from the control but the high rate of FGDG numerically had the lowest values.

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Figure 1. 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 2. 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.



Figure 3. Percent sodium (%Na) 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 4. Percent sodium (%Na) 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.

Table 1. 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

Table 2. Tiled-site 0-15 cm soil respiration and soil analysis after 76 days of incubation.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Microbial Respiration** | | |  | **Microcosm Analysis** | | | | | | |
| **Cumulative Efflux** | **Labile C** | **Decay Rate** |  | **EC1:1** | **pH1:1** | **Na** | **IC†** | **OC‡** | **TC§** | **DOC¶** |
| Mg ha-1 | ------------g CO2-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 3. Non tiled soil respiration and soil analysis after 76 days of incubation.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Microbial Respiration** | | |  | **Microcosm Analysis** | | | | | | |
| **Cumulative Efflux** | **Labile C** | **Decay Rate** |  | **EC1:1** | **pH1:1** | **Na** | **IC†** | **OC‡** | **TC§** | **DOC¶** |
| Mg ha-1 | -----------g CO2-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