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

Naeem Kalwar (Extension Soil Health Specialist)

INTRODUCTION

Saline and sodic soils have been reported in North Dakota since the 1960s. NDSU Extension Bulletin No. 2 reported that more than one million acres were affected by high salt levels, whereas, more than two million acres had excessive levels of sodicity (Salt Affected Problem Soils in North Dakota, Their Properties and Management by Gordon A. Johnsgard, reprinted in 1974). Another study by Brennan J., and M. Ulmer reported 5.8 million saline acres in North Dakota (Salinity in the Northern Great Plains, Natural Resources Conservation Service, Bismarck, N.D. 2010). That is 15% of the 39 million acres of cropland in North Dakota. This is a result of high salt and sodium (Na^+) levels in the soil parent material and the underlying sodium-rich shale present in the bedrock below the soil sediments. Rising groundwater depths and resulting capillary rise of soil water leads to the accumulation of excessive soluble salts (salinity) and Na^+ causing sodicity in the topsoil.

Saline soils will have excessive levels of soluble salts in the soil water, 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 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 Na^+ ions at the soil cation exchange sites (negative charges of clay and humus particles that attract positively charged chemical ions). 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 as if they have “no bottom” to them, and when dry, they can be very hard.

Note: if Na^+ is present as a salt, it will not cause dispersion as its positive charges will be neutralized by the negatively charged chemical ions such as sulfates (SO_4^{2-}) or chloride (Cl^-). However, high levels of Na^+ based salts in the soil water can result in sodicity due to the exchange of Na^+ from soil water to cation exchange sites.

OBJECTIVES

Remediation of soil sodicity requires application of amendments that add Ca^{2+} to the soil, followed by salinity remediation practices of improving soil drainage and lowering the groundwater depths. Ca^{2+} displaces Na^+ from the clay and humus particles (cation exchange sites) and Na^+ moves into soil water where it converts into a salt (Na_2SO_4) and leaches out with rain or irrigation water.

An effective way to lower groundwater depths 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^+ causing sodicity. In cases of high Na^+ levels causing sodicity, not adding Ca^{2+} can render tiling ineffective. Salinity and sodicity levels can be determined by sampling the areas in question and getting the samples analyzed by a soil laboratory for Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR). For detailed information on sampling and testing soils for salts and sodicity, 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. **What if soil sodicity levels are high in the fields they would like to tile?**
2. **In cases of high sodicity levels, 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 sodicity 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 in July and August of 2015, one year after tiling.

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 groundwater depths and resulting soil salt and sodicity 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 the USDA Web Soil Survey, soil series are a mix of Cavour-Cresbard and Hamerly-Cresbard loams.

TRIAL DESIGN AND PLOT SIZE

Trial design is randomized block. Each plot is 325 X 80 feet (0.6 acre).

METHODOLOGY

Soil Chemical Analysis

Four-foot deep soil samples in 12" increments were collected from each plot in September 2014, right after tiling. Using the same protocol, the site was sampled again in June 2016 (two years after tiling and one year after applying the amendments), in June 2017 (three years after tiling and two years after applying the amendments) and in June of 2018 (four years after tiling and three years after applying the amendments). Sampling depths were separated in 12-inch increments and each sampling activity included 48 soil samples (12 plots x 4 depths = 48 samples). All samples were analyzed for Electrical Conductivity or EC (salts), Sodium Adsorption Ratio or SAR (sodicity), pH, calcium carbonate equivalent or CCE, bicarbonates (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 zero to four-foot depths. Soil phosphorus (P) and organic matter percent (O.M. %) were analyzed for the 0-12 inch and 12-24 inch depths. In addition, cation exchange capacity (CEC) was analyzed for the first foot.

Weekly Groundwater Depth Measurements

Groundwater depths were measured on a weekly basis in 2015, 2016, 2017 and 2018 from May-October through the seven-foot deep observation wells, which were installed in each plot in May 2015.

Water Sample Analysis

Water samples were collected from the lift station, upstream and downstream in November of 2015, May, July and September of 2016, May and August of 2017, and June 2018. These 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.

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 23rd, 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

The findings below are based on the statistical analysis of the effects of soil amendments (treatments) and average annual growing-season groundwater depths on the 2014, 2016, 2017 and 2018 soil EC (salinity), SAR (sodicity) and pH levels measured at zero to four-foot depths by using SAS package 9.4 at 95% confidence interval. The 2014 results represent soil samples collected at the time when field was tiled, 2016 results represent samples collected two years after tiling and one year after the application of soil amendments, 2017 results are for samples collected three years after tiling and two years after applying the amendments and 2018 results are for the samples collected four years after tiling and three years after applying the amendments.

Soil EC, SAR and pH Levels at the Time of Tiling (2014)

At the time of tiling, all plots had moderately high EC levels with control plots having the lowest levels (mean = 7.39 dS/m) and gypsum plots having the highest levels (mean = 9.58 dS/m). The soil SAR levels in all of the plots were high to very high with control plots having the lowest levels (mean = 12.58) and gypsum plots having the highest levels (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 EC, SAR 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

Effect of Soil Amendments on EC, SAR and pH Levels

Differences in Soil EC Levels

Statistically, there were significant differences in the annual soil EC levels among treatments and between replications (Table 3) compared to the EC levels at the time of tiling (2014).

Table 3. Statistical Differences in Soil EC (dS/m) Levels.

Source	Mean Square	P > F
Year	202.87	<.0001
Treatment	43.48	<.0001
Replication	40.91	<.0001
Soil Depths	8.50	0.1584
Year vs Treatment	1.11	0.9799
Treatment vs Soil Depths	2.27	0.8924
Year vs Treatment vs Soil Depths	1.12	1.0000

The 2016, 2017 and 2018 soil EC levels were significantly lower than 2014. However, EC levels increased in 2017 and 2018 significantly compared to 2016 due to drier weather and resulting capillary rise (wicking up) of soil water. In addition, soil EC levels of gypsum, E-Sulfur (elemental sulfur) and VersaLime treatments were significantly higher than the control treatments. There were no significant differences among rest of the treatments. In terms of subsurface salinity, EC levels in the 12-24 inch depths remained significantly higher than the EC levels in 36-48 inch depths. Overall, highest EC levels were measured in 12-24 inch depths, followed by 24-36 inch, 0-12 inch and 36-48 inch depths. Details are in Table 4.

Table 4. Soil EC (dS/m) Level Differences between Years, Treatments and Soil Depths.

Annual Means	
2014	8.77
2016	3.75
2017	6.59
2018	6.24
Treatment Means	
Control	4.92
E-Sulfur	6.74
Gypsum	6.77
VersaLime	6.93
Means for Soil Depths	
0-12 inch	6.17
12-24 inch	6.85
24-36 inch	6.46
36-48 inch	5.87

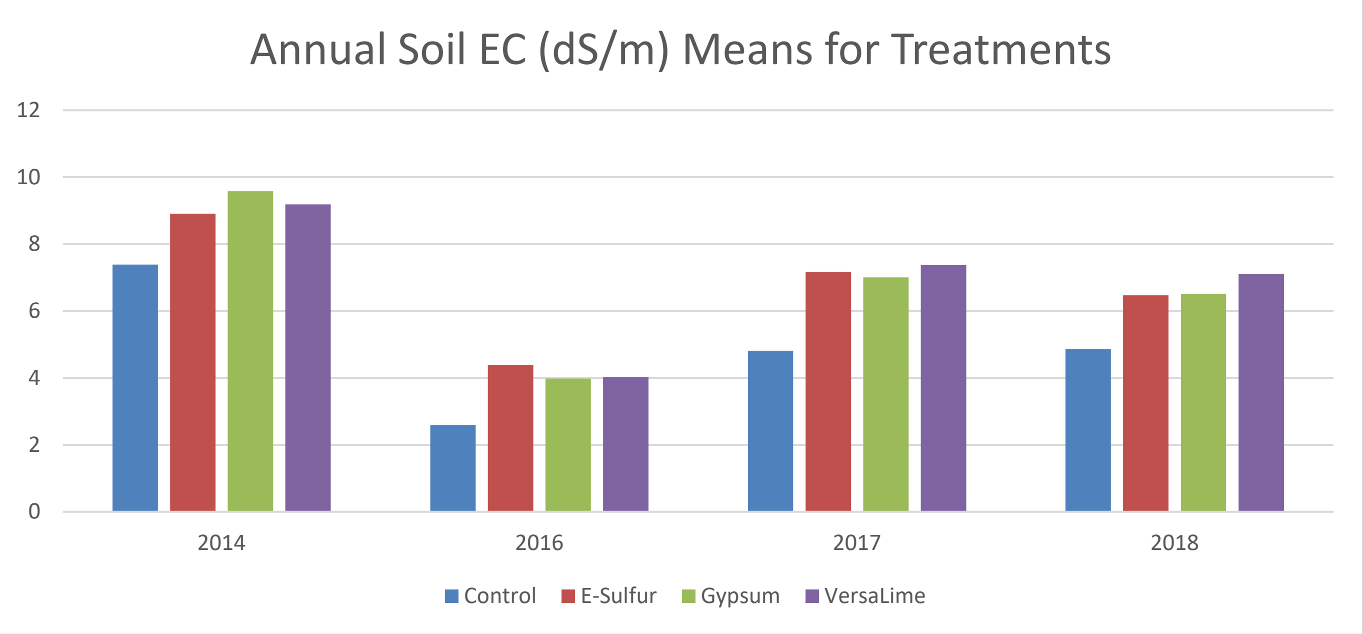
Based on the differences in the annual means of soil EC levels (Table 5), in 2016, EC levels dropped significantly compared to 2014 despite higher rainfall and shallower average annual growing-season groundwater depths. In 2017 and 2018, EC levels remained lower than 2014, however, compared to 2016, EC levels increased despite lower average annual growing-season groundwater depths due to drier weather. That could be attributed to the increased capillary rise of soil water due to increased evapotranspiration. In 2018, EC levels remained more or less the same like 2017.

Table 5. Annual Differences in the Means of Soil EC (dS/m) Levels among Treatments.

	Least Square Means			
Year	**Control**	**E-Sulfur**	**Gypsum**	**VersaLime**
2016	2.59	4.39	3.98	4.03
2014	7.39	8.91	9.58	9.19
Difference	-4.80	-4.52	-5.60	-5.16
2017	4.81	7.17	7.01	7.37
2014	7.39	8.91	9.58	9.19
Difference	-2.58	-1.74	-2.57	-1.82
2018	4.86	6.47	6.52	7.11
2014	7.39	8.91	9.58	9.19
Difference	-2.53	-2.44	-3.06	-2.08
2017	4.81	7.17	7.01	7.37
2016	2.59	4.39	3.98	4.03
Difference	2.22	2.78	3.03	3.34
2018	4.86	6.47	6.52	7.11
2016	2.59	4.39	3.98	4.03
Difference	2.27	2.08	2.54	3.08
2018	4.86	6.47	6.52	7.11
2017	4.81	7.17	7.01	7.37
Difference	0.05	-0.70	-0.49	-0.26

The chart below (Figure 1) has the annual soil EC means for the four treatments.

Figure 1. Annual Means of Soil EC (dS/m) Levels for all Four Treatments.



Differences in Soil SAR Levels

Statistically, there were significant differences in the annual soil SAR (sodicity) levels among treatments and soil depths (Table 6) compared to the levels at the time of tiling (2014).

Table 6. Statistical Differences in Soil SAR Levels.

Source	Mean Square	P > F
Year	119.38	0.0074
Treatment	370.94	<.0001
Replication	9.23	0.7244
Soil Depths	456.08	<.0001
Year vs Treatment	39.54	0.2018
Treatment vs Soil Depths	20.54	0.6901
Year vs Treatment vs Soil Depths	17.13	0.9611

In 2018, soil SAR levels increased significantly versus the rest of the years. The soil SAR levels of control treatments remained significantly lower than the rest of the treatments. In addition, SAR levels in the gypsum treatments remained significantly higher than the rest of the treatments. The 0-12 and 12-24 inch soil depths had significantly lower SAR levels that the 24-36 and 36-48 inch depths. Overall, soil SAR levels increased with soil depths. Details are in Table 7.

Table 7. Soil SAR Level Differences between Years, Treatments and Soil Depths.

Annual Means	
2014	15.96
2016	16.45
2017	15.15
2018	18.82
Treatment Means	
Control	13.00
E-Sulfur	16.88
Gypsum	19.79
VersaLime	16.72
Means for Soil Depths	
0-12 inch	13.69
12-24 inch	14.78
24-36 inch	17.28
36-48 inch	20.63

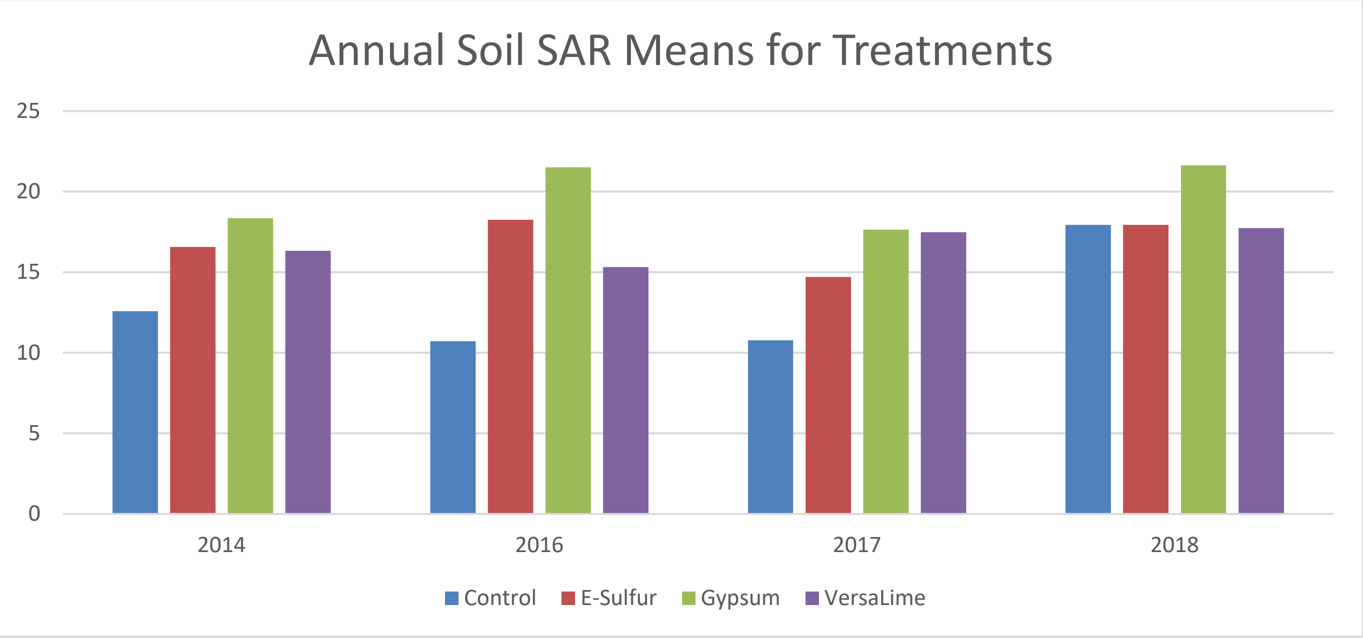
Based on the differences in the annual means of soil SAR levels (Table 8), in 2018 SAR levels increased in all treatments, notably in control versus 2014, 2016 and 2017. Whereas, in 2016 and 2017, SAR levels fluctuated irrespective of the treatments.

Table 8. Annual Differences in the Means of Soil SAR (sodicity) Levels among Treatments.

	Means			
Year	**Control**	**E-Sulfur**	**Gypsum**	**VersaLime**
2016	10.72	18.26	21.51	15.32
2014	12.58	16.58	18.36	16.33
Difference	-1.86	1.68	3.15	-1.01
2017	10.77	14.71	17.64	17.48
2014	12.58	16.58	18.36	16.33
Difference	-1.81	-1.87	-0.72	1.15
2018	17.95	17.95	21.64	17.75
2014	12.58	16.58	18.36	16.33
Difference	5.37	1.37	3.28	1.42
2017	10.77	14.71	17.64	17.48
2016	10.72	18.26	21.51	15.32
Difference	0.05	-3.55	-3.87	2.16
2018	17.95	17.95	21.64	17.75
2016	10.72	18.26	21.51	15.32
Difference	7.23	-0.31	0.13	2.43
2018	17.95	17.95	21.64	17.75
2017	10.77	14.71	17.64	17.48
Difference	7.18	3.24	4.00	0.27

The chart below (Figure 2) has the annual soil SAR means for the four treatments.

Figure 2. Annual Means of Soil SAR Levels for all Four Treatments.



Differences in Soil pH Levels

Statistically, there were significant differences in the annual soil pH levels (Table 9). In addition, pH levels significantly differed for soil depths.

Table 9. Statistical Differences in Soil pH Levels.

Source	Mean Square	P > F
Year	9.82	<.0001
Treatment	0.07	0.3206
Replication	0.14	0.1240
Soil Depths	1.65	<.0001
Year vs Treatment	0.03	0.8555
Treatment vs Soil Depths	0.04	0.6892
Year vs Treatment vs Soil Depths	0.03	0.9809

The 2016, 2017 and 2018 soil pH levels were significantly higher than the pH levels in 2014. However, there were no significant differences in soil pH during 2016, 2017 and 2018. The lower soil pH levels in 2014 can be attributed to the lower soil moisture levels at the time of sampling (September 2014) compared to rest of the years. There were no significant differences in soil pH among the four treatments. Soil pH in the 36-48 inch depth remained significantly higher than the 0-12 and 12-24 inch depths. Overall, soil pH levels increased with soil depths due to the increased soil moisture levels. Details are in Table 10.

Table 10. Annual Differences in Soil pH Levels.

Annual Means	
2014	7.04
2016	7.90
2017	7.92
2018	8.01
Treatment Means	
Control	7.72
E-Sulfur	7.66
Gypsum	7.74
VersaLime	7.75
Means for Soil Depths	
0-12 inch	7.48
12-24 inch	7.67
24-36 inch	7.81
36-48 inch	7.91

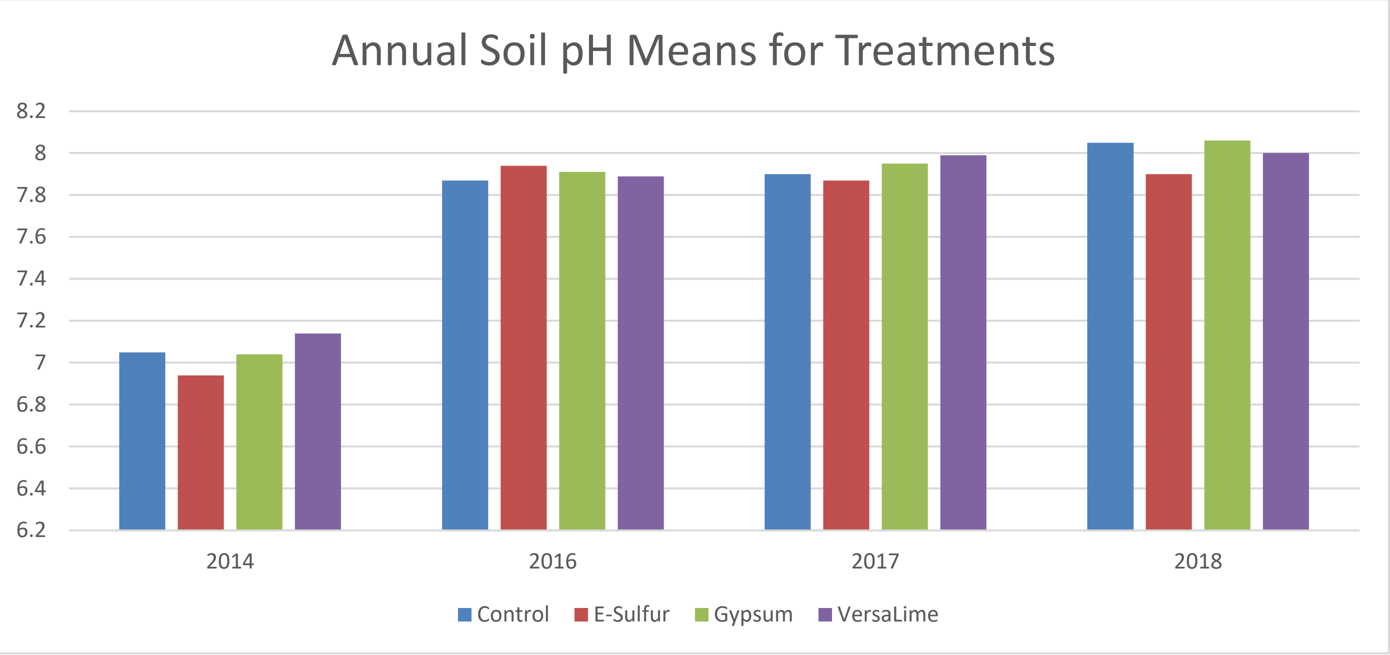
Based on the differences in the annual means of soil pH (Table 11), 2014 pH levels were lower than the rest of the years due to the lower soil moisture conditions at the time of sampling (September 2014). In 2016, 2017 and 2018, soil samples were collected in June when moisture levels were higher.

Table 11. Annual Differences in the Means of Soil pH Levels among Treatments.

	Means			
Year	**Control**	**E-Sulfur**	**Gypsum**	**VersaLime**
2016	7.87	7.94	7.91	7.89
2014	7.05	6.94	7.04	7.14
Difference	0.82	1.00	0.87	0.75
2017	7.90	7.87	7.95	7.99
2014	7.05	6.94	7.04	7.14
Difference	0.85	0.93	0.91	0.85
2018	8.05	7.90	8.06	8.00
2014	7.05	6.94	7.04	7.14
Difference	1.00	0.96	1.02	0.86
2017	7.90	7.87	7.95	7.99
2016	7.87	7.94	7.91	7.89
Difference	0.03	-0.07	0.04	0.10
2018	8.05	7.90	8.06	8.00
2016	7.87	7.94	7.91	7.89
Difference	0.18	-0.04	0.15	0.11
2018	8.05	7.90	8.06	8.00
2017	7.90	7.87	7.95	7.99
Difference	0.15	0.03	0.11	0.01

The chart below has the annual soil pH means for the four treatments (Figure 3).

Figure 3. Annual Means of Soil pH Levels for all Four Treatments.



Effect of Average Annual Growing-Season Groundwater Depths on EC, SAR and pH Levels

For statistical analysis, 2016, 2017 and 2018 average annual growing-season groundwater depths were measured at zero to seven foot depths. However, since observation wells were installed in 2015, Table 12 contains differences between 2015, 2016, 2017 and 2018 average annual growing-season groundwater depths. Based on the data in Table 12, 2016 groundwater depths were shallower than the 2015, 2017 and 2018 depths. The lowest average annual growing-season groundwater depths were recorded in 2018 groundwater.

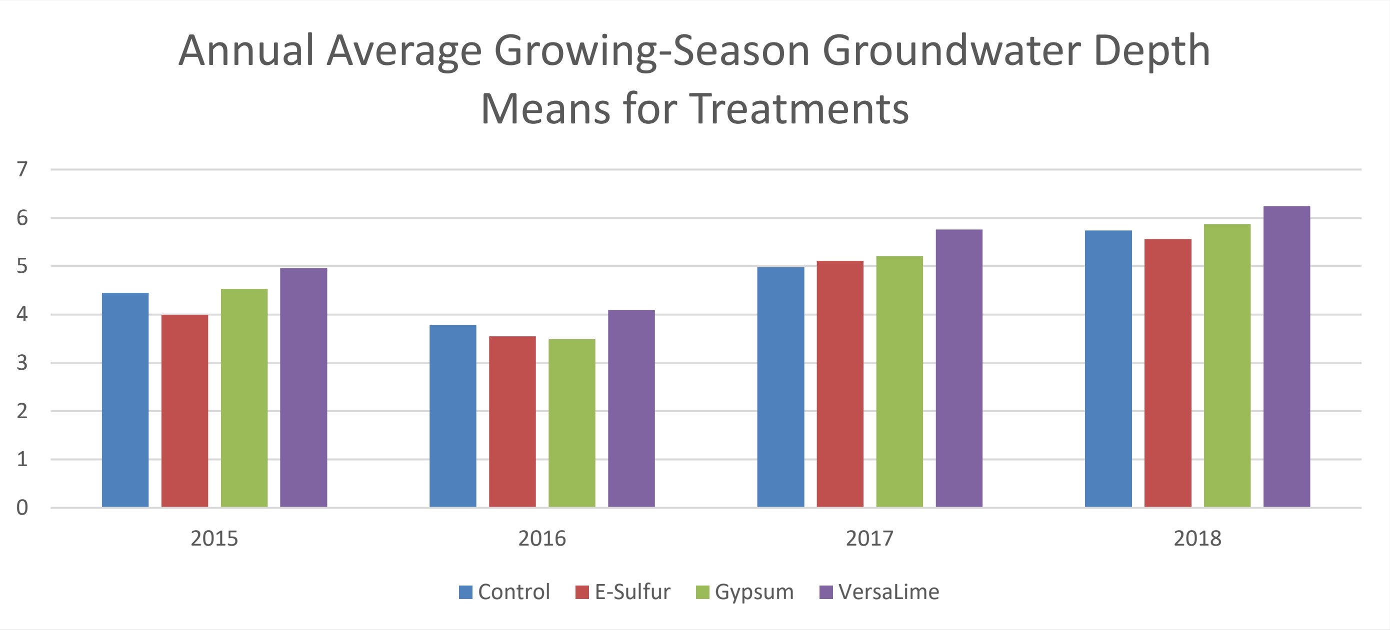
Table 12. Average Annual Growing-Season Groundwater Depth Differences among Treatments in feet.

	Average Annual Growing-Season Groundwater Depths in feet			
Year	**Control**	**E-Sulfur**	**Gypsum**	**VersaLime**
2015	4.45	3.99	4.53	4.96
2016	3.78	3.55	3.49	4.09
Difference	0.67	0.44	1.04	0.87
2015	4.45	3.99	4.53	4.96
2017	4.98	5.11	5.21	5.76
Difference	-0.53	-1.12	-0.68	-0.80
2015	4.45	3.99	4.53	4.96
2018	5.74	5.56	5.87	6.24
Difference	-1.29	-1.57	-1.34	-1.28
2016	3.78	3.55	3.49	4.09
2017	4.98	5.11	5.21	5.76
Difference	-1.20	-1.56	-1.72	-1.67
2016	3.78	3.55	3.49	4.09

2018	5.74	5.56	5.87	6.24
Difference	-1.96	-2.01	-2.38	-2.15
2017	4.98	5.11	5.21	5.76
2018	5.74	5.56	5.87	6.24
Difference	-0.76	-0.45	-0.66	-0.48

Figure 4 has the average annual growing-season groundwater depths for the four treatments in feet.

Figure 4. Annual Means of Average Growing-Season Groundwater Depths for all Four Treatments in feet.



This fluctuation in the groundwater depths is also reflective of a very wet 2016 versus drier weather in 2017 and 2018 (Table 13).

Table 13. Four-year Rainfall versus Evapotranspiration Data of the NDSU Langdon Research Extension Center, North Dakota Agricultural Weather Network (NDAWN) Station.

Time Period	Total Potential Evapotranspiration (Penman)	Total Rainfall (inches)	Total Normal Rainfall (inches)
April 1 – Oct. 31, 2015	41.37”	18.46”	16.68”
April 1 – Oct. 31, 2016	35.29”	24.91”	
April 1 – Oct. 31, 2017	38.72”	10.24”	
April 1 – Oct. 31, 2018	38.28”	11.41”	

Differences in Soil EC Levels

Statistically, there were significant differences in the soil EC levels due to the changes in the average annual growing-season groundwater depths (Table 14).

Table 14. Statistical Differences in Soil EC (dS/m) Levels.

Source	**Mean Square**	**F-value**	**P > F**
Replication	4.77	1.22	0.2994
Year	23.14	5.89	0.0035
Groundwater Depth	234.457	59.72	<.0001

The 2016 soil EC levels were significantly lower than the 2017 EC levels. In 2017, EC levels increased due to drier weather (Table 13) resulting in capillary rise despite lower groundwater depths.

Differences in Soil SAR Levels

Statistically, there were no significant effects on soil SAR levels (Table 15) due to the changes in the average annual growing-season groundwater depths. However, 2018 SAR levels were significantly higher than the SAR levels at the time of tiling (2014).

Table 15. Statistical Differences in Soil SAR Levels.

Source	Mean Square	F-value	P > F
Replication	73.99	1.90	0.1537
Year	180.99	4.64	0.0112
Groundwater Depth	4.54	0.12	0.7331

There were no significant differences in the 2016, 2017 and 2018 soil SAR levels due to the changes in the average annual growing-season groundwater depths.

Differences in Soil pH Levels

Statistically, there were no significant effects of the average annual growing-season groundwater depths on soil pH levels (Table 16).

Table 16. Statistical Differences in Soil pH Levels.

Source	Mean Square	F-value	P > F
Replication	0.07	1.10	0.3363
Year	0.05	0.88	0.4165
Groundwater Depth	0.18	2.77	0.0981

In addition, there were no significant differences in the 2016, 2017 and 2018 soil pH levels due to the changes in the average annual growing-season groundwater depths.

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

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

CONCLUSION

Based on the four-year data, changes in soil EC (salinity) levels were consistent with the fluctuations in the annual rainfall and evapotranspiration data. Tiling the saline-sodic site alone did not seem to make a big difference as the highest annual decrease in EC levels was recorded in 2016 with shallower groundwater levels and higher seasonal rainfall (24.91”). Drier weather in 2017 and 2018, resulted in an increase in EC levels despite lower annual average growing-season groundwater depths. That could be due to the absence of a decent amount of rain to push the salts deeper and increased evapotranspiration resulting in capillary rise of soil water. Consistently higher SAR (sodicity) levels could also be contributing to the slower leaching of excessive salts from the top four feet of soil due to the poor permeability.

Soil sodicity levels remained inconsistent three years after applying the amendments and the site being tiled for four years. This could be due to the absence of a decent amount of rain to dissolve the amendments and create the desired chemical reaction for the conversion of sodicity into salinity.

The changes in soil pH were found to be consistent with soil moisture availability at the time of sampling. No effects of soil amendments were observed on pH three years after application.

Producers and landowners, who are thinking about tiling entire fields, may want to consider looking at the following points before making a final decision:

- Under drier weather, **"tiling may not be necessary as average annual growing-season groundwater depths may lower naturally."**
- If the potential fields have unproductive or marginal areas, **"they should be sampled three to four feet deep and analyzed for EC (salinity) and SAR (sodicity) levels."**
- Tiling saline fields alone under drier weather **"will not lower salinity as moving the excess salts into deeper depths will also require a decent amount of rain."**
- Under drier weather, **"salinity levels can increase despite tiling due to the increased evaporation and resulting capillary rise of soil water."**
- Tiling sodic or saline-sodic fields alone **"will not remediate sodicity and will require application of amendments."**
- If sodicity problems are established, **"amendments should always be applied before tiling in order for the amendments to convert sodicity into salinity."**
- Conversion of sodicity into salinity by amendments **"may take years, especially under drier weather."**