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

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Figure 1. The NDSU Langdon Research Extension Center Groundwater Management Research Project Lift Station.

This research report is an extension of an ongoing long-term research trial on a tiled saline-sodic site. The main objectives of the trial are:

- Does soil sodicity negatively affect tile drainage performance?
- Will tiling lower soil salinity under wet and dry weather conditions?
- Does the drained water from a tiled field increase salinity and sodicity levels of the surface water resources?

This abbreviated report only summarizes annual soil Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), pH, bulk density and key drained water quality analysis results. If you would like to access the information about the trial background, objectives, location, site, description, design, methodology and complete set of data collected annually, please contact the NDSU Langdon Research Extension Center:

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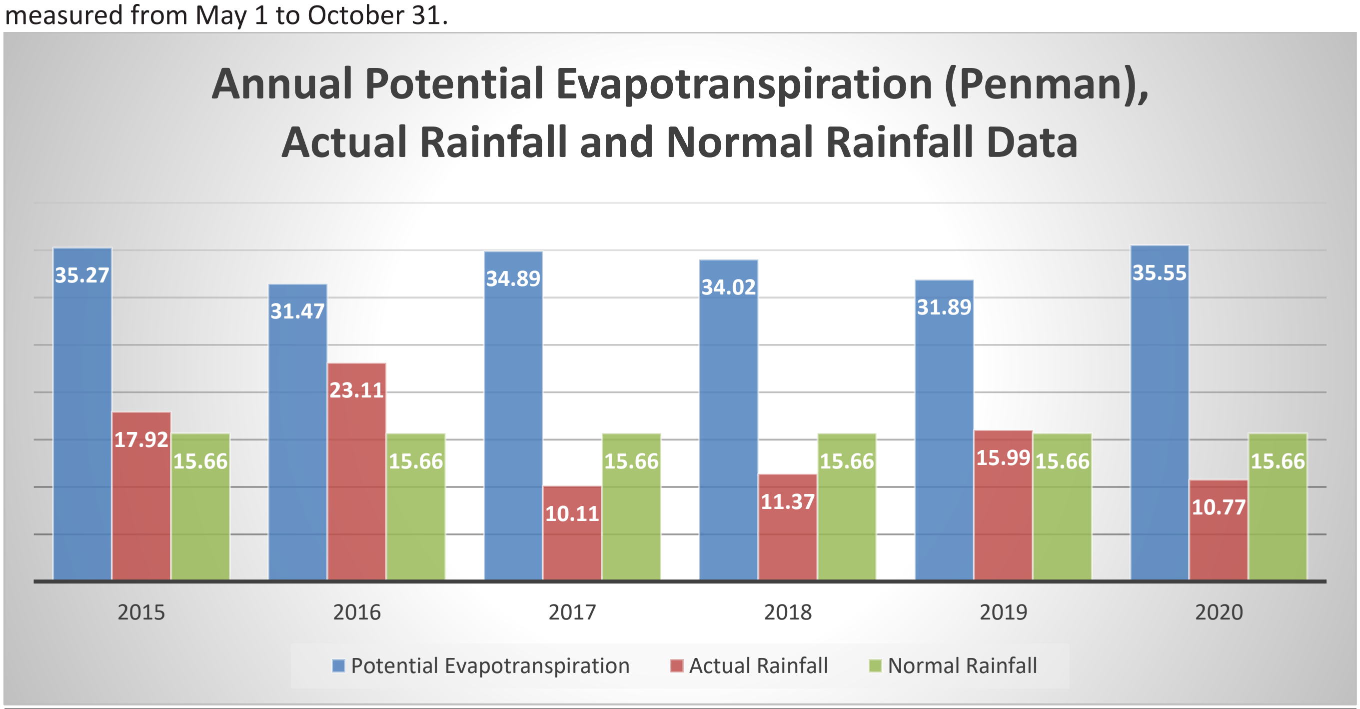
RESULTS AND DISCUSSION

The findings below are based on the statistical analysis of soil electrical conductivity (EC), sodium adsorption ratio (SAR), pH and bulk density. In addition, included are the results of conductivity (mmhos/cm), dissolved solids (mg/L), SAR and pH of the water quality analysis. This was done to measure the differences in these properties at the time of tiling compared to after applying the soil amendments (treatments). In addition, effects of annual growing-season rainfall, resulting average annual growing-season groundwater depths and potential evapotranspiration (Penman) were measured from May to October on a weekly basis and noted for any changes in these properties. Water quality analysis results are also presented to determine if water drained from the tiled field is adding more salts and sodicity to the surface water resources. The treatment means of EC, SAR and pH represent 2014, 2016, 2017, 2018, 2019 and 2020 results of three replications for the zero to four-foot soil depths. The treatment means of groundwater depths represent 2015 to 2020 results of three replications measured for zero to seven and a half-foot soil depths. Water quality analysis results represent 2015 to 2020 water samples that were collected from the tile drainage lift station as well as upstream and downstream of the lift station from the surface water drainage ditch in which tile drainage water has been draining. These water samples were collected one to three times a year depending upon the weather.

Annual Changes in Weather and Soil Groundwater Depths

Changes in soil chemical properties are also greatly influenced by the fluctuations in the weather such as annual evapotranspiration and rainfall (Figure 2), and resulting groundwater depths and capillary rise of soil water.

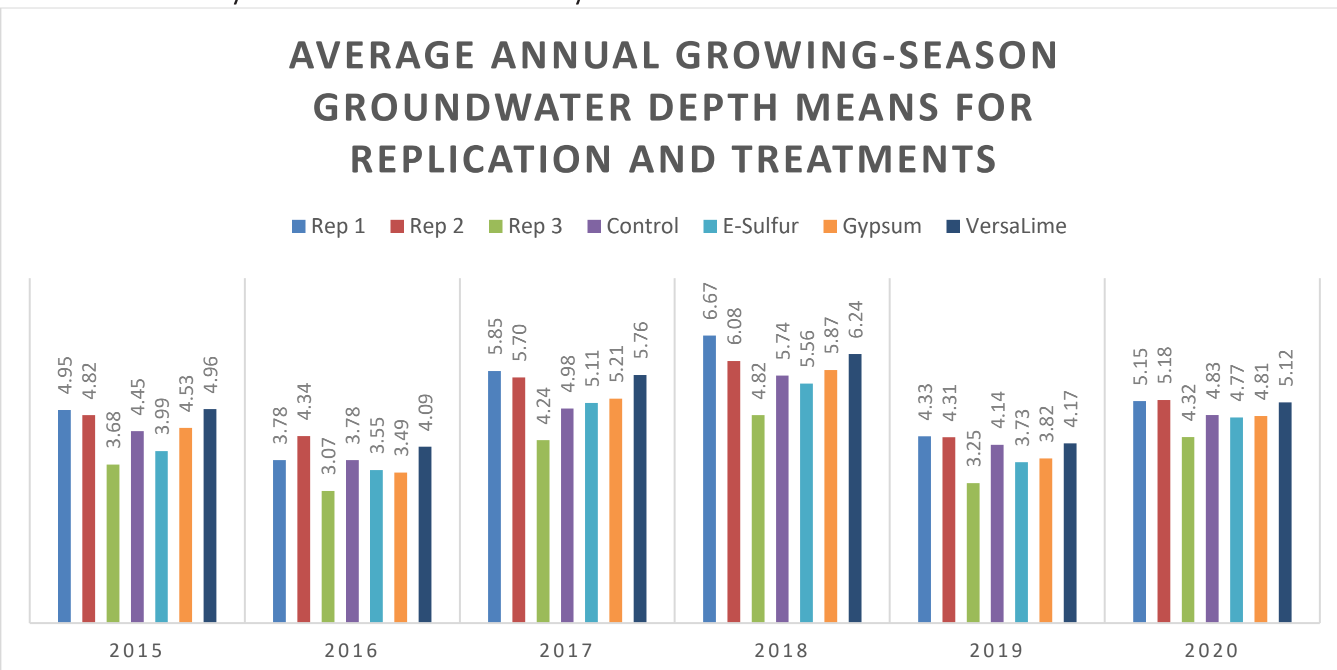
Figure 2. Annual growing-season potential evapotranspiration (Penman), actual rainfall and normal rainfall in inches measured from May 1 to October 31.



A bigger gap between evapotranspiration and rainfall means increased capillary rise of soil water, less leaching of soluble salts and slower dissolution of soil amendments. A narrower gap between these two could result in shallower groundwater depths, however, under good soil water infiltration and improved drainage, not only excess salts can be moved out of the fields but soil amendments can also produce favorable results. In addition, a narrower gap between evapotranspiration and rainfall will result in reduced capillary rise of soil water (wicking up). In 2016 on the tiled site, the gap between evapotranspiration and rainfall was narrow and the infiltration was still good as higher levels of soluble salts were neutralizing the dispersion caused by sodicity. This resulted in the highest decrease in soil salt levels since the site has been tiled in 2014. In 2017, there was a significant increase in soil salt levels compared to 2016, which could be due to an increase in the capillary rise of soil water due to the greater differences between annual evapotranspiration and rainfall. That trend continued in 2018, early part of 2019 and 2020 due to the drier weather.

Figure 3 below has the average annual growing-season groundwater depth means for replications and treatments for 2015 to 2020. These means of groundwater depths represent actual annual measurements of groundwater depths measured from May 1 to October 31 on a weekly basis.

Figure 3. Annual means of average growing-season groundwater depths for replications and treatments in feet measured from May 1 to October 31 on a weekly basis.



Note: In 2015, groundwater depths were only measured from mid-June to the end of October.

The 2016 groundwater depths were shallower than the depths in 2015, 2017, 2018, 2019 and 2020, whereas, the 2018 groundwater depths were the deepest versus the other years. Replication 3 had significantly shallower average annual growing-season groundwater depths compared to replications 1 and 2 during all years.

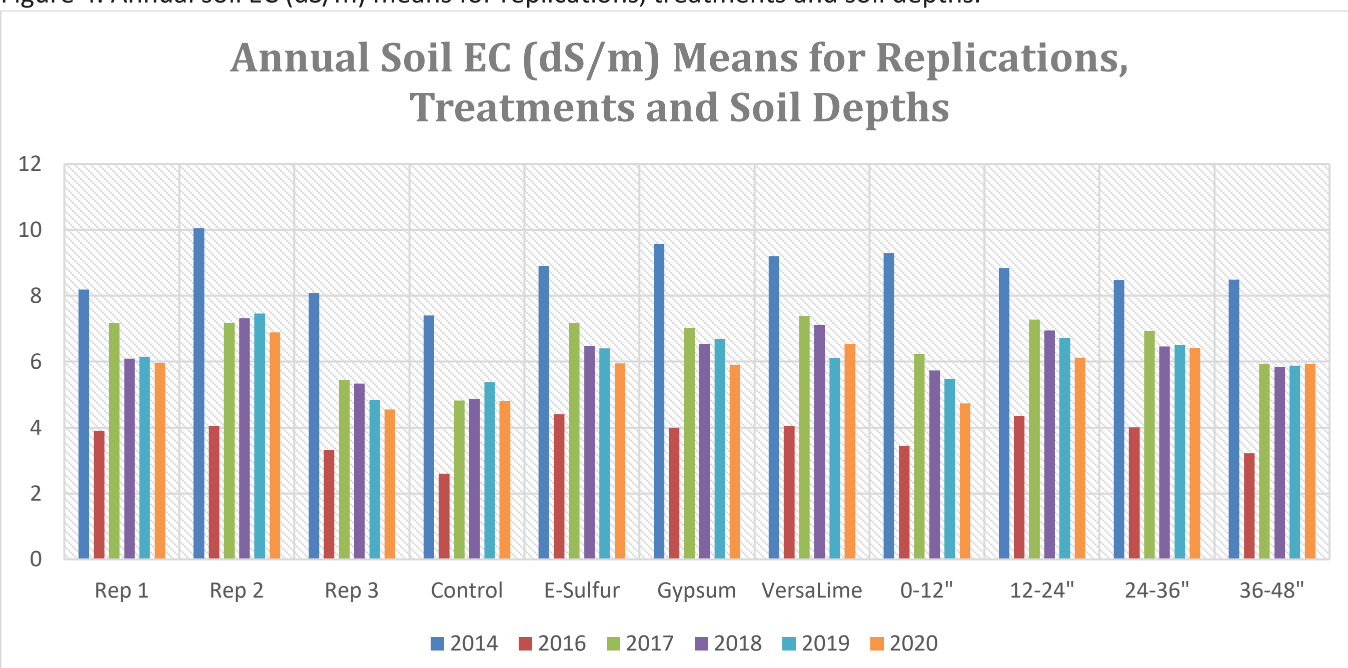
These fluctuations in groundwater depths are also reflective of a very wet 2016 versus drier weather in 2017 and 2018. In 2019, weather was dry until July 30th. After which, it started getting wet. The NDSU Langdon Research Extension Center, North Dakota Agricultural Weather Network (NDAWN) Station recorded 5.88 inches of rainfall from May 1st to July 30th in 2019 versus a normal of 9.71 inches. The total potential evapotranspiration (Penman) for the same period was 21.44 inches. The same station recorded 9.74 inches of rain versus a normal of 4.76 inches from July 31st to October 5th, 2019. The total potential evapotranspiration (Penman) for the same period was 9.04 inches. On July 31st, 0.77 inches was recorded and in August of 2019, 2.48 inches of rain were recorded versus a normal of 2.57 inches. September 2019 was the wettest month of the year and 5.87 inches of rain were recorded versus a normal of 1.81 inches. Overall, most of the early growing-season was dry, whereas, fall was very wet which also created harvest issues. The 2020 total potential evapotranspiration (Penman) and actual rainfall numbers were similar to the 2017 numbers.

Differences in Soil Electrical Conductivity (Salinity) Levels

Soil EC levels have been directly related to the annual growing-season rainfall and resulting moisture levels in the topsoil. A narrower gap between annual total potential evapotranspiration and rain means more leaching of salts and less capillary rise of soil water, whereas, a wider gap indicates less leaching and increased capillary rise. This is evident from the significant decrease in 2016 EC levels despite shallow average annual growing-season groundwater depths due to excess rainfall and improved drainage under tiling. Electrical conductivity spiked in 2017 and that trend continued in 2018, 2019 (until July 30, 2019) and 2020 despite average annual growing-season groundwater depths being deeper than the depth of the tiles (four-feet) and land being tiled. That was a result of increased capillary rise of soil water due to low rainfall and higher evapotranspiration. This defies the common belief that just lowering the groundwater depths will cause excess salts to leach out. Lowering soil EC levels will need an optimum combination of low enough groundwater depths combined with sufficient rain and good soil water infiltration to push the salts into deeper depths. Importance of good soil water infiltration is also evident from the fact that the highest EC levels were observed in 12-24 and 24-36 inch soil depths. This could be an indication of decent infiltration through the first foot, however, much slower water movement through the second and third feet of soil resulting in higher levels of salts. Sufficient rain will also result in improved moisture levels in the topsoil resulting in decreased capillary rise. Based on soil test EC levels, establishing a salt-tolerant annual crop (barley, oat) or perennial grass mix is also very important as that will reduce evaporation and consequently capillary rise.

Electrical conductivity in 2014 were the highest followed by 2017, 2018, 2019, 2020 and 2016. Replication 2 had the highest EC levels followed by replications 1 and 3. VersaLime treatments had the highest levels followed by gypsum, E-sulfur and control treatments. The highest EC levels were found in the 12-24 inch soil depths followed by 24-36 inch, 36-48 inch and 0-12 inch depths. Details of soil EC (dS/m) levels are shown in Figure 4.

Figure 4. Annual soil EC (dS/m) means for replications, treatments and soil depths.

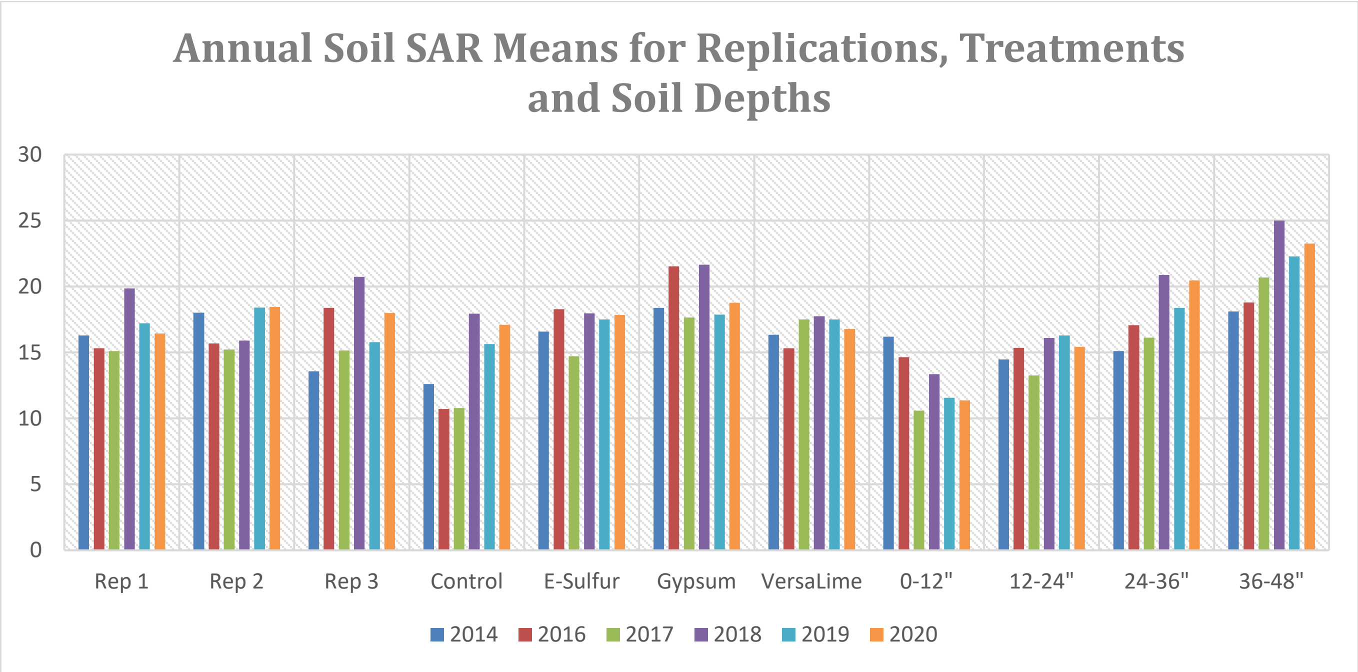


Differences in Soil Sodium Adsorption Ratio SAR (Sodicity) Levels

Soil SAR levels have been inconsistent irrespective of soil amendment applications (even after five-years), weather conditions, resulting average annual growing-season groundwater depths and tiling. It could be due to the drier weather in 2017, 2018, the early part of 2019 and 2020 resulting in insufficient soil water to dissolve the amendments and create the desired chemical reaction for sodicity remediation. This could also be a good insight that lowering SAR levels is more complex than lowering EC, which will take a longer time and equal or higher than normal annual rainfall. In addition, soil SAR levels increased with soil depth showing 0-12 inch depths having the lowest SAR levels and 36-48 inch depths having the highest SAR levels.

Sodium adsorption ratio remained the highest in 2018 followed by 2020, 2019, 2016, 2014 and 2017. Replication 2 had the highest SAR levels followed by replications 3 and 1. Gypsum treatments had the highest levels followed by E-sulfur, VersaLime and control treatments. The 36-48 inch soil depths had the highest SAR levels followed by 24-36 inch, 12-24 inch and 0-12 inch depths. Details of soil SAR levels are shown in Figure 5.

Figure 5. Annual soil SAR means for replications, treatments and soil depths.

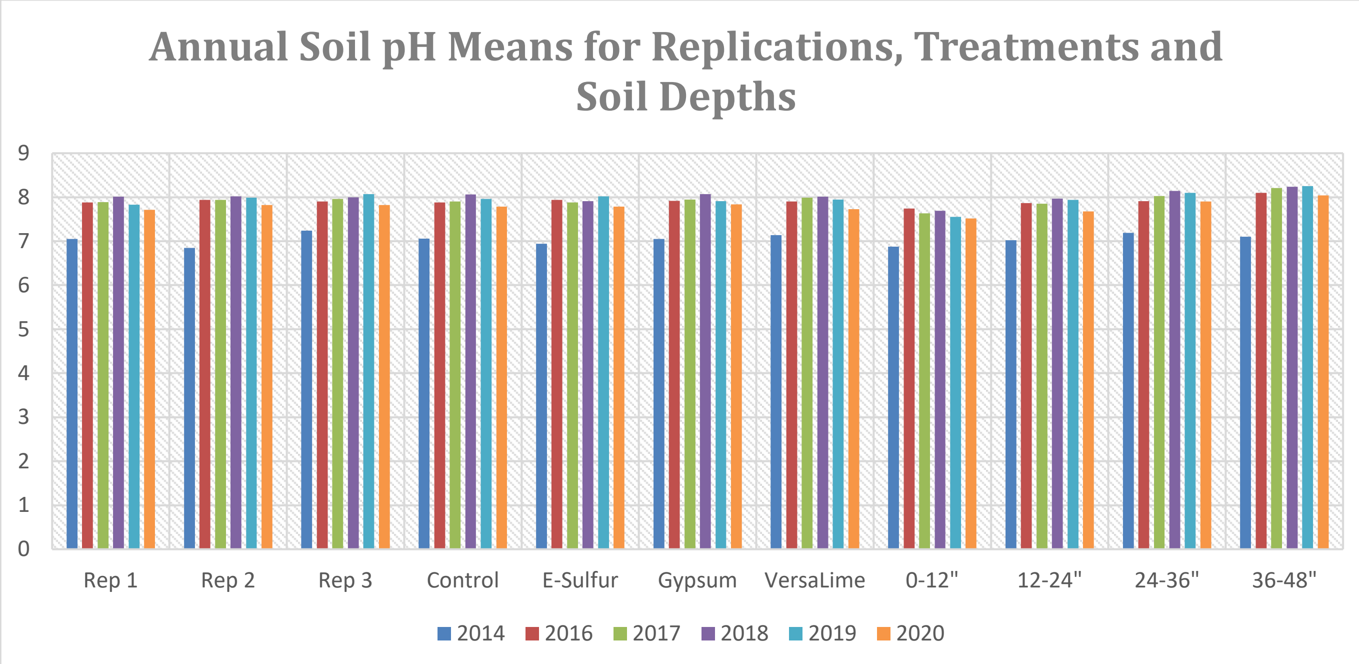


Differences in Soil pH Levels

Soil pH levels were consistent with the annual growing-season rainfall and resulting soil moisture levels and have had no impact so far related to the application of soil amendments. Like SAR, soil pH significantly increased with soil depth and the 0-12 inch depth having the lowest pH levels and the 36-48 inch depths having the highest pH levels. An increase in pH with soil depth was due to the increase in soil moisture levels.

Soil pH levels remained the highest in 2018 followed by 2019, 2017, 2016, 2020 and 2014 while replication 3 had the highest pH levels followed by replications 2 and 1. That is interesting as generally replication 3 has the shallowest average annual growing-season groundwater depths followed by replications 2 and 1 every year. The VersaLime treatments had the highest levels followed by gypsum, control and E-sulfur treatments. The 36-48 inch soil depths had the highest pH levels followed by 24-36 inch, 12-24 inch and 0-12 inch depths. Details of soil pH levels are shown in Figure 6.

Figure 6. Annual soil pH means for replications, treatments and soil depths.

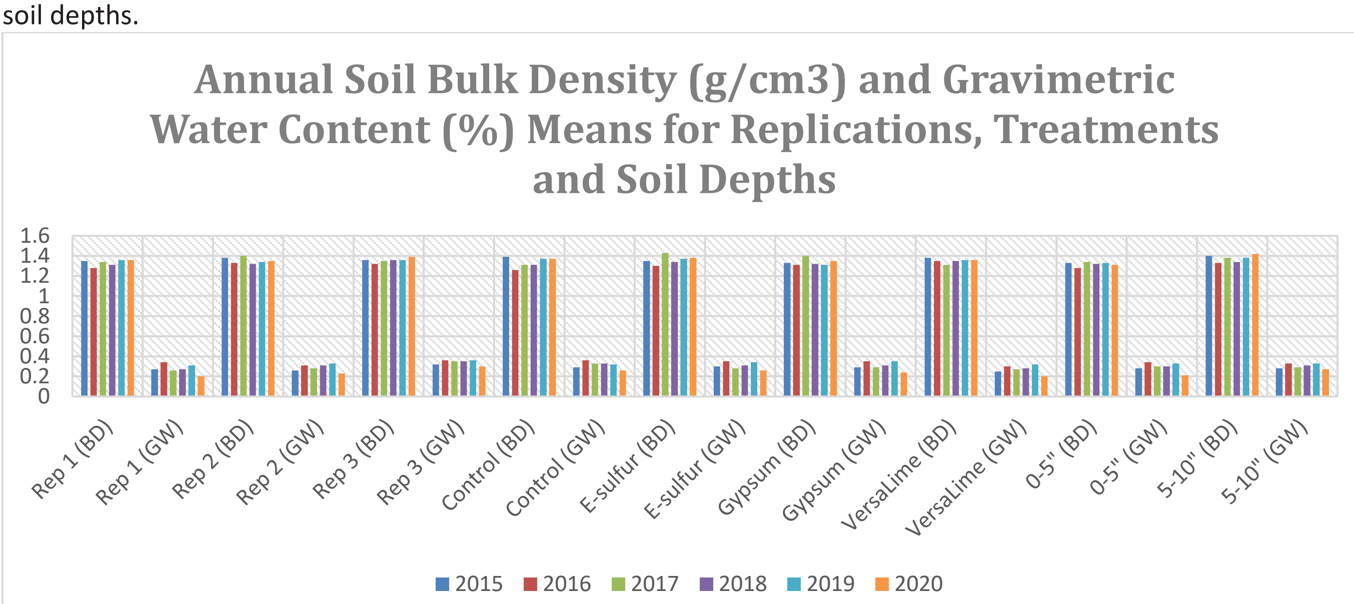


Differences in Soil Bulk Density Levels

Soil bulk density increased with soil depths. Despite not being a clear trend, bulk density increased as the gravimetric soil water content decreased.

Bulk density levels in 2020 were the highest followed by 2015, 2017, 2019, 2018 and 2016 at 24, 28, 29, 33, 31 and 34 percent gravimetric water levels respectively. Replication 3 had the highest bulk density levels followed by replications 2 and 1 at 34, 28 and 27 percent gravimetric water levels. E-sulfur treatments had the highest levels followed by VersaLime, control and gypsum treatments at 30, 27, 32 and 30 percent gravimetric water levels. The 0-12 inch soil depths had lower bulk density levels compared to 5-10 inch depths at 29 and 30 percent gravimetric water levels. Soil bulk density (g/cm^3) and corresponding gravimetric water content (%) levels are shown in Figure 7.

Figure 7. Annual means of soil bulk density (g/cm^3) and gravimetric water (%) levels for replications, treatments and soil depths.



Is Drained Water from the Tiled Saline and Sodic Field Adding More Salts and Sodicity to the Surface Water Resources?

Based on the cumulative means of all sampling times, conductivity, total dissolved solids and SAR levels of the lift station samples were higher than the upstream and downstream samples (Figures 8 and 9). The pH means of upstream, lift station and downstream samples were roughly equal. These trends point out that over time depending upon the site specific soil chemistry, tile drainage water can add salts and sodicity to the surface water resources. Details of conductivity, dissolved solids, SAR and pH of each sampling activity are outlined in Table 1.

Table 1. Results of conductivity (µmhos/cm), dissolved solids (mg/L), Sodium Adsorption Ratio (SAR) and pH for each water sampling activity.

Date	Site	Conductivity (µmhos/cm)	Total Dissolved Solids (mg/L)	Sodium Adsorption Ratio (SAR)	pH
November 9, 2015	Upstream	5650	4510	13.10	8.27
	Lift Station	10200	8840	17.40	7.91
	Downstream	6800	5700	16.30	8.37
May 11, 2016	Upstream	7220	6060	16.60	8.92
	Lift Station	7200	7170	14.90	7.96
	Downstream	7560	6390	17.60	9.23
July 11, 2016	Upstream	999	647	3.54	7.60
	Lift Station	8140	6820	16.20	8.32
	Downstream	966	627	3.07	7.56
September 8, 2016	Upstream	3440	2570	8.55	8.31
	Lift Station	7220	5960	15.60	8.10
	Downstream	3200	2340	6.87	7.92
May 10, 2017	Upstream	6920	5840	14.20	8.27
	Lift Station	5980	4950	13.50	8.08
	Downstream	6070	5200	14.00	8.28
August 17, 2017	Upstream	3360	2590	8.36	7.60
	Lift Station	6590	6010	22.60	7.99
	Downstream	2100	1430	6.52	7.67
June 12, 2018	Upstream	5130	3910	13.80	7.70
	Lift Station	4470	3420	11.00	8.00
	Downstream	4840	3680	13.50	7.92
August 26, 2019	Upstream	3710	2860	10.70	7.92
	Lift Station	5430	4290	14.70	8.03
	Downstream	5070	4080	14.60	8.11
September 30, 2019	Upstream	754	488	3.11	7.77
	Lift Station	6460	5620	15.20	7.78
	Downstream	1350	891	4.55	7.71
July 6, 2020	Upstream	3510	2630	7.93	7.76
	Lift Station	6760	5560	15.4	7.95
	Downstream	4240	3380	11.2	7.76

Figure 8. Cumulative means of conductivity (µmhos/cm) and dissolved solids (mg/L) for all sampling activities.

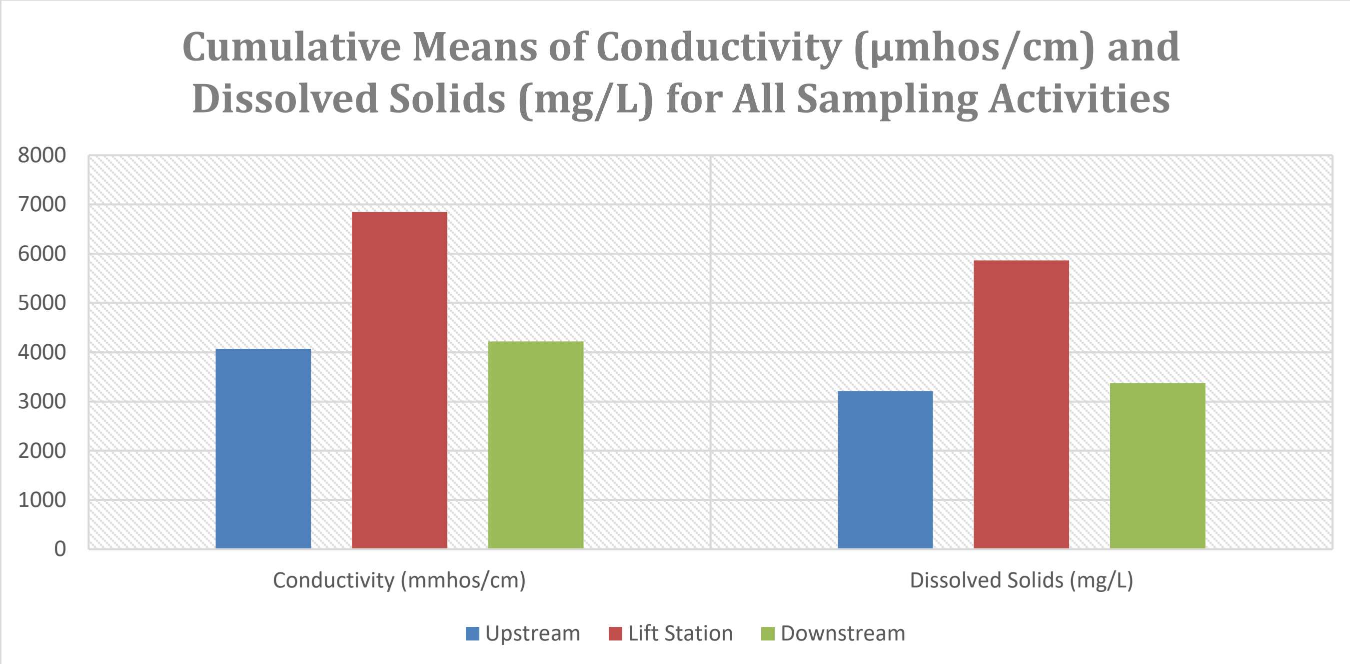
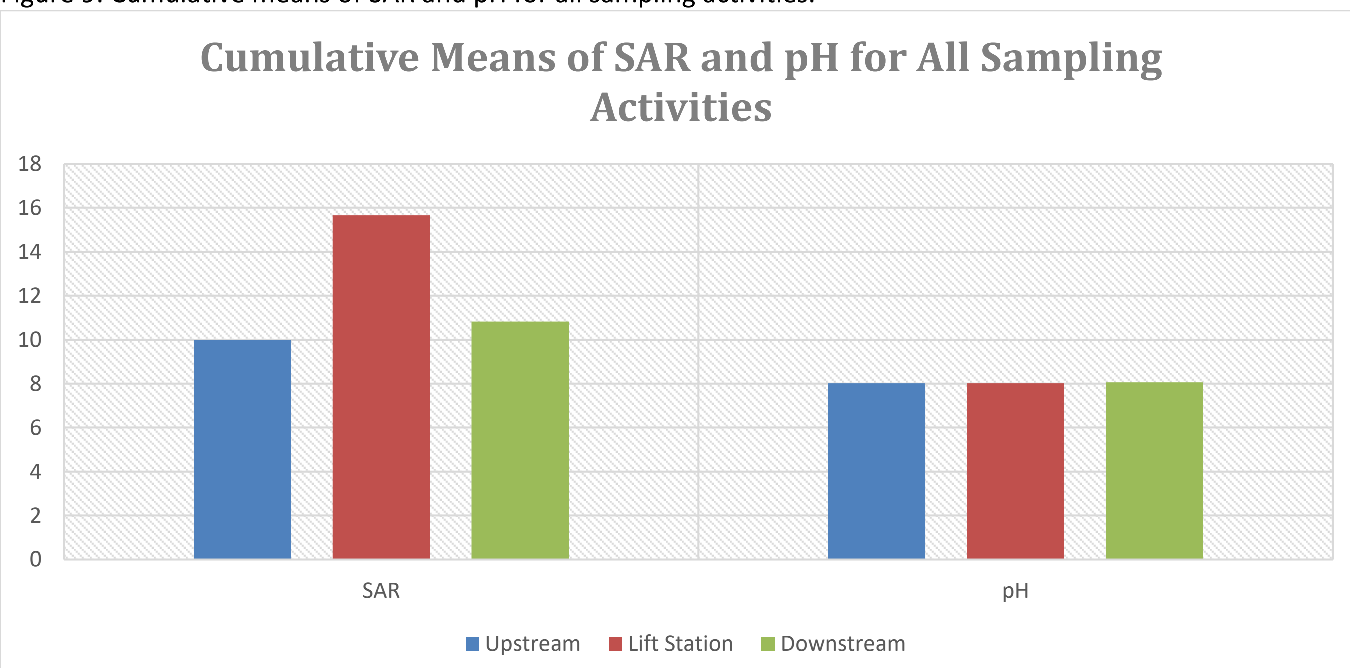


Figure 9. Cumulative means of SAR and pH for all sampling activities.



SUMMARY

Research data and observations are not conclusive at this point. However, producers and landowners having unproductive areas with potential soil dispersion issues (due to sodicity or excessive swelling of the soils due to the higher magnesium (Mg^{2+}) versus calcium (Ca^{2+}) levels) and may be thinking about tiling entire fields as a single-step strategy to reclaim potential saline-sodic areas. They may want to consider the following points before making a final decision:

Under Wet Weather

- Depending upon soil texture, tiling may drain excess water timely **under good soil water infiltration.**
- If the potential fields have unproductive or marginal areas, **they may want to sample these areas three to four-feet deep and analyze the samples for EC (salinity), SAR (sodicity) and pH by using the saturated paste extract method.** That will be a very inexpensive activity compared to tiling and will help them make informed decisions.
- Based on the soil SAR results, if sodicity is established **they may want to consider applying the soil amendments before tiling as amendments will convert sodicity into a salinity issue.** Once sodicity levels are lowered, soil water infiltration will also improve and tiles will help drain the excess water along with leaching the excess salts.
- Tiling sodic or saline-sodic fields alone **will not remediate sodicity and will require application of amendments at some point in time.**
- Note: calculating the rates of soil amendments will also require analyzing the 0-12 inch depth samples for **Cation Exchange Capacity (CEC) by using sodium saturation and ammonium extraction method.**
- Based on soil EC levels, **it will be beneficial to plant a salt-tolerant annual crop or a perennial salt-tolerant grass mix on the saline or saline-sodic areas.** That will use excess soil water, reduce evaporation, and minimize capillary rise of soil water as well as upward movement of excess water soluble salts.

Under Drier Weather

- **Tiling entire fields may not be necessary as average annual growing-season groundwater depths may lower naturally.**
- Tiling alone **may not lower salinity as moving the excess water soluble salts into the deeper soil depths will require sufficient rain resulting in free or gravitational water.**
- **Salinity levels can actually increase despite tiling due to the increased evaporation and resulting capillary rise of soil water.**
- If the potential fields have unproductive or marginal areas, **they may still be sampled three to four-feet deep and analyzed for EC (salinity), SAR (sodicity) and pH levels by using the saturated paste extract method. This** will be a very inexpensive activity compared to tiling.
- Based on the soil SAR results, if sodicity is established **they may still want to consider applying the soil amendments before tiling as amendments will convert sodicity into a salinity issue.** Once sodicity levels are lowered, soil water infiltration will also improve, which will help leach salts during spring-melt or decent rain events.
- Tiling sodic or saline-sodic fields alone **will not remediate sodicity and will require the application of amendments at some point in time.**
- Note: calculating the rates of soil amendments will require analyzing the 0-12 inch depth samples for **Cation Exchange Capacity (CEC) by using sodium saturation and the ammonium extraction method.**
- Despite applying amendments, conversion of sodicity into salinity **will take longer, possibly several years.**
- Based on soil EC levels, **it will be beneficial to plant a salt-tolerant annual crop or a perennial salt-tolerant grass mix on the saline or saline-sodic areas**, which will reduce evaporation, minimize capillary rise of soil water and minimize upward movement of excess soluble salts.

CONCLUSION

Since most soils in North Dakota are clayey, the general belief is that these soils will infiltrate water slower and we cannot do much about it. That is true if we only compare the texture of clay soils with silty or sandy soils. However, a clayey soil with high to very high dispersion or swelling will infiltrate water much slower than the same clay type not having these issues. Reducing soil dispersion and/or swelling combined with no or minimum-till practices and increasing organic matter will improve soil particle aggregation, structure, pore space and water infiltration.