Impact of drainage water management and subirrigation on soil and water quality

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Situation statement

Soybean production needs good water and soil conditions to produce the highest yield possible for the growing season. Following the wet weather cycle of the last two decades, subsurface drainage, commonly called tile, drainage, has become an important farm management practice. It can remove excess water from the root zone, reduce soil salinity, and provide timely field access for planting and harvest. However, highly soluble salts, including nitrate, phosphorus, and sulfate, are found in the tile outflow. These dissolved salts are valuable crop nutrients if they remained in the field. However, if they leave the field and enter a receiving stream, then they are contaminants and can cause water quality problems. To balance the need of tile drainage with the control of soluble salts lost from fields, a new practice called controlled drainage can be used. Controlled drainage uses a structure at the tile outlet that contains adjustable boards to control when and how much water leaves the field. If an adequate water source is available in July and August, a tile system with controlled drainage structures can be used for subirrigation. The combination of controlled drainage and subirrigation can reduce the nutrient loss from the field, maintain optimum soil moisture for the crop, and result in a higher crop yield. However, the effects of controlled drainage and subirrigation on water and soil qualities needs further study in the Red River Valley.

Objectives

1. To evaluate water quality differences among different drainage water management practices (no tile, only surface drainage - undrained (UD), tile drainage with gravity outlet – free drainage (FD), tile drainage with flow control – controlled drainage (CD), and CD + subirrigation (SI) using measureable parameters, including nutrients and salt content in surface and subsurface outflow.
2. To assess the soil quality changes due to SI practices via soil salinity mapping and soil chemistry, infiltration, and conductivity measurements.

Description of the research conducted

Six fields at two existing sites are used to study the impact of drainage water management and subirrigation on soil and water quality in 2015-2016. The Clay County, MN site has four fields with four water management practices, UD, FD, CD, and SI (http://mysare.sare.org/sare_project/lnc11-332/). The Richland County, ND site has two fields with two water management practices, UD and CD+SI (http://www.ndwatermonit.org/2016_Conference/2_Wednesday/1_Jia_TileDrainageWQ.pdf, Jia et al. 2012). When possible, we have collected water samples from surface runoff, tile drainage outflow, subirrigation water, and the surface drainage ditch on a weekly schedule for four fields in Clay County, MN and analyzed the chemical constitutions. For the two fields in Richland County, ND, when possible, we collected water samples on a biweekly schedule and sent the water samples to the ND Department of Health for analysis of a suite of dissolved minerals and the results can be found at http://mapservice.swc.nd.gov/ for the last four years. We also measured the drainage outflow, subirrigation inflow, water table, rainfall, snowfall, soil moisture and temperature profiles, relative humidity and air temperature using various instruments. At the end of the season, we have collected soil samples from several locations around a buried tile and performed several analyses on each soil sample. On each field we constructed a soil salinity map using an EM38. In 2015, sugerbeet, soybean, and corn were planted in the six fields and we obtained yield estimations for each.

Findings

This project, which centers on the effects to water and soil quality effect due to drainage water management and subirrigation, is an important component in a multi-state project funded by National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2015-68007-23193, “Managing Water for Increased Resiliency of Drained Agricultural Landscapes” (http://transformingdrainage.org). With most of the results found in this report on the transforming drainage website, we will focus on what we believe is most important to ND soybean growers, e.g., the nutrient and salinity changes due to tile drainage, and drainage water management.

Nitrate nitrogen (NO_3-N) was measured in water samples from surface runoff, the tile outlets, controlled drainage outlets, and the legal surface drainage ditches, which represent a mixture of surface and subsurface flow. Figure 1 shows the NO_3-N measurements at the Clay County, MN site and Figure 2 shows the results at the Richland County, ND site in 2015. Water samples were also collected in 2016, but the chemical analysis in the lab takes time and the data are not available for this report.

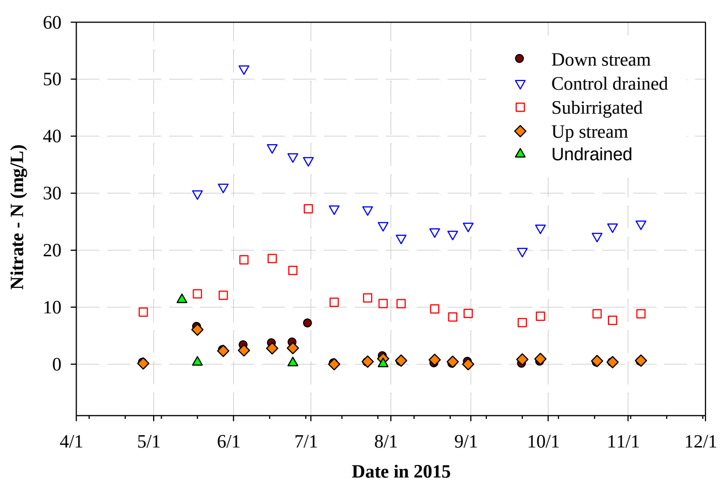

Figure 1. Nitrate-Nitrogen concentrations from the drainage ditch upstream and downstream of the monitoring fields, surface runoff from the undrained field, and from the controlled drained and controlled drained plus subirrigated outlet, and surface runoff from the undrained fields at the Clay County, MN site in 2015.

From Figure 1, we can see clearly that the NO_3-N in the control drainage outlet were much higher than the NO_3-N in the surface drainage ditch, which is a mixture of surface and subsurface runoff flow, either upstream or downstream of the fields. In average for the 2015 season, the NO_3-N was 28.3 and 11.9 mg/L in the CD and SI fields, but only 1.29 and 1.59 mg/L in the up and down stream ditch of the field. This resulted in an 8.3 and 20 times higher NO_3-N concentration from tile drained field compared to the NO_3-N in surface water system. Without the drainage control, this NO_3-N rich water would be flowing to the surface water. However, the control drainage board was closed and has retained the drainage outflow with high NO_3-N in the field for potential crop use. The drainage was closed in the spring time to retain moisture, and opened from July 8 till the end of the season to release the water due to concerns of sugarbeet root disease. Subirrigation was not applied because the soil had sufficient moisture in the root zone. Additional measurement in the surface runoff from the UD field showed a relatively low NO_3-N (< 1 mg/L), with an exception on May 12, which had an 8.8 and 13.8 mg/L NO_3-N at the south and north end of the surface ditch. The NO_3-N concentration from the FD field was only caught once on June 24 with a concentration of 11.9 mg/L.

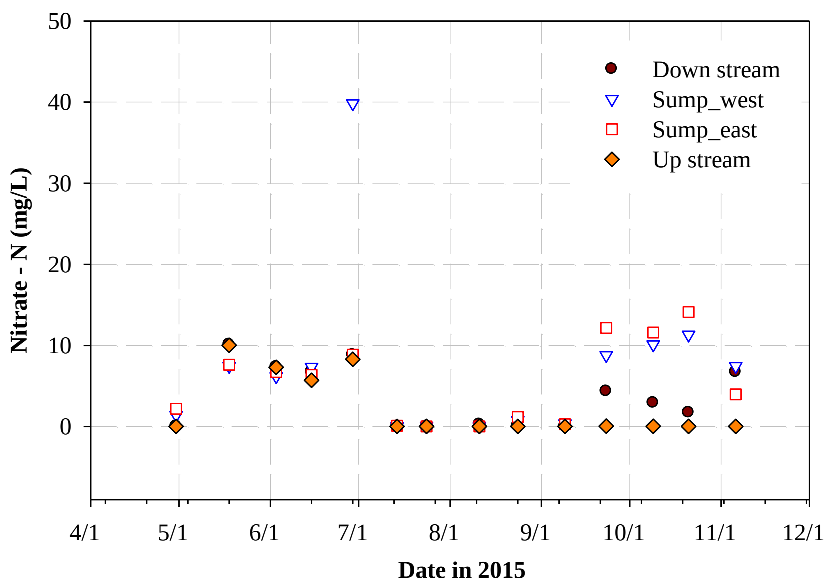

Figure 2. Nitrate-Nitrogen concentration from the drainage ditch, upstream and downstream from the field, and two controlled drained plus subirrigated fields (Sump_west and Sump_east) at the Richland County, ND site in 2015.

From Figure 2, we can see that NO_3-N was elevated while in drainage mode during May and June, and after a killing frost in late September. A slightly higher NO_3-N was found in the ditch water downstream from the field, possibly affected by the drainage outflow of the study field because in the fall, the study field was the only field with a running drainage. However, in the spring time, the NO_3-N concentrations were similar from the outlet and in the surface drainage ditch. This implies that there are contributions from tile drainage systems in the area that discharged into the ditch, or the surface drainage had a similar NO_3-N concentration as the subsurface flow. However, we were unable to catch any surface runoff water for comparison.

Ortho Phosphorus (P) is another important parameter affecting the surface water quality. Figure 3 shows the P monitoring at the Clay County, MN site.

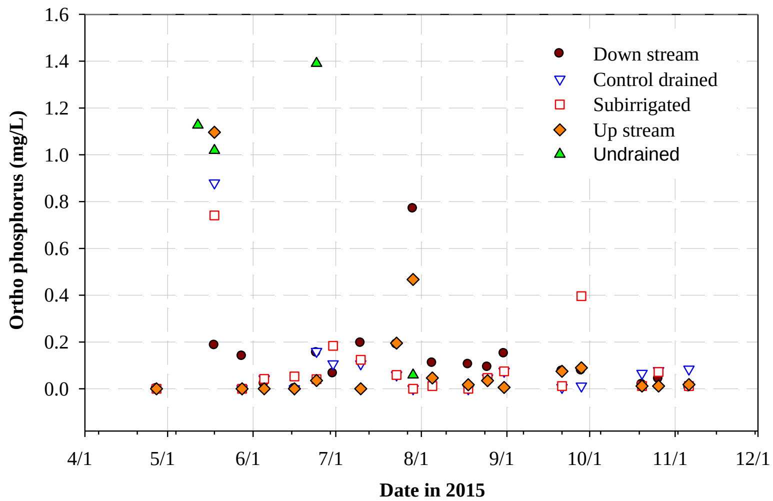

Figure 3. Ortho phosphorus concentration in upstream and downstream ditches from the field, controlled drained, and controlled drained plus subirrigated fields at the Clay County, MN site in 2015.

The P results confirmed that tile drainage flow had a lower P concentration (0.10 mg/L) than that in the surface drainage ditch (0.12 mg/L). The surface runoff water had a P value averaged as 1.0 mg/L, with the highest 1.4 mg/L on June 24, 2015. If using the 0.02 mg/L as the threshold for surface water quality, then both surface and subsurface flow exceeded the ND water quality standard for surface water.

Salts in water samples were analyzed at the both sites. Figure 4 and 5 show the electrical conductivity, a parameter representing total dissolved salts in a water sample at the MN and ND locations.

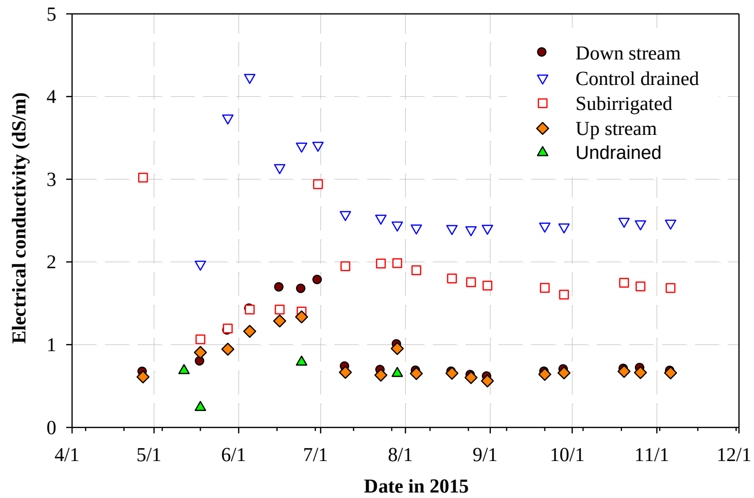

Figure 4. Electrical conductivity in upstream and downstream ditches from the field, controlled drained, controlled drained plus subirrigated, and surface runoff in the undrained fields at the Clay County, MN site in 2015.

Since the board was closed and drainage outflow was held in the field until July 8, the high salts in the CD field in early spring were not released from the field, and might be potentially harmful to the crops (4 dS/m as the threshold). However, the EC in the two fields were highly different in the spring, indicating that the soil properties were different. The EC in the downstream of the field was also higher than that in the upstream, indicating the EC contribution from the field, or the field in the north but drained to the same legal drainage ditch.

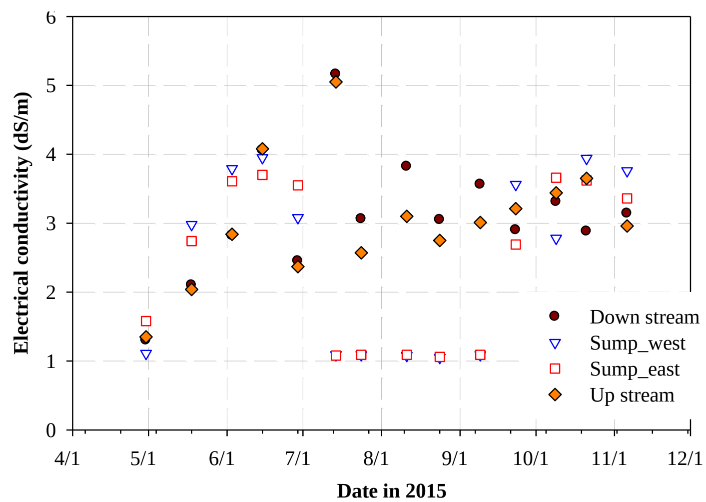

Figure 5. Electrical conductivity in upstream and downstream ditches from the field, and two controlled drained plus subirrigated fields (Sump_west and Sump_east) at the Richland County, ND site in 2015.

The ND site has a much higher EC level than that at the MN site, and the EC in the drainage outflow were around the 4 dS/m limiting delineation. This indicated that without tile drainage, the field would have suffered from a high soil salinity and crop yield would be limited. As the landowner indicated, before the tile drainage was installed, the lower quarter of the field was implantable. During the SI period in the summer, the EC was low because SI water has a lower EC. In the fall, when tile drainage was running again, the EC was higher than that in the summer, but lower than that in the spring, implying the mixture between drainage and irrigation water was beneficial.

Soil salinity is common and unique in the Red River Valley due to rich parent materials in the region. Tile drainage is probably the only effective way to reduce soil salinity and make the land farmable. Depending on the salts in the soil and water, sodic soils that with high exchangeable sodium can be different from saline soil. The SI water at the ND site has a sodium adsorption ratio (SAR) 6, which may potentially cause the soil to be more sodic with tile drainage. Therefore, a periodic soil sampling around the tile drains has been conducted since 2007. Figure 6 shows the soil analysis results at the ND site.

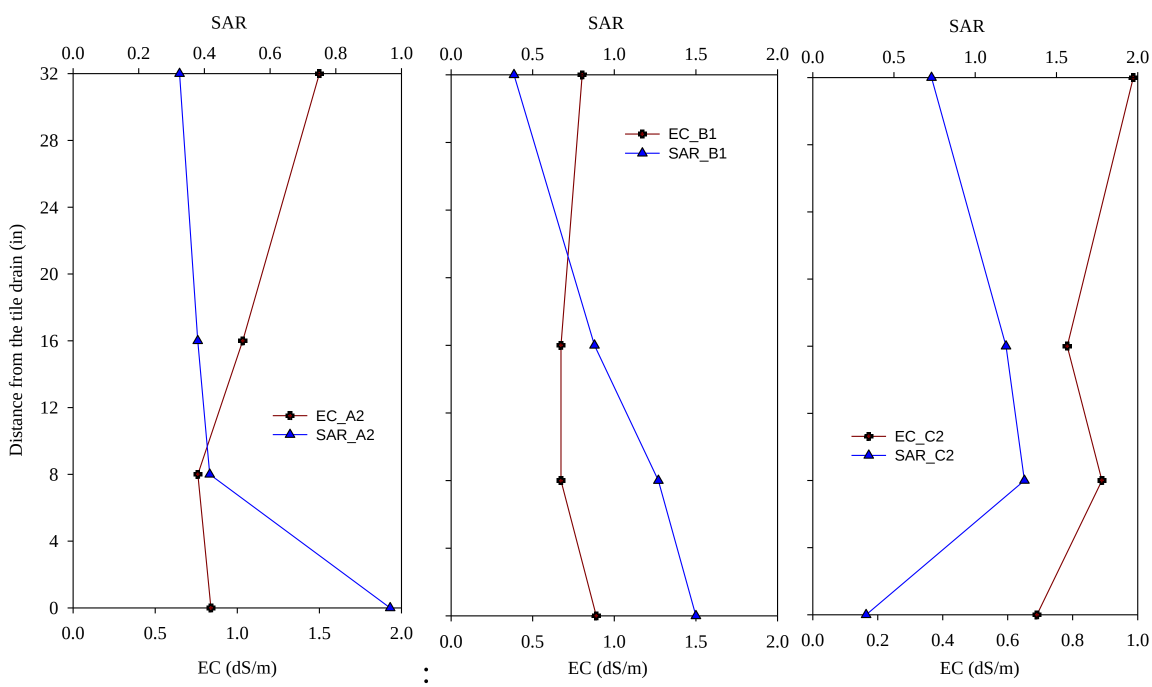

Figure 6. Soil electrical conductivity (EC) and sodium adsorption ratio (SAR) at distance away from the tile drains at three locations (A2, B1, and C2) at the Richland County, ND site in 2015.

As seen from Figure 6, for all three locations, the SAR is greater near the tile, and smaller away from the tile drain. This indicated a slight built-up of sodium near the tile due to the introduction of SI water. Among these three sites, C2 has been subirrigated longer than the other two sites and is the lowest elevation spot in the field. The lower SAR and EC at the C2 location implies that there is no alarming signal for soil sodicity at this time. It is safe to continue SI at this location.

Figure 7 shows the soil chemical analysis around the tile drains at the Clay County, MN site.

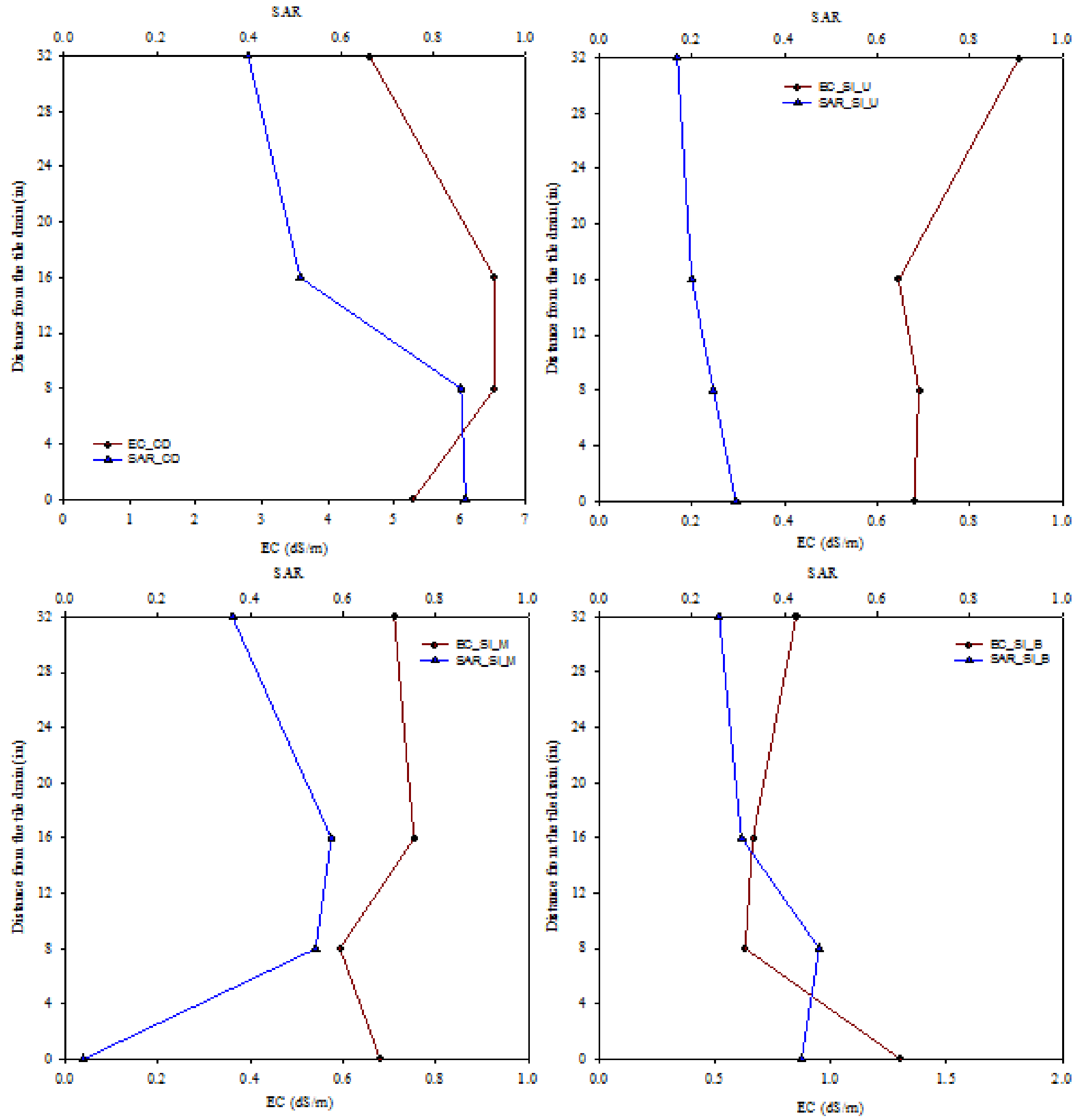

Figure 7. Soil electrical conductivity (EC) and sodium adsorption ratio (SAR) at distance away from the tile drain in the control drained field (CD), upper subirrigated field (SI_U), middle subirrigated field (SI_M), and bottom of subirrigated field (SI_B) at the Clay County, MN site in 2015.

The results at the MN site showed that the CD has a much higher soil salinity (EC = 5-7 dS/m) and potential sodicity than the SI field that with an EC less than 1.4 dS/m. It is also interesting to notice that the higher EC was in the middle of the soil profile, instead on top or close to tile. This implies that the soil salinity was high initially, but over time, soil salinity was washed away from the top of the soil and through the tile drains. For the SI field, a slightly higher soil salinity was found at the bottom of the field instead of top and middle section of the field.

Soil salinity map is a visual way to show the spatial distribution of the soil salts. A soil salinity mapping up to 1 m soil depth was conducted using EM38 with soils samples taken to calibrate the readings. The results are shown in Figure 8, 9 and 10.

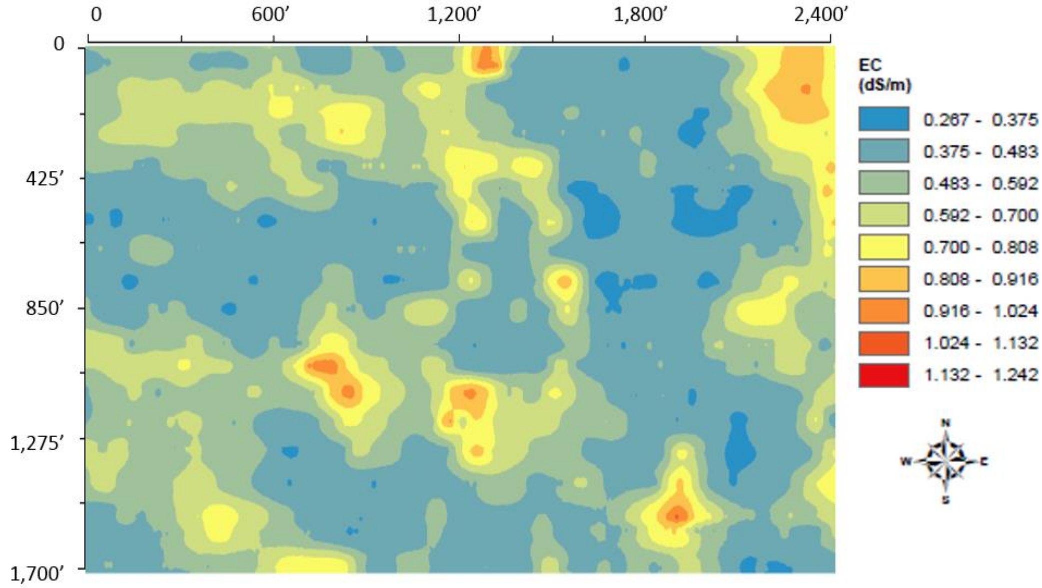

Figure 8. Soil salinity map for the control drained, and control drained plus subirrigated field at the Clay County, MN site in fall 2015.

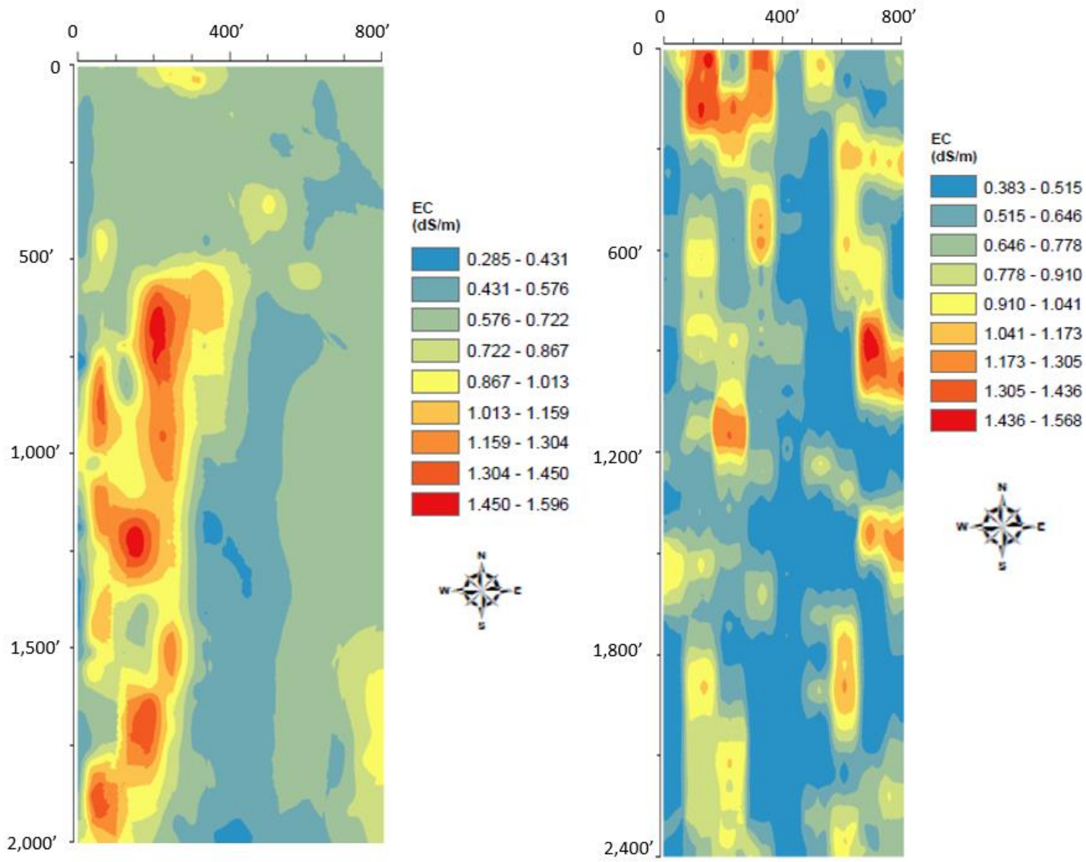

Figure 9. Soil salinity maps for the undrained (left) and free drained (right) fields at the Clay County, MN site in fall 2015.

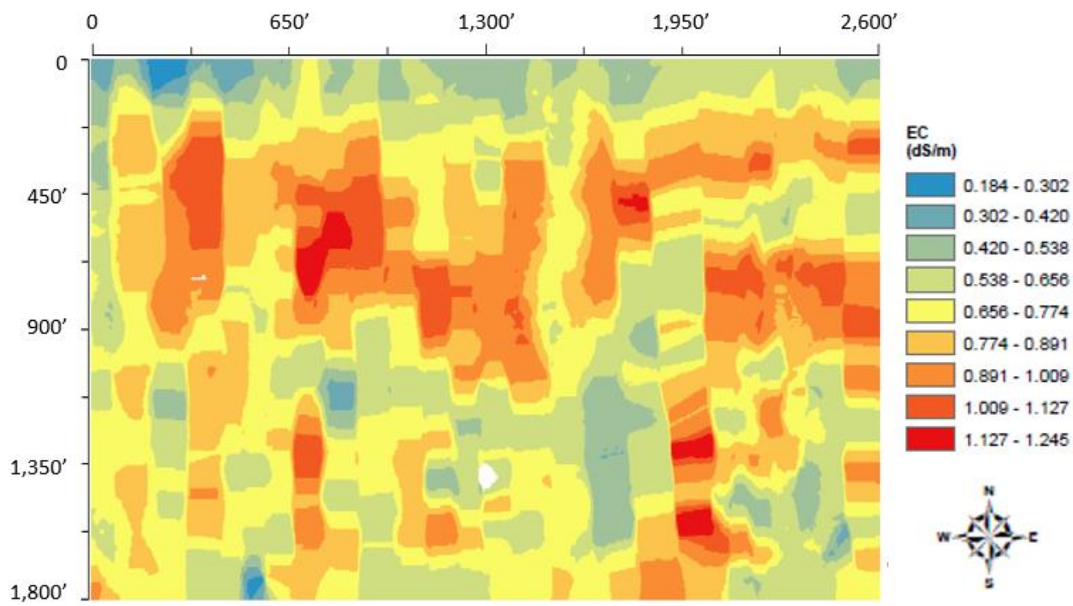

Figure 10. Soil salinity map for the control drained plus subirrigated field at the Richland County, ND site in fall 2014.

From the salinity maps, we can see that the soil salinity was lower at the MN site, and higher at the ND site. However, the west side of the UD field had visual saline seeps as shown in the soil salinity map as well. For the fields at the MN site, this is the first time we conducted soil salinity maps, but for the ND site, we have been doing soil salinity maps for three times since fall 2007. A clear trend of soil salinity decrease can be seen for the north half of the field since the tile drainage was installed in 2011. For the south half of the field, the soil salinity was stabled around 1 dS/m, which is a good benefit of continuous tile drainage and subirrigation in the field.

Crop yields in 2015 were listed in Table 1, with the county average yield for that crop listed in the table as well.

Table 1. Comparison of crop yields in 2015 for undrained (UD), conventional tile drained (FD), control drained (CD), and CD and subirrigated (SI) at the Clay County, MN and Richland County, ND sites.

Location	Practice	Crop type	Yield (bu/ac or tons/ac)	County Average Yield (bu/ac or tons/ac)	Difference (bu/ac)	Difference (%)
MN site	UD	Soybean	46	40.6	5.4	13.3
	FD	Corn	181	156.5	24.5	15.7
	CD	Sugarbeet	25.6	27.7	-2.1	-7.6
	SI	Sugarbeet	25.6	27.7	-2.1	-7.6
ND site	UD	Corn	175.8	160.5	15.3	9.5
	SI	Soybean	55.7	38	17.7	46.6

The SI field in Richland County, ND has been providing steady and consistent higher yield in the last four years. One of the most important reasons was the good understanding of how to manage the water. While both the drainage and SI systems were automatically controlled at the sump pump using the water level at the sump and in the lower part of the field, the crop field have received good soil moisture for the crop production. However, at the MN site, the control drainage and SI system are very unique for this site. While crop production is not controlled by only water, the lower sugarbeet yield was a result of many factors, such as root disease, fertilizer application, variety, nutrients and water management.