DETERMINING THE ECONOMIC RESPONSE OF SODIC SOILS TO REMEDIATION BY GYPSUM, ELEMENTAL SULFUR AND VERSALIME IN NORTHEAST NORTH DAKOTA ON TILED FIELDS

By

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INTRODUCTION:

Saline and sodic soils have been reported in North Dakota since the 1960s. NDSU Extension Bulletin No. 2 reported more than 1 million acres are affected by high salt levels, whereas, more than 2 million acres are said to have excessive levels of sodium (Salt Affected Problem Soils in North Dakota, Their Properties and Management by Gordon A. Johnsgard, reprinted in 1974). This is a result of high salt and sodium levels in the soil parent material and the underlying sodium-rich shale present in the bedrock below the soil sediments. Rising groundwater levels and resulting capillary rise of soil water leads to the accumulation of excessive soluble salts (salinity) and sodium (sodicity).

Saline soils will have excessive levels of soluble salts in the soil solution which are a combination of positively and negatively charged ions (for example, table salt; Na^+Cl^-). High levels of ions (positive and negative) from soluble salts restrict normal water uptake by plant roots, even when soils are visibly wet, resulting in drought-stressed plants ("osmotic effect").

Saline soils having higher levels of calcium (Ca^{2+}) based salts will have good structure. That happens as calcium (Ca^{2+}) ions encourage aggregation of soil particles called flocculation (clumping together), resulting in well-defined pores facilitating free water movement through the soil profile.

In contrast to saline soils, sodic soils are highly saturated with sodium ions (Na^+) at the soil cation exchange sites. High Na^+ levels compared to Ca^{2+} in combination with low salt levels can promote "soil dispersion," which is the opposite of flocculation. Soil dispersion causes the breakdown of soil aggregates, resulting in poor soil structure (low "tilth" qualities). Due to the poor soil structure, sodic soils have dense soil layers, resulting in very slow permeability of water through the soil profile. Due to poor soil structure, when wet, sodic soils will be gummy and may seem like they have "no bottom" to them, and when dry, they can be very hard.

OBJECTIVES:

Remediation of soil sodicity requires application of amendments that supply Ca^{2+} followed by salinity remediation practices of improving soil drainage and lowering the groundwater level. Ca^{2+} displaces Na^+ from the cation exchange sites and Na^+ moves into soil solution where it converts into a salt (Na_2SO_4) and leaches out with rainfall or irrigation.

An effective way to lower groundwater levels is to install a field tile drainage system. Since tiles are generally three to four feet below the surface, the efficiency of a tile drainage system depends upon the permeability of soil layers above the tiles. This requires analyzing soils for salts and Na^+. In case of high Na^+ levels, not adding Ca^{2+} can render tiling ineffective. That could be achieved by sampling the areas in question and getting the samples analyzed by a soil laboratory. For detailed information on sampling for salts and Na^+, please refer to the NDSU Publication: SF-1809; "Soil Testing Unproductive Areas". Another NDSU publication that provides detailed information regarding the suitability of soils for tiling is: SF-1617; "Evaluation of Soils for Suitability for Tile Drainage Performance".
Challenges for landowners considering tiling could be:

1. **If the Na^+ levels are high in the soils they would like to tile?**
2. **In case of high levels of Na^+, what should they do first, tile or apply the amendments?**

In July 2014, the Langdon Research Extension Center (LREC) tiled a field that had excessive levels of Na^+ and moderately high levels of soluble salts. This consisted of 12 research plots with three replications. In order to replicate field conditions, the project site was tiled in July 2014 prior to starting sodicity remediation by applying soil amendments that are suitable and easily available to northeast North Dakota growers. Soil amendments were applied one-year after tiling in July and August of 2015.

The following objectives were set in order to achieve research goals.

- Can tiling be successful on sodic or saline-sodic soils prior to starting sodicity remediation?
- Comparing the relationship between varying water table levels and resulting soil salt and Na^+ levels.
- Analyzing water samples from the lift station, upstream and downstream for human and livestock health.

TRIAL LOCATION AND SITE DESCRIPTION:

This trial site is located at the NDSU Langdon Research Extension Center, Langdon, North Dakota. As per web soil survey, soil series are Cavour-Cresbard and Hamerly-Cresbard loams.

TRIAL DESIGN AND PLOT SIZE:

Trial design is a randomized complete block. Each plot is 325 X 80 feet.

METHODOLOGY:

Soil Chemical Analysis

Four feet deep soil samples in 12" increments from each plot were collected in September 2014, directly after tiling. Using the same protocol, site was sampled again in June 2016 (two-year after tiling and one-year after applying the amendments) and in June 2017 (three years after tiling and two years after applying the amendments). Each sampling activity included 48 soil samples (12 plots x 4 depths = 48 samples). All samples were analyzed for Salts (Electrical Conductivity or EC) and sodium (Sodium Adsorption Ratio or SAR), pH, calcium carbonate equivalent (CCE), bicarbonate (HCO_3^-), chlorides (Cl^-), sulfates (SO_4^{2-}), saturation percentage, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) and nitrate-nitrogen (NO_3-N^-) for 0-4 feet depths. Soil phosphorus (P) and organic matter percent (O.M. %) were analyzed at the 0-2 feet depths. In addition, cation exchange capacity (CEC) was measured for the first foot.

Weekly Groundwater Level Measurements

Groundwater levels were measured on a weekly basis in 2015, 2016 and 2017 from May-October through the seven-foot deep observation wells installed in each plot in 2015.

Water Sample Analysis

Water samples were collected from the lift station, upstream and downstream in fall-2015 and May, July and September of 2016 and in May and August of 2017. The samples were analyzed by the ND Department of Health for Group 2 complete mineral chemistry, Group 7 trace metals and Group 30 nutrients.

Treatments and Replications

Soil amendment rates were calculated to bring the SAR (SAR-final) numbers to an acceptable level of 3 in the first foot. This was done by deducting three from the actual SAR numbers (SAR-initial). SAR-final values were converted into Exchangeable Sodium Percentage (ESP) by using the formula given in "Diagnosis and Improvement of Saline and Alkali Soils" (USDA Salinity Laboratory Staff, Agriculture Handbook No. 60, 1954, Page-26). Gypsum rates were then calculated by using a standard formula given in the same handbook (page-49). For each ton of 100% pure gypsum, 0.19 ton of 100% pure elemental sulfur was applied (Reclaiming Saline, Sodic, and Saline-Sodic Soils. University of California, ANR Publication 8519, August 2015). Considering the very low solubility of VersaLime, for each ton of 100% pure gypsum, three tons of VersaLime were applied. Differences in amendment purities were compensated by using the formula given in “Reclaiming Sodic and Saline/Sodic Soils” (Drought Tips Number 92-33, University of California Cooperative Extension, 1993).

The following treatments were applied in three replications.

i. Control.
ii. Full rate of 99.5% pure gypsum to lower soil SAR-final levels to 3.
iii. Full rate of VersaLime to lower the soil SAR-final levels to 3.
iv. Full rate of 90% pure elemental sulfur (S°) to lower the soil SAR-final levels to 3.

Details of amendment rates for each treatment and replication are in Table 1 below.

Table 1. Details of Amendment Rates for each Treatment.

Treatments and Replications	99.5% Gypsum tons/plot	90% Elemental Sulfur tons/plot	VersaLime tons/plot
R1T1	0	0	0
R1T2	4.47	0	0
R1T3	0	0	8.74
R1T4	0	2.10	0
R2T1	0	0	0
R2T2	7.25	0	0
R2T3	0	0	30.45
R2T4	0	0.61	0
R3T1	0	0	0
R3T2	10.67	0	0
R3T3	0	0	22.93
R3T4	0	2.16	0
Total	22.40	4.87	62.14

Note: Gypsum and elemental sulfur were applied on June 29th, whereas, VersaLime was applied on July 23, 2015. After spreading, all of the amendments were rototilled into the soil. Control plots were also rototilled for uniformity purposes. Control structures for all of the treatments were fully opened right after the incorporation of the amendments in order to simulate free drainage and achieve maximum leaching conditions.

RESULTS AND DISCUSSION:

This is a preliminary report as the data is still being analyzed. The findings below are based on the statistical analysis of the 2016 and 2017 soil salt, Na^+ and pH levels versus 2014 results by using SAS package 9.4 at 95% confidence interval. In addition, soil analysis results used for statistical analysis were averages of the zero to four feet depths of each plot (treatment).

<u>At the Time of Tiling (2014):</u>

At the time of tiling, all plots had moderately high salt levels with control plots having the lowest levels (EC mean = 7.39 dS/m) and gypsum plots having the highest levels (EC mean = 9.58 dS/m). The soil Na^+ levels in all of the plots were high to very high with control having the lowest levels (SAR mean = 12.58) and gypsum plots having the highest levels (SAR mean = 18.36). Soil pH of all plots were close to neutral. Details are in Table 2.

Table 2. The Treatment means of the Soil Salt, Na^+ and pH Levels at the Time of Tiling (2014).

Soil Property	2014 Treatment Means			
	Control	Gypsum	VersaLime	E-Sulfur
EC (dS/m)	7.39	9.58	9.19	8.91
SAR	12.58	18.36	16.33	16.58
pH	7.05	7.04	7.14	6.94

Two-years After Tiling and One-year After the Application of Soil Amendments (2016):

Statistically, there were no significant differences in the soil EC (salts), SAR (Na^+) and pH levels (Table 3) compared to the levels at the time of tiling.

Table 3. 2016 Statistical Data of the Soil Salt, Na^+ and pH Levels.

Soil Properties	Mean	C.V. %	LSD	F-value	P > F
EC (dS/m)	3.75	18.70	1.32	3.82	0.0576
SAR	16.45	27.65	8.57	3.04	0.0924
pH	7.90	0.88	0.13	0.48	0.7074

Based on the differences in treatment means, compared to 2014, soil salt levels decreased in 2016 in all plots irrespective of the treatment effects under improved drainage due to tiling. The largest decrease was observed in control plots, followed by gypsum, VersaLime and E-sulfur. This is logical as initially gypsum, VersaLime and E-sulfur reactions lead to higher salt levels. In addition, despite having the highest EC levels at the time of tiling, gypsum plots recorded the highest decrease in EC after the control plots. Soil Na^+ levels, however, increased in gypsum and E-sulfur plots by 17% and 10% respectively. In 2016, soil pH levels increased in all plots compared to 2014. The reason for higher soil pH levels in 2016 could be due to the higher soil moisture levels at the time of sampling in June 2016 when North Dakota Agriculture Weather Network (NDAWN) Langdon Station recorded a monthly total of 3.97" of rainfall. At the time of 2014 sampling in September, Langdon recorded a monthly total of 0.68" of rainfall. Detailed comparisons of treatment means are in Table 4.

Table 4. Comparison of 2016 and 2014 Treatment Means.

	Comparison of 2016 and 2014 Treatment Means			
Treatment	**Year**	**EC (dS/m)**	**SAR**	**pH**
Control	2016	2.59	10.72	7.87
	2014	7.39	12.58	7.05
	Difference	-4.80	-1.86	0.81
Gypsum	2016	3.98	21.51	7.91
	2014	9.584	18.36	7.04
	Difference	-5.59	3.15	0.86
VersaLime	2016	4.03	15.32	7.89
	2014	9.19	16.33	7.14
	Difference	-5.16	-1.01	0.75
E-Sulfur	2016	4.39	18.27	7.94
	2014	8.91	16.58	6.94
	Difference	-4.51	1.68	0.99

Three-years After Tiling and Two-years After the Application of Soil Amendments (2017):

In 2017, soil SAR levels (Na^+) were significantly lower in control plots versus gypsum and VersaLime plots. This may be a result of control plots having the lowest EC and SAR levels at the time of tiling (2014). No significant differences were found in soil EC (salts) and pH. Details are in Table 5.

Table 5. 2017 Statistical Data of the Soil Salt, Na^+ and pH Levels.

Soil Properties	Mean	C.V. %	LSD	F-value	P > F
EC (dS/m)	6.59	21.82	2.71	2.07	0.1829
SAR	15.15	15.14	4.32	5.88	0.0202
pH	7.92	1.62	0.24	0.49	0.6995

The comparisons of 2017 and 2014 treatment means showed a steady decrease in soil salt levels in 2017 as well. Like 2016, gypsum plots recorded highest decrease in EC after control plots. This could be due to the higher solubility and fast reacting nature of gypsum versus VersaLime and E-sulfur. Soil Na^+ levels decreased in control, gypsum and e-sulfur plots, whereas, an increase (SAR mean = 1.14) was observed in the VersaLime plots. Soil pH levels also increased in 2017 compared to 2014 in all plots. That may again be due to the higher soil moisture levels in June of 2017 when soil samples were taken as Langdon recorded 2.94" of rainfall during the month (Table 6).

Table 6. Comparison of 2017 and 2014 Treatment Means.

	Comparison of 2017 and 2014 Treatment Means			
Treatment	**Year**	**EC (dS/m)**	**SAR**	**pH**
Control	2017	4.81	10.77	7.90
	2014	7.39	12.58	7.05
	Difference	-2.58	-1.81	0.84
Gypsum	2017	7.01	17.64	7.95
	2014	9.58	18.36	7.04
	Difference	-2.56	-0.72	0.90
VersaLime	2017	7.37	17.48	7.99
	2014	9.19	16.33	7.14
	Difference	-1.82	1.14	0.85
E-Sulfur	2017	7.17	14.71	7.87
	2014	8.91	16.58	6.94
	Difference	-1.73	-1.86	0.93

Changes in Soil Salt and Sodium Levels in 2017 versus 2016:

Based on the differences in the treatment means, in 2017, soil salt levels increased in all plots versus 2016. This could be an effect of drier weather in 2017, which resulted in the accumulation of soluble salts in the first four feet depth instead of downward movement. In 2017, Langdon recorded 10.11" of rainfall with a Potential Evapotranspiration (PET) of 34.89" from May 1 to October 31. For the same period in 2016, Langdon recorded 23.11" of rainfall with a Potential Evapotranspiration of 31.47". Soil Na^+ levels increased in VersaLime plots in 2016, whereas, in 2017 increase was observed in VersaLime and control plots. Details are in Table 7.

Table 7. Comparison of 2017 and 2016 Treatment Means.

	Comparison of 2014 and 2017 Treatment Means			
Treatment	**Year**	**EC (dS/m)**	**SAR**	**pH**
Control	2017	4.81	10.77	7.90
	2016	2.59	10.72	7.87
	Difference	2.21	0.05	0.02
Gypsum	2017	7.01	17.64	7.95
	2016	3.98	21.51	7.91
	Difference	3.02	-3.87	0.03
VersaLime	2017	7.37	17.48	7.99
	2016	4.03	15.32	7.89
	Difference	3.33	2.16	0.09
E-Sulfur	2017	7.17	14.71	7.87
	2016	4.39	18.27	7.94
	Difference	2.77	-3.55	-0.06

Relationship between Groundwater Levels and the Varying Salt and Sodium Levels

The fluctuations in seasonal rainfall and resulting groundwater levels did affect soil salt levels. Largest decrease in EC levels were recorded in 2016 with shallower groundwater levels and higher seasonal rainfall (23.11”). In 2017, soil EC levels went up versus 2016, under lower groundwater levels and lower seasonal rainfall (10.11”). Overall, average individual groundwater levels in 2017 were 1.07 to 1.98 feet lower than 2016 (Table 8) with a rainfall shortfall of 13.0”. No effect of groundwater levels were recorded on SAR levels in 2015, 2016 and 2017 as gypsum plots had the highest means and control had the lowest means in all three years. The changes in soil pH were found to be consistent with soil moisture availability. Considering the four feet sampling depth, higher rainfall combined with shallower groundwater levels will result in higher soil moisture levels and high soil pH.

Table 8. Comparison of 2016 and 2017 Groundwater Level Treatment Means

Treatment	2015 Means	2016 Means	2017 Means
Control	4.44	3.78	4.98
Gypsum	4.53	3.49	5.20
VersaLime	4.96	4.09	5.75
E-Sulfur	3.99	3.55	5.11

Water Quality Draining from the Research Project Site for Human and Livestock Health

All minerals and nutrients affecting human and livestock health, were found to be within the acceptable limits in the samples coming out the Langdon REC Groundwater Management Research Project site.

CONCLUSION:

Based on four year’s data, soil salt levels consistently decreased in 2016 and 2017 compared to the levels at the time of tiling. However, sodium levels did increase in 45.83% of the individual soil samples in 2016 as well as in 2017. Increased sodium levels mean higher amendment costs and longer wait to achieve maximum productivity. Landowners considering tiling, should consider the following recommendations before installing an expensive tile system. That will save them money and ensure correct use of technology:

- Potential fields **“should be analyzed for salts and sodium”**.
- If sodicity is established, **“application of soil amendments should be considered before tiling”**.