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

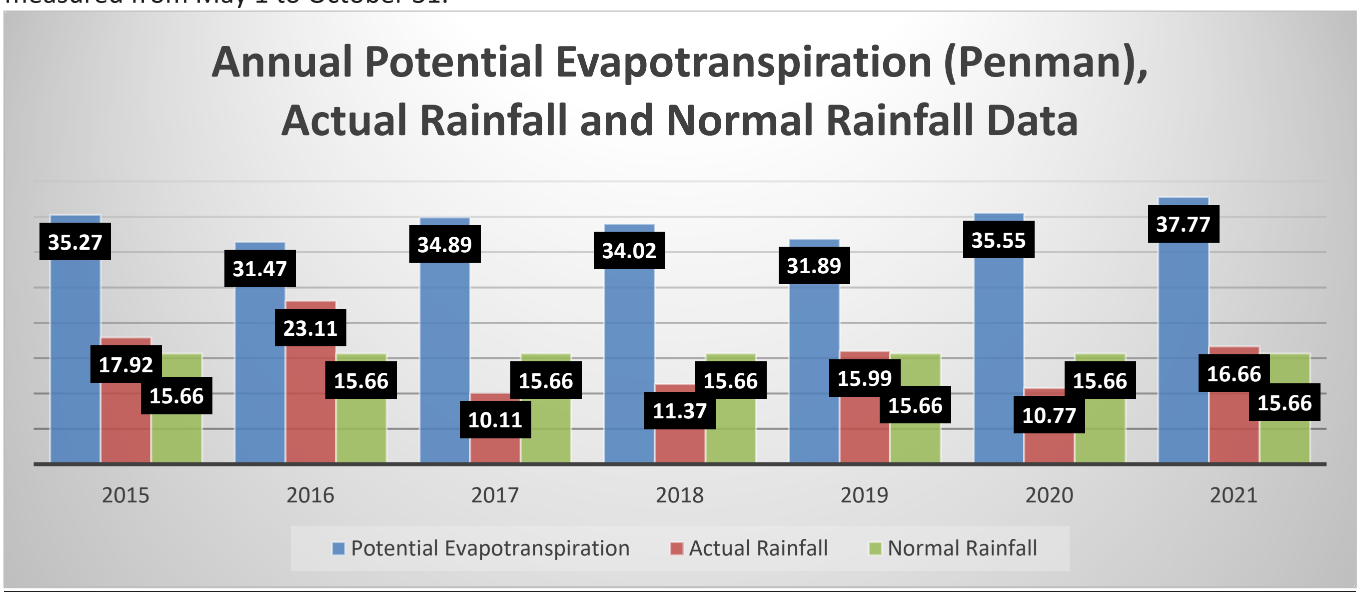
The findings below are based on the statistical analysis of soil electrical conductivity (EC dS/m), sodium adsorption ratio (SAR), pH and bulk density (g/cm^3) and its corresponding gravimetric water content (%). This was done to measure the differences in these properties at the time of tiling compared to after applying the soil amendments (treatments). In addition, effects of annual growing-season rainfall and potential evapotranspiration (Penman) were noted on the resulting average annual growing-season groundwater depths from May to October. The treatment means of EC, SAR and pH represent 2014 and 2016-2021 results of three replications for the zero to four-foot soil depths. The treatment means of groundwater depths represent 2015 to 2021 results of three replications measured for zero to seven and a half-foot soil depth.

In addition, included are the results of conductivity (mmhos/cm), dissolved solids (mg/L), SAR and pH of the tile-drained water quality analysis. 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. Water quality analysis results represent 2015 to 2021 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 at times when significant rain (an inch or more) allowed the fresh flow of tiled-drained water and measurable water level in the drainage ditch for collecting upstream and downstream water samples.

Annual Changes in Weather and Soil Groundwater Depths

Changes in soil chemical properties are 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.

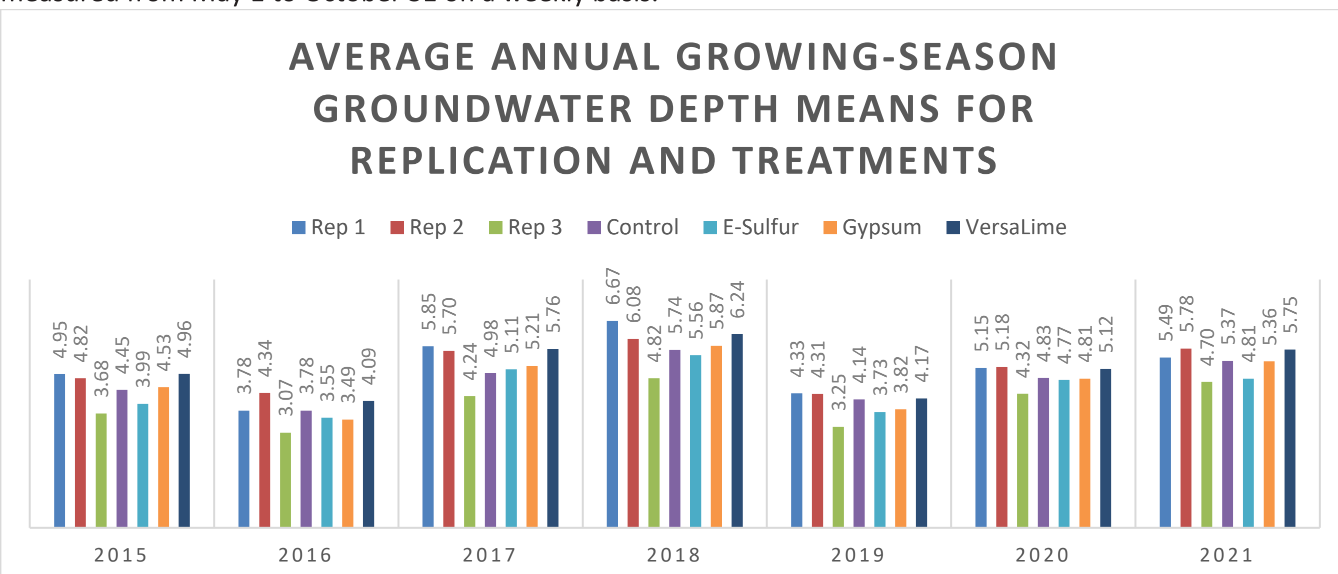
Figure 2. Annual growing-season potential evapotranspiration (Penman), actual rainfall and normal rainfall in inches measured from May 1 to October 31.



A bigger gap between evapotranspiration and rainfall generally results in lower groundwater depths, but less leaching of soluble salts, increased capillary rise of soil water and slower dissolution of soil amendments. A smaller 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 smaller 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 small 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, 2020 and 2021 due to the drier weather.

It is important to note that while the total annual evapotranspiration and rainfall numbers are important, they do not reflect the weather trends for the entire growing-season. For example, from May 1 to October 31, 2021, Langdon Research Extension Center NDAWN station recorded 37.77 inches of total potential evapotranspiration and 16.66 inches of actual rainfall versus a normal of 15.66 inches. That means Langdon area received 106.38 percent rain versus the normal in 2021. However, during the early part of the 2021 growing-season from May 1 to August 8, Langdon NDAWN recorded 25.62 inches of total potential evapotranspiration and only 6.43 inches of actual rainfall versus a normal of 10.49 inches. That was a gap of 19.19 inches between total annual evapotranspiration and rainfall and 38.70 percent less rainfall versus normal for that period, which created moderate to severe drought. On August 9, Langdon area received 3.68 inches of rain and kept getting significant showers afterwards. Overall, Langdon NDAWN recorded 12.16 inches of total annual evapotranspiration and 10.22 inches of rain versus a normal of 5.17 inches from August 9 to October 31. So, during the latter part of the growing-season, the gap between total annual evapotranspiration and rainfall was only 1.94 inches with 197.67 percent rain compared to the normal. It was important to receive the much-needed moisture during that time, however, most of the growing-season was over.

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 2019 growing-season roughly had the same weather pattern when 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 1 to July 30 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 31 to October 5, 2019. The total potential evapotranspiration (Penman) for the same period was 9.04 inches. On July 31, 0.77 inch 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.

Figure 3 has the average annual growing-season groundwater depth means for replications and treatments for 2015 to 2021. These means of groundwater depths represent actual annual measurements of groundwater depths measured from May 1 to October 31 on a weekly basis.

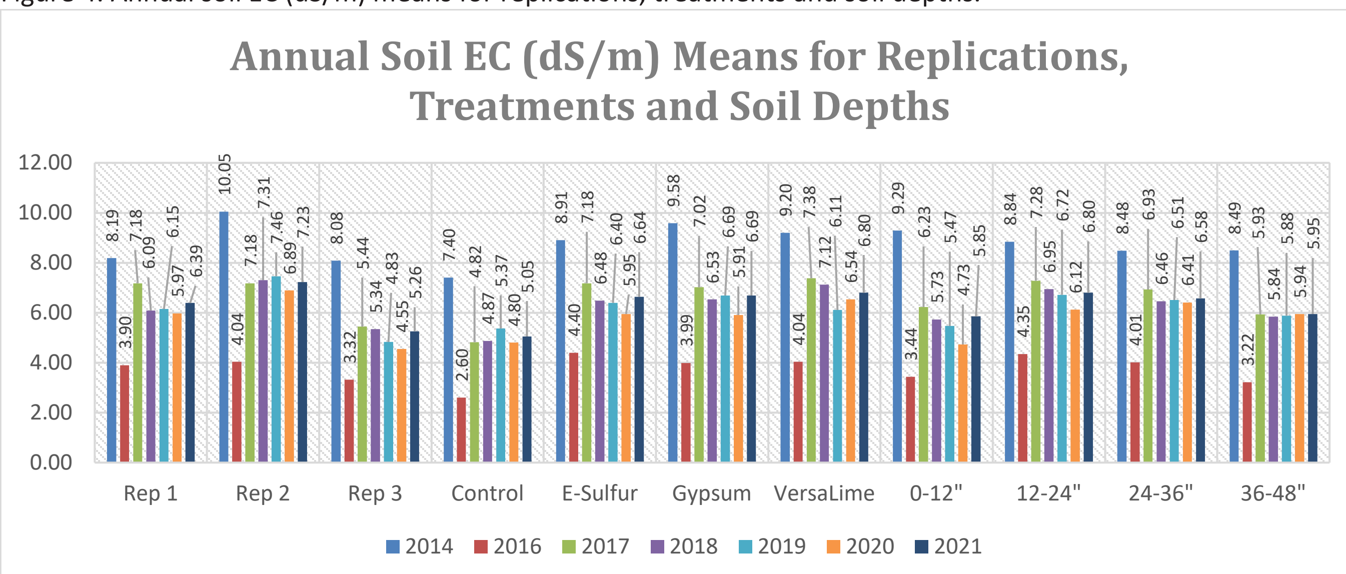
The 2016 average growing-season groundwater depths for treatments and replications were shallowest (3.07 to 4.34 feet deep) followed by the depths in 2015, 2017, 2018, 2019, 2020 and 2021. The 2018 average growing-season groundwater depths were the deepest (4.82 to 6.67 feet deep) versus rest of the 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, 2018, 2020 and 2021.

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 2018-2021 despite land being tiled and average annual growing-season groundwater depths being deeper than the depth of the tiles, which is four-feet deep (Figure 4). That was a result of increased capillary rise of soil water due to low rainfall and higher evapotranspiration.

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



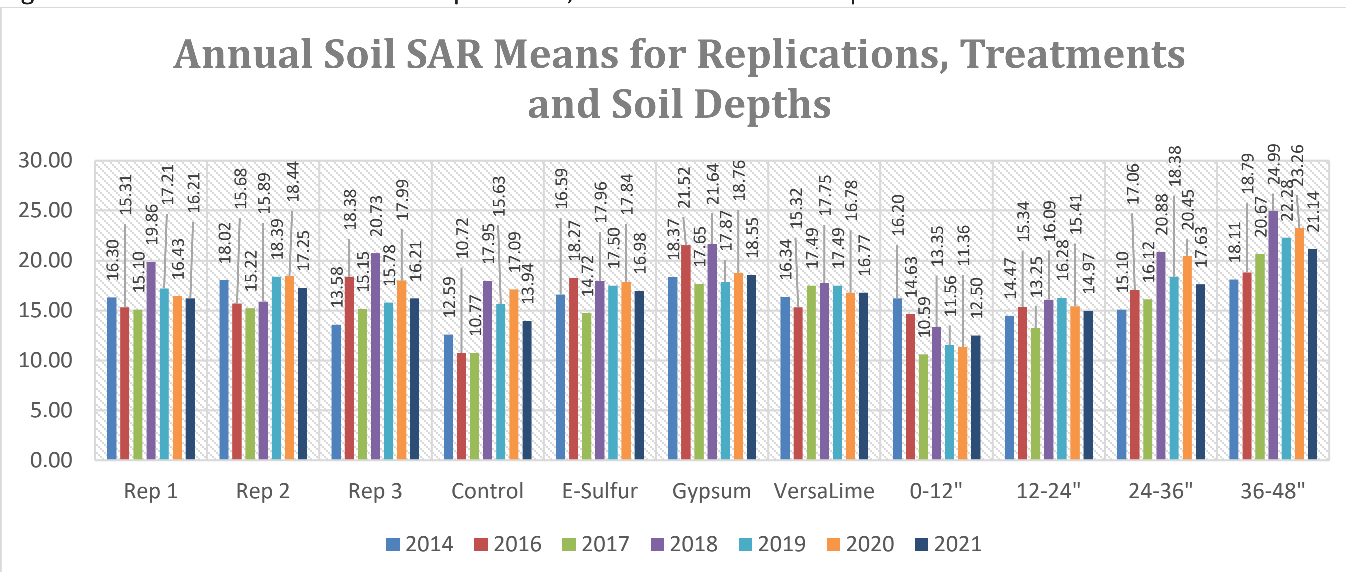
This defies the common belief that just lowering the groundwater depths will cause excess salts to leach out. Lowering soil EC levels will need an optimum combination of low enough groundwater depths combined with sufficient rain and good soil water infiltration to push the salts into deeper depths. 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 (especially under lower sodicity levels), however, much slower water movement through the second and third feet of soil resulting in higher levels of salts. An example of slower soil water infiltration in the 12-24 and 24-36 inch depths could be that despite receiving 3.68 inches in less than twenty-four hours on August 9, 2021. It took the lift station pump four to seven days to start pumping the excess water into the drainage ditch. A similar event occurred in fall-2019 when the Langdon NDAWN recorded 1.52 inches from September 9 to 13. There was standing water at the soil surface in low areas with the lift station pump not running. Sufficient rain will 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 salt-tolerant grass mix is also very important as that will reduce evaporation and consequently capillary rise.

Electrical conductivity levels in 2014 were the highest followed by the levels in 2021 and 2017-2020 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.

Differences in Soil Sodium Adsorption Ratio SAR (Sodicity) Levels

Soil SAR levels have been inconsistent despite tiling the site in 2014 and applying soil amendment in 2015. It could be due to the drier weather in 2017-2021 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 and that it will take a longer time and equal or higher than normal annual rainfall to remediate sodicity. Too little will not be enough and too much coming down too fast will not infiltrate through the soils. A slow and steady rain of at least ½ inch, preferably up to two inches spread over three to four days will be ideal for dissolving soil amendments and leaching excess salts into deeper depths. Despite the recent drier annual weather, for the first time in six-years, SAR levels in 2021 were the lowest compared to rest of the years. This could be beginning of a positive trend (Figure 5).

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



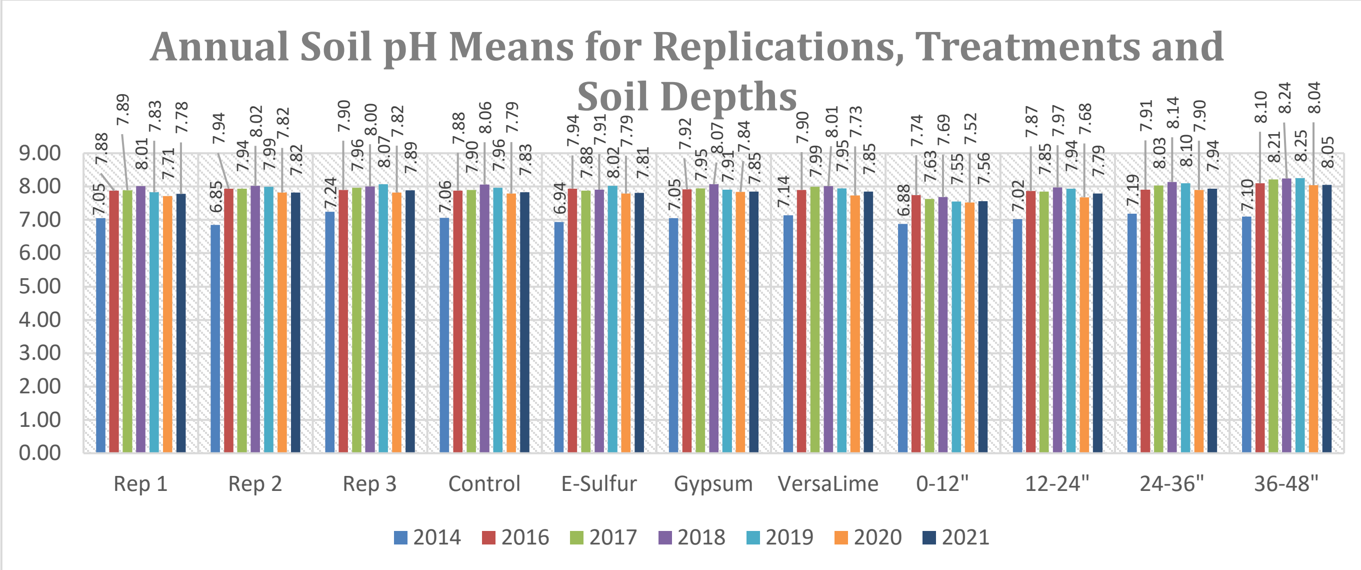
Overall, sodium adsorption ratio remained the highest in 2018 followed by 2020, 2019, 2016, 2014, 2017 and 2021. Replication 2 had the highest SAR levels, whereas, replications 1 and 3 had similar SAR levels. Gypsum treatments had the highest levels followed by E-sulfur, VersaLime and control treatments. 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. Details of soil SAR levels are shown in Figure 5.

Differences in Soil pH Levels

Soil pH levels were generally consistent with the soil moisture levels at the time of sampling and have had no impact so far related to the application of soil amendments (Figure 6).

Overall, soil pH levels remained the highest in 2021 followed by 2018, 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 in most years. VersaLime and gypsum treatments had the highest levels followed by control and E-sulfur treatments. Like SAR, soil pH significantly increased with soil depth and 0-12 inch depths had the lowest pH levels , whereas, 36-48 inch depths had the highest pH levels. An increase in pH with soil depth was due to the increase in soil moisture levels. Details of soil pH levels are shown in Figure 6.

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

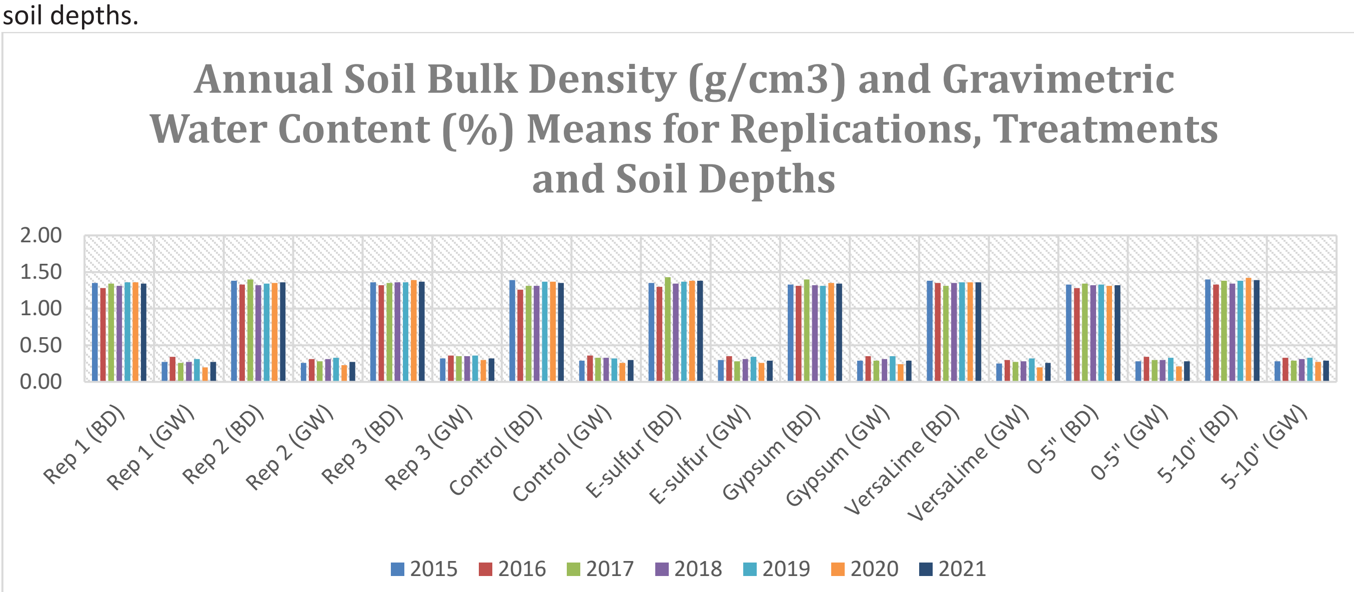


Differences in Soil Bulk Density Levels

Soil bulk density increased with soil depths. In addition, despite not being a clear trend, bulk density increased as the gravimetric soil water content decreased (Figure 7).

Bulk density levels in 2021 were the highest followed by 2020, 2015 and 2017, 2019, 2018 and 2016 at 21, 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 32, 27 and 27 percent gravimetric water levels. E-sulfur treatments had the highest levels followed by VersaLime, control and gypsum treatments at 29, 26, 30 and 29 percent gravimetric water levels. The 0-12 inch soil depths had lower bulk density levels compared to 5-10 inch depths at 28 and 29 percent gravimetric water levels. Soil bulk density (g/cm^3) and corresponding gravimetric water content (%) levels are shown in Figure 7.

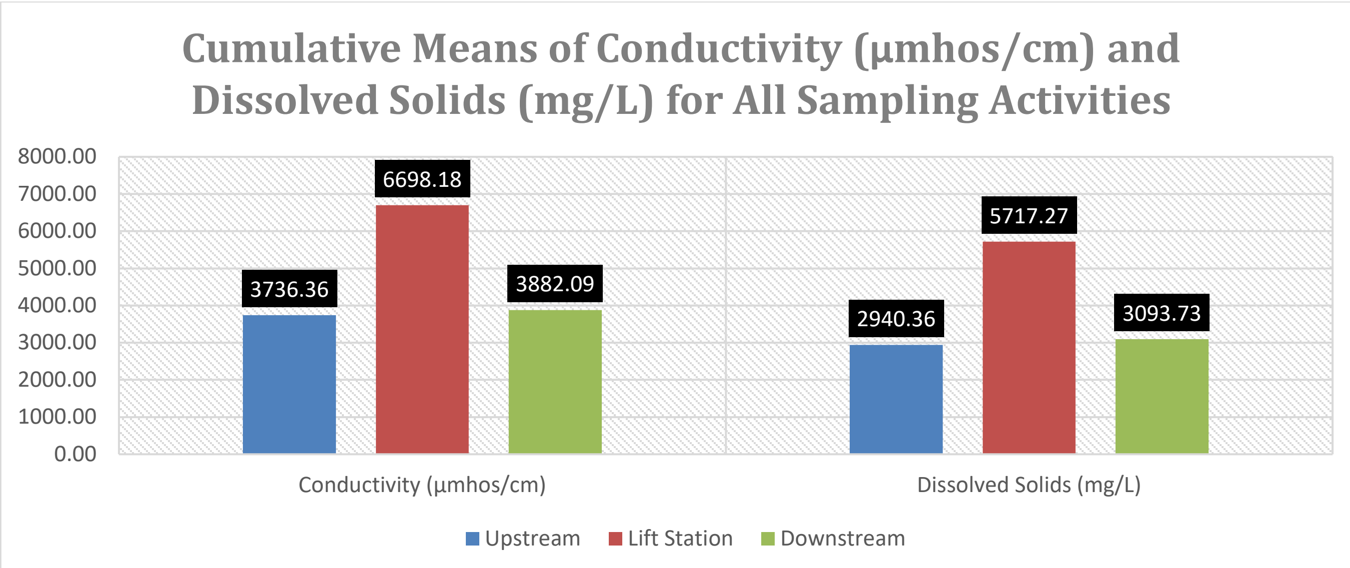
Figure 7. Annual means of soil bulk density (g/cm^3) and gravimetric water (%) levels for replications, treatments and soil depths.



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

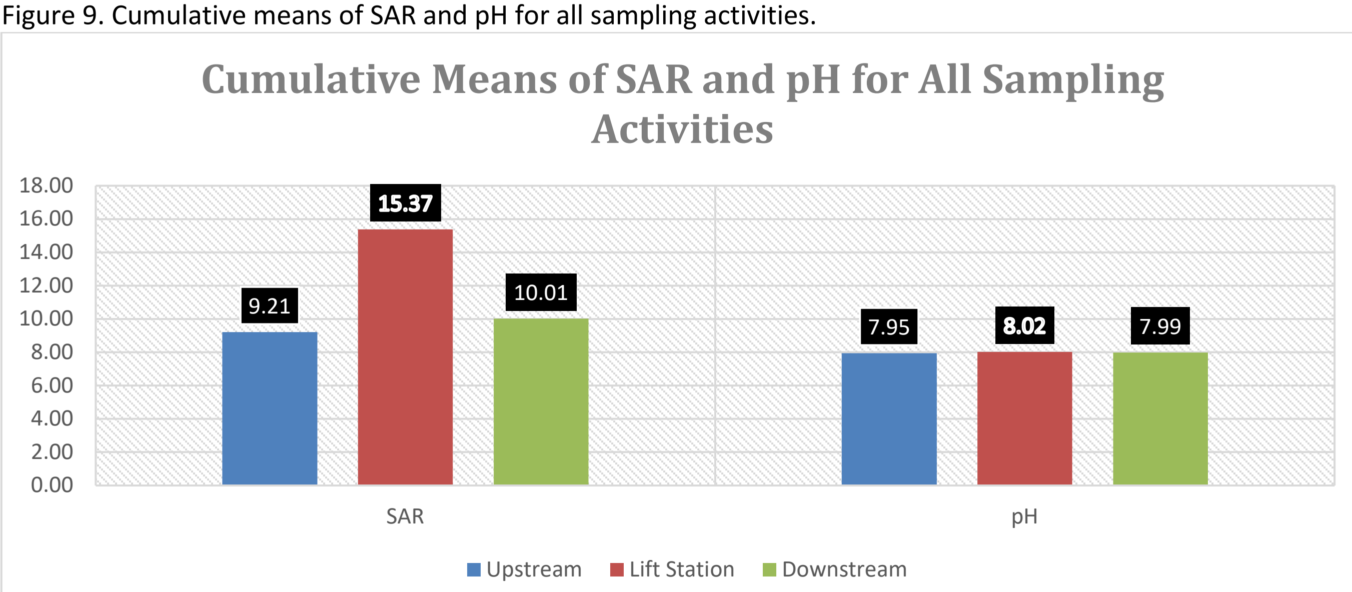
Based on the cumulative means of all sampling times, conductivity, total dissolved solids and SAR levels of the lift station samples were higher than the upstream and downstream samples (Figures 8 and 9).

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



The pH means of upstream, lift station and downstream samples were roughly equal (Figure 9). 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.

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



SUMMARY

Research data and observations are not conclusive at this point. However, 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 clayey 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.

Based on the observations seven-years after tiling and six-years after applying the soil amendments, below are the answers for the three main objectives of this long-term research trial:

Does soil sodicity negatively affect tile drainage performance?

Yes, soil sodicity has negatively affected the performance of tile drainage at this site and despite heavy rains and standing water at the soil surface, sometimes it takes days for the lift station pump to start draining excess water. That eventually happens, however, it takes time. Another evidence of slower water infiltration is roughly no change in groundwater depths for two to three days even after a heavy rain. Two specific examples are:

- Despite receiving 3.68 inches in less than twenty-four hours on August 9, 2021, it took lift station pump four to seven days to start pumping the excess water into the drainage ditch.
- In 2019, the Langdon NDAWN recorded 1.52 inches from September 9 to 13 and there was visible standing water at the soil surface in low areas, however, lift station pump was not running. It took lift station pump three to four days to start running and drain the excess soil water.

Will tiling lower soil salinity under wet and dry weather conditions?

Tiling has lowered soil salinity (EC) levels under wet weather in 2016. However, under drier weather, salinity levels have actually increased in 2017-2021. That is due to the lack of rain water to force excess water-soluble salts into deeper depths and increased rise of capillary water due to increased evapotranspiration.

Does the drained water from a tiled field increase salinity and sodicity levels of the surface water resources?

Yes, tile-drained water has added conductivity, total dissolved solids and SAR to the drainage ditch or the surface water resource. So, over time depending upon the site-specific soil chemistry, tile drainage water can add salts and sodicity to the surface water resources.