# 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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This research report is an extension of an ongoing research trial. If you would like to know more about the trial background, objectives, location, site description, design and methodology, please refer to the previous Langdon Research Extension Center's Annual Reports.

## RESULTS AND DISCUSSION

The findings below are based on the statistical analysis of the effects of soil amendments (treatments) and average annual growing-season groundwater depths on the 2014, 2016, 2017, 2018 and 2019 soil EC (salinity), SAR (sodicity) and pH levels measured at zero to four-foot depths by using SAS package 9.4 at 95% confidence interval. The 2014 results represent soil samples collected at the time when the field was tiled, 2016 results represent samples collected two years after tiling and one year after the application of soil amendments, 2017 results are for samples collected three years after tiling and two years after applying the amendments, 2018 results are for the samples collected four years after tiling and three years after applying the amendments and 2019 results are for the samples collected five years after tiling and four years after applying the amendments.

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

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

Table 2. The Treatment means of the Soil EC, SAR and pH Levels at the time of Tiling (2014).

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

## Effect of Soil Amendments on EC, SAR and pH Levels

### Differences in Soil EC Levels

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

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

| **Source** | **Mean Square** | **P > F** |
|---|---|---|
| Year | 152.53 | <.0001 |
| Treatment | 44.67 | <.0001 |
| Replication | 65.19 | <.0001 |
| Soil Depths | 11.30 | 0.0647 |

| | | |
|---|---|---|
| Year vs Treatment | 1.50 | 0.9642 |
| Treatment vs Soil Depths | 1.93 | 0.9227 |
| Year vs Treatment vs Soil Depths | 1.08 | 1.0000 |

The 2016, 2017, 2018 and 2019 soil EC levels were significantly lower than 2014. However, EC levels increased in 2017, 2018 and 2019 significantly compared to 2016 due to drier weather and resulting capillary rise (wicking up) of soil water. In addition, soil EC levels of gypsum, E-Sulfur (elemental sulfur) and VersaLime treatments were significantly higher than the control treatments. There were no significant differences among gypsum, E-Sulfur and VersaLime treatments. The EC levels in the 12-24 inch depths also remained significantly higher than the EC levels in the 0-12 inch and 36-48 inch depths. Overall, highest EC levels were measured in 12-24 inch depths, followed by 24-36 inch, 0-12 inch and 36-48 inch depths. Details are in Table 4.

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

| Annual Means | |
|---|---|
| 2014 | 8.77 |
| 2016 | 3.75 |
| 2017 | 6.59 |
| 2018 | 6.24 |
| 2019 | 6.14 |
| Treatment Means | |
| Control | 5.01 |
| E-Sulfur | 6.67 |
| Gypsum | 6.76 |
| VersaLime | 6.76 |
| Means for Soil Depths | |
| 0-12 inch | 6.03 |
| 12-24 inch | 6.82 |
| 24-36 inch | 6.47 |
| 36-48 inch | 5.87 |

Based on the differences in the annual means of soil EC levels (Table 5), in 2016, EC levels dropped significantly compared to 2014 despite higher rainfall and shallower average annual growing-season groundwater depths. In 2017, 2018 and 2019, EC levels remained lower than 2014, however, compared to 2016, EC levels increased despite lower average annual growing-season groundwater depths due to drier weather. That could be attributed to the increased capillary rise of soil water due to increased evapotranspiration. The differences in EC levels of 2017, 2018 and 2019 were not significant.

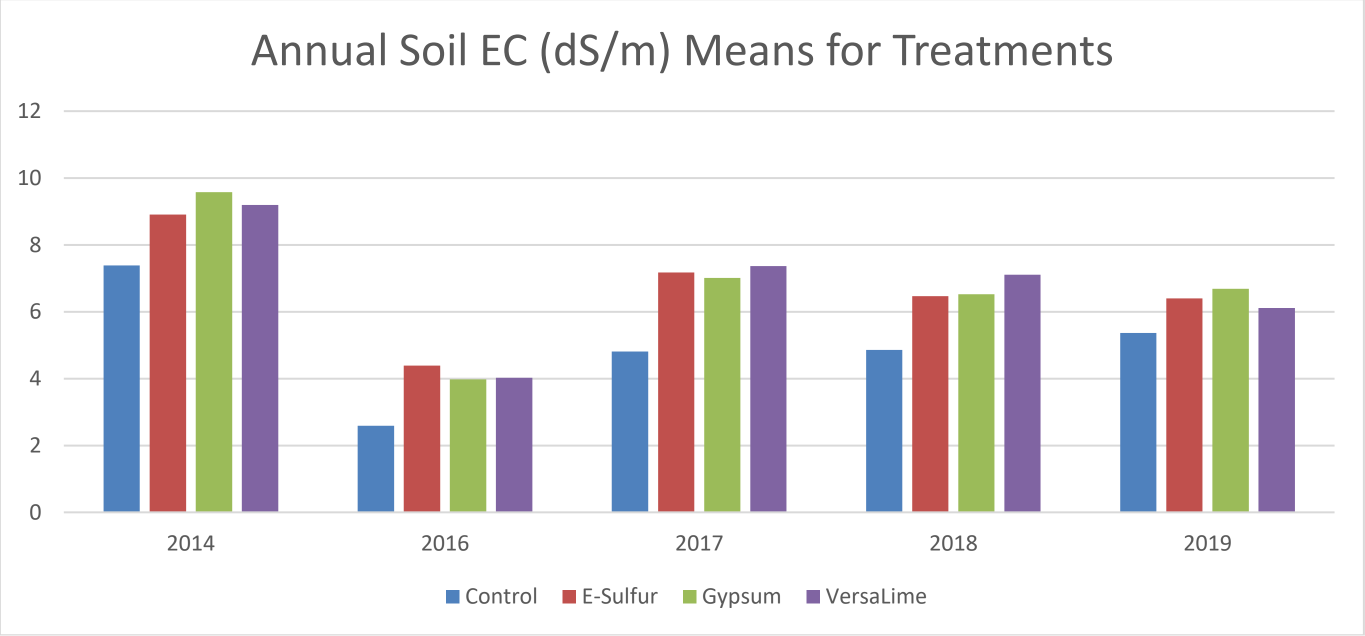
Table 5. Annual Differences in the Means of Soil EC (dS/m) Levels among Treatments.

| | **Least Square Means** | | | |
|---|---|---|---|---|
| **Year** | **Control** | **E-Sulfur** | **Gypsum** | **VersaLime** |
| 2016 | 2.59 | 4.39 | 3.98 | 4.03 |
| 2014 | 7.39 | 8.91 | 9.58 | 9.19 |
| Difference | -4.80 | -4.52 | -5.60 | -5.16 |
| 2017 | 4.81 | 7.17 | 7.01 | 7.37 |
| 2014 | 7.39 | 8.91 | 9.58 | 9.19 |
| Difference | -2.58 | -1.74 | -2.57 | -1.82 |
| 2018 | 4.86 | 6.47 | 6.52 | 7.11 |

| | | | | |
|---|---|---|---|---|
| 2014 | 7.39 | 8.91 | 9.58 | 9.19 |
| Difference | -2.53 | -2.44 | -3.06 | -2.08 |
| 2019 | 5.37 | 6.40 | 6.69 | 6.11 |
| 2014 | 7.39 | 8.91 | 9.58 | 9.19 |
| Difference | -2.02 | -2.51 | -2.89 | -3.08 |
| 2017 | 4.81 | 7.17 | 7.01 | 7.37 |
| 2016 | 2.59 | 4.39 | 3.98 | 4.03 |
| Difference | 2.22 | 2.78 | 3.03 | 3.34 |
| 2018 | 4.86 | 6.47 | 6.52 | 7.11 |
| 2016 | 2.59 | 4.39 | 3.98 | 4.03 |
| Difference | 2.27 | 2.08 | 2.54 | 3.08 |
| 2019 | 5.37 | 6.40 | 6.69 | 6.11 |
| 2016 | 2.59 | 4.39 | 3.98 | 4.03 |
| Difference | 2.78 | 2.01 | 2.71 | 2.08 |
| 2018 | 4.86 | 6.47 | 6.52 | 7.11 |
| 2017 | 4.81 | 7.17 | 7.01 | 7.37 |
| Difference | 0.05 | -0.70 | -0.49 | -0.26 |
| 2019 | 5.37 | 6.40 | 6.69 | 6.11 |
| 2017 | 4.81 | 7.17 | 7.01 | 7.37 |
| Difference | 0.56 | -0.77 | -0.32 | -1.26 |
| 2019 | 5.37 | 6.40 | 6.69 | 6.11 |
| 2018 | 4.86 | 6.47 | 6.52 | 7.11 |
| Difference | 0.51 | -0.07 | 0.17 | -1.00 |

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

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



## Differences in Soil SAR Levels

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

Table 6. Statistical Differences in Soil SAR Levels.

| **Source** | **Mean Square** | **P > F** |
|---|---|---|
| Year | 92.14 | 0.0292 |
| Treatment | 349.73 | <.0001 |
| Replication | 0.27 | 0.9919 |
| Soil Depths | 664.71 | <.0001 |
| Year vs Treatment | 38.01 | 0.3339 |
| Treatment vs Soil Depths | 24.21 | 0.5211 |
| Year vs Treatment vs Soil Depths | 18.29 | 0.9359 |

The 2018 soil SAR levels remained significantly higher versus 2014, 2016 and 2017. The soil SAR levels of control treatments remained significantly lower than the rest of the treatments. In addition, SAR levels in the gypsum treatments remained significantly higher than E-sulfur and VersaLime treatments. There was a significant increase in SAR levels with soil depth, with 0-12 inch depths having the lowest SAR levels and 36-48 inch depths having the highest SAR levels. Details are in Table 7.

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

| Annual Means | |
|---|---|
| 2014 | 15.96 |
| 2016 | 16.45 |
| 2017 | 15.15 |
| 2018 | 18.82 |
| 2019 | 17.12 |
| Treatment Means | |
| Control | 13.53 |
| E-Sulfur | 17.00 |
| Gypsum | 19.40 |
| VersaLime | 16.87 |
| Means for Soil Depths | |
| 0-12 inch | 13.26 |
| 12-24 inch | 15.08 |
| 24-36 inch | 17.50 |
| 36-48 inch | 20.96 |

Based on the differences in the annual means of soil SAR levels (Table 8), 2018 SAR levels remained significantly higher than the SAR levels in 2014, 2016 and 2017. Whereas, there were no significant differences in 2014, 2016 2017 and 2019 SAR levels.

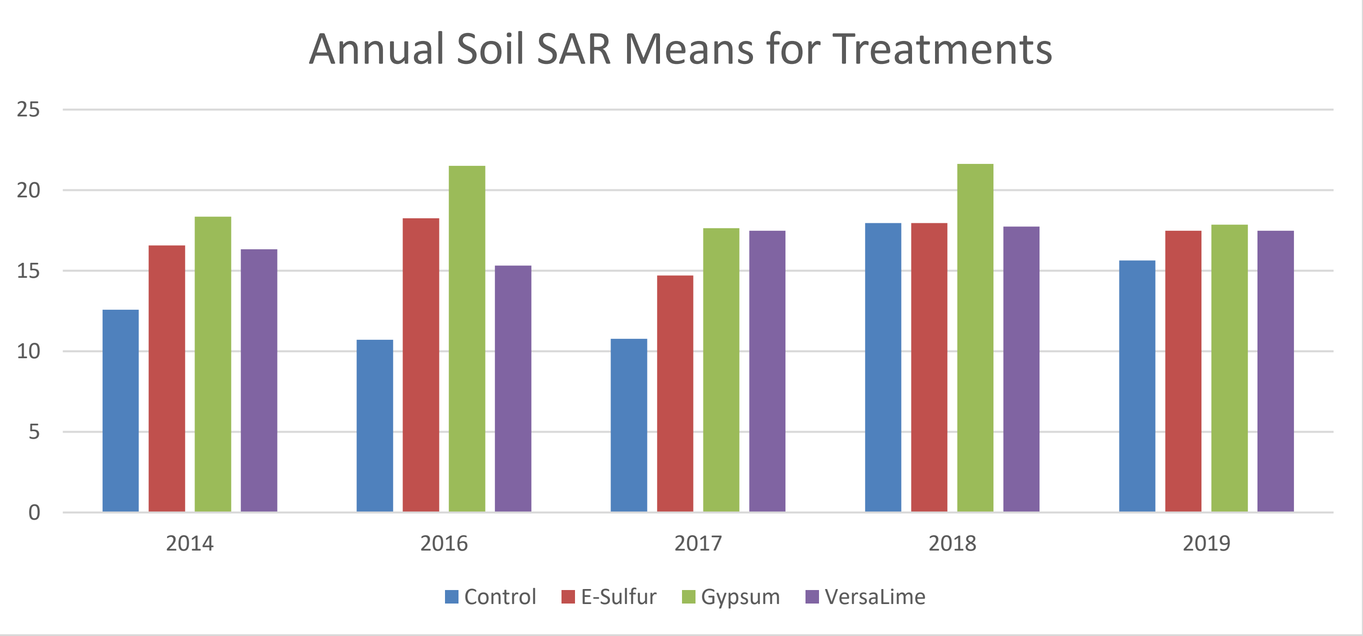
Table 8. Annual Differences in the Means of Soil SAR (sodicity) Levels among Treatments.

| | **Means** | | | |
|---|---|---|---|---|
| **Year** | **Control** | **E-Sulfur** | **Gypsum** | **VersaLime** |
| 2016 | 10.72 | 18.26 | 21.51 | 15.32 |
| 2014 | 12.58 | 16.58 | 18.36 | 16.33 |
| Difference | -1.86 | 1.68 | 3.15 | -1.01 |
| 2017 | 10.77 | 14.71 | 17.64 | 17.48 |
| 2014 | 12.58 | 16.58 | 18.36 | 16.33 |

| | | | | |
|---|---|---|---|---|
| Difference | -1.81 | -1.87 | -0.72 | 1.15 |
| 2018 | 17.95 | 17.95 | 21.64 | 17.75 |
| 2014 | 12.58 | 16.58 | 18.36 | 16.33 |
| Difference | 5.37 | 1.37 | 3.28 | 1.42 |
| 2019 | 15.63 | 17.49 | 17.87 | 17.49 |
| 2014 | 12.58 | 16.58 | 18.36 | 16.33 |
| Difference | 3.05 | 0.91 | -0.49 | 1.16 |
| 2017 | 10.77 | 14.71 | 17.64 | 17.48 |
| 2016 | 10.72 | 18.26 | 21.51 | 15.32 |
| Difference | 0.05 | -3.55 | -3.87 | 2.16 |
| 2018 | 17.95 | 17.95 | 21.64 | 17.75 |
| 2016 | 10.72 | 18.26 | 21.51 | 15.32 |
| Difference | 7.23 | -0.31 | 0.13 | 2.43 |
| 2019 | 15.63 | 17.49 | 17.87 | 17.49 |
| 2016 | 10.72 | 18.26 | 21.51 | 15.32 |
| Difference | 4.91 | -0.77 | -3.64 | 2.17 |
| 2018 | 17.95 | 17.95 | 21.64 | 17.75 |
| 2017 | 10.77 | 14.71 | 17.64 | 17.48 |
| Difference | 7.18 | 3.24 | 4.00 | 0.27 |
| 2019 | 15.63 | 17.49 | 17.87 | 17.49 |
| 2017 | 10.77 | 14.71 | 17.64 | 17.48 |
| Difference | 4.86 | 2.78 | 0.23 | 0.01 |
| 2019 | 15.63 | 17.49 | 17.87 | 17.49 |
| 2018 | 17.95 | 17.95 | 21.64 | 17.75 |
| Difference | -2.32 | -0.46 | -3.77 | -0.26 |

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

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



## Differences in Soil pH Levels

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

Table 9. Statistical Differences in Soil pH Levels.

| Source | Mean Square | P > F |
|---|---|---|
| Year | 7.90 | <.0001 |
| Treatment | 0.03 | 0.7602 |
| Replication | 0.25 | 0.0716 |
| Soil Depths | 2.59 | <.0001 |
| Year vs Treatment | 0.04 | 0.9333 |
| Treatment vs Soil Depths | 0.04 | 0.6939 |
| Year vs Treatment vs Soil Depths | 0.04 | 0.9761 |

The 2016, 2017, 2018 and 2019 soil pH levels were significantly higher than the pH levels in 2014. However, there were no significant differences in pH between 2016, 2017, 2018 and 2019. 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. Like SAR, soil pH significantly increased with soil depth, with 0-12 inch depths having the lowest pH levels and 36-48 inch depths having the highest pH levels. Increase in pH with soil depth was due to the increase in soil moisture levels. There were no significant differences in soil pH among the four treatments. Details are in Table 10.

Table 10. Annual Differences in Soil pH Levels.

| Annual Means | |
|---|---|
| 2014 | 7.04 |
| 2016 | 7.90 |
| 2017 | 7.92 |
| 2018 | 8.01 |
| 2019 | 7.96 |
| Treatment Means | |
| Control | 7.77 |
| E-Sulfur | 7.73 |
| Gypsum | 7.77 |
| VersaLime | 7.79 |
| Means for Soil Depths | |
| 0-12 inch | 7.49 |
| 12-24 inch | 7.73 |
| 24-36 inch | 7.87 |
| 36-48 inch | 7.97 |

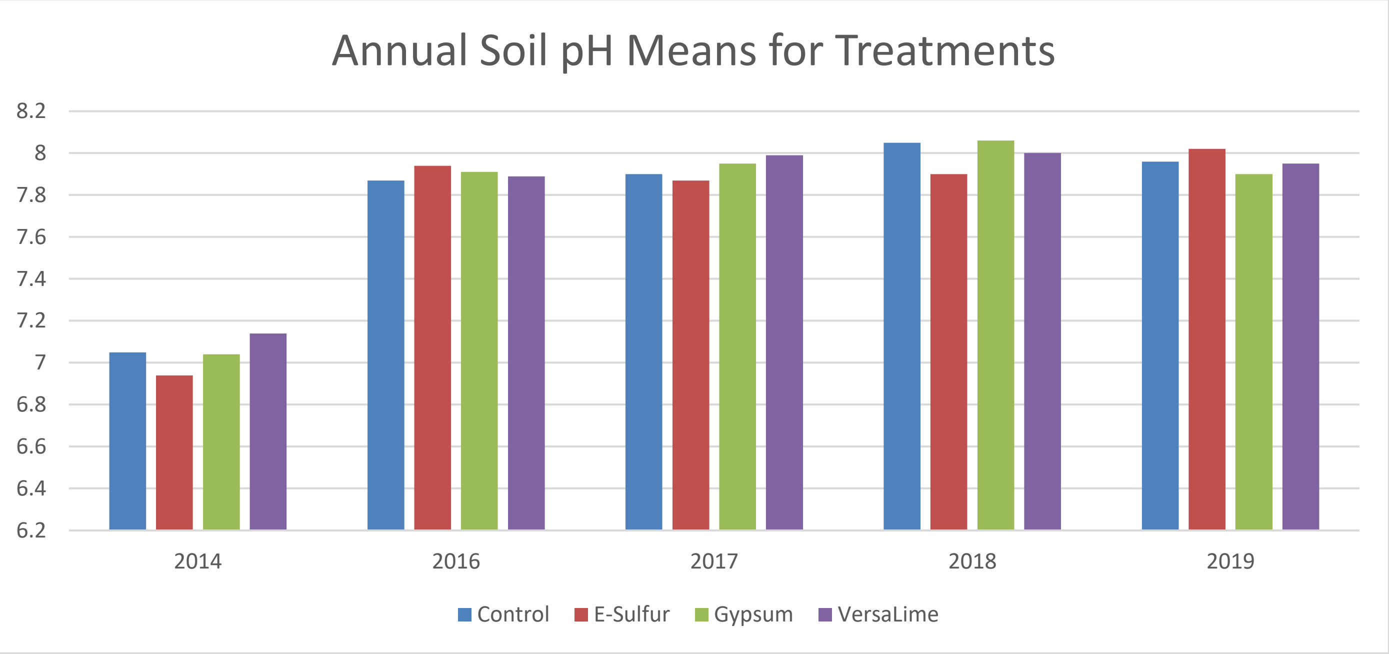
Based on the differences in the annual means of soil pH (Table 11), 2014 pH levels were lower than the rest of the years due to the lower soil moisture conditions at the time of sampling (September 2014). In 2016, 2017, 2018 and 2019, soil samples were collected in June of each year when moisture levels were higher than September 2014.

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

| | **Means** | | | |
|---|---|---|---|---|
| **Year** | **Control** | **E-Sulfur** | **Gypsum** | **VersaLime** |
| 2016 | 7.87 | 7.94 | 7.91 | 7.89 |
| 2014 | 7.05 | 6.94 | 7.04 | 7.14 |
| Difference | 0.82 | 1.00 | 0.87 | 0.75 |
| 2017 | 7.90 | 7.87 | 7.95 | 7.99 |
| 2014 | 7.05 | 6.94 | 7.04 | 7.14 |
| Difference | 0.85 | 0.93 | 0.91 | 0.85 |
| 2018 | 8.05 | 7.90 | 8.06 | 8.00 |
| 2014 | 7.05 | 6.94 | 7.04 | 7.14 |
| Difference | 1.00 | 0.96 | 1.02 | 0.86 |
| 2019 | 7.96 | 8.02 | 7.90 | 7.95 |
| 2014 | 7.05 | 6.94 | 7.04 | 7.14 |
| Difference | 0.91 | 1.08 | 0.86 | 0.81 |
| 2017 | 7.90 | 7.87 | 7.95 | 7.99 |
| 2016 | 7.87 | 7.94 | 7.91 | 7.89 |
| Difference | 0.03 | -0.07 | 0.04 | 0.10 |
| 2018 | 8.05 | 7.90 | 8.06 | 8.00 |
| 2016 | 7.87 | 7.94 | 7.91 | 7.89 |
| Difference | 0.18 | -0.04 | 0.15 | 0.11 |
| 2019 | 7.96 | 8.02 | 7.90 | 7.95 |
| 2016 | 7.87 | 7.94 | 7.91 | 7.89 |
| Difference | 0.09 | 0.08 | -0.01 | 0.06 |
| 2018 | 8.05 | 7.90 | 8.06 | 8.00 |
| 2017 | 7.90 | 7.87 | 7.95 | 7.99 |
| Difference | 0.15 | 0.03 | 0.11 | 0.01 |
| 2019 | 7.96 | 8.02 | 7.90 | 7.95 |
| 2017 | 7.90 | 7.87 | 7.95 | 7.99 |
| Difference | 0.06 | 0.15 | -0.05 | -0.04 |
| 2019 | 7.96 | 8.02 | 7.90 | 7.95 |
| 2018 | 8.05 | 7.90 | 8.06 | 8.00 |
| Difference | -0.09 | 0.12 | -0.16 | -0.05 |

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

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



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

For statistical analysis, 2016, 2017, 2018 and 2019 average annual growing-season groundwater depths measured at zero to seven foot depths were used. However, since observation wells were installed in 2015, Table 12 contains differences between 2015, 2016, 2017, 2018 and 2019 average annual growing-season groundwater depths. Also, 2015 average annual growing-season groundwater depths were not measured for the entire growing-season (April to October). Based on the data in Table 12, 2016 groundwater depths were shallower than the 2015, 2017, 2018 and 2019 depths. The lowest average annual growing-season groundwater depths were recorded in 2018 groundwater.

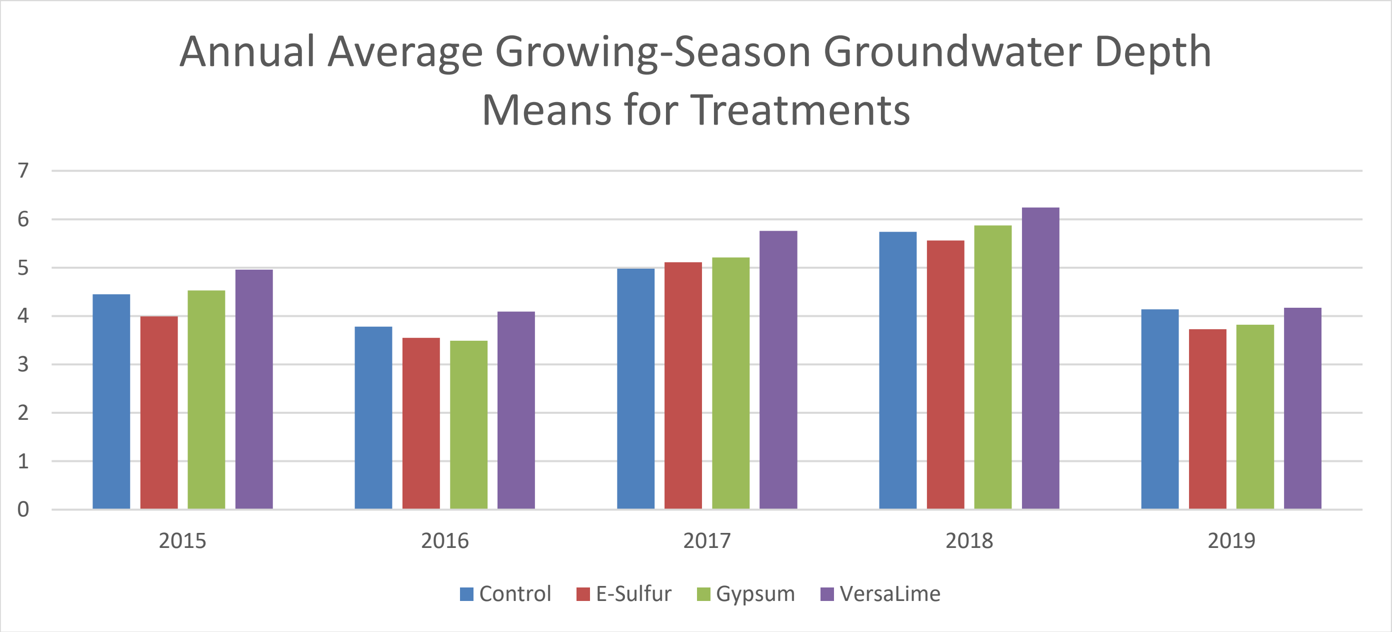
Table 12. Average Annual Growing-Season Groundwater Depth Differences among Treatments in feet.

| | **Average Annual Growing-Season Groundwater Depths in feet** | | | |
|---|---|---|---|---|
| **Year** | **Control** | **E-Sulfur** | **Gypsum** | **VersaLime** |
| 2015 | 4.45 | 3.99 | 4.53 | 4.96 |
| 2016 | 3.78 | 3.55 | 3.49 | 4.09 |
| Difference | 0.67 | 0.44 | 1.04 | 0.87 |
| 2015 | 4.45 | 3.99 | 4.53 | 4.96 |
| 2017 | 4.98 | 5.11 | 5.21 | 5.76 |
| Difference | -0.53 | -1.12 | -0.68 | -0.80 |
| 2015 | 4.45 | 3.99 | 4.53 | 4.96 |
| 2018 | 5.74 | 5.56 | 5.87 | 6.24 |
| Difference | -1.29 | -1.57 | -1.34 | -1.28 |
| 2015 | 4.45 | 3.99 | 4.53 | 4.96 |
| 2019 | 4.14 | 3.73 | 3.82 | 4.17 |
| Difference | 0.31 | 0.26 | 0.71 | 0.79 |

| | | | | |
|---|---|---|---|---|
| 2016 | 3.78 | 3.55 | 3.49 | 4.09 |
| 2017 | 4.98 | 5.11 | 5.21 | 5.76 |
| Difference | -1.20 | -1.56 | -1.72 | -1.67 |
| 2016 | 3.78 | 3.55 | 3.49 | 4.09 |
| 2018 | 5.74 | 5.56 | 5.87 | 6.24 |
| Difference | -1.96 | -2.01 | -2.38 | -2.15 |
| 2016 | 3.78 | 3.55 | 3.49 | 4.09 |
| 2019 | 4.14 | 3.73 | 3.82 | 4.17 |
| Difference | -0.36 | -0.18 | -0.33 | -0.08 |
| 2017 | 4.98 | 5.11 | 5.21 | 5.76 |
| 2018 | 5.74 | 5.56 | 5.87 | 6.24 |
| Difference | -0.76 | -0.45 | -0.66 | -0.48 |
| 2017 | 4.98 | 5.11 | 5.21 | 5.76 |
| 2019 | 4.14 | 3.73 | 3.82 | 4.17 |
| Difference | 0.84 | 1.38 | 1.39 | 1.59 |
| 2018 | 5.74 | 5.56 | 5.87 | 6.24 |
| 2019 | 4.14 | 3.73 | 3.82 | 4.17 |
| Difference | 1.60 | 1.83 | 2.05 | 2.07 |

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

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



Fluctuations in groundwater depths is also reflective of a very wet 2016 versus drier weather in 2017 and 2018 (Table 13). In 2019, weather was dry until July 30th and started getting wet from July 31st. The NDSU Langdon Research Extension Center, North Dakota Agricultural Weather Network (NDAWN) Station recorded 6.28 inches of rainfall versus a normal of 10.73 inches from April 1st to July 30th of 2019. The Total Potential Evapotranspiration (Penman) for the same period was 25.17 inches. Same station recorded 9.74 inches of rain versus a normal of 4.76 inches for July 31st to October 5th 2019 time period. The Total Potential Evapotranspiration (Penman) for the same period was 9.04 inches. On July 31st 0.77 inches were recorded and in August of 2019, 2.48 inches of rain was recorded versus a normal of 2.57 inches. September 2019 was wettest and 5.87 inches of rain was recorded versus a normal of 1.81 inches. Overall, growing-season was dry, whereas, fall was very wet which created a lot of harvest issues.

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

| Time Period | Total Potential Evapotranspiration (Penman) | Total Rainfall (inches) | Total Normal Rainfall (inches) |
|---|---|---|---|
| April 1 – Oct. 31, 2015 | 41.37” | 18.46” | 16.68” |
| April 1 – Oct. 31, 2016 | 35.29” | 24.91” | |
| April 1 – Oct. 31, 2017 | 38.72” | 10.24” | |
| April 1 – Oct. 31, 2018 | 38.28” | 11.41” | |
| April 1 – Oct. 31, 2019 | 35.62” | 16.39” | |

## Differences in Soil EC Levels

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

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

| **Source** | **Mean Square** | **P > F** |
|---|---|---|
| Year | 152.53 | 0.0003 |
| Treatment | 44.67 | 0.0106 |
| Replication | 65.19 | 0.0056 |
| Soil Depths | 11.30 | 0.1652 |
| Year vs Groundwater Depths | 6.93 | 0.3307 |
| Groundwater Depths vs Soil Depths | 2.53 | 0.9074 |
| Year vs Groundwater Depths vs Soil Depths | 3.41 | 0.6452 |

The 2016 soil EC levels were significantly lower than the 2017, 2018 and 2019 EC levels despite the shallowest average annual growing-season groundwater depths. The average annual growing-season groundwater depths lowered in 2017, 2018 due to drier weather (Table 13) resulting in increased capillary rise and EC levels. That trend continued in 2019 during most of the growing-season except late fall when 5.87 inches of rain was recorded during September versus a normal of 1.81 inches. Overall, 9.74 inches of rain was recorded versus a normal of 4.76 inches during July 31st to October 5th. Among treatments, EC levels in the control treatments were significantly lower than the EC levels in E-sulfur, gypsum and VersaLime treatments. In addition, replication 2 had significantly higher EC levels than replications 1 and 3, whereas, replication 1 had significantly higher EC levels than replication 3.

## Differences in Soil SAR Levels

Statistically there were significant differences in the annual soil SAR levels between treatments and soil depths due to the changes in the average annual growing-season groundwater depths (Table 15). The SAR levels in 2018 were significantly higher than the SAR levels in 2016, 2017 and 2019. In addition, SAR levels in 2019 were significantly higher than the SAR levels in 2017. The control treatment had significantly lower SAR levels compared to gypsum, E-sulfur and VersaLime treatments, whereas, gypsum treatments had the highest SAR levels versus the rest of the treatments. The SAR levels also increased significantly with an increase in soil depths with 0-12 inch depths having the lowest SAR levels and 36-48 inch depths being the highest.

Table 15. Statistical Differences in Soil SAR Levels.

| Source | Mean Square | P > F |
|---|---|---|
| Year | 92.14 | 0.0111 |
| Treatment | 349.73 | 0.0004 |
| Replication | 0.27 | 0.9744 |
| Soil Depths | 664.71 | <.0001 |
| Year vs Groundwater Depths | 61.31 | 0.0166 |
| Groundwater Depths vs Soil Depths | 14.81 | 0.3567 |
| Year vs Groundwater Depths vs Soil Depths | 32.83 | 0.0955 |

### Differences in Soil pH Levels

Statistically there were significant effects of the average annual growing-season groundwater depths on soil pH levels between replication and soil depths (Table 16). Soil pH levels in 2014 were significantly lower than 2016, 2017, 2018 and 2019. Since groundwater depths could not be measured in 2014, it cannot be concluded that these differences were due to the differences in average annual growing-season groundwater depths.

Table 16. Statistical Differences in Soil pH Levels.

| Source | Mean Square | P > F |
|---|---|---|
| Year | 7.90 | <.0001 |
| Treatment | 0.03 | 0.5462 |
| Replication | 0.25 | 0.0465 |
| Soil Depths | 2.59 | <.0001 |
| Year vs Groundwater Depths | 0.11 | 0.1211 |
| Groundwater Depths vs Soil Depths | 0.04 | 0.6585 |
| Year vs Groundwater Depths vs Soil Depths | 0.03 | 0.6247 |

Replication 3 had significantly higher pH levels than replication 1 and 2. That could be a result of shallower average annual groundwater depths in replication 3 resulting in higher soil moisture levels. The effect of soil moisture levels on pH was also evident due to the difference in pH levels between different soil depths. The pH levels also increased significantly with an increase in soil depths with 0-12 inch depths having the lowest pH levels and 36-48 inch depths being the highest.

## CONCLUSION

Based on the data collected five years after tiling and four years after applying soil amendments, changes in soil EC (salinity) levels were consistent with the fluctuations in the annual rainfall and evapotranspiration data. Tiling the saline-sodic site alone did not seem to make a big difference as the highest annual decrease in EC levels was recorded in 2016 with shallower groundwater levels and higher seasonal rainfall (24.91”). Drier weather in 2017, 2018 and early part of 2019, resulted in an increase in EC levels despite lower annual average growing-season groundwater depths. That could be due to the absence of a decent amount of rain to push the salts deeper and increased evapotranspiration resulting in capillary rise of soil water. Consistently higher SAR (sodicity) levels could also be contributing to the slower leaching of excessive salts from the top four feet of soil due to the poor permeability.

Tiling seemed to help when there was excess water to drain in 2016 and help maintain slightly lower groundwater depths. However, under drier weather, groundwater depths lowered naturally and salt levels increased due to capillary rise (wicking up) despite tiling.

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

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

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

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