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.

INTRODUCTION

Saline and sodic soils have been reported in North Dakota since the 1960s. NDSU Extension Bulletin No. 2 reported more than one million acres affected by high salt levels and more than two million acres, which had excessive levels of sodicity (Johnsgard, reprinted in 1974) in 1967. Another study estimated 5.8 million saline acres in North Dakota (Brennan and Ulmer, 2010). That is nearly 15% of the 39 million acres of cropland in North Dakota. Soil salinity and sodicity are 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 capillary rise of soil water results in 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 optimum water movement through the soil profile depending upon texture. Calcium ions are able to flocculate soil particles together as they act like a bridge between them due to being divalent. In addition, as they have smaller hydrated ionic sizes, Ca^{2+} ions hold on to the negative charges of soil particles tighter, so the bond is strong. Magnesium (Mg^{2+}) ions are also divalent so they can promote flocculation, however, due to their bigger hydrated ionic sizes, the bond between soil particles and resulting soil structure is not as strong as in case of calcium.

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 (Seelig, 2000). 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 the positive charges of Na^+ ions will be neutralized by the negatively charged chemical ions such as sulfates (SO_4^{2-}) or chloride (Cl^-).
- However, due to the constant exchange of positively charged ions like Ca^{2+}, Mg^{2+} and Na^+ between soil water and the soil clay and humus particle negative charges, high levels of Na^+ based salts in the soil water can result in sodicity as more negative charges will be saturated with Na^+.
- Clayey soils will infiltrate water slower than sandy soils, however, higher sodicity levels can drastically reduce the soil water infiltration irrespective of soil texture. A clayey soil without dispersion issues will infiltrate water much faster than the same clay soil having dispersion.

OBJECTIVES

Remediation of soil sodicity requires application of amendments that add Ca^{2+} to the soil followed by salinity remediation practices of establishing a good vegetative cover to reduce evaporation and lowering the groundwater depths to desirable levels by promptly draining the excess soil water under wet conditions. The newly added Ca^{2+} will displace 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. Once that happens, a combination of Ca^{2+} with clay/humus promotes flocculation resulting in improved soil aggregation, structure, pore space and infiltration.

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 ability of a tile drainage system to drain excess soil water in a timely manner greatly depends upon how fast water moves or infiltrates through the soil layers above the tiles. This is especially important, if soils are suspected of having dispersion. That will require sampling and analyzing potential areas for salts, Na^+ causing sodicity (resulting in dispersion) and pH up to the deepest proposed depth of tiles in one-foot increments. Salinity and sodicity levels can be determined by sampling the areas in question and getting the samples and depths analyzed by a soil laboratory for Electrical Conductivity or EC (for salinity) and Sodium Adsorption Ratio or SAR (for sodicity) by using the “saturated paste extract” method. If sodicity is established, in order to calculate the rates of soil amendments, samples will also need to be analyzed for cation exchange capacity (CEC) by using “sodium saturation, ammonium extraction” method. Generally, analyzing the first foot (0-12 inch) depth for CEC is sufficient. In case of high Na^+ levels causing sodicity, not adding Ca^{2+} can render tiling ineffective. 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 (revised July 2020); "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?**

Due to the growing concerns of producers and landowners about the effects and effectiveness of tiling, the Langdon Research Extension Center (LREC) tiled a field that had excessive levels of sodicity and moderately high levels of soluble salts in July 2014. Layout included 12 research plots with three replications (Figure 1). In order to replicate field conditions, the project site was tiled prior to starting sodicity remediation. Remediation of the area was accomplished 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.

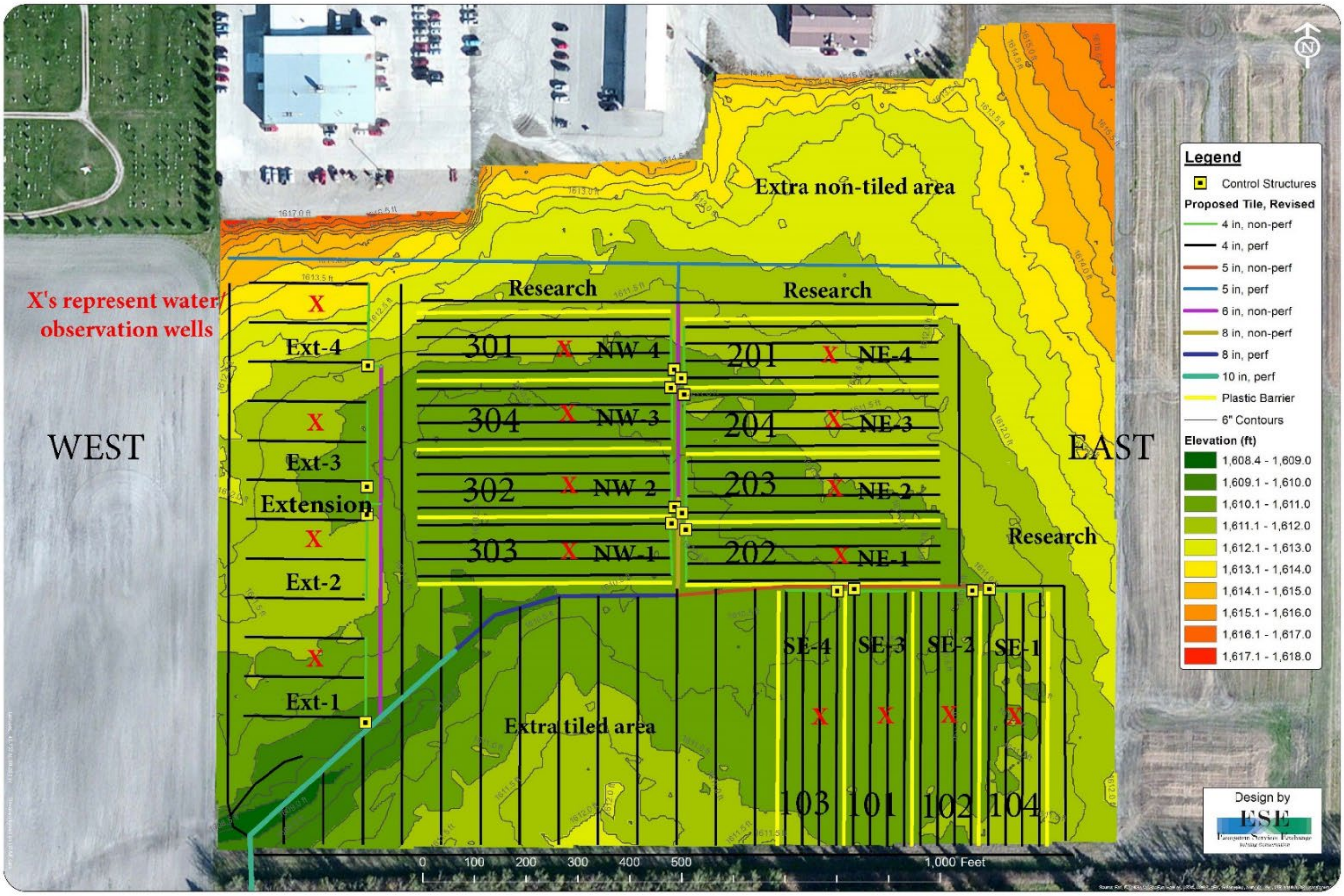


Figure 1. Final layout of the Langdon Research Extension Center Groundwater Management Research Project having twelve research plots and three replications. Replication 1 is on the southeast and includes SE-1, SE-2, SE-3 and SE-4 plots, replication 2 is on the northeast and includes NE-1, NE-2, NE-3 and NE-4 plots and replication 3 includes NW-1, NW-2, NW-3 and NW-4 plots on the northwest. Treatments range from 101 to 104, 201 to 204 and 301 to 304. The red color X's represent the seven and 1/2-foot deep observation wells and yellow boxes indicate the location of water control structures that are placed four-feet deep.

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

- **Does soil sodicity negatively affect tile drainage performance?**
    - Evaluate sodicity levels annually and monitor the removal rates of excess water after heavy rains by recording groundwater depths and how quickly lift station pump starts draining water out of the tiled area.
- **Will tiling lower soil salinity under wet and dry weather conditions?**
    - Evaluate salinity levels annually along with recording the varying annual growing-season groundwater depths.
- **Does the drained water from a tiled field increase salinity and sodicity levels of the surface water resources?**
    - Evaluate the quality and suitability of water samples collected at the tile drainage lift station as well as upstream and downstream of the lift station 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. Prior to tiling in 2014, site was conventionally tilled, fertilized annually and annual crops like soybean, spring-wheat and canola were planted without much success. Site is also one of the lowest areas at the Research Extension Center, which results in shallow groundwater depths, salinity and sodicity. These effects were maximized due to the poor germination and growth of the annual crops. As per the USDA Web Soil Survey, soil series is a mix of Cavour-Cresbard and Hamerly-Cresbard loams (Figure 2).

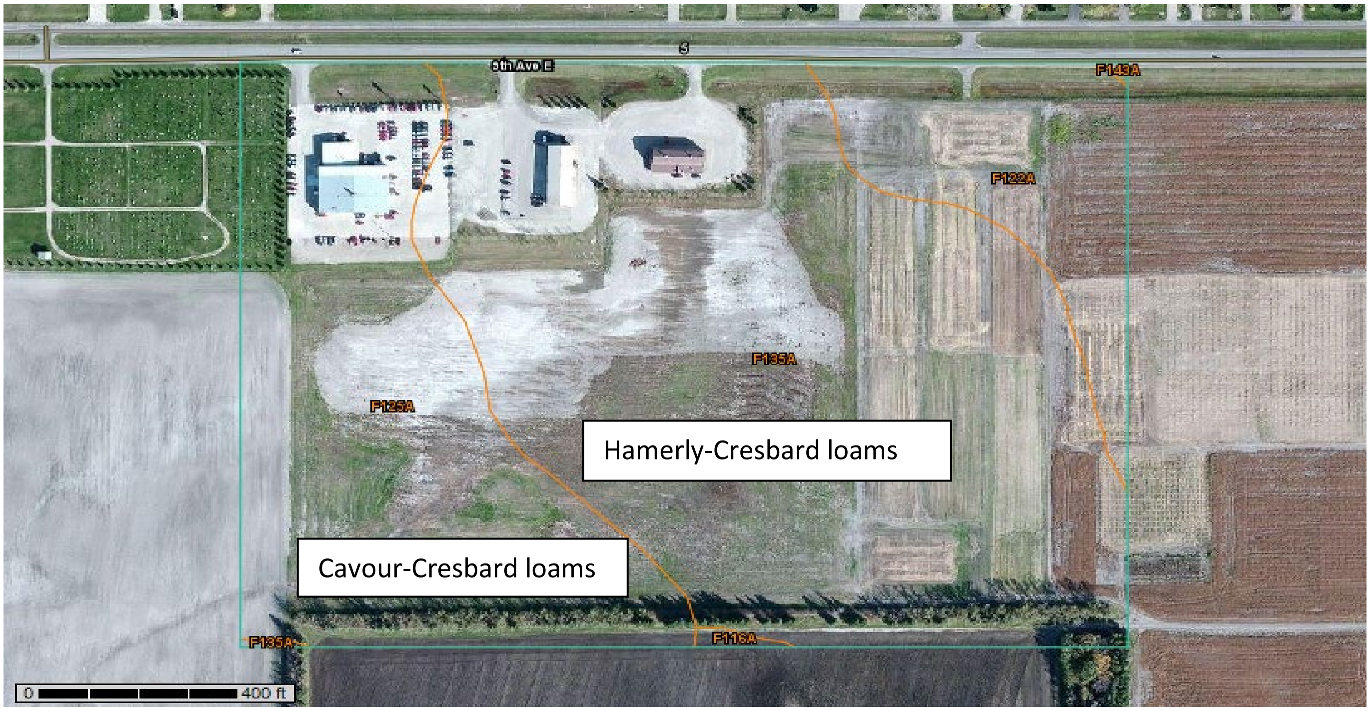


Figure 2. USDA Web Soil Survey map of the Langdon Research Extension Center Groundwater Management Research Project before tiling the site along with the soil series descriptions.

TRIAL DESIGN AND PLOT SIZE

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

METHODOLOGY

Soil Textural Analysis

Right after tiling, soil textural analysis was performed for all research plots for 0-12, 12-24, 24-36 and 36-48 inch depths by using Hydrometer method (Dar, P.R. 1956 and 1965) in September 2014. This analysis was not repeated in the following years unlike chemical and physical properties as soil texture rarely changes except some catastrophic events such as extreme flooding or dust storms, which can bring new soil sediments and deposit them over the existing soil layers.

Soil Chemical Analysis

Three random four-foot deep soil cores were collected from each plot to complete representative soil samples 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), in June of 2018 (four years after tiling and three years after applying the amendments), in June 2019 (five years after tiling and four years after applying the amendments), in June 2020 (six years after tiling and five years after applying the amendments) and in June 2021 (seven years after tiling and six years after applying the amendments). Sampling depths were separated into 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 (EC), Sodium Adsorption Ratio (SAR), pH, calcium carbonate equivalent (CCE), bicarbonates (HCO_3^-), chlorides (Cl^-), sulfates (SO_4^{2-}), soil water 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. All of the soil tests were performed by the North Dakota State University Soil Testing Laboratory located in Fargo, ND by using the following methods:

- Soil EC, SAR, pH, soil water saturation percent, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^- and SO_4^{2-} were analyzed by using the Saturation Paste Extract method (Miller, R.O., Gavlak, R. and Horneck, D., 2013).
- Soil CCE percent by using Pressure Calcimeter Principle method (Horvath, B., Opara-Nadi, O. and Beese, F., 2005).
- Soil NO_3-N^- by using Transnitration of Salicyclic Acid method (Vendrell, P. and Zupancic, J., 1990).
- Soil P by using Olsen or Sodium Bicarbonate method (North Central Regional Research Publication No. 221, page-6.5. Revised August, 2015).
- Soil O.M. by using Loss-on-Ignition method (North Central Regional Research Publication No. 221, page-12.2 Revised August, 2015).
- Soil CEC by using the Sodium Saturation, Ammonium Extraction method (Chapman, H.D., 1965).

Soil Physical Analysis:

Ten eighteen-inch deep soil compaction measurements were measured in one-inch increments in each treatment with the Field Scout SC 900-meter penetrometer in 2015, 2016, 2017, 2018, 2019, 2020 and 2021. At the time of penetrometer measurements, gravimetric water content was also measured for the eighteen-inch depths in six-inch increments. Soil bulk density was measured for the top ten-inch depths in five-inch increments by taking undisturbed soil cores using a Humboldt Density Sampler in 2015, 2016, 2017, 2018, 2019, 2020 and 2021. At the time of bulk density sampling, gravimetric water content was also measured for the 0-5 inch and 5-10 inch soil depths.

Weather Data

Considering the significant effects of annual precipitation, growing-season rainfall and evapotranspiration on soil groundwater depths and capillary rise of soil water, weather data was also taken into consideration. Annual potential evapotranspiration (Penman), actual rainfall and normal rainfall numbers from May 1 to October 31 were recorded by using North Dakota Agricultural Weather Network (NDAWN) Langdon Station data. These dates were selected to match the time period for recording the annual growing-season groundwater depths, which were also measured annually from May 1 to October 31 on a weekly basis. Annual precipitation numbers were taken from the data recorded by the National Weather Service Langdon Station.

Weekly Groundwater Depth Measurements

Seven and ½-foot deep observation wells were installed in each treatment (research plot) in May 2015. In 2015, weekly groundwater depths were measured from June to October on a weekly basis, whereas, in 2016, 2017, 2018, 2019, 2020 and 2021 groundwater depths were measured on a weekly basis from May to October by using a Solinst TLC 107 Meter.

Water Sample Analysis

Water samples were collected from the tile drainage lift station as well as 100-150 feet upstream and downstream of the lift station from the surface water drainage ditch in which tile drainage water was draining, in November of 2015, May, July and September of 2016, May and August of 2017, June 2018 and August, September of 2019, July of 2020 and August of 2021. 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 below:

$$\text{ESP} = \frac{(100(-0.0126+(0.01475*SAR)))}{(1+(-0.0126+(0.01475*SAR)))}$$

(USDA Handbook No. 60, Page-26).

ESP and cation exchange capacity (CEC) values of the 1st foot were used to calculate the milliequivalent of exchangeable Na/100 grams of soil by using the following formula:

$$Exchangeable\ Na\ Meq\ per\ 100\ grams\ of\ soil = \frac{CEC * Ex.Na\%}{100}$$

(USDA Handbook No. 60, P-49).

The milliequivalent of exchangeable Na/100 grams of soil numbers were then multiplied by 1.7 to get tons of 100% pure gypsum/acre foot.

For each ton of 100% pure gypsum, 0.19 ton of 100% pure elemental sulfur was applied (O'Geen, 2015). Considering the very low solubility of Versalime (locally known as beetlime), for each ton of 100% pure gypsum, three tons of VersaLime were applied. Differences in amendment purities were compensated by using the following formula:

$$\frac{100}{purity\%} * tons\ equivalent\ to\ 1\ ton\ of\ pure\ gypsum$$

(Hanson, 1993).

Following were the final treatments that were applied in three replications.

1. Control.
2. Full rate of 99.5% pure gypsum to lower soil SAR-final levels to 3.
3. Full rate of VersaLime (spent beetlime) to lower the soil SAR-final levels to 3.
4. Full rate of 90% pure elemental sulfur (S°) to lower the soil SAR-final levels to 3.

Details of the final amendment rates applied to 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 (101)	0	0	0
R1T2 (102)	4.47	0	0
R1T3 (103)	0	0	8.74
R1T4 (104)	0	2.10	0
R2T1 (201)	0	0	0
R2T2 (202)	7.25	0	0
R2T3 (203)	0	0	30.45
R2T4 (204)	0	0.61	0
R3T1 (301)	0	0	0
R3T2 (302)	10.67	0	0
R3T3 (303)	0	0	22.93
R3T4 (304)	0	2.16	0
Total	22.40	4.87	62.14

Note:

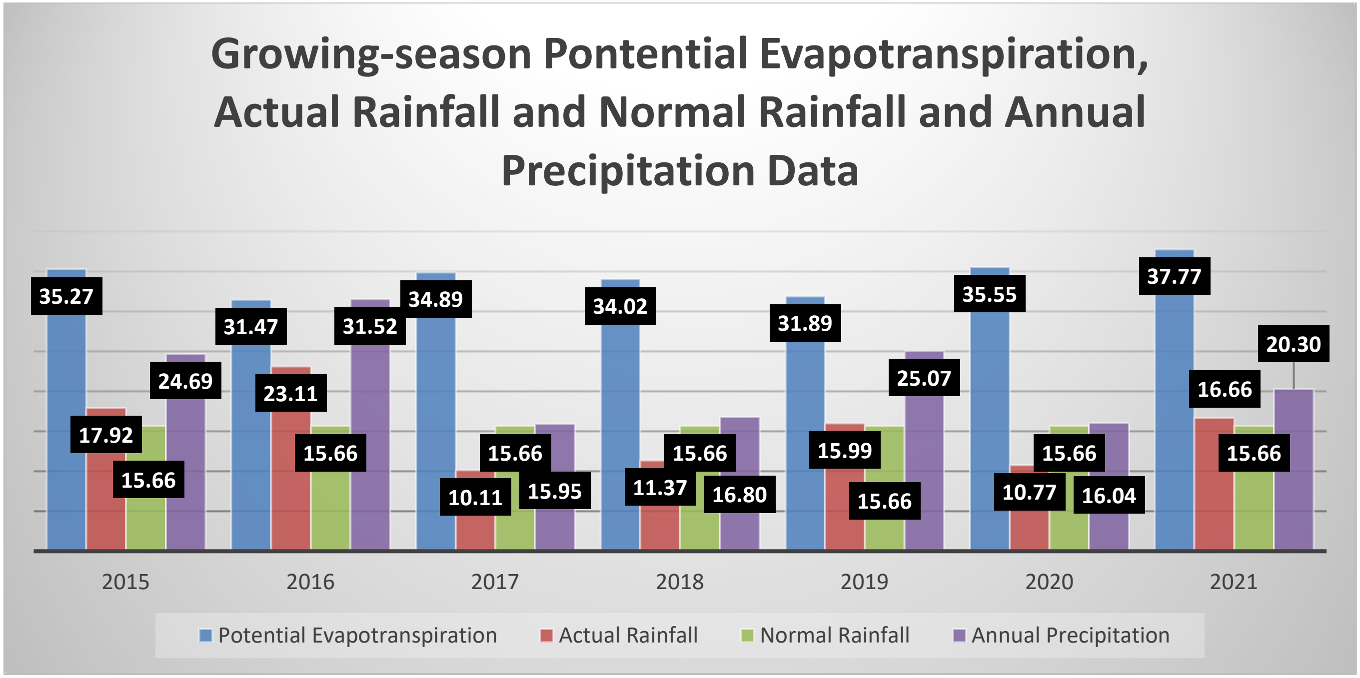
- Rates of 99.5% pure gypsum and 90% pure E-sulfur amendments were adjusted comparable to 100% pure sources.
- Gypsum and elemental sulfur were applied on June 29th, 2015, whereas, VersaLime was applied on July 23rd, 2015. After spreading, amendment treated plots were rototilled to incorporate amendments into the soil three to four inches deep. Control plots were also rototilled for uniformity purposes. Rototilling was done to uniformly mix the amendments into the soil to achieve optimum contact between amendments and soil particles.
- Control structures of all of the treatments were fully opened right after incorporating soil amendments in order to allow free drainage and achieve maximum leaching conditions.
- After applying soil amendments, an equal mix of tall, slender, intermediate and green (AC Saltlander) wheatgrasses and Russian Wildrye were hand broadcasted and harrowed in on August 28th, 2015 at the rate of 7 lbs./acre on all treatments. That was done to minimize evaporation. This salt-tolerant perennial vegetative cover has been mowed three to four times a year since 2016.

RESULTS AND DISCUSSION

Changes in the Annual and Growing-Season Weather

Changes in soil chemical, physical and biological properties are greatly influenced by the fluctuations in the weather such as growing-season evapotranspiration and rainfall and annual precipitation (Figure 3). These changes affect air-to-water ratio in soil pores, how much water is available to plants versus free (gravitational) water, groundwater depths and capillary rise/movement of soil water just to name a few. However, considering the main objectives of the research trial, this report will focus the effects of changes in weather on groundwater depths and capillary rise/movement of soil water.

Figure 3. Annual growing-season potential evapotranspiration (Penman), actual rainfall and normal rainfall in inches measured from May 1 to October 31 and annual precipitation measured from January 1 to December 31.

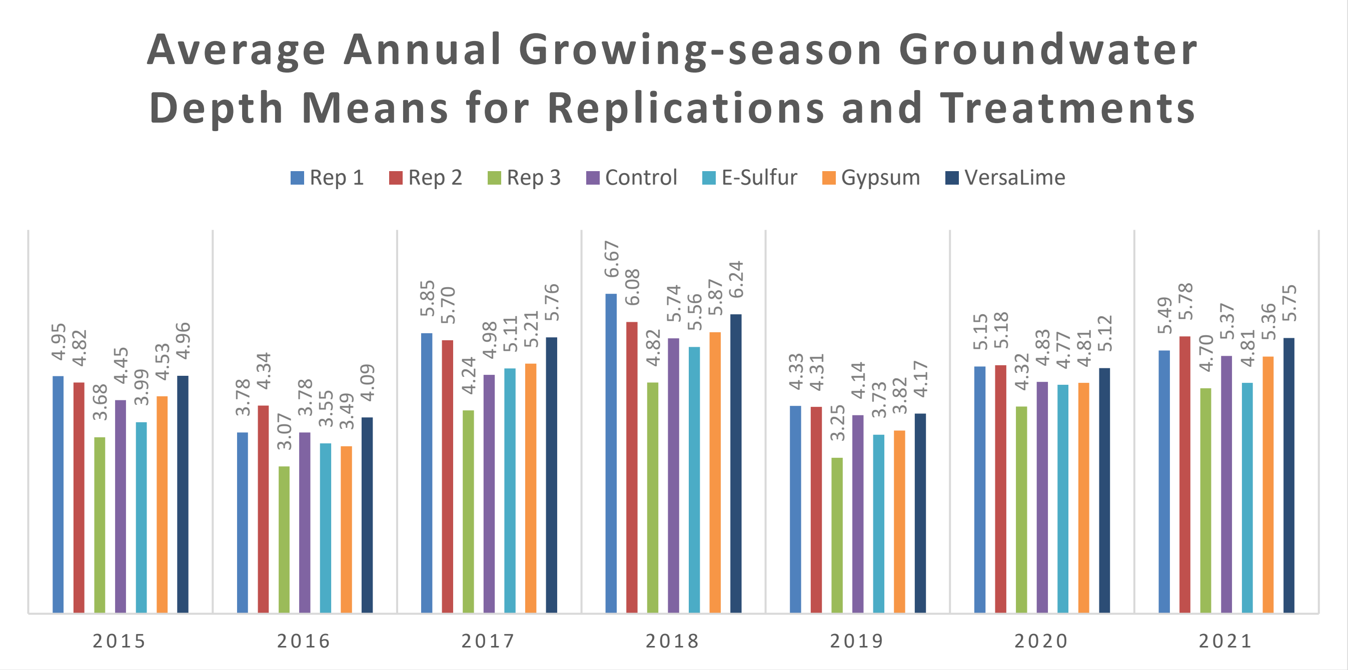


A wider gap between growing-season evapotranspiration and actual rainfall generally will result in increased capillary rise of soil water and less leaching of soluble salts. A narrower gap between them could result in shallower groundwater depths, however, under good soil water infiltration and improved drainage, excess salts can be moved out of the topsoil or affected fields. In addition, a narrower gap between growing-season evapotranspiration and actual rainfall generally could result in reduced capillary rise of soil water (wicking up). In 2016, the gap between evapotranspiration and rainfall was narrow, site was tiled and the soil water infiltration was still decent as higher levels of soluble salts were neutralizing the dispersion caused by sodicity. That resulted in the highest decrease in soil salt levels since the site has been tiled in 2014. In 2017, there was an increase in soil salt levels compared to 2016, which could be a result of increased capillary rise of soil water due to a wider gap between annual evapotranspiration and actual rainfall despite tiled-land. That trend continued in 2018, 2019, 2020 and 2021.

Since annual precipitation includes snow along with other forms of water (liquid or solid), it is important to note that not all snow will turn into liquid water after melting. Depending upon how dry or wet snow is, there is a wide range for calculating how many inches of snow will actually melt into one inch of water.

Figure 4 below has the average annual growing-season groundwater depth means for replications and treatments for 2015, 2016, 2017, 2018, 2019, 2020 and 2021. The means of groundwater depths represent actual annual measurements of groundwater depths measured from May 1 to October 31 on a weekly basis.

Figure 4. Annual means of average growing-season groundwater depths for replications and treatments in feet.



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

The 2016 groundwater depths were shallower than the depths in 2015, 2017, 2018, 2019, 2020 and 2021, whereas, the 2018 groundwater depths were the deepest versus rest of the years. Replication 3 had significantly shallower annual groundwater depths compared to replication 1 and 2 during all years.

These fluctuations in the groundwater depths are also reflective of a very wet 2016 versus drier weather in 2017, 2018 and 2020 and early parts of the 2019 and 2021 growing-seasons. It is also important to look at the overall annual data from the perspective of early and late growing-seasons as they can vary significantly. In 2019, weather was dry until July 30th. From July 31st, it started getting wet. The NDSU Langdon Research Extension Center, NDAWN Station recorded 5.88 inches of rainfall versus a normal of 9.71 inches from May 1st to July 30th of 2019. The Total Potential Evapotranspiration (Penman) for the same period was 21.44 inches. 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 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 serious harvest issues. Same pattern was observed in 2021 when Langdon NDAWN Station recorded 6.44 inches of rain versus a normal of 11.51 inches from April 1st to August 8th. Whereas, same Station recorded 10.22 inches of rain versus a normal of 5.17 inches from August 9th to October 31st.

Soil Textural Analysis Results

Soil textural analysis results are shown in Table 2. Based on the results in Table 2, all of the samples either had clay or clay loam texture except 0-12 inch depth of R1T1 sample. Details of the sand, silt, clay percent and the textural class of each treatment (plot) and depth are in Table 2.

Table 2. Details of the soil textural classes of each plot from zero to four-foot depth in 12-inch increments.

Treatments and Replications	Depths (inches)	Sand (%)	Silt (%)	Clay (%)	Soil Texture

R1T1 (101)	0-12	14	40	46	Silty Clay
	12-24	12	38	56	Clay
	24-36	16	36	48	Clay
	36-48	27	39	34	Clay Loam
R1T2 (102)	0-12	18	34	48	Clay
	12-24	17	33	50	Clay
	24-36	25	31	44	Clay
	36-48	40	28	32	Clay Loam
R1T3 (103)	0-12	20	38	42	Clay
	12-24	24	30	46	Clay
	24-36	27	31	42	Clay
	36-48	32	32	36	Clay Loam
R1T4 (104)	0-12	24	32	44	Clay
	12-24	26	24	50	Clay
	24-36	32	30	38	Clay Loam
	36-48”	41	29	30	Clay Loam
R2T1 (201)	0-12	26	33	41	Clay
	12-24	20	34	46	Clay
	24-36	33	29	38	Clay Loam
	36-48	36	29	35	Clay Loam
R2T2 (202)	0-12	26	34	40	Clay Loam
	12-24	24	27	49	Clay
	24-36	23	34	43	Clay
	36-48	40	30	30	Clay Loam
R2T3 (203)	0-12	26	34	40	Clay Loam
	12-24	28	26	46	Clay
	24-36	20	36	44	Clay
	36-48	28	36	36	Clay Loam
R2T4 (204)	0-12	24	34	42	Clay
	12-24	24	31	45	Clay
	24-36	34	30	36	Clay Loam
	36-48	38	34	28	Clay Loam
R3T1 (301)	0-12	26	36	38	Clay Loam
	12-24	23	31	46	Clay
	24-36	28	32	40	Clay Loam
	36-48	45	27	28	Clay Loam
R3T2 (302)	0-12	20	36	44	Clay
	12-24	20	32	48	Clay
	24-36	24	28	48	Clay
	36-48	24	31	45	Clay
R3T3 (303)	0-12	18	38	44	Clay
	12-24	14	29	57	Clay
	24-36	21	37	42	Clay
	36-48	24	33	43	Clay
R3T4 (304)	0-12	26	38	36	Clay Loam
	12-24	20	32	48	Clay
	24-36	23	27	50	Clay
	36-48	20	39	41	Clay

Changes in Soil Chemical and Physical Properties

The findings below are based on the statistical analysis of the soil chemical properties analyzed in 2014, 2016, 2017, 2018, 2019, 2020 and 2021 and soil physical properties measured in 2015, 2016, 2017, 2018, 2019, 2020 and 2021. That was done to compare the differences in soil chemical properties due to the effects of treatments (soil amendments). In addition, effects of annual growing-season rainfall and potential evapotranspiration (Penman) and resulting average annual growing-season groundwater depths measured during May to October on a weekly basis were noted for any change in the soil chemical properties. For the soil physical properties, differences were compared due to the effects of treatments (soil amendments) and the available soil moisture levels measured as the gravimetric soil water content at the time of bulk density sampling or penetrometer resistance measurements. For both comparisons, SAS package 9.4 was used at 95% confidence interval. The treatment means of EC, SAR, pH, NO_3-N, soil water saturation, CCE, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+ represent annual results of three replications for the zero to four-foot depths. The treatment means of P and O.M. represent annual results of three replications for zero to two-foot depths, whereas, the treatment means of CEC represent annual results of three replications for zero to one-foot depths. The treatment means of soil bulk density represent annual results of three replications for zero to ten-inch depths. The treatment means of soil penetrometer resistance represent annual results of three replications for zero to eighteen-inch depths. The treatment means of groundwater depths represent annual results of three replications measured for zero to seven and a half-foot depth.

Soil Chemical Analysis Results at the Time of Tiling (2014)

At the time of tiling in 2014, all treatments (plots) had moderately high EC levels with control treatments having the lowest levels (mean = 7.39 dS/m) and gypsum treatments having the highest levels (mean = 9.58 dS/m).

Table 3. The treatment means of the soil chemical properties at the time of tiling (2014) and before the application of soil amendments.

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
NO_3^--N (pounds/acre)	33.16	33.83	26.00	34.66
P (ppm)	13.50	12.33	14.00	13.50
O.M. (%)	3.61	3.73	3.55	3.25
CEC (meq/100 g of soil)	42.70	47.20	44.93	39.96
Soil Water Saturation (%)	69.41	79.77	80.26	69.90
CCE (%)	7.25	8.90	9.35	9.75
HCO_3^- (mg/L)	105.97	110.64	104.44	103.93
Cl^- (mg/L)	123.30	88.71	89.62	67.76
SO_4^{2-} (mg/L)	4398.51	5439.34	5476.92	5622.24
Ca^{2+} (mg/L)	508.58	422.41	529.08	578.25
Mg^{2+} (mg/L)	189.25	215.08	218.91	209.33
Na^+ (mg/L)	1280.00	1807.50	1694.16	1710.83
K^+ (mg/L)	6.75	6.83	6.75	7.16

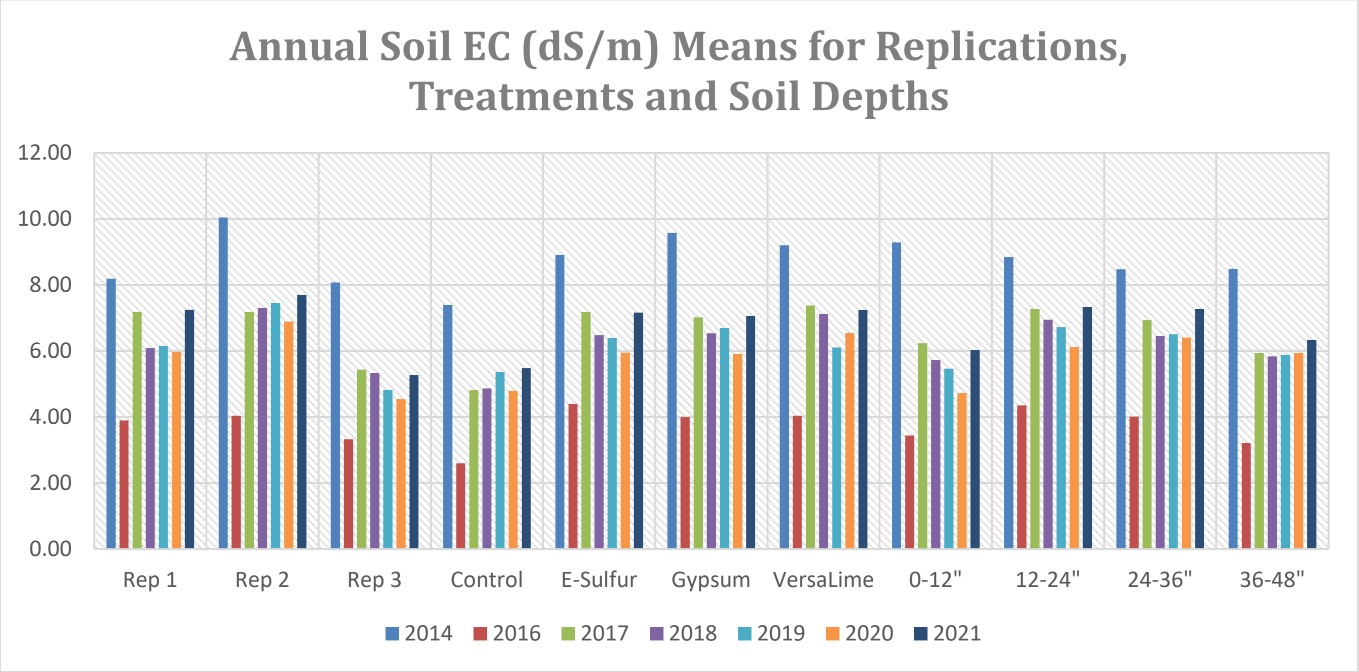
The soil SAR levels in all of the treatments were high to very high with control treatments having the lowest levels (mean = 12.58) and gypsum treatments having the highest levels (mean = 18.36). Soil pH of all treatments were close to neutral. Soil NO_3^--N and P levels were moderate, whereas O.M. levels were moderately high in all treatments. Soil CEC and saturation % were in the higher range in all treatments. Among anions, SO_4^{2-} levels were very high followed by HCO_3^- and Cl^-. The CCE % levels also remained high. For major cations, Na^+ levels remained the highest followed by Ca^{2+}, Mg^{2+} and K^+. Details are in Table 3.

Changes in Soil Chemical Properties

Differences in Soil Electrical Conductivity (EC) Levels

Statistically, there were significant differences in the annual soil EC (dS/m) levels in replications, treatments and soil depths (Figure 5).

Figure 5. Annual soil EC (dS/m) means for replications, treatments and soil depths.



At the time of tiling in 2014, replication 2 had significantly higher EC levels compared to replications 1 and 3. Overall, EC levels in all three replications remained high in 2014 versus rest of the years, whereas, 2016 EC levels were the lowest in all replications versus the EC levels during 2014, 2017, 2018, 2019, 2020 and 2021.

In 2014, Gypsum and VersaLime treatments had significantly higher EC levels compared to control, which also had numerically lower EC levels compared to E-Sulfur treatment. The 2016 EC levels in control treatment decreased significantly versus EC levels in all treatments in 2014, 2017, 2018, 2019, 2020 and 2021. In addition, 2016 gypsum and VersaLime treatments had significantly lower EC levels compared to all treatments in 2014 and gypsum, VersaLime and E-sulfur treatments in 2017-2021. Overall, EC levels in all treatments were high in 2014 and low in 2016. Despite decrease in 2016, EC levels increased back in 2017 and that trend continued in 2018, 2019, 2020 and 2021 due to drier weather and resulting capillary rise (wicking up) of soil water.

In 2014, 0-12 inch soil depth had the highest EC levels versus all depths in 2016-2021. In addition, in 2014, EC levels in the 0-12 inch depth were numerically highest followed by 12-24, 36-48 and 24-36 inch soil depths. In 2016-2021, highest EC levels were recorded in 12-24 inch depths followed by 24-36-inch depths, whereas, in 2018-2021 highest EC levels were recorded in the order of 12-24, 24-36, 36-48 and 0-12 inch depths. Overall, like replications and treatments, EC levels in all soil depths in 2014 were higher than rest of the years, whereas, 2016 EC levels were the lowest in all soil depths.

There were also some interesting effects of annual growing-season rainfall and total potential evapotranspiration (Penman) on resulting average annual growing-season groundwater depths and potential capillary water rise/movement on soil EC levels. (Figure 3 and 4).

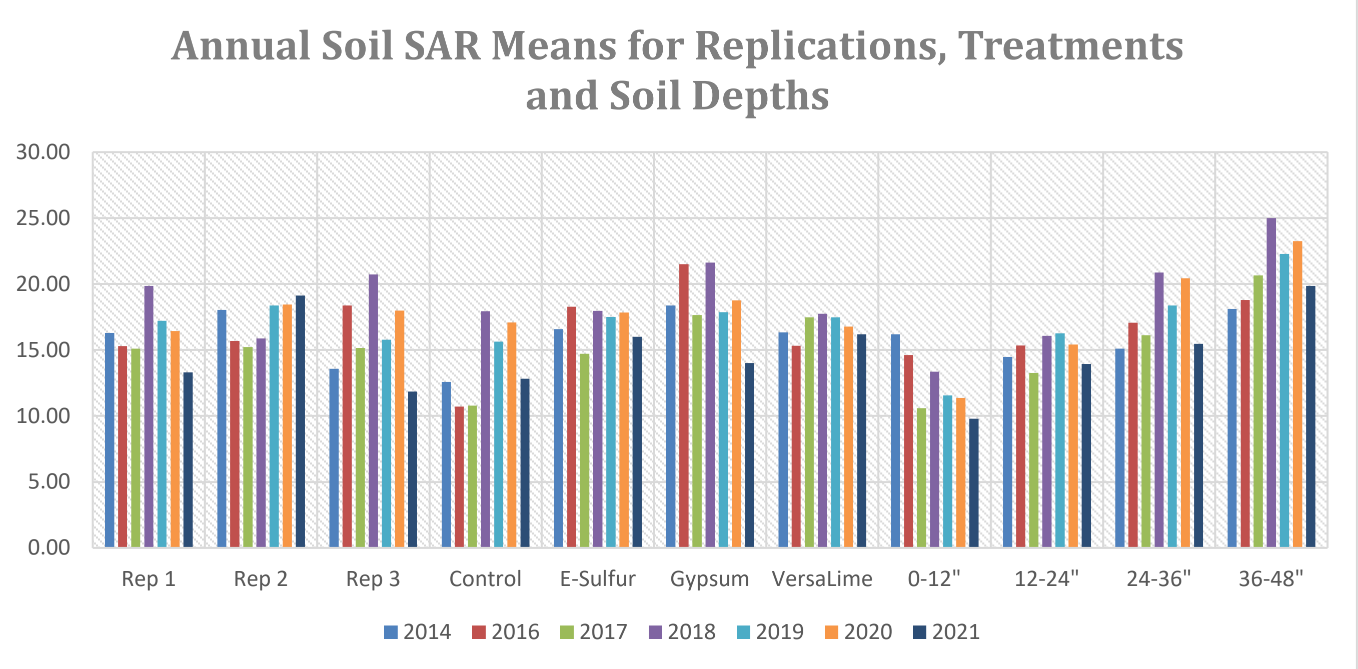
The 2016 EC levels were lower than the EC levels in 2014, 2017, 2018, 2019, 2020 and 2021 because of the highest annual growing-season rainfall (23.11 inches) under shallowest average annual growing-season groundwater depths (Figure 4). The average annual growing-season groundwater depths lowered in 2017, 2018, 2020 and 2021 compared to 2016 due to the drier weather, which also resulted in increased capillary rise of soil water and higher EC levels. The lower groundwater depth trend continued in 2019 during early part of the growing-season. However, weather started getting wet later in the season and 5.87 inches of rain was recorded during September versus a normal of 1.81 inches. Overall, 9.74 inches of rain was recorded between July 31st and October 5th versus a normal of 4.76 inches.

Overall, EC levels remained the highest in 2014 followed by 2021, 2017, 2018, 2019, 2020 and 2016, replication 2 had the highest EC levels followed by replications 1 and 3, VersaLime treatment had the highest levels followed by gypsum, E-sulfur and control treatments and 12-24 inch soil depth had the highest EC levels followed by 24-36 inch, 36-48 inch and 0-12 inch depths.

Differences in Soil Sodium Adsorption Ratio (SAR) Levels

Statistically, there were significant differences in the annual soil SAR (sodicity) levels in treatments and soil depths (Figure 6).

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



At the time of tiling (2014), gypsum treatment had significantly higher SAR levels versus control treatment. After tiling, gypsum treatment in 2018 had significantly higher SAR levels versus control treatment in 2014, 2016, 2017, 2019 and 2021, gypsum treatment in 2021, VersaLime treatment in 2014, 2016, 2020 and 2021 and E-sulfur treatment in 2014, 2017 and 2021. In addition, gypsum treatment in 2016, had significantly higher SAR levels versus control treatment in 2014, 2016, 2017, 2019 and 2021, gypsum treatment in 2021, VersaLime treatment in 2014, 2016, and 2021 and E-sulfur treatment in 2014, 2017 and 2021. Also, control treatments in 2016 and 2017 had significantly lower SAR levels versus rest of the treatments in all years except control in 2014 and 2021, gypsum in 2021, VersaLime in 2016 and E-sulfur in 2017.

Except 2014 (at the time of tiling), there was a consistent trend in SAR levels for soil depths in 2016-2021 and SAR levels increased with soil depths. The 36-48 inch depth in 2018 had significantly higher SAR levels all depths in all years except 24-36 inch depth in 2018 and 36-48 inch depth in 2019 and 2020. In addition, 24-36 inch depth in 2018 and 2020 and 36-48 inch depth in 2017-2020 had significantly higher SAR levels versus 0-12 and 12-24 inch depths in 2014-2021 and 24-36 inch depth in 2014, 2017 and 2021.

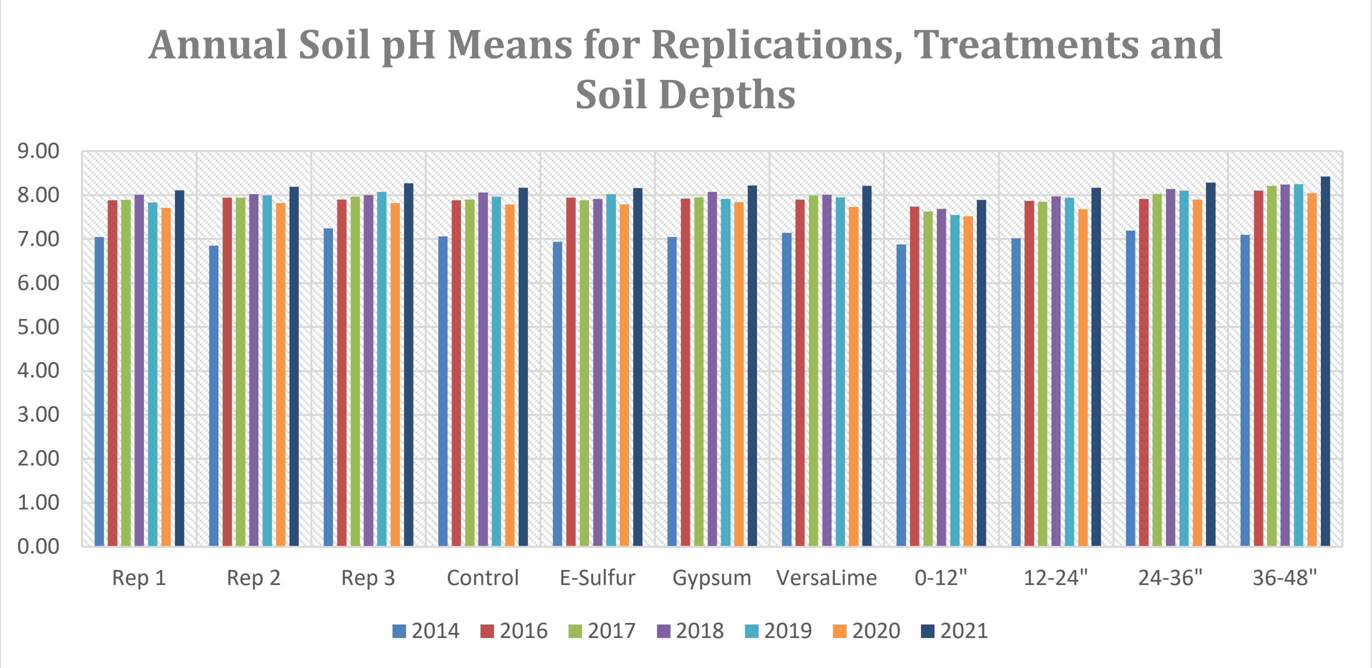
Unlike soil EC, there were no noticeable effects of annual growing-season rainfall and potential evapotranspiration (Penman) on resulting average annual growing-season groundwater depths and capillary water rise/movement on soil SAR levels.

Overall, highest SAR levels were recorded in 2018 followed by 2020, 2019, 2016, 2014, 2017 and 2021, replication 2 had the highest SAR levels followed by replications 3 and 1, gypsum treatment had the highest levels followed by E-sulfur, VersaLime and control treatments and 36-48 inch soil depth had the highest SAR levels followed by 24-36 inch, 12-24 inch and 0-12 inch depths.

Differences in Soil pH Levels

Statistically, there were significant differences in the annual soil pH levels in replications, treatments and soil depths (Figure 7).

Figure 7. Annual soil pH means for replications, treatments and soil depths.



At the time of tiling (2014) all of the replications had significantly lower pH levels versus the pH levels in all three replications in 2016-2021. 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 when samples were taken in June.

Similarly, 2014 pH levels of all treatments were lower versus all treatments in 2016-2021. Again, that could be attributed to the lower soil moisture levels at the time of sampling (September 2014) compared to rest of the years. In addition, 2021 pH levels in all treatments were significantly higher than the control treatments in 2014, 2016, 2017 and 2020, gypsum treatment in 2014, 2016, 2019 and 2020, VersaLime treatment in 2014, 2016 and 2020 and E-sulfur treatment in 2014, 2017, 2018 and 2020.

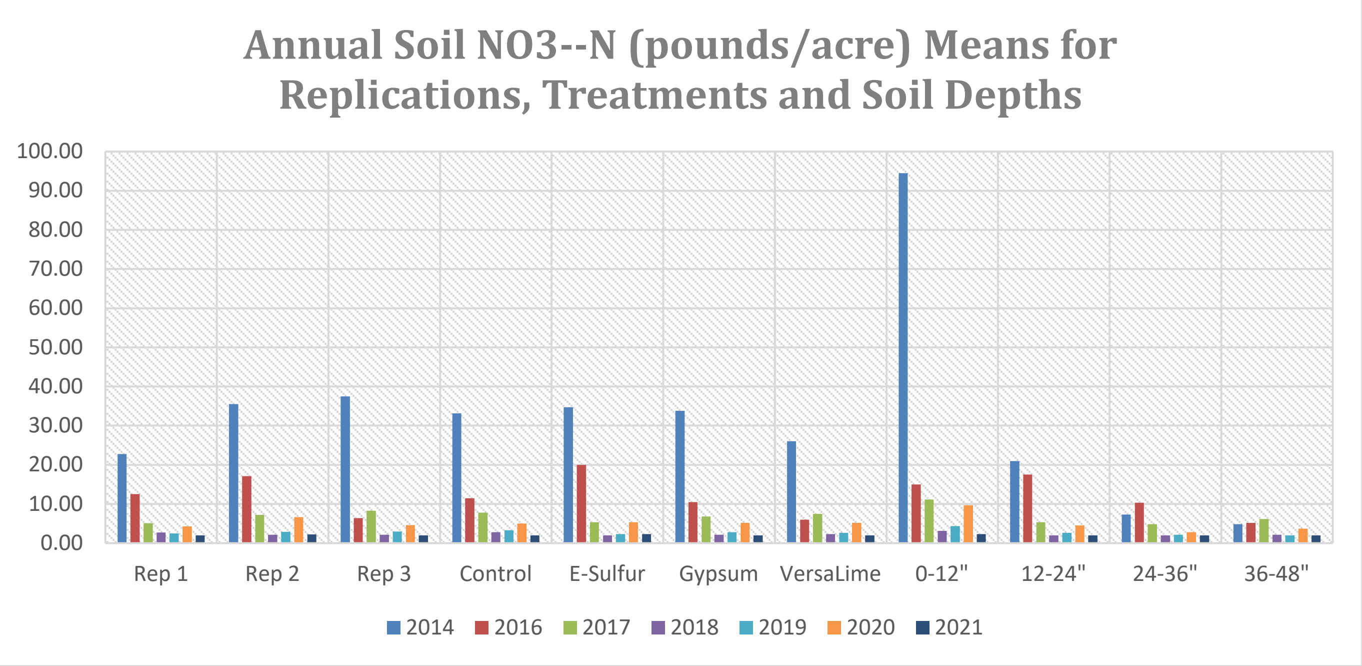
An identical trend was observed in soil pH levels for soil depths like SAR as overall annual pH increased with soil depth. The 2018, 2019 and 2021 pH levels in 36-48 inch depth and 2021 pH in the 24-36 inch depth were significantly higher than the levels in rest of the depths in 2014-2021. In addition, 2014 pH levels in all depths were significantly lower than all depths in 2016-2021. Since soil moisture levels had a prominent effect on soil pH, annual growing-season rainfall and potential evapotranspiration (Penman) and resulting groundwater depths and capillary water movement also had an effect on soil pH.

Overall, pH levels remained the highest in 2021 followed by 2018, 2019, 2017, 2016, 2020 and 2014 and replication 3 had the highest pH levels followed by replications 2 and 1. That is again a trend as generally, replication 3 has the shallowest average annual growing-season groundwater depths followed by replications 2 and 1 every year. The VersaLime and gypsum treatments had the highest pH levels followed by control and E-sulfur treatments and 36-48 inch soil depth had the highest pH levels followed by 24-36 inch, 12-24 inch and 0-12 inch depths.

Differences in Soil Nitrate-Nitrogen ($NO_3^{-}N$) Levels

Statistically, there were significant differences in the annual soil NO_3^--N (pounds/acre) levels in replications, treatments and soil depths (Figure 8).

Figure 8. Annual soil NO_3^--N (pounds/acre) means for replications, treatments and soil depths.



The 2014 (at the time of tiling) soil NO_3^--N levels in replications 3 and 2 were significantly higher than replication 1 in 2014 and all of the replications in 2016-2021. In addition, replication 1 in 2014 had significantly higher NO_3^--N levels versus replication 3 in 2016 and all replications in 2017-2021.

The 2014 soil NO_3^--N levels in all treatments were significantly higher than the levels in control, gypsum and VersaLime treatments in 2016 and all treatments in 2017-2021. In addition, E-sulfur treatment in 2016 had significantly higher NO_3^--N levels versus VersaLime treatment in 2016, E-sulfur treatment in 2017 and all treatments in 2018-2021.

At the time of tiling (2014), 0-12 inch soil depth had significantly higher NO_3^--N levels versus 12-24, 24-36 and 36-48 inch depths in 2014 and all of the depths in 2016-2021. In addition, 12-24 inch depth in 2014 had significantly higher NO_3^--N levels versus 24-36 and 36-48 inch depths in 2014 and 2016, and all depths in 2017-2021.

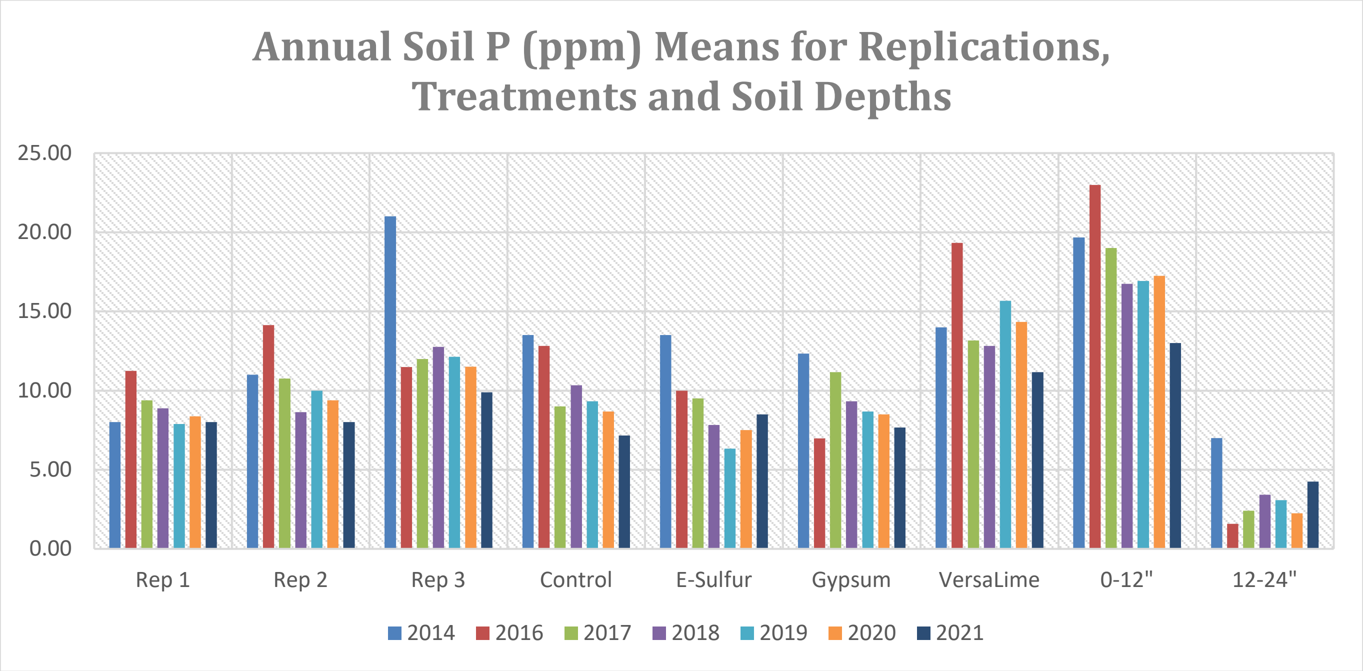
Higher NO_3^--N levels prior to tiling (2014), could be due to the annual fertilization this site received at the time of planting. In addition, a steady decline in soil NO_3^--N levels may also be due to leaching, removal by the perennial grass mix and no application since 2014. Since NO_3^--N is very susceptible to leaching, annual growing-season rainfall and resulting average annual growing-season groundwater depths may also have prominent effects on NO_3^--N levels.

Overall, NO_3^--N levels remained the highest in 2014 followed by 2016, 2017, 2020, 2019, 2018 and 2021, replication 2 had the highest NO_3^--N levels followed by replications 3 and 1, E-sulfur treatment had the highest levels followed by control, gypsum and VersaLime treatments and 0-12 inch soil depth had the highest NO_3^--N levels followed by 12-24 inch, 24-36 inch and 36-48 inch depths.

Differences in Soil Phosphorous (P) Levels

Differences in soil P (ppm) levels are shown in Figure 9. Statistically, there were significant differences in the annual soil P (ppm) levels in soil depths only.

Figure 9. Annual soil P (ppm) means for replications, treatments and soil depths.



The 0-12 inch soil depth had significantly higher P levels versus 12-24 inch depth in all years. In addition, 0-12 inch depth in 2014 2016 had significantly higher P levels versus 12-24 inch depth in 2016.

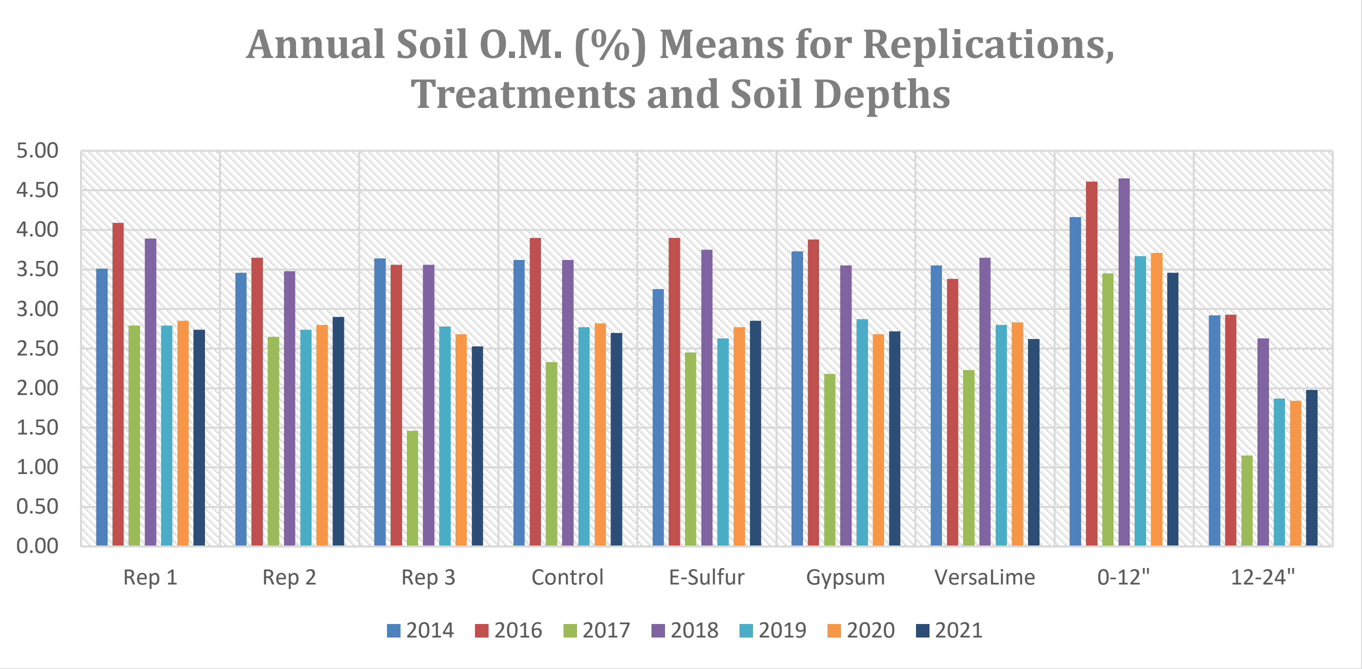
Overall, P levels remained the highest in 2014 followed by 2016, 2017, 2018, 2019, 2020 and 2021, replication 3 had the highest P levels followed by replications 2 and 1, VersaLime treatment had the highest levels followed by control, gypsum and E-sulfur treatments and 0-12 inch soil depth had the highest P levels followed by 12-24 inch depth.

It is also important to note that like nitrogen, no phosphate fertilizer has been applied to the site since 2014. Before 2014, site was planted with annual crops and chemical fertilizers were applied annually. That is evident from a steady decline in soil P levels every year.

Differences in Soil Organic Matter Percent (SOM) Levels

Soil organic matter (%) levels are shown in Figure 10. Statistically, there were significant differences in the annual O.M. levels in replications and soil depths.

Figure 10. Annual soil O.M. (%) means for replications, treatments and soil depths.



In 2016, replication 1 had significantly higher O.M. levels versus replications 1, 2 and 3 in 2017, 2019, 2020 and 2021. In addition, replication 1 in 2018 had significantly higher O.M. levels versus replications 1 and 3 in 2017, 2019, 2020 and 2021 and replication 2 in 2017, 2019 and 2020.

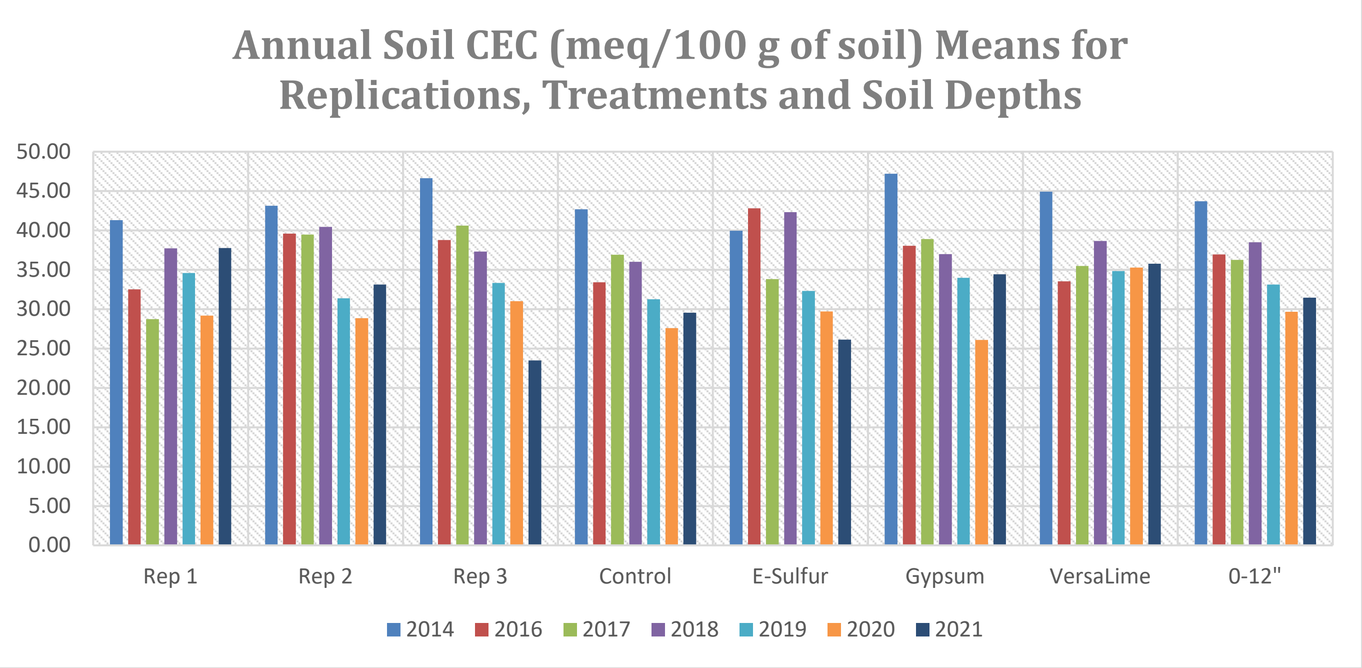
The 0-12 inch soil depth had significantly higher O.M. levels than the 12-24 inch depth in 2014-2021. There were also some significant differences in the annual O.M. levels within the 0-12 inch depth. The 2016 and 2018 O.M. levels in in the 0-12 inch soil depth were significantly higher than the levels in 0-12 inch depth in 2014, 2017, 2019, 2020 and 2021. In addition, 2016 O.M. levels in 12-24 inch soil depth were significantly higher than the levels in the same depth in 2017, 2019, 2020 and 2021.

Overall, O.M. levels remained the highest in 2016 followed by 2018, 2014, 2020, 2019, 2021 and 2017, replication 1 had higher O.M. levels followed by replication 2 and 3, control treatments had the highest levels followed by E-sulfur, gypsum and VersaLime treatments and 0-12 inch soil depth had the highest O.M. levels followed by 12-24 inch depth.

Differences in Soil Cation Exchange Capacity (CEC) Levels

Soil cation exchange capacity (meq/100 g of soil) levels are shown in Figure 11. Statistically, there were significant differences in the annual soil CEC levels in replications and in the 0-12 inch soil depth.

Figure 11. Annual soil CEC (meq/100 g of soil) means for replications, treatments and soil depths.



Replication 3 in 2014 had significantly higher CEC levels versus replication 1 in 2016-2020, replication 2 in 2019-2021 and replication 3 in 2018-2021. In addition, replication 2 in 2014 had significantly higher CEC levels versus replication 1 in 2016, 2017 and 2020 and replications 2 and 3 in 2019-2021.

The 0-12 inch soil depth in 2014 had significantly higher CEC levels versus CEC levels in 2016, 2017, 2019, 2020 and 2021. In addition, 2018 CEC levels were significantly higher than the levels in 2020 and 2021.

Overall, CEC levels remained the highest in 2014 followed by 2018, 2016, 2017, 2019, 2021 and 2020, replication 2 had the highest CEC levels followed by replications 3 and 1 and VersaLime treatment had the highest levels followed by gypsum, E-sulfur and control treatments.

Differences in Soil Water Saturation Percent Levels

Soil water saturation (%) levels are shown in Figure 12. Statistically, there were significant differences in the annual soil water saturation levels in replications, treatments and soil depths.

Replication 1 in 2018 had significantly higher soil water saturation levels versus replication 1 in 2014, 2017, 2019, 2020 and 2021, replication 2 in 2014-2021 and replication 3 in 2016, 2020 and 2021. In addition, replication 3 in 2014 and 2018 had significantly higher soil water saturation levels versus replication 1 in 2014, 2017, 2019, 2020 and 2021, replication 2 in 2014, 2016, 2019, 2020 and 2021 and replication 3 in 2016 and 2020.

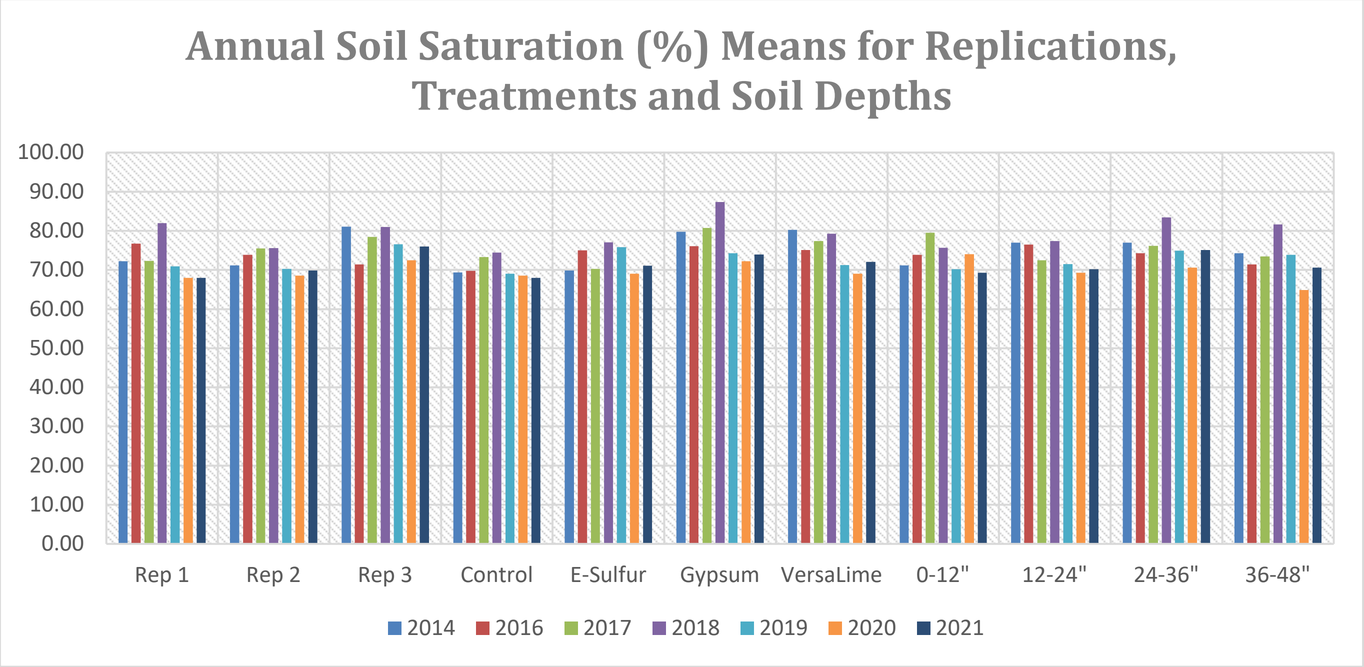
The soil water saturation levels in gypsum treatment in 2018 were significantly higher than the levels in control, E-sulfur, gypsum and VersaLime treatments in 2018 and all four treatments in 2014-2021. In addition, gypsum treatment in 2017 had significantly higher soil water saturation levels than control treatment in 2014-2017 and 2019-2021, E-sulfur treatment in 2014, 2017, 2020 and 2021, gypsum treatment in 2020-2021 and VersaLime treatment in 2019-2021.

The 24-36 inch soil depth in 2018 had significantly higher soil water saturation levels than the levels in 0-12 inch depth in 2014, 2016 and 2018-2021, 12-24 and 24-36 inch depths in 2016, 2017, 2019-2021and 36-48 inch depth in 2014-2017 and 2019-2021. In addition 36-48 inch depth in 2018 had significantly higher levels versus the levels in

0-12 inch depth in 2014, 2016 and 2019-2021, 12-24 inch depth in 2017, 2019-2021, 24-36 inch depth in 2016 and 2020 and 36-48 inch depth in 2014-2017 and 2019-2021.

Overall, soil water saturation levels remained the highest in 2018 followed by 2017 and 2014, 2016, 2019, 2021 and 2020, replication 3 had the highest saturation levels followed by replications 1 and 2, gypsum treatment had the highest levels followed by VersaLime, E-sulfur and control treatments and 24-36 inch soil depth had the highest soil water saturation levels followed by 12-24, 0-12 and 36-48 inch depths.

Figure 12. Annual soil saturation (%) means for replications, treatments and soil depths.



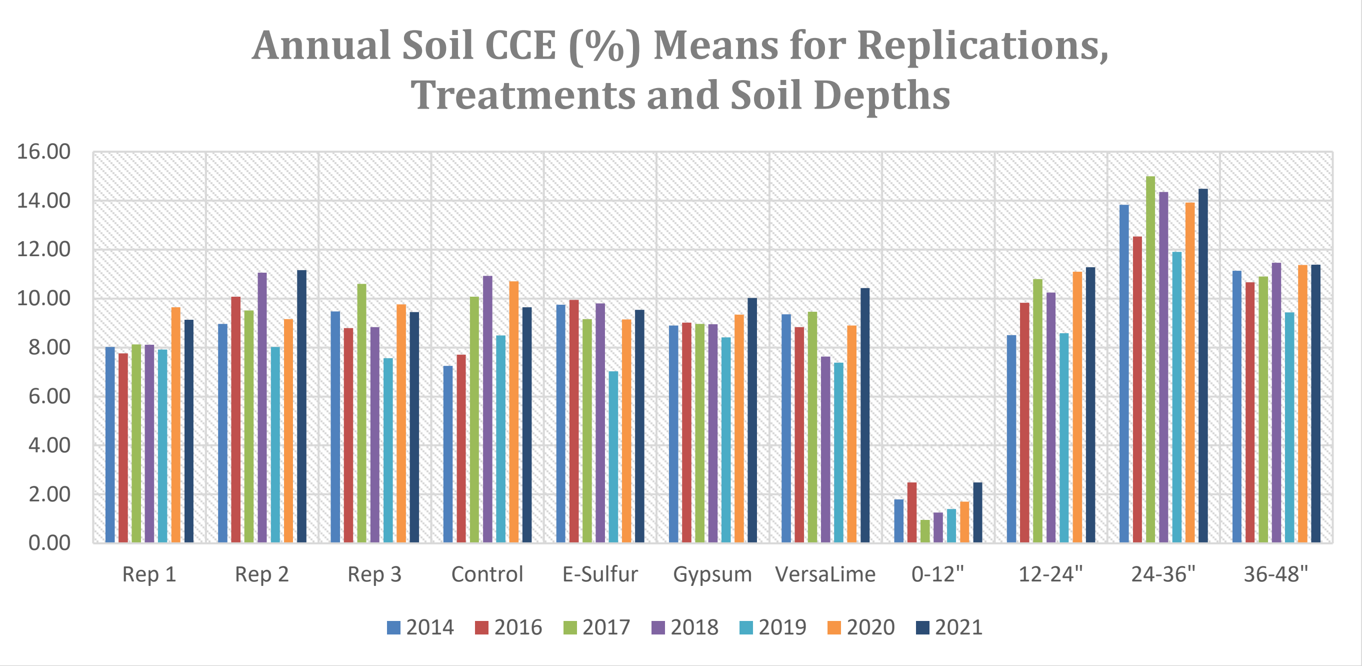
Differences in Soil Calcium Carbonate Equivalent Percent (CCE) Levels

Soil calcium carbonate equivalent (%) levels are shown in Figure 13. Statistically, there were significant differences in the annual soil CCE levels in soil depths.

The soil calcium carbonate equivalent levels in the 0-12 inch depth in 2014-2021 remained significantly lower than the levels in rest of the soil depths. In addition, 24-36 inch soil depth in 2017 had significantly higher CCE levels versus 0-12, 12-24 and 36-48 inch depths in 2014-2021 and 24-36 inch depth in 2019.

Overall, soil calcium carbonate equivalent remained the highest in 2021 followed by 2020, 2017, 2018, 2016, 2014 and 2019, replications 2 had the highest CCE levels followed by replication 3 and 1, control treatment had higher CCE levels followed by E-sulfur, gypsum and VersaLime treatments and 24-36 inch soil depth had the highest CCE levels followed by 36-48 inch, 12-24 inch and 0-12 inch soil depths.

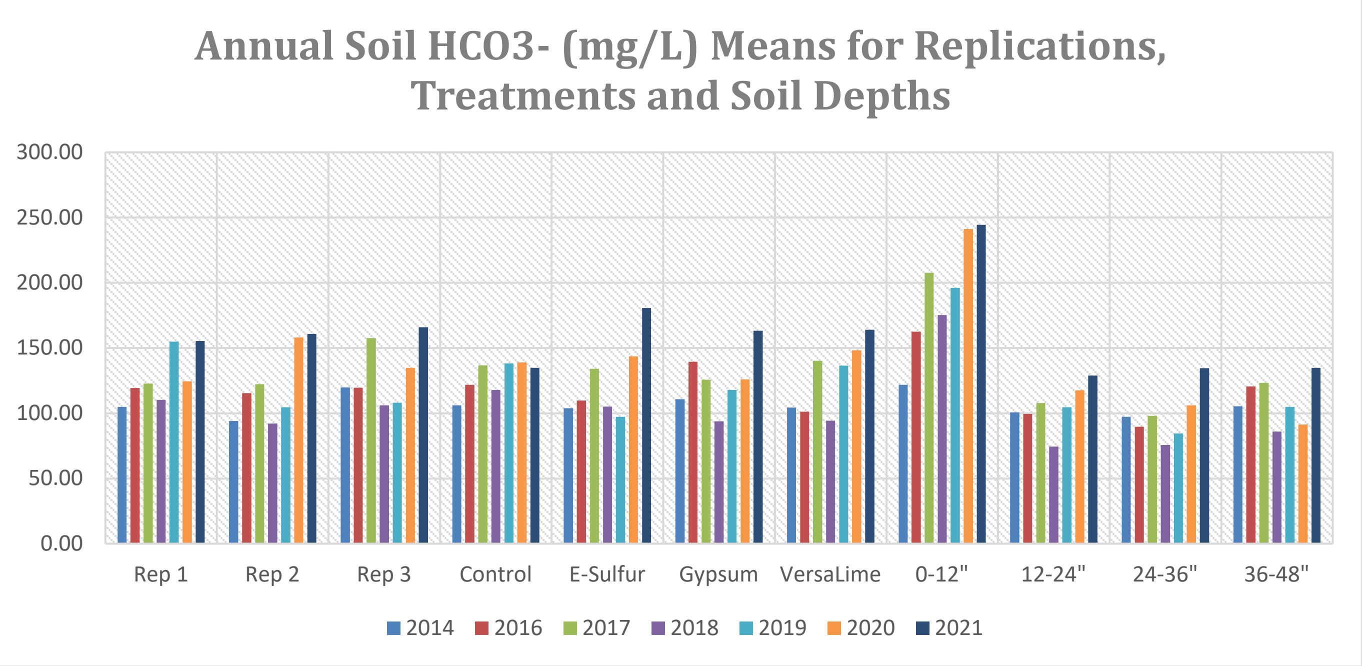
Figure 13. Annual soil CCE (%) means for replications, treatments and soil depths.



Differences in Soil Bicarbonate (HCO_3^-) Levels

Soil bicarbonate (mg/L) levels are shown in Figure 14. Statistically, there were significant differences in the annual HCO_3^- levels in replications and soil depths.

Figure 14. Annual soil HCO_3^- (mg/L) means for replications, treatments and soil depths.



Replication 3 in 2021 had significantly higher soil HCO_3^- levels versus replication 1 in 2014-2018, replication 2 in 2014-2019 and replication 3 in 2014, 2016, 2018 and 2019. In addition, replication 2 in 2021 had significantly higher HCO_3^- levels versus replication 1 in 2014 and 2018, replication 2 in 2014, 2016, 2018 and 2019 and replication 3 in 2018 and 2019.

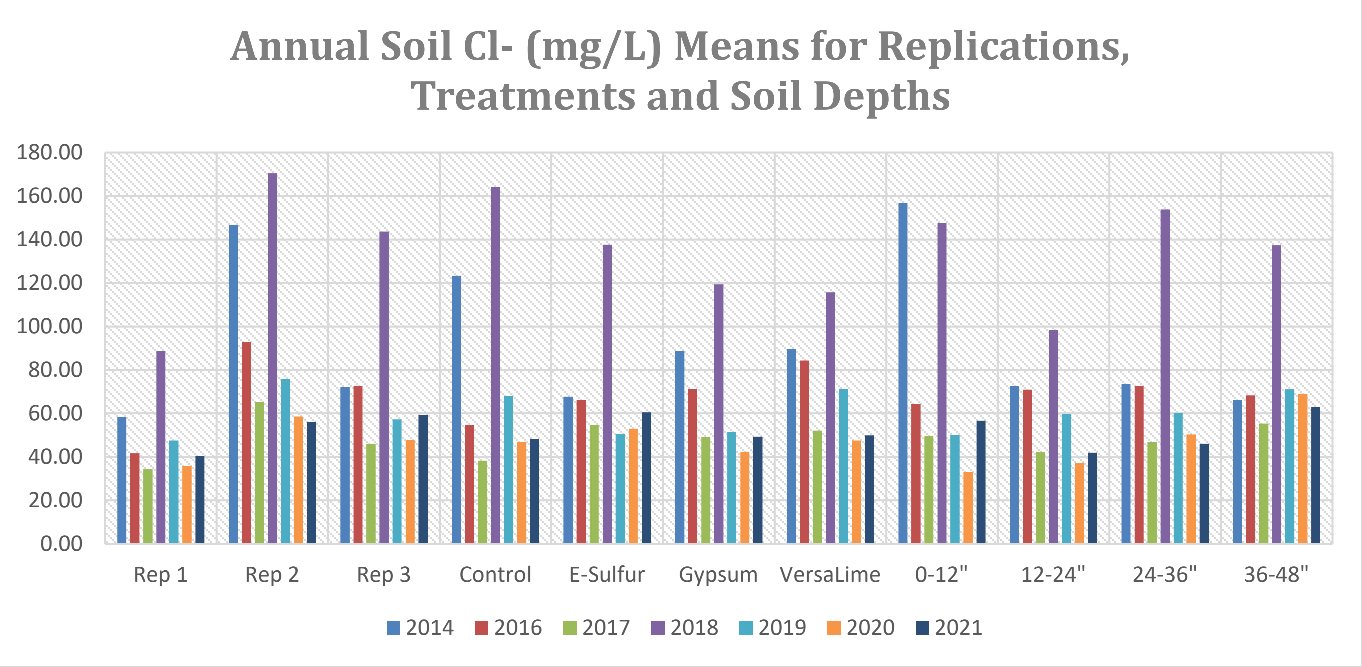
The 0-12 inch soil depth in 2020 and 2021 had significantly higher soil HCO_3^- levels versus 0-12 inch depth in 2014, 2016, 2018 and 2019 and 12-24, 24-36 and 36-48 inch depths in 2014-2021. In addition, 0-12 inch depth in 2017 had significantly higher soil HCO_3^- levels versus 0-12 inch depth in 2014 and 2016 and 12-24, 24-36 and 36-48 inch depths in 2014-2021.

Overall, soil HCO_3^- levels remained the highest in 2021 followed by 2020, 2017, 2019, 2016, 2014 and 2018, replication 3 had the highest HCO_3^- levels followed by replications 1 and 2, control treatment had the highest levels followed by VersaLime, gypsum, and E-sulfur treatments and 0-12 inch soil depth had the highest HCO_3^- levels followed by 36-48 inch, 12-24 inch and 24-36 inch depths.

Differences in Soil Chloride (Cl^-) Levels

Soil chloride (mg/L) levels are shown in Figure 15. Statistically, there were significant differences in the annual Cl^- levels in replications, treatments and soil depths.

Figure 15. Annual soil Cl^- (mg/L) means for replications, treatments and soil depths.



Replication 2 in 2014 and 2018 and replication 3 in 2018 had significantly higher soil Cl^- levels than replication 1 in 2014-2021, replication 2 in 2016-2017 and 2019-2021 and replication 3 in 2014-2017 and 2019-2021. In addition, replication 2 in 2016 had significantly higher Cl^- levels than replication 1 in 2016, 2017 and 2019-2021 and replication 3 in 2017 and 2020.

The control treatment in 2018 had significantly higher soil Cl^- levels versus control treatment in 2016, 2017 and 2019-2021 and E-sulfur, gypsum and VersaLime treatments in 2014-2017 and 2019-2021. In addition, E-sulfur treatment in 2018 had significantly higher soil Cl^- levels versus control, gypsum and VersaLime treatments in 2016, 2017 and 2019-2021 and E-sulfur treatment in 2014-2017 and 2019-2021.

The 0-12 soil depth in 2014 and 24-36 inch depth in 2018 had significantly higher soil Cl^- levels versus 0-12 inch depth in 2016, 2017 and 2019-2021, 12-24 inch depth in 2014-2021 and 24-36 and 36-48 inch depths in 2014-2017 and 2019-2021. In addition, 0-12 and 36-48 inch depths in 2018 had significantly higher soil Cl^- levels compared to 0-12 inch depth in 2016, 2017, 2019-2021 and 12-24, 24-36 and 36-48 inch depths in 2014-2017 and 2019-2021.

Overall, Cl^- levels remained the highest in 2018 followed by 2014, 2016, 2019, 2021, 2017 and 2020, replication 2 had the highest Cl^- levels followed by replications 3 and 1, control treatment had the highest levels followed by VersaLime, E-sulfur and gypsum treatments and 0-12 inch soil depth had the highest Cl^- levels followed by 36-48, 24-36 inch and 12-24 inch depths.

Differences in Soil Sulfate (SO_4^{2-}) Levels

Soil sulfate (mg/L) levels are shown in Figure 16. Statistically, there were significant differences in the annual SO_4^{2-} levels in replications, treatments and soil depths.

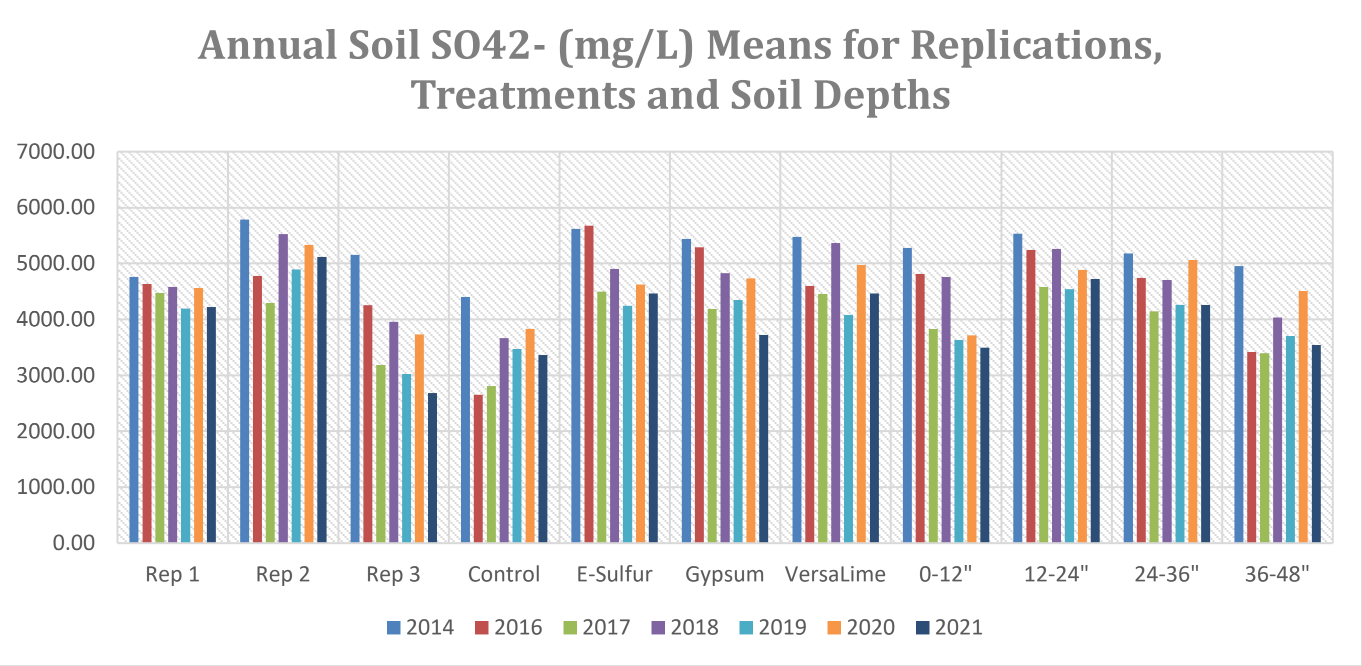
Replication 2 in 2014 had significantly higher SO_4^{2-} levels versus replication 1 in 2017-2021, replication 2 in 2017 and replication 3 in 2016-2021. In addition, replication 2 in 2018 had significantly higher SO_4^{2-} levels than replication 1 in 2019 and 2021, replication 2 in 2017 and replication 3 in 2016-2021.

The E-sulfur treatment in 2014 and 2016 had significantly higher SO_4^{2-} levels versus control treatment in 2016-2021, E-sulfur and VersaLime treatments in 2019 and gypsum treatment in 2017 and 2021. In addition, VersaLime treatment in 2014 had significantly higher SO_4^{2-} levels versus control treatment in 2016-2021, gypsum in 2021 and VersaLime treatment in 2019.

The 12-24 inch soil depth in 2014 had significantly higher soil SO_4^{2-} levels versus 0-12 inch depth in 2017 and 2019-2021 and 36-48 inch depth in 2016-2019 and 2021. In addition, 0-12 inch depth in 2014 and 12-24 inch depth in 2018 had significantly higher soil SO_4^{2-} levels versus 0-12 inch depth in 2017 and 2019-2021 and 36-48 inch depth in 2016, 2017, 2019 and 2021.

Overall, soil SO_4^{2-} levels remained the highest in 2014 followed by 2018, 2016, 2020, 2019, 2021 and 2017, replication 2 had the highest SO_4^{2-} levels followed by replications 1 and 3, E-sulfur treatment had the highest levels followed by VersaLime, gypsum and control treatments and 12-24 inch soil depth had the highest SO_4^{2-} levels followed by 24-36, 0-12 and 36-48 inch depths.

Figure 16. Annual soil SO_4^{2-} (mg/L) means for replications, treatments and soil depths.



Differences in Soil Calcium (Ca^{2+}) Levels

Soil calcium (mg/L) levels are shown in Figure 17. Statistically, there were significant differences in the annual Ca^{2+} levels in replications, treatments and soil depths.

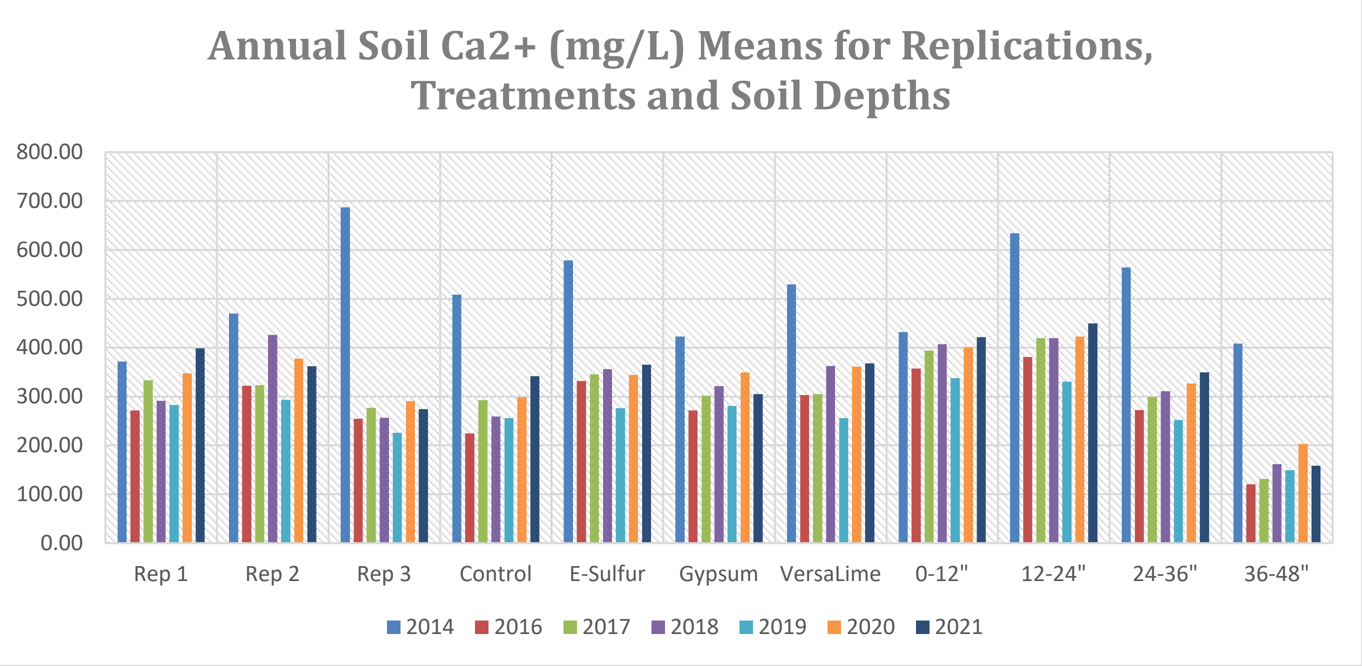
Replication 3 in 2014, had significantly higher Ca^{2+} levels versus replications 1 and 2 in 2014 and all replications in 2016-2021. In addition, replication 2 in 2014 had significantly higher Ca^{2+} levels versus replication 1 in 2016-2019, replication 2 in 2016, 2017 and 2019 and replication 3 in 2016-2021.

The E-sulfur and VersaLime treatments in 2014, had significantly higher Ca^{2+} levels versus all four treatments in 2016-2021. In addition, control treatment in 2014 had significantly higher Ca^{2+} levels versus control and gypsum treatments in 2016-2021, E-sulfur treatment in 2016, 2017, 2019 and 2020 and VersaLime treatment in 2016, 2017 and 2019.

The 12-24 inch soil depth in 2014 had significantly higher Ca^{2+} levels versus 0-12 and 36-48 inch depths in 2014 and all four depths in 2016-2021. In addition, 24-36 inch depth in 2014 had significantly higher Ca^{2+} levels versus 0-12 and 24-36 inch depths in 2016-2021, 12024 inch depth in 2016-2020 and 36-48 inch depth in 2014-2021.

Overall, Ca^{2+} levels remained the highest in 2014 followed by 2021, 2020, 2018, 2017, 2016 and 2019, replication 2 had the highest Ca^{2+} levels followed by replications 1 and 3, E-sulfur treatment had the highest levels followed by VersaLime, gypsum and control treatments and 12-24 inch soil depth had the highest Ca^{2+} levels followed by 0-12, 24-36 and 36-48 inch soil depths.

Figure 17. Annual soil Ca^{2+} (mg/L) means for replications, treatments and soil depths.



Differences in Soil Magnesium (Mg^{2+}) Levels

Soil magnesium (mg/L) levels are shown in Figure 18. Statistically, there were significant differences in the annual Mg^{2+} levels in replications, treatments and soil depths.

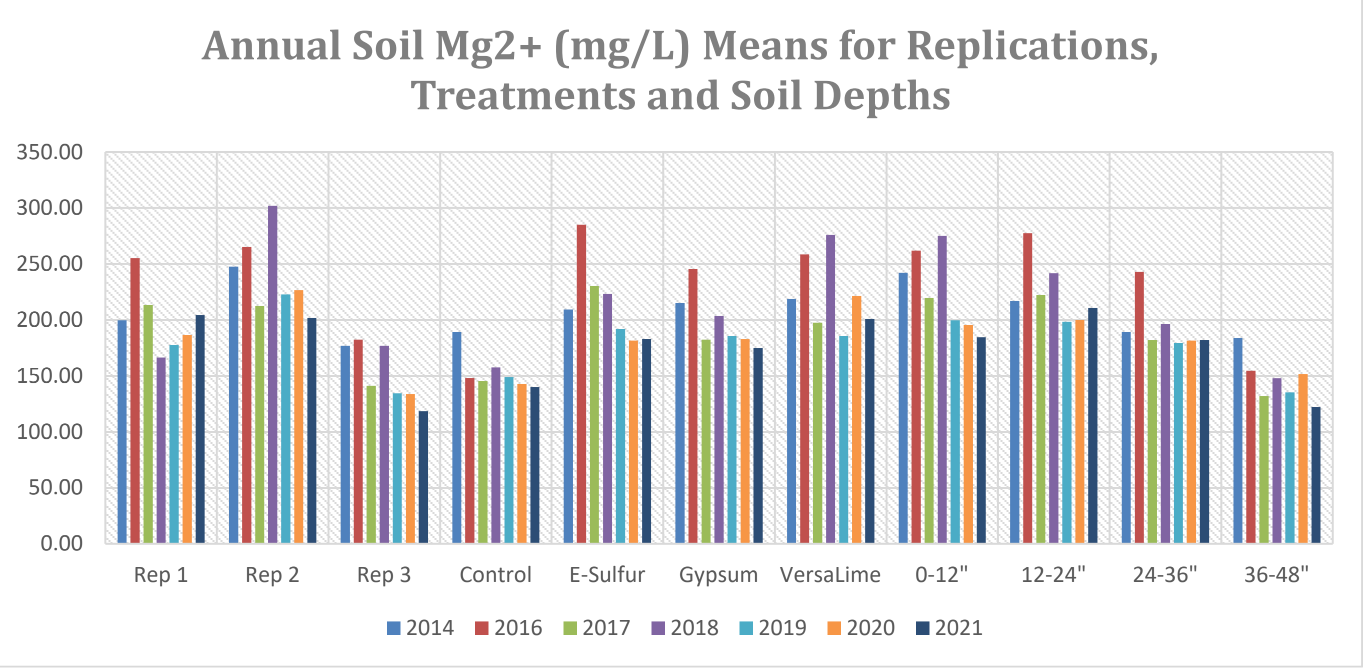
Replication 2 in 2018, had significantly higher Mg^{2+} levels versus replication 1 in 2014 and 2017-2021, replication 2 in 2017 and 2019-2021 and replication 3 in 2014-2021. In addition, replication 2 in 2016, had significantly higher Mg^{2+} levels versus replication 1 in 2014, 2018-2021, replication 2 in 2021 and replication 3 in 2014-2021.

The E-sulfur treatment in 2016 had significantly higher Mg^{2+} levels versus control treatment in 2014-2021, E-sulfur treatment in 2014 and 2019-2021, gypsum treatment in 2017-2021 and VersaLime treatment in 2017, 2019 and 2021. In addition, VersaLime treatment in 2018 had significantly higher Mg^{2+} levels versus control treatment in 2014-2021, E-sulfur treatment in 2019-2021, gypsum treatment in 2017-2021 and VersaLime treatment in 2017, 2019 and 2021.

The 0-12 inch depth in 2018 and 12-24 inch depth in 2016 had significantly higher Mg^{2+} levels versus 0-12 inch depth in 2019-201, 12-24 inch depth in 2019 and 2020, 24-26 inch depth in 2014 and 2017-2021 and 36-48 inch depth in 2014-2021. In addition, the 0-12 inch depth in 2016 had significantly higher Mg^{2+} levels versus 0-12 inch depth in 2021, 24-36 inch depth in 2014, 2017 and 2019-2021 and 36-48 inch depth in 2014-2021.

Overall, soil Mg^{2+} levels remained the highest in 2016 followed by 2018, 2014, 2017, 2020, 2019 and 2021, replication 2 had the highest Mg^{2+} levels followed by replications 1 and 3, VersaLime treatment had the highest Mg^{2+} levels followed by E-sulfur, gypsum and control treatments and 0-12 inch soil depth had the highest Mg^{2+} levels followed by 12-24, 24-36 and 36-48 inch depths.

Figure 18. Annual soil Mg^{2+} (mg/L) means for replications, treatments and soil depths.



Differences in Soil Sodium (Na^+) Levels

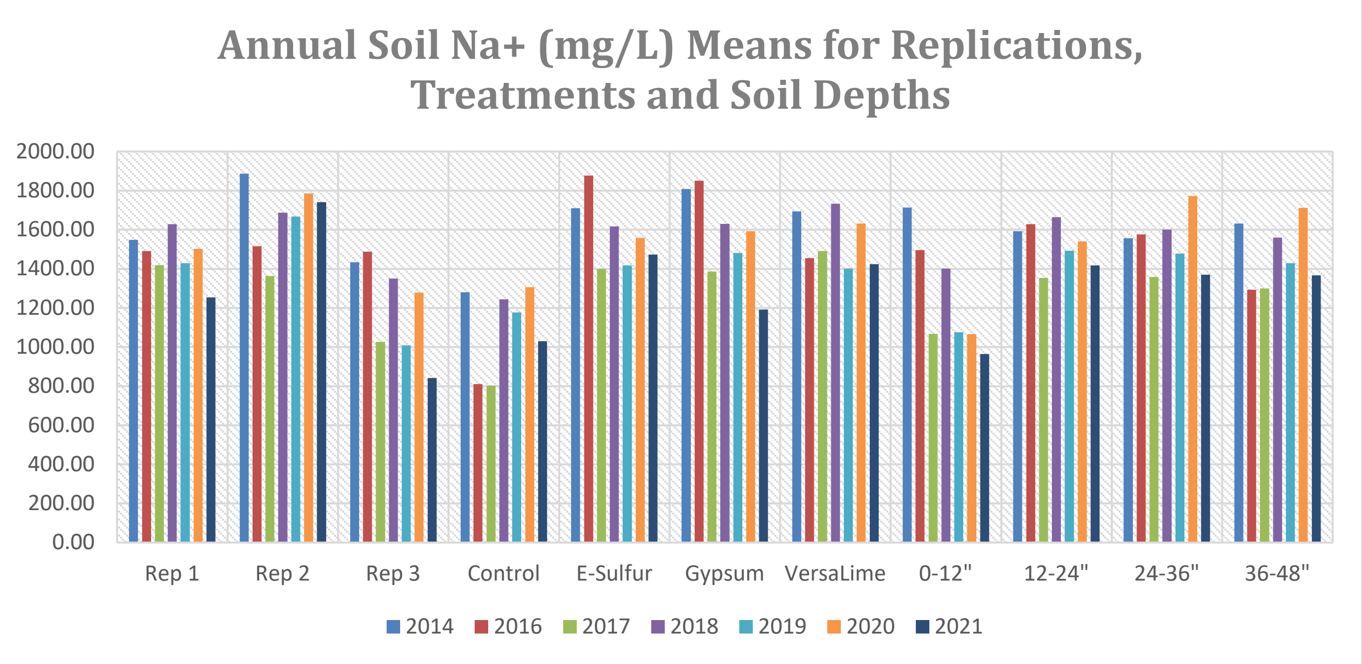
Soil sodium (mg/L) levels are shown in Figure 19. Statistically, there were significant differences in the annual Na^+ levels in replications and treatments.

Replication 2 in 2014, had significantly higher Na^+ levels versus replication 1 in 2017, 2019 and 2021, replication 2 in 2017 and replication 3 in 2014 and 2017-2021. In addition, replication 2 in 2020 had significantly higher Na^+ levels compared to replication 1 in 2021, replication 2 in 2017 and replication 3 in 2017-2021.

The E-sulfur treatment in 2016 had significantly higher Na^+ levels versus control treatment in 2014-2021, E-sulfur treatment in 2017, gypsum treatment in 2017 and 2021 and VersaLime treatment in 2019. In addition, gypsum treatment in 2016 had significantly higher Na^+ levels versus control treatment in 2014-2021 and gypsum treatment in 2021.

Overall, Na$^+$ levels remained the highest in 2014 followed by 2018, 2020, 2016, 2019, 2021 and 2017, replication 2 had the highest Na$^+$ levels followed by replications 1 and 3, E-sulfur treatment had the highest Na$^+$ levels followed by gypsum, VersaLime and control treatments and 24-36 inch soil depth had the highest Na$^+$ levels followed by 12-24, 36-48 and 0-12 inch depths.

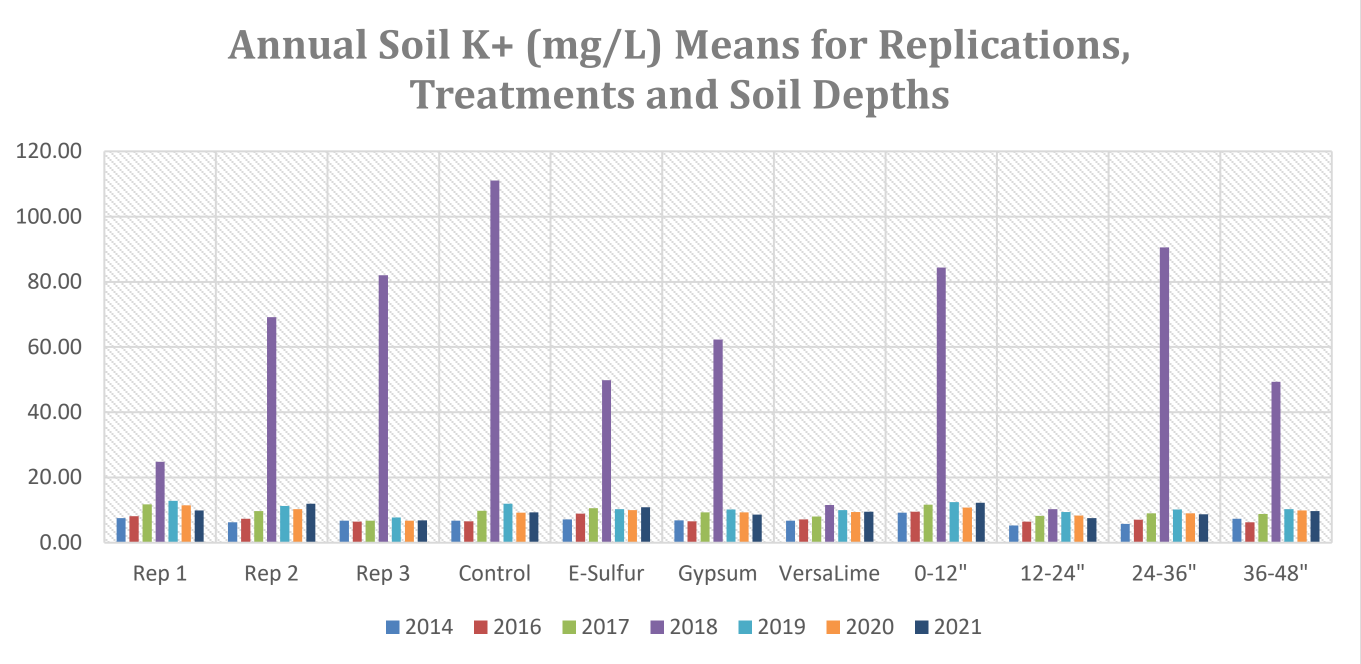
Figure 19. Annual soil Na$^+$ (mg/L) means for replications, treatments and soil depths.



Differences in Soil Potassium (K$^+$) Levels

Soil potassium (mg/L) levels are shown in Figure 20. Statistically, there were significant differences in the annual K$^+$ levels in replications, treatments and soil depths.

Figure 20. Annual soil K$^+$ (mg/L) means for replications, treatments and soil depths.



Replications 3 and 2 in 2018 had significantly higher K^+ levels versus replication 1 in 2018 and all three replications in 2014-2017 and 2019-2021.

The control treatment in 2018 had significantly higher K^+ levels versus E-sulfur, gypsum and VersaLime treatments in 2018 and all four treatments in 2014-2017 and 2019-2021. In addition, gypsum treatment in 2018 had significantly higher K^+ levels versus VersaLime treatment in 2018 and all four treatments in in 2014-2017 and 2019-2021.

The 24-36 inch soil depths in 2018 had significantly higher K^+ levels versus 12-24 and 36-48 inch depths in 2018 and all of the depths in 2014-2017 and 2019-2021. In addition, 0-12 depth in 2018 had significantly higher K^+ levels versus 12-24 inch depth in 2018 and all four depths in 2014-2017 and 2019-2021.

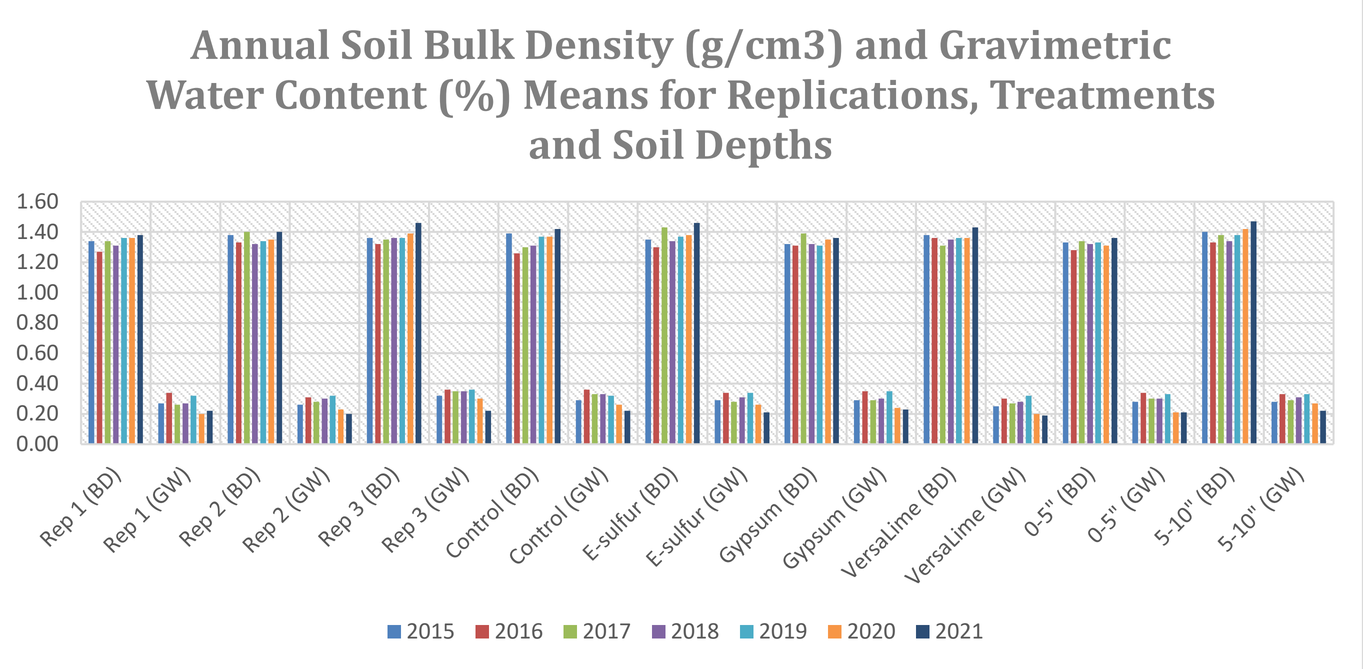
Overall, K^+ levels remained the highest in 2018 followed by 2019, 2021, 2020, 2017, 2016 and 2014, replication 2 had the highest K^+ levels followed by replications 3 and 1, control treatment had the highest levels followed by gypsum, E-sulfur and VersaLime treatments and 0-12 inch soil depth had the highest K^+ levels followed by 24-36, 36-48 and 12-24 inch depths.

Changes in Soil Physical Properties

Differences in Soil Bulk Density (BD) Levels

Soil bulk density (g/cm^3) and corresponding gravimetric water content (%) levels are shown in Figure 21. Statistically, there were significant differences in the annual soil bulk density levels in replications, treatments and soil depths.

Figure 21. Annual means of soil bulk density (g/cm^3) and gravimetric water (%) levels for replications, treatments and soil depths.



Replication 3 in 2021 had significantly higher bulk density levels than the levels in replication 1 in 2015-2020, replication 2 in 2015, 2016 and 2018-2020 and replication 3 in 2015-2019. In addition, replication 2 in 2021 had significantly higher bulk density levels versus replication 1 in 2016 and 2018 and replication 2 in 2018.

The E-sulfur treatment in 2021 had significantly higher bulk density levels versus control treatment in 2016-2018, E-sulfur treatment in 2015-2016 and 2018, gypsum treatment in 2015-2016 and 2018-2021 and VersaLime treatment in 2016-2020. In addition, E-sulfur treatment in 2017 had significantly higher bulk density levels versus control treatment in 2016-2018, E-sulfur treatment in 2016, gypsum treatment in 2015-2016 and 2018-2019 and VersaLime treatment in 2017.

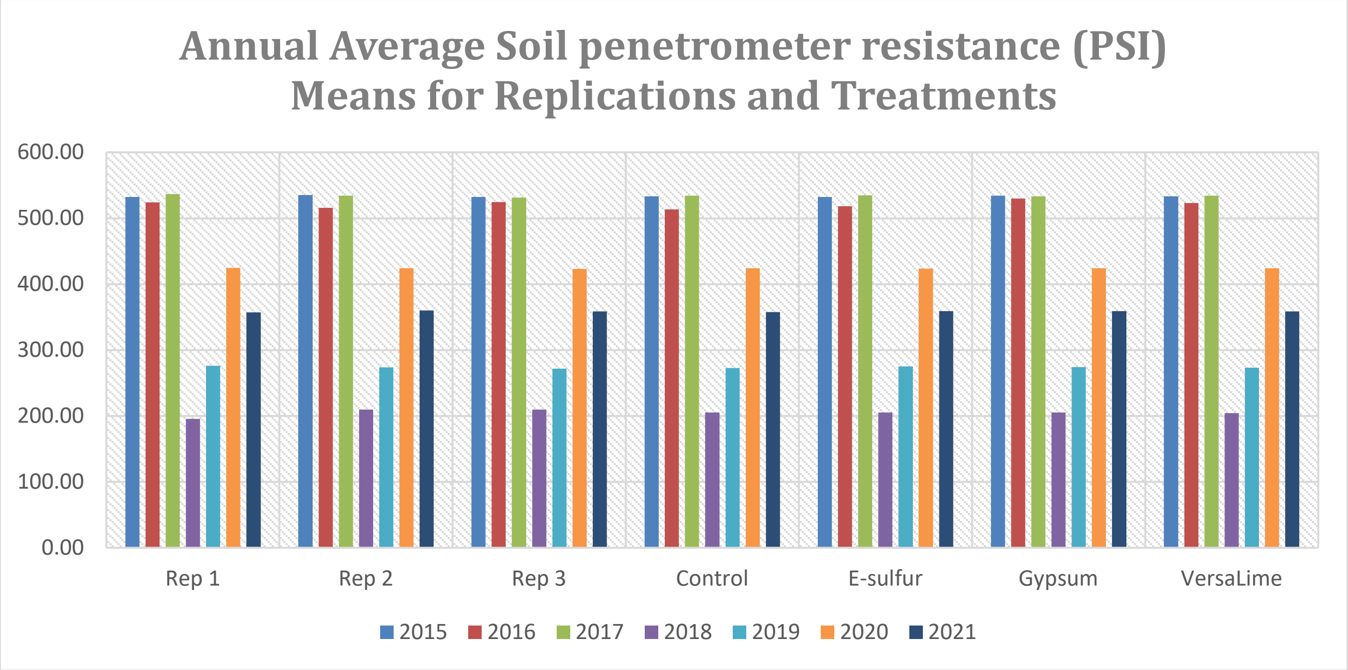
The 5-10 inch soil depth in 2021 had significantly higher bulk density levels versus 0-5 inch soil depth in 2015-2021 and 5-10 inch depth in 2015-2019 and 2021. In addition, 5-10 inch soil depth in 2020 had significantly higher bulk density levels versus 0-5 inch depth in 2015-2020 and 5-10 inch depth in 2016 and 2018.

Overall, soil bulk density levels remained the highest in 2021 followed by 2020, 2015, 2017, 2019, 2018 and 2016, replication 3 had the highest bulk density levels followed by replications 2 and 1, E-sulfur treatment had the highest levels followed by VersaLime, control and gypsum treatments and 5-10 inch soil depth had higher bulk density levels compared to 0-5 inch depth.

Differences in Soil Penetrometer Meter Resistance Levels

Average soil penetrometer resistance measurements for replications, treatments and soil depths are shown in Figure 22 and 23. Each measurement is an average of ten penetrometer measurements for each soil depth. Soil depths ranged from 1-18 inches in one inch increments. Statistically, there were significant differences in the annual soil penetrometer resistance measurements measured in pounds of force per square inch (psi) in replications, treatments and soil depths.

Figure 22. Annual means of average soil penetrometer resistance measurements for the 1-18 inch depths (pounds of force per square inch or psi) for replications and treatments.

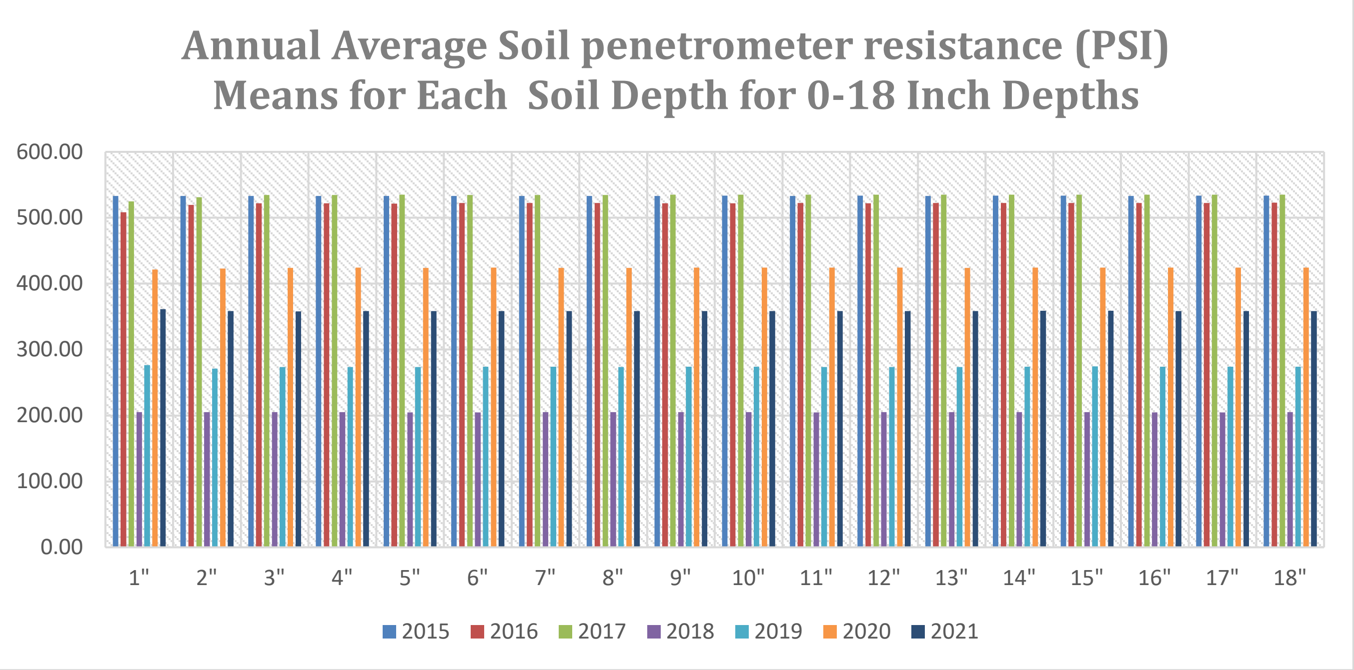


Replication 1 in 2017 showed significantly higher penetrometer resistance versus replication 1 in 2015, 2016 and 2018-2021, replication 2 in 2016-2021 and replication 3 in 2015-2021. In addition, replication 2 in 2015 had significantly higher penetrometer resistance versus replication 1 in 2015, 2016 and 2018-2021, replication 2 in 2016 and 2018-2021 and replication 3 in 2015-2021.

The E-sulfur treatment in 2017 had significantly higher penetrometer resistance versus control, gypsum and VersaLime treatments in 2016 and 2018-2021 and E-sulfur treatment in 2015, 2016 and 2018-2021. In addition, control, gypsum and VersaLime treatments in 2015 and 2017 and E-sulfur treatment in 2015 had significantly higher penetrometer resistance versus all four treatments in 2016 and 2018-2021.

The 1 to 18 inch soil depths in 2015 and 2 to 18 inch depths in 2017 had significantly higher penetrometer resistance versus 0 to 1 inch depth in 2017 and 1 to 18 inch depths in 2016 and 2018-2021. In addition, 0 to 1 inch depth in 2017 had significantly higher penetrometer resistance measurements versus 1 to 2 inch depths in 2016 and 1 to 18 inch depths in 2018-2021.

Figure 23. Annual means of average penetrometer resistance (pounds of force per square inch or psi) for each soil depth for 1-18 inch depths.



Overall, penetrometer resistance remained the highest in 2017 followed by 2015, 2016, 2020, 2021, 2019 and 2018, replication 2 had the highest penetrometer resistance followed by replications 3 and 1, gypsum treatment had the highest resistance followed by VersaLime, E-sulfur and control treatments and 15 inch soil depth had the highest penetrometer resistance measurements followed by 18, 17, 14, 16, 10, 11, 12, 9, 13, 6, 7, 8, 4, 5, 3, 2 and 1 inch depths.

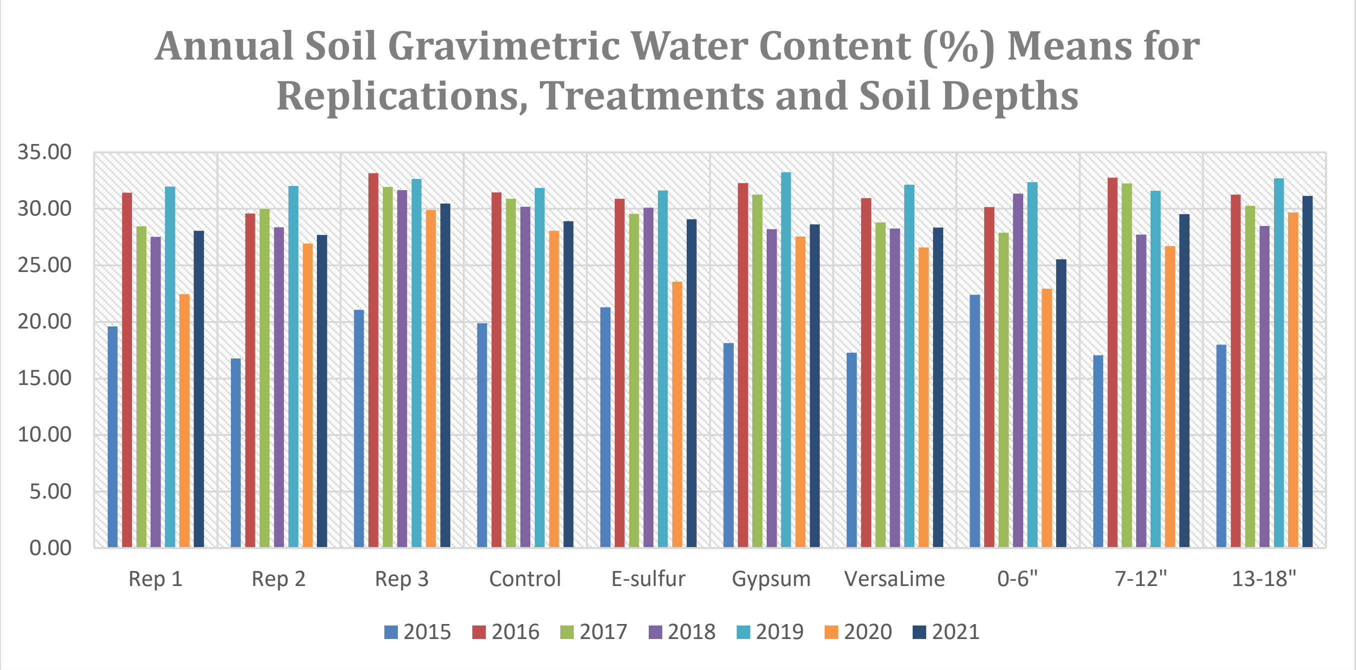
Since penetrometer resistance is strongly related to the soil water content at the time of recording the measurements, soil gravimetric water content was also measured for the 0-6, 7-12 and 13-18 inch soil depths. Like penetrometer resistance, there were statistically significant differences in the annual soil gravimetric water content measured in percent (%) in replications, treatments and soil depths (Figure 24).

Replication 3 in 2016 had significantly higher gravimetric water content versus replication 1 in 2015, 2017-2018 and 2020-2021, replication 2 in 2015-2018 and 2020-2021 and replication 3 in 2015 and 2020. In addition, replication 3 in 2019 had significantly higher gravimetric water content versus replication 1 in 2015, 2017-2018 and 2020-2021, replication 2 in 2015-2016, 2018 and 2020-2021 and replication 3 in 2015.

Gypsum treatment in 2019 had significantly higher gravimetric water content versus control and E-sulfur treatments in 2015 and 2020-2021, gypsum treatment in 2015, 2018 and 2020-2021 and VersaLime treatment in 2015, 2017-

2018 and 2020-2021. In addition, gypsum treatment in 2016 and VersaLime treatment in 2019 had significantly higher gravimetric water content levels versus control and E-sulfur treatments in 2015 and 2020, gypsum treatment in 2015, 2018 and 2020 and VersaLime treatment in 2015, 2018 and 2020-2021.

Figure 24. Annual means of soil gravimetric water content (%) for replications, treatments and soil depths.



The 7-12 inch soil depth in 2016 and 13-18 inch depth in 2019 had significantly higher gravimetric water content levels versus 0-6 inch depth in 2015, 2017 and 2020-2021, 7-12 depth in 2015, 2018 and 2020-2021 and 13-18 inch depth in 2015, 2018 and 2020. In addition, 0-6 inch depth in 2019 and 7-12 inch depth in 2017 and 2019 had significantly higher gravimetric water content levels versus 0-6 inch depth in 2015, 2017 and 2020-2021, 7-12 inch depth in 2015, 2018 and 2020 and 13-18 inch depth in 2015 and 2018.

Overall, soil gravimetric water content remained the highest in 2019 followed by 2016, 2017, 2018, 2021, 2020 and 2015, replication 3 had the highest gravimetric water content followed by replications 2 and 1, control treatment had the highest gravimetric water content followed by gypsum, E-sulfur and VersaLime treatments and 13-18 inch soil depth had the highest gravimetric water content followed by 7-12 and 0-6 inch soil depths.

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

Water samples from upstream, tile drainage lift station and downstream were collected one to three times a year depending upon the weather by using North Dakota Department of Health protocols and were sent to its Chemical Laboratory for analysis in 2015, 2016, 2017, 2018, 2019 and 2020. Samples were collected after a decent rain event of close to an inch or more that allowed fresh flow of water from the tiled field to lift station and fresh water in the ditch for collecting upstream, downstream and tile-drained lift station samples. Upstream samples were collected at the beginning of the drainage ditch 100-150 feet north of the lift station. Lift station samples represented water quality coming out of tiles, whereas, downstream samples were collected 100-150 feet south of the lift station in the direction where ditch and tiled-drained water flows. Each sampling activity included collecting a separate set of samples from upstream, lift station and downstream, 10-15 minutes apart on the same day. Each sampling activity included three sampling sets and each sample set included the following:

1. 500 mL to analyze major cations, anions and bromide (procedures 200.7, 300 and 2320-B, USEPA).
2. 250 mL preserved with 2mL of Nitric Acid (HNO_3) for trace metals (procedure 200.8, USEPA).
3. 500 mL preserved with Sulfuric Acid (H_2SO_4) to analyze for nutrients that included total nitrogen, Kjeldahl nitrogen, nitrite + nitrate nitrogen and phosphorous (procedures 353.2, Lachat Method No. 10-107-04-1-C, 353.2, Lachat Method No. 10-107-04-1-O, and 200.7, Lachat Method 10-115-01-1-E, USEPA).
4. 200 mL filtered and then preserved with Sulfuric Acid (H_2SO_4) to analyze dissolved phosphorous (procedure 365.1, Lachat Method 10-115-01-1-E, USEPA).

All samples were preserved in a cooler with icepacks right after collection and were shipped to the Chemical Laboratory of ND Department of Health through overnight delivery.

Below is the breakdown of the annual water quality analysis of the samples collected from upstream, lift Station and downstream locations. Please note that CO_3^{2-}, OH^-, silica, beryllium, chromium, silver, cadmium, antimony, thallium and lead are not discussed in the results below as analysis results were below the detectable levels at almost all of the sampling times. In addition, “ND” in the result tables stands for “Not Detectable”.

Differences in Salts, Dissolved Solids, Total Hardness as CaCO3 and Total Alkalinity as CaCO3 Levels

Based on the results of each sampling activity, conductivity (mmhos/cm) levels in the lift station were higher than the upstream and downstream samples, except samples taken on May 11, 2016, May 10, 2017 and June 12, 2018. Differences between upstream and downstream samples fluctuated and there was no consistent trend. Concentration of total dissolved solids (mg/L) of the lift station samples were higher than the upstream and downstream samples, except the samples taken on May 10, 2017 and June 12, 2018. Total hardness as $CaCO_3$ (mg/L) concentrations were also higher in the lift station samples versus upstream and downstream samples, except the samples taken on May 10, 2017. Total alkalinity as $CaCO_3$ (mg/L) levels were higher in the lift station samples versus all of the upstream and downstream samples. Details are in Table 4.

Based on the average of all sampling activities, conductivity (mmhos/cm), total dissolved solids (mg/L), total hardness as $CaCO_3$ (mg/L) and total alkalinity as $CaCO_3$ (mg/L) concentrations of the lift station samples were higher than the upstream and downstream samples (Figure 25).

Since it was important to assess the total dissolved solids (TDS) coming out of the tiled area represented by the lift station samples compared to upstream and downstream samples, total dissolved solid results of each sampling activity are also presented in a line chart below (Figure 26). We can see that except samples taken on May 10, 2017 and June 12, 2018, the TDS levels of the lift station samples were noticeably higher than the upstream and downstream samples.

Table 4. Results of conductivity (µmhos/cm), total dissolved solids (mg/L), total hardness as $CaCO_3$ (g/G) and total alkalinity as $CaCO_3$ for each sampling activity.

Date	Site	Conductivity (µmhos/cm)	Total Dissolved Solids (mg/L)	Total Hardness as $CaCO_3$ (mg/L)	Total Alkalinity as $CaCO_3$ (mg/L)
November 9, 2015	Upstream	5650	4510	1110	326
	Lift Station	10200	8840	2160	564
	Downstream	6800	5700	1460	370
May 11, 2016	Upstream	7220	6060	1500	230
	Lift Station	7200	7170	1720	501
	Downstream	7560	6390	1500	202
July 11, 2016	Upstream	999	647	243	127
	Lift Station	8140	6820	1610	507
	Downstream	966	627	251	105
September 8, 2016	Upstream	3440	2570	787	467
	Lift Station	7220	5960	1500	630
	Downstream	3200	2340	771	338
May 10, 2017	Upstream	6920	5840	1680	387
	Lift Station	5980	4950	1360	543
	Downstream	6070	5200	1370	504
August 17, 2017	Upstream	3360	2590	774	158
	Lift Station	6590	6010	1220	615
	Downstream	2100	1430	381	173
June 12, 2018	Upstream	5130	3910	887	288
	Lift Station	4470	3420	926	517
	Downstream	4840	3680	816	369
August 26, 2019	Upstream	3710	2860	757	337
	Lift Station	5430	4290	1000	700
	Downstream	5070	4080	903	635
September 30, 2019	Upstream	754	488	200	142
	Lift Station	6460	5620	1390	530
	Downstream	1350	891	285	174
July 6, 2020	Upstream	3510	2630	926	429
	Lift Station	6760	5560	1370	599
	Downstream	4240	3380	1050	506
August 12, 2021	Upstream	407	239	119	95.5
	Lift Station	5230	4250	1070	426
	Downstream	507	313	144	95.5

Figure 25. Average conductivity (mmhos/cm), dissolved solids (mg/L), total hardness as $CaCO_3$ (mg/L) and total alkalinity as $CaCO_3$ for all sampling activities.

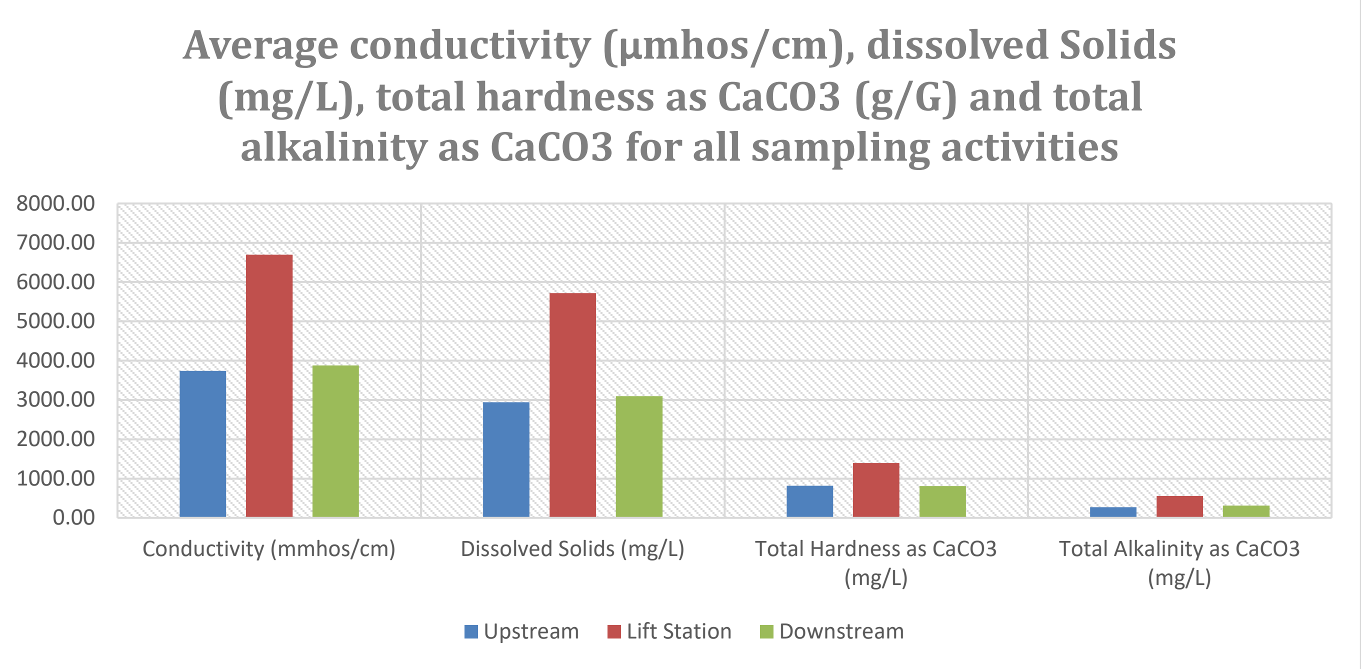
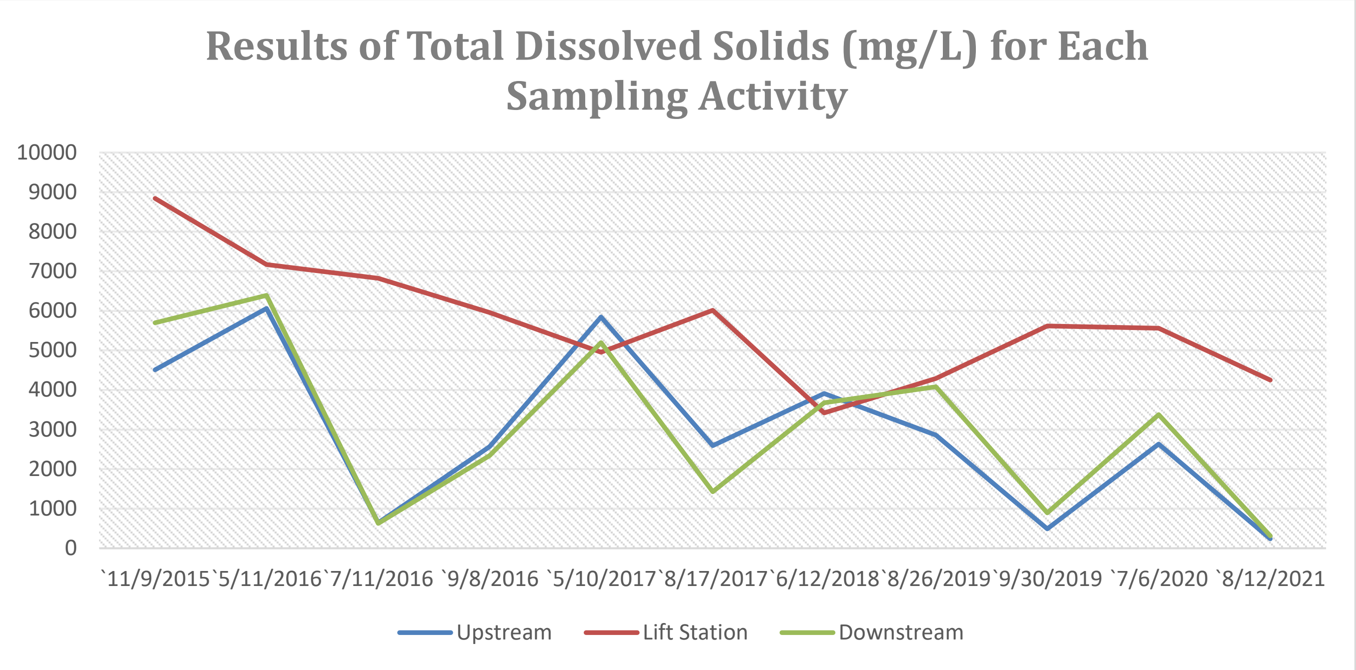


Figure 26. Results of total dissolved solids (mg/L) for each sampling activity.



Differences in Sodium Adsorption Ratio (SAR) and pH Levels

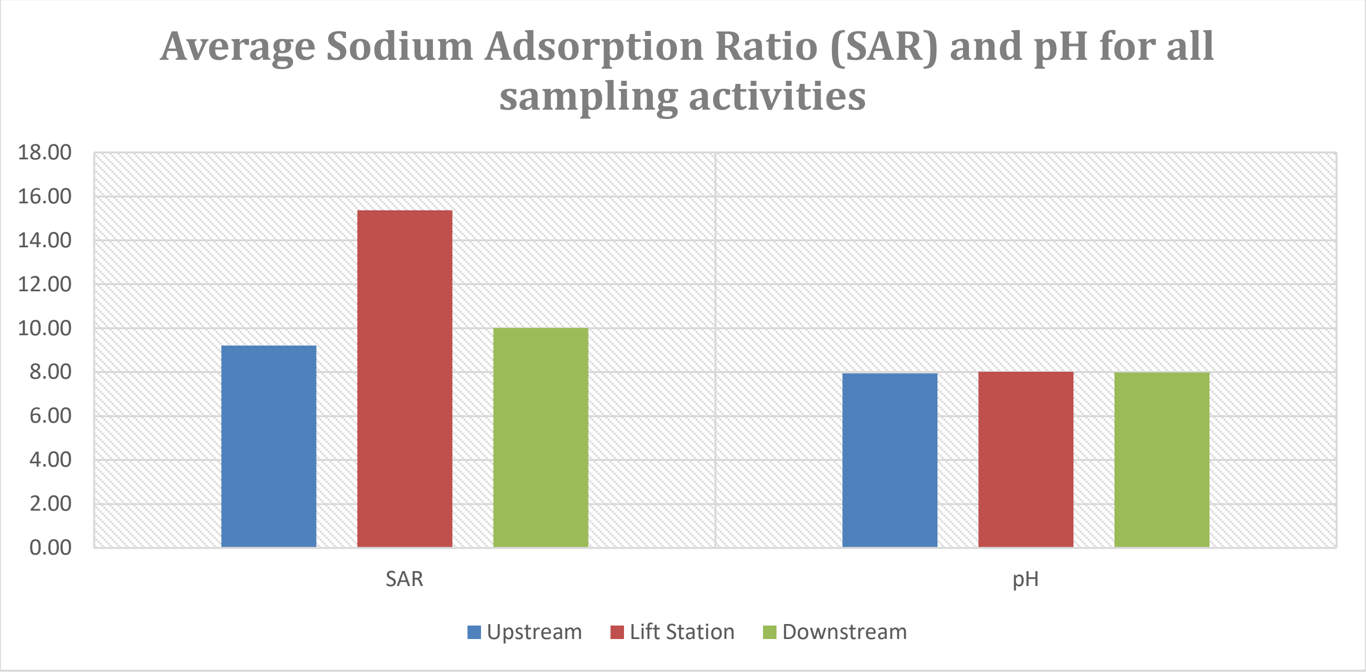
Based on the results of each sampling activity, SAR levels of the lift station samples were higher than the upstream and downstream samples, except in the samples that were taken on May 11, 2016, May 10, 2017 and June 12, 2018. The differences between the soil pH levels of upstream, lift station and downstream samples were inconsistent. Details are in Table 5.

Table 5. Results of Sodium Adsorption Ratio (SAR) and pH for each sampling activity.

Date	Site	Sodium Adsorption Ratio (SAR)	pH
November 9, 2015	Upstream	13.10	8.27
	Lift Station	17.40	7.91
	Downstream	16.30	8.37
May 11, 2016	Upstream	16.60	8.92
	Lift Station	14.90	7.96
	Downstream	17.60	9.23
July 11, 2016	Upstream	3.54	7.60
	Lift Station	16.20	8.32
	Downstream	3.07	7.56
September 8, 2016	Upstream	8.55	8.31
	Lift Station	15.60	8.10
	Downstream	6.87	7.92
May 10, 2017	Upstream	14.20	8.27
	Lift Station	13.50	8.08
	Downstream	14.00	8.28
August 17, 2017	Upstream	8.36	7.60
	Lift Station	22.60	7.99
	Downstream	6.52	7.67
June 12, 2018	Upstream	13.80	7.70
	Lift Station	11.00	8.00
	Downstream	13.50	7.92
August 26, 2019	Upstream	10.70	7.92
	Lift Station	14.70	8.03
	Downstream	14.60	8.11
September 30, 2019	Upstream	3.11	7.77
	Lift Station	15.20	7.78
	Downstream	4.55	7.71
July 6, 2020	Upstream	7.93	7.76
	Lift Station	15.40	7.95
	Downstream	11.20	7.76
August 12, 2021	Upstream	1.37	7.28
	Lift Station	12.60	8.15
	Downstream	1.90	7.33

Based on the average of all sampling activities, SAR levels in the lift station samples remained higher than the upstream and downstream samples, whereas, differences in the pH levels were inconsistent and negligible.

Figure 27. Average Sodium Adsorption Ratio (SAR) and pH for all sampling activities.



Differences in the Major Cation and Anion levels

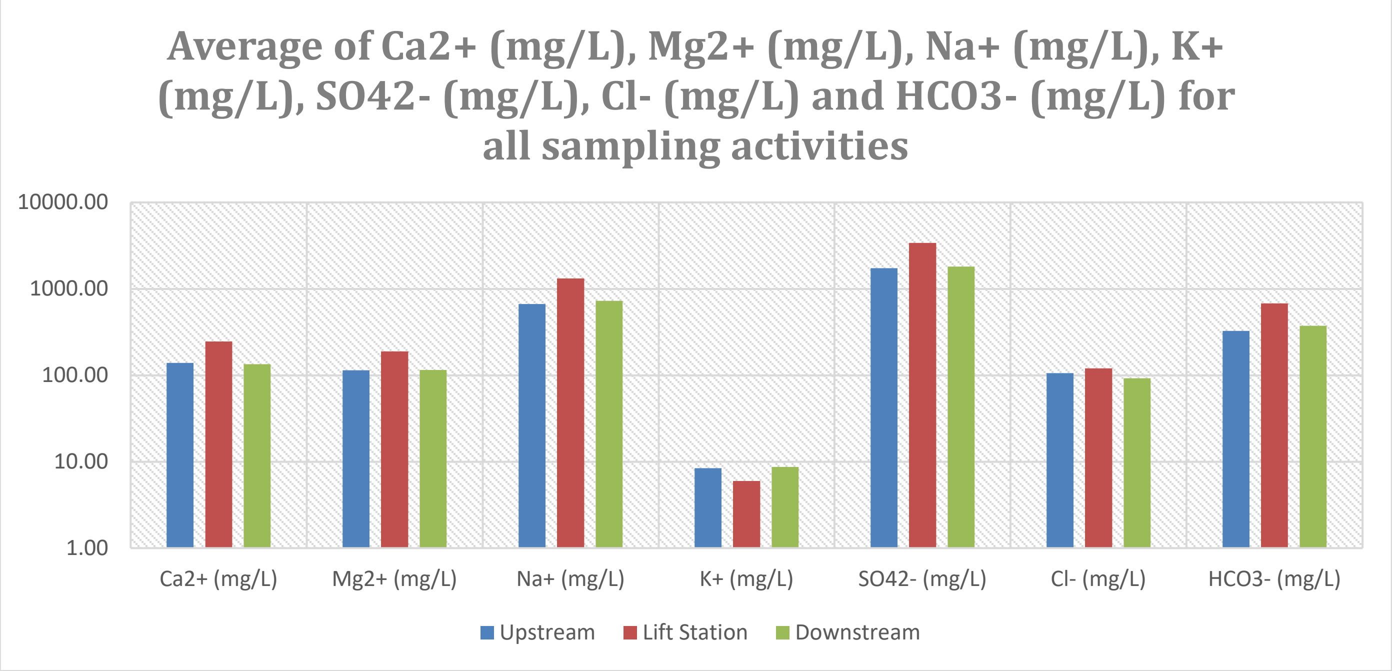
Based on the results of each sampling activity, Ca^{2+} (mg/L) levels of the lift station samples were higher than the upstream and downstream samples, except in the samples taken on May 10, 2017. Mg^{2+} (mg/L), Na^{+} (mg/L) and SO_4^{2-} (mg/L) levels of the lift station samples were higher than the samples taken from upstream and downstream samples except the samples that were taken on May 11, 2016, May 10, 2017 and June 12, 2018. K^{+} (mg/L) levels of the lift station samples were mostly lower or similar versus the levels in the upstream and downstream samples at all sampling times. Cl^{-} (mg/L) levels of the lift station samples were higher than the samples taken from upstream and downstream samples except the samples that were taken on May 11, 2016, May 10, 2017, June 12, 2018 and August 26, 2019. HCO_3^{-} (mg/L) levels of the lift station samples remained higher than the upstream and downstream samples at all sampling times. Details are in Table 6.

Table 6. Results of Ca^{2+} (mg/L), Mg^{2+} (mg/L), Na^{+} (mg/L), K^{+} (mg/L), SO_4^{2-} (mg/L), Cl^{-} (mg/L) and HCO_3^{-} (mg/L) for each sampling activity.

Date	**Site**	**Ca^{2+} (mg/L)**	**Mg^{2+} (mg/L)**	**Na^{+} (mg/L)**	**K^{+} (mg/L)**	**SO_4^{2-} (mg/L)**	**Cl^{-} (mg/L)**	**HCO_3^{-} (mg/L)**
November 9, 2015	Upstream	187	156	1000	NA	2790	148	397
	Lift Station	398	284	1860	NA	5710	208	688
	Downstream	223	220	1430	11	3420	157	436
May 11, 2016	Upstream	173	260	1480	9.9	3790	203	220
	Lift Station	271	253	1420	5.9	3700	178	611
	Downstream	161	266	1570	10.6	4050	206	149
July 11, 2016	Upstream	55.2	25.6	127	7.9	320	29.6	155
	Lift Station	251	239	1500	6.3	4330	148	609
	Downstream	59.1	25.1	112	7.1	329	25.3	128
September 8, 2016	Upstream	147	102	552	8.6	1390	92.9	565
	Lift Station	271	199	1390	7.6	3560	128	769
	Downstream	157	92	439	16.1	1320	107	412
May 10, 2017	Upstream	263	249	1340	12.4	3490	255	472
	Lift Station	223	196	1150	5.2	2900	131	662
	Downstream	200	212	1190	6.7	3090	162	615
August 17, 2017	Upstream	160	91	535	9.7	1580	117	192
	Lift Station	221	163	1820	6.8	3290	126	751
	Downstream	72.6	48.6	293	6.5	818	81.1	212
June 12, 2018	Upstream	121	142	944	3.3	2420	101	351
	Lift Station	191	109	770	3.9	1950	72.7	631
	Downstream	129	120	889	5.2	2230	80.6	450
August 26, 2019	Upstream	149	93.5	679	9.1	1650	72.7	411
	Lift Station	202	121	1070	5.2	2400	72.4	854
	Downstream	182	109	1010	4.8	2320	67.2	775
September 30, 2019	Upstream	45.9	20.7	101	5.8	201	25.7	173
	Lift Station	245	188	1300	5.4	3470	88.4	647
	Downstream	60.4	32.7	177	7.3	462	36.4	213
July 6, 2020	Upstream	201	103	555	8.93	1390	111	524
	Lift Station	232	192	1310	5.62	3340	112	730
	Downstream	203	132	836	10.3	1800	86.1	617
August 12, 2021	Upstream	28.80	11.40	34.40	8.21	87.90	8.30	117
	Lift Station	202	137	946	5.01	2640	60.30	520
	Downstream	33.80	14.40	52.30	10.00	131	9.32	117

Based on the average of all sampling activities, Ca^{2+} (mg/L), Mg^{2+} (mg/L), Na^{+} (mg/L), SO_4^{2-} (mg/L), Cl^{-} (mg/L) and HCO_3^{-} (mg/L) levels of the lift station samples remained higher than the upstream and downstream samples, whereas, K^{+} (mg/L) levels of the lift station samples were lower than the upstream and downstream samples.

Figure 28. Average Ca^{2+} (mg/L), Mg^{2+} (mg/L), Na^{+} (mg/L), K^{+} (mg/L), SO_4^{2-} (mg/L), Cl^{-} (mg/L) and HCO_3^{-} (mg/L) for all sampling activities.



Differences in the Nitrogen and Phosphorous levels

Based on the results of each sampling activity, nitrate + nitrite nitrogen (mg/L) levels of the lift station remained higher than the upstream and downstream samples at all sampling times, except two downstream samples collected on May 10, 2017 and September 30, 2019 and upstream and downstream samples taken on July 6, 2020. Opposite trend was observed for the Kjeldahl nitrogen (mg/L) levels, which remained lower than the upstream and downstream samples taken at all times, except one upstream sample taken on September 30, 2019. The total nitrogen (mg/L) levels, which were a sum of Kjeldahl nitrogen (mg/L) and nitrate + nitrite nitrogen (mg/L) levels were higher in the lift station samples versus upstream and downstream samples, except the upstream and downstream samples that were collected on November 9, 2015 and July 6, 2020, downstream sample collected on May 10, 2017 and September 30, 2019 and upstream samples collected on August 26, 2019. The total phosphorous (mg/L) levels of the lift station samples were lower or similar than the upstream and downstream samples except one downstream sample collected on November 9, 2015. In addition, dissolved phosphorous (mg/L) levels of the lift station samples remained lower than the levels in the upstream and downstream samples except, upstream and downstream samples collected on November 9, 2015 and June 12, 2018, upstream sample collected on May 11, 2016 and downstream samples collected on May 10, 2017 and August 17, 2017. Details are in Table 7.

Table 7. Results of total nitrogen (mg/L), Kjeldahl nitrogen (mg/L), nitrate + nitrite nitrogen (mg/L), total phosphorous (mg/L) and dissolved phosphorous (mg/L) for each sampling activity.

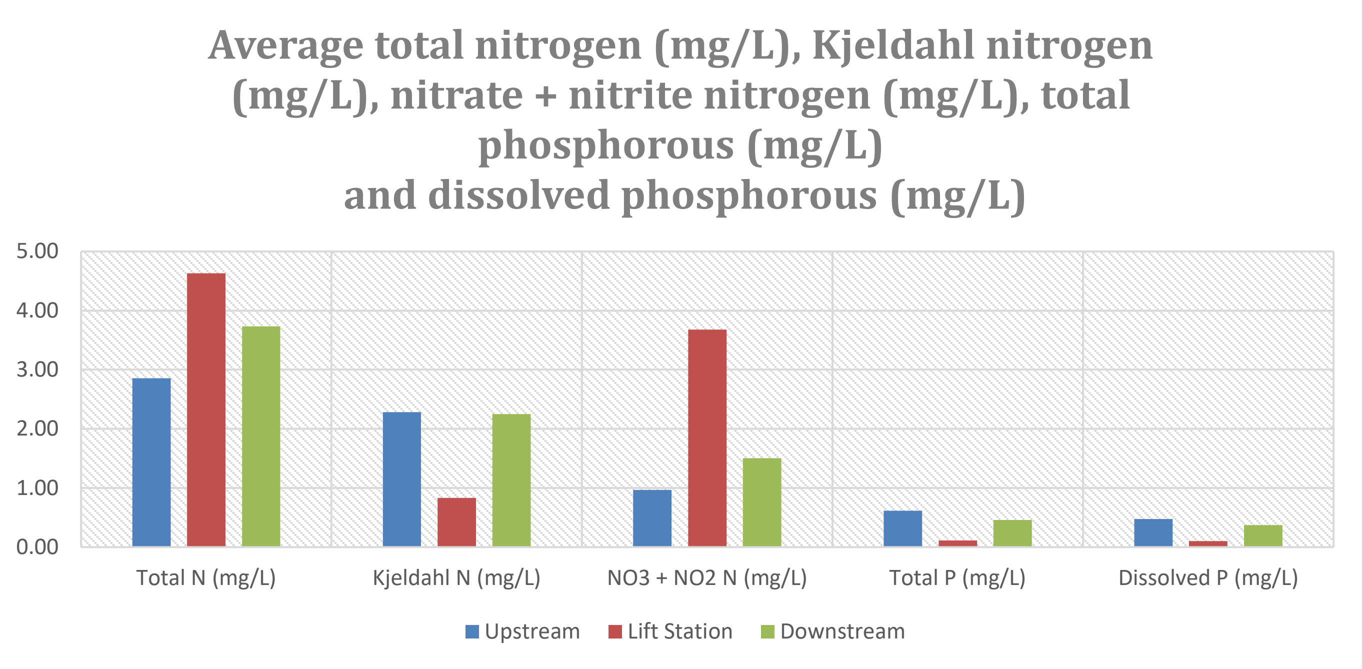
Date	Site	Total N (mg/L)	Kjeldahl N (mg/L)	$NO_3 + NO_2$ N (mg/L)	Total P (mg/L)	Dissolved P (mg/L)
November 9, 2015	Upstream	7.51	3.17	4.34	0.16	0.02
	Lift Station	7.30	0.64	6.66	0.06	0.08
	Downstream	11.70	8.40	3.30	0.03	0.02
May 11, 2016	Upstream	3.65	2.67	0.98	0.09	0.02
	Lift Station	10.10	1.42	8.68	0.06	0.06
	Downstream	2.59	2.56	0.03	0.22	0.08
July 11, 2016	Upstream	2.37	1.71	0.66	0.92	0.88
	Lift Station	9.08	0.90	8.18	0.21	0.21
	Downstream	2.46	1.54	0.92	0.79	0.75
September 8, 2016	Upstream	2.11	2.08	0.03	0.93	0.69
	Lift Station	5.53	0.41	5.12	0.02	0.05
	Downstream	3.03	2.28	0.75	0.61	0.50
May 10, 2017	Upstream	3.02	2.99	0.03	0.51	0.19
	Lift Station	4.49	0.08	4.57	0.20	0.04
	Downstream	7.47	0.83	6.64	0.20	0.03
August 17, 2017	Upstream	1.80	1.77	0.03	0.18	0.12
	Lift Station	3.16	0.93	2.23	0.08	0.07
	Downstream	1.38	1.35	0.03	0.20	0.06
June 12, 2018	Upstream	2.02	1.99	0.03	0.14	0.03
	Lift Station	2.23	0.84	1.39	0.14	0.14
	Downstream	1.29	1.26	0.03	0.14	0.02
August 26, 2019	Upstream	2.13	2.07	0.05	0.39	0.29
	Lift Station	1.13	0.87	0.26	0.13	0.13
	Downstream	1.04	0.93	0.11	0.20	0.18
September 30, 2019	Upstream	0.78	0.69	0.09	0.54	0.50
	Lift Station	1.99	0.93	1.06	0.14	0.14
	Downstream	3.22	1.41	1.81	0.55	0.49
July 6, 2020	Upstream	4.42	4.39	4.39	2.01	1.67
	Lift Station	3.41	0.96	0.96	0.07	0.07
	Downstream	4.66	2.44	2.44	1.11	1.04
August 12, 2021	Upstream	1.63	1.60	0.03	0.93	0.84
	Lift Station	2.52	1.17	1.35	0.15	0.14
	Downstream	2.23	1.76	0.47	0.99	0.91

Note:

- Total Nitrogen is a sum of the Kjeldahl N and $NO_3 + NO_2$ N.
- Kjeldahl N is a sum of free ammonium and organic nitrogen.

Based on the average of all sampling activities, total nitrogen (mg/L) and nitrate + nitrite nitrogen (mg/L) levels of the lift station samples were higher than the levels in the upstream and downstream samples. Whereas, Kjeldahl nitrogen (mg/L) levels of the lift station samples remained lower than the levels in upstream and downstream samples. Both total phosphorous (mg/L) and dissolved phosphorous (mg/L) levels of the lift station samples remained lower than the levels in upstream and downstream samples.

Figure 29. Average total nitrogen (mg/L), Kjeldahl nitrogen (mg/L), nitrate + nitrite nitrogen (mg/L), total phosphorous (mg/L) and dissolved phosphorous (mg/L) for all sampling activities.



Differences in the Boron, Aluminum, Nickel, Copper and Zinc levels

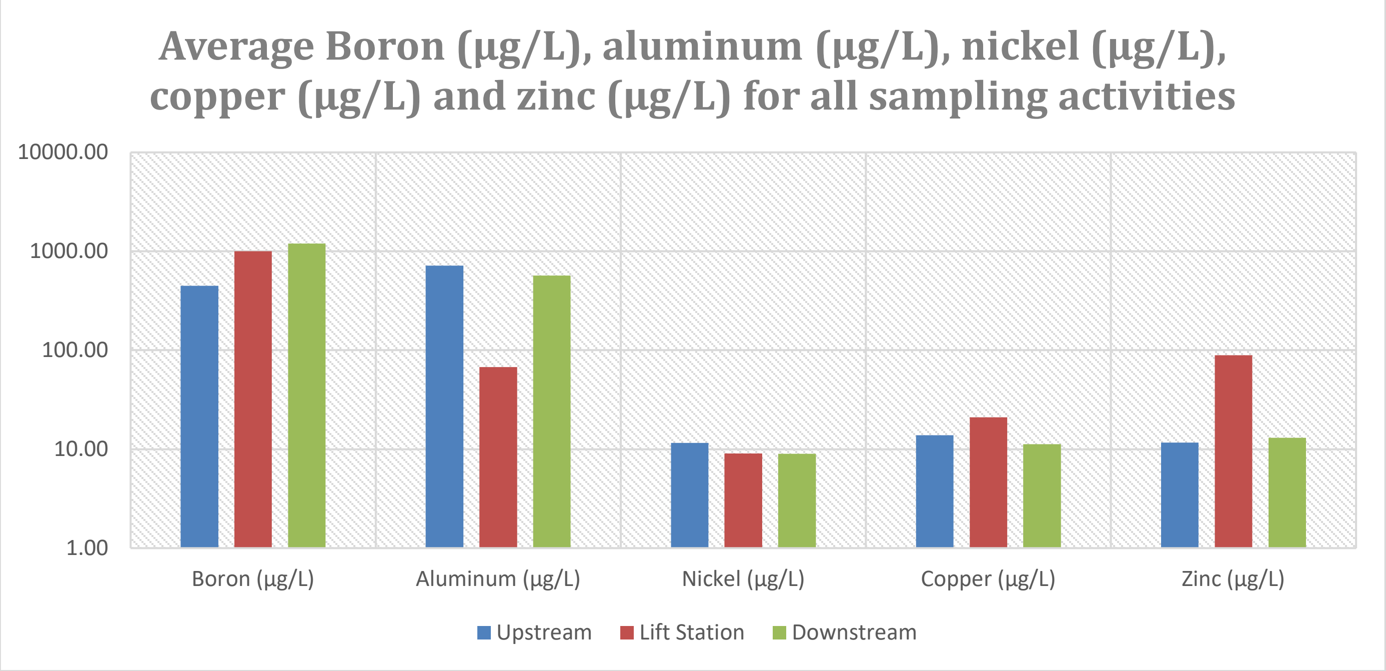
Based on the results of each sampling activity, lift station boron (μg/L) levels were higher than the levels in most upstream and downstream samples except, upstream and downstream samples taken on July 11, 2016 and June 12, 2018 and downstream samples collected on November 9, 2015 and May 10, 2017. Aluminum (μg/L) levels of the lift station samples remained well below the levels in upstream and downstream samples at all sampling times. Nickel (μg/L) levels of the lift station samples were mostly lower than the upstream and downstream samples except, in the upstream and downstream samples taken on July 11, 2016, September 30, 2019 and August 12, 2021 and downstream samples collected on August 17, 2017 and August 26, 2019. Copper (μg/L) levels of the lift station samples were higher than the levels in upstream and downstream samples except, upstream and downstream samples collected on May 10, 2017 and upstream samples collected on May 11, 2016, September 8, 2016 and June 12, 2018. Zinc (μg/L) levels of the lift station samples were also higher than the upstream and downstream samples at all sampling times except, one set of samples that was collected on May 10, 2017. Details are in Table 8.

Table 8. Results of Boron (µg/L), aluminum (µg/L), nickel (µg/L), copper (µg/L) and zinc (µg/L) for each sampling activity.

Date	Site	Boron (µg/L)	Aluminum (µg/L)	Nickel (µg/L)	Copper (µg/L)	Zinc (µg/L)
November 9, 2015	Upstream	580.00	887.00	9.10	9.96	17.20
	Lift Station	1260.00	ND	ND	18.80	25.40
	Downstream	7880.00	560.00	9.31	12.50	22.10
May 11, 2016	Upstream	685.00	134.00	8.87	14.20	9.98
	Lift Station	741.00	ND	6.99	14.00	15.00
	Downstream	635.00	82.00	9.36	13.70	8.66
July 11, 2016	Upstream	185.00	994.00	6.22	6.67	12.70
	Lift Station	87.00	ND	23.50	50.40	83.50
	Downstream	186.00	945.00	5.83	6.16	11.20
September 8, 2016	Upstream	318.00	250.00	13.30	42.20	7.060
	Lift Station	1700.00	52.00	9.48	34.60	10.80
	Downstream	355.00	98.00	12.50	12.10	ND
May 10, 2017	Upstream	471.00	1980.00	23.90	20.70	22.70
	Lift Station	821.00	ND	7.67	17.40	10.50
	Downstream	855.00	358.00	9.79	22.60	22.60
August 17, 2017	Upstream	445.00	333.00	12.10	10.30	ND
	Lift Station	1620.00	ND	11.70	25.80	598
	Downstream	276.00	775.00	10.20	6.40	10.40
June 12, 2018	Upstream	783.00	541.00	12.30	9.03	17.60
	Lift Station	724.00	ND	6.43	7.26	182.00
	Downstream	777.00	369.00	10.30	7.22	17.90
August 26, 2019	Upstream	754.00	ND	8.04	12.10	7.15
	Lift Station	1300.00	ND	5.36	16.20	18.90
	Downstream	1170.00	ND	5.35	16.00	10.40
September 30, 2019	Upstream	135.00	1360.00	ND	ND	8.26
	Lift Station	911.00	ND	6.66	18.60	9.60
	Downstream	187.00	1680.00	ND	ND	9.23
July 6, 2020	Upstream	451	402	17.30	8.65	7.83
	Lift Station	1000	25	6.65	16.00	10.90
	Downstream	685	476	12.50	10.90	9.65
August 12, 2021	Upstream	125	280	5.00	5.00	6.32
	Lift Station	843	126	6.19	12.60	15.00
	Downstream	150	356	5.00	5.00	7.83

Based on the average of all sampling activities, boron, copper and zinc (µg/L) levels of the lift station samples were higher than the upstream and downstream samples. Aluminum (µg/L) levels of the lift station samples were very low compared to the upstream and downstream samples, whereas, nickel (µg/L) levels of upstream samples were slightly higher than the lift station and downstream samples.

Figure 30. Average Boron (µg/L), aluminum (µg/L), nickel (µg/L), copper (µg/L) and zinc (µg/L) for all sampling activities.



Differences in the Arsenic, Selenium, Molybdenum and Barium levels

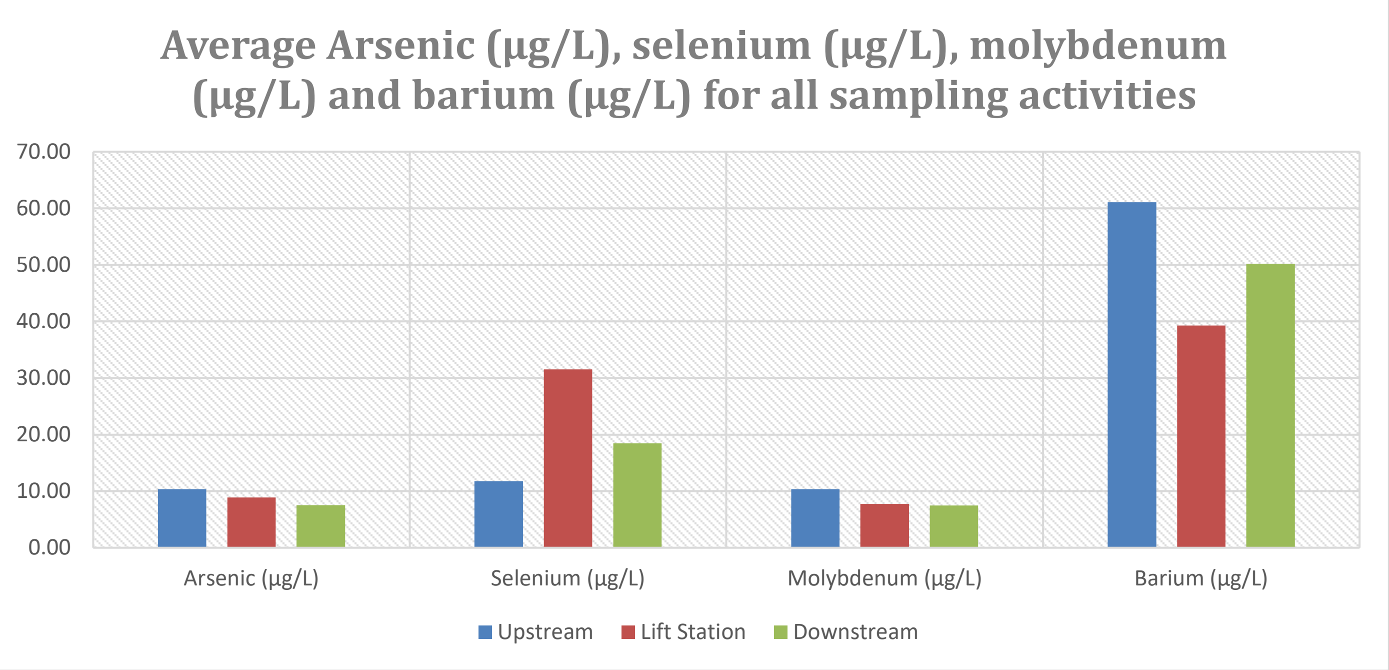
Based on the results of each sampling activity, arsenic (µg/L) levels of the lift station samples were mostly lower than the upstream and downstream samples except in the samples taken on July 11, 2016, September 30, 2019 and August 12, 2021. Selenium (µg/L) levels were higher in the lift station samples at all sampling times compared to the upstream and downstream samples. Molybdenum (µg/L) levels in the lift station samples were mostly lower than the detectable levels (5.00 µg/L) compared to the upstream and downstream samples except in the samples that were collected on July 11, 2016, September 30, 2019 and August 12, 2021. Barium levels of the lift station samples were mostly lower compared to the upstream and downstream samples except upstream and downstream samples collected on July 11, 2016, September 30, 2019 and August 12, 2021 and upstream samples collected on May 11, 2016 and August 26, 2019. Details are in Table 9.

Table 9. Results of Arsenic (µg/L), selenium (µg/L), molybdenum (µg/L) and barium (µg/L) for each sampling activity.

Date	Site	Arsenic (µg/L)	Selenium (µg/L)	Molybdenum (µg/L)	Barium (µg/L)
November 9, 2015	Upstream	8.19	16.10	ND	58.80
	Lift Station	ND	57.10	ND	24.80
	Downstream	5.65	28.50	6.60	47.40
May 11, 2016	Upstream	11.60	26.10	6.25	30.00
	Lift Station	11.00	31.20	ND	32.00
	Downstream	11.30	23.50	7.71	32.60
July 11, 2016	Upstream	ND	ND	ND	57.40
	Lift Station	23.70	110.00	16.60	86.80
	Downstream	ND	ND	ND	58.60
September 8, 2016	Upstream	9.34	ND	6.14	52.90
	Lift Station	ND	26.80	ND	25.30
	Downstream	5.94	ND	5.63	51.10
May 10, 2017	Upstream	10.50	7.83	9.45	118.00
	Lift Station	ND	21.70	ND	29.10
	Downstream	ND	20.30	ND	34.10
August 17, 2017	Upstream	ND	ND	5.87	33.10
	Lift Station	ND	13.90	ND	26.90
	Downstream	5.96	ND	ND	51.30
June 12, 2018	Upstream	5.15	ND	6.57	43.10
	Lift Station	ND	10.30	ND	41.30
	Downstream	6.71	ND	ND	53.20
August 26, 2019	Upstream	8.59	6.26	19.40	30.40
	Lift Station	5.03	11.70	ND	33.10
	Downstream	5.97	10.00	ND	39.70
September 30, 2019	Upstream	ND	ND	ND	36.70
	Lift Station	5.36	21.20	5.23	43.80
	Downstream	ND	ND	ND	37.90
July 6, 2020	Upstream	19.30	2.50	18.80	185
	Lift Station	2.50	23.00	2.50	44.10
	Downstream	11.30	9.91	9.88	117.00
August 12, 2021	Upstream	ND	ND	ND	26.40
	Lift Station	5.87	19.70	6.68	44.70
	Downstream	ND	ND	ND	29.30

Based on the average of all sampling activities, arsenic (µg/L) and molybdenum (µg/L) levels of lift station samples were lower than the upstream samples and slightly higher than the downstream samples. However, selenium (µg/L) and Barium (µg/L) levels of the lift station samples were higher than the upstream and downstream samples.

Figure 31. Average Arsenic (µg/L), selenium (µg/L), molybdenum (µg/L) and barium (µg/L) for all sampling activities.



Differences in the Ammonia, Manganese, Bromide and Iron levels

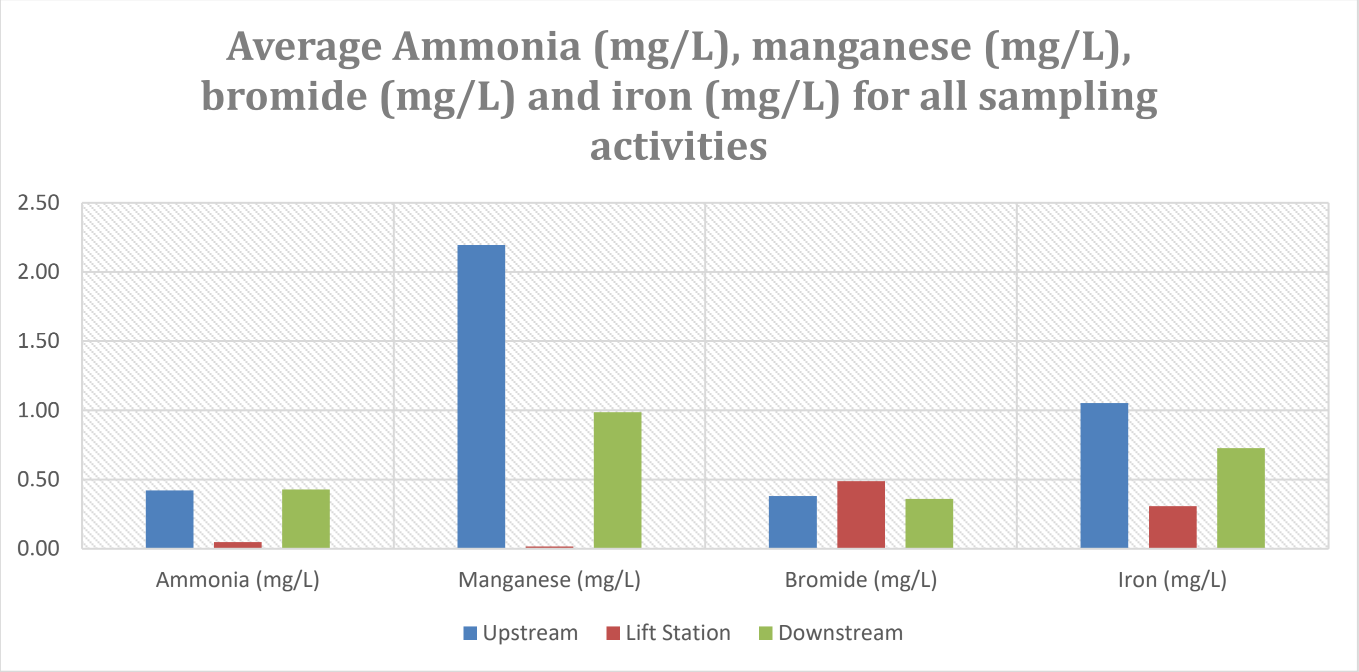
Based on the results of each sampling activity, ammonia (mg/L) levels were mostly lower or similar than the levels in the upstream and downstream samples except upstream and downstream samples that were collected on June 12, 2018 and upstream samples collected on September 30, 2019. The manganese (mg/L) levels of the lift station samples were lower than the levels in upstream and downstream samples at all times. Bromide (mg/L) levels of the lift station samples were mostly higher than the upstream and downstream samples except upstream and downstream samples that were collected on May 11, 2016, May 10, 2017, and June 12, 2018. Iron (mg/L) levels of the lift station samples were either non-detectable (0.50 mg/L) or were lower than the upstream and downstream samples except, one set of samples that was collected on August 17, 2017. Details are in Table 10.

Table 10. Results of Ammonia (mg/L), manganese (mg/L), bromide (g/L) and iron (mg/L) for each sampling activity.

Date	**Site**	**Ammonia (mg/L)**	**Manganese (mg/L)**	**Bromide (mg/L)**	**Iron (mg/L)**
November 9, 2015	Upstream	1.77	0.26	NA	1.30
	Lift Station	ND	ND	NA	ND
	Downstream	2.10	0.23	NA	0.93
May 11, 2016	Upstream	0.05	0.59	0.87	0.24
	Lift Station	ND	0.01	0.71	ND
	Downstream	0.08	0.94	0.85	0.18
July 11, 2016	Upstream	0.29	0.11	0.05	1.14
	Lift Station	0.03	0.01	0.64	0.35
	Downstream	0.06	0.07	0.05	0.99
September 8, 2016	Upstream	0.06	2.54	0.43	0.58
	Lift Station	ND	0.02	0.64	0.08
	Downstream	0.13	0.77	0.33	0.24
May 10, 2017	Upstream	0.25	6.29	0.64	2.89
	Lift Station	0.03	0.01	0.53	0.05
	Downstream	0.13	0.62	0.68	0.44
August 17, 2017	Upstream	0.09	0.61	0.29	0.62
	Lift Station	0.03	0.02	0.51	1.28
	Downstream	0.03	0.80	0.32	1.11
June 12, 2018	Upstream	0.04	1.81	0.35	0.83
	Lift Station	0.05	0.04	0.33	ND
	Downstream	0.04	1.65	0.36	0.72
August 26, 2019	Upstream	0.08	1.32	0.23	0.12
	Lift Station	ND	ND	0.42	ND
	Downstream	ND	0.16	0.32	0.12
September 30, 2019	Upstream	0.04	0.06	ND	1.64
	Lift Station	0.14	ND	0.40	0.31
	Downstream	0.52	0.08	0.05	1.86
July 6, 2020	Upstream	1.55	9.75	0.19	1.77
	Lift Station	0.01	0.01	0.42	0.02
	Downstream	1.15	4.66	0.29	0.86
August 12, 2021	Upstream	ND	0.78	ND	0.45
	Lift Station	ND	ND	0.29	0.06
	Downstream	0.03	0.86	ND	0.54

Based on the average of all sampling activities, ammonia (mg/L), manganese (mg/L) and iron (mg/L) levels of the lift station samples were lower than the upstream and downstream samples, whereas, bromide (mg/L) levels of the lift station samples were higher than the upstream and downstream samples.

Figure 32. Average Ammonia (mg/L), manganese (mg/L), bromide (mg/L) and iron (mg/L) for all sampling activities.



SUMMARY

Below is the summary of changes in the soil chemical and physical properties based on the compilation of data six-years after applying the soil amendments and seven-years after tiling the saline and sodic site.

Soil EC levels: have been directly related to the annual growing-season rainfall and moisture levels in the topsoil. Narrower gap between annual total potential evapotranspiration and actual rain has resulted in shallow groundwater depths, increased leaching, lower levels of soluble salts and less capillary rise/movement of soil water. Whereas a wider gap has indicated lower groundwater depths, less leaching, higher soluble salt levels and increased capillary rise. That 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. However, EC levels spiked up in 2017 and that trend continued in 2018, 2019, 2020 and 2021 despite average annual growing-season groundwater depths deeper than the depth of tiles (four-feet) on tiled-land. That was a result of increased capillary rise of soil water due to lower rainfall and higher evapotranspiration resulting in dry topsoil. This defies the common belief that lowering the groundwater depths will cause excess soluble salts to leach out. However, lowering soil EC levels will need an optimum combination of low enough groundwater depths, 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 during 2016, 2017, 2018, 2019, 2020 and 2021 the highest EC levels were observed in 12-24 and 24-36 inch soil depths. That could be indication of decent infiltration through the first foot, however, a 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 decrease in 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 in order to reduce evaporation and consequently capillary rise.

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. In addition, soil SAR levels increased with soil depth with 0-12 inch depth having the lowest SAR levels and 36-48 inch depth having the highest SAR levels. Despite the recent drier annual weather, for the first time in six-years, the overall SAR levels in 2021 were the lowest compared to rest of the years. This could be beginning of a positive trend.

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

Soil NO_3^--N levels: have been consistent with the annual growing-season rainfall and groundwater depths, soil drainage and how much N is being applied through fertilizers annually. A steady decline in soil NO_3^--N levels was observed that could be due to leaching, removal by the perennial salt-tolerant grass mix and no application since 2014. In addition, soil NO_3^--N levels decreased with increasing soil depth.

Soil P levels: decreased with time. That could be due to no phosphate fertilizer application since 2014. Before 2014, site was planted with annual crops and chemical phosphate fertilizer was applied annually. The 0-12 inch soil depth also had very high P levels versus 12-24 inch depth. In addition, except the first-year of amendment application (2015), VersaLime treatment had higher soil P levels in both soil depths (0-12 and 12-24 inch) versus rest of the treatments, which could be due to 42.50 ppm of available P levels in the VersaLime that was applied to the site.

Soil O.M. levels: decreased slightly until 2017 and then remained steady after that with no or poor vegetation before 2016. This is especially crucial for areas with high EC (salinity) and SAR (sodicity) levels where most of the annual crops do not do well. Establishing plant species, which will grow on saline and sodic areas such as a mix of perennial salt-tolerant grasses will keep adding above-the ground and below-the-ground plant biomass. Adding plant biomass will increase soil microorganism's population. When microbes die, dead microbes will turn into in microbial biomass. Both plant and microbial biomass will help increase soil organic matter levels. However, creating favorable growth environment for soil microbes and conversion of organic material into organic matter takes time. Replication 1 had highest organic matter levels followed by replications 2 and 3. That could be due to lower levels of EC and SAR and resultingly improved stands of perennial salt-tolerant grasses in replication 1 versus replications 2 and 3.

Soil CEC levels: showed a similar trend like organic matter. However, future perennial salt-tolerant grass biomass decomposition and increase in organic matter could result in higher CEC.

Soil Water Saturation levels: showed some trends where soil amendments were applied, how soluble each amendment was, average growing-season rain and potential evapotranspiration and average annual growing-season groundwater depths. More moisture, especially at the time of sampling resulted in higher soil water saturation levels. Over all, soil water saturation levels mostly remained higher gypsum, E-sulfur and VersaLime treatments compared to control. In addition, replication 3 had the shallowest groundwater depth in all years and had higher soil water saturation levels versus replications 1 and 2.

Soil CCE levels: remained mostly unchanged despite changes in the annual growing-season rainfall, moisture levels in the topsoil and average annual growing-season groundwater depths.

Soil HCO_3^- levels: mostly were inconsistent, however, had an increase from 2019-2021. In addition, HCO_3^- levels in the 0-12 inch depth remained significantly higher than rest of the soil depths, whereas, differences between the 12-24 and 24-36 and 36-48 inch soil depths were non-significant.

Soil Cl^- levels: have not shown a consistent trend due to the application of soil amendments, annual growing-season rainfall or average annual growing-season groundwater depths. However, the significantly higher Cl^- levels in 2018 under deepest average annual growing-season groundwater depths could be an indication of lack of soil water to leach Cl^- ions into the deeper soil depths.

Soil SO_4^{2-} levels: have also not shown a consistent trend due to the application of soil amendments, annual growing-season rainfall or changes in the average annual growing-season groundwater depths. Being an anion like Cl^-, SO_4^{2-} levels also fluctuate considerably due to the fluctuations in rain, groundwater depths and capillary rise/movement of soil water.

Soil Ca^{2+} levels: were significantly higher in 2014 at the time of tiling than rest of the years. Soil Ca^{2+} levels in 2016, decreased significantly in all treatments under higher rainfall, shallow average annual groundwater depths and tile drainage. Levels increased slightly in 2017 and 2018, decreased again in 2019 and increased back in 2020 and 2021. That pattern is somewhat consistent with the weather as under drier weather Ca^{2+} levels remained slightly higher. In addition, there were some differences in the Ca^{2+} levels among treatments with E-sulfur treatment resulting in the highest levels followed by VersaLime, gypsum and control treatments.

Soil Mg^{2+} levels: generally remained inconsistent between years, however, there were some differences in the Mg^{2+} levels among treatments with VersaLime treatment resulting in the highest levels followed by E-sulfur, gypsum and control treatments. In addition, Mg^{2+} levels decreased with increase in soil depth.

Soil Na^+ levels: have been inconsistent like SAR levels despite some annual changes. In addition, 0-12 inch depth had the lowest Na^+ levels, whereas, 12-24 and 24-36 inch depths had the highest Na^+ levels.

Soil K^+ levels: mostly remained steady, however, there has been a significant increase in K^+ levels in 2018 versus rest of the years. That could be an outlier, however, it needs to be verified in the future.

Soil Bulk Density levels: increased with soil depths. In addition, most years bulk density increased at lower gravimetric soil water contents. Hence, annual growing-season rainfall, resulting moisture levels in the topsoil and average annual growing-season groundwater depths had an effect on soil bulk density.

Soil Penetrometer Resistance measurements: were somewhat correlated with the gravimetric soil water contents. Generally, lower soil gravimetric water contents resulted in higher penetrometer resistance. An example could be 2015 when the second highest penetrometer resistance measurements were recorded at the lowest annual soil gravimetric water contents.

Quality of Water Draining from the Tiled Research Project Site for Human and Livestock Health: Based on average of all sampling times, conductivity, total dissolved solids, total hardness as $CaCO_3$, total alkalinity as $CaCO_3$, SAR, Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, HCO_3^-, Cl^-, total nitrogen, nitrate + nitrite nitrogen, copper, zinc, selenium and bromide levels of the lift station samples were higher than the upstream and downstream samples. The pH average of upstream, lift station and downstream samples were roughly similar. The K^+, Kjeldahl nitrogen, total phosphorous, dissolved phosphorous, aluminum, barium, ammonia, manganese and iron averages of the lift station samples were lower than the upstream and downstream samples. These trends point out that over time depending upon the site-specific soil chemistry, tile drainage water can add salts, alkalinity, sodicity, soluble nitrogen and some trace elements to the surface water resources.

CONCLUSIONS

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 not much can be done about it. That is correct if we only compare the texture of clayey soils with silty or sandy soils. However, a clayey soil with high to very high dispersion and/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 adopting practices that help increase organic matter will improve soil particle aggregation, structure, pore space, water infiltration and permeability.

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

Does soil sodicity negatively affect tile drainage performance?

Potentially, 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 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 did not run for three to four days to start 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 had actually increased in 2017-2021. That is due to the lack of rain water to force the 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.

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