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Evaluation of Soils for Suitability for Tile Drainage Performance

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The purpose of a properly designed and installed tile drainage system when properly functioning is to drain excess, non-plant available soil water in a timely manner. This helps maintain groundwater levels at desired depths providing aerated soil conditions in the plant root zone that promotes good plant growth and productivity. It also promotes early-season warming of the topsoil to provide a favorable environment for seed germination and seedling establishment.

Periods of excess precipitation may bring groundwater levels nearer to the soil surface in farm fields throughout North Dakota. Groundwater near the surface reduces oxygen in these saturated soil layers, resulting in an unfavorable growth environment for plants.

In addition, the shallow groundwater can have high levels of water-soluble salts and sodium (Na^+), leading to increased soil salinity and sodicity.



Figure 1. A low area in a field with a shallow groundwater depth impacts crop growth in Cavalier County, North Dakota. (N. Kalwar, NDSU)

The higher levels of soluble salts are due to marine shale materials in glacially deposited parent materials where, in many places, the parent material is in contact with underlying Na^+ -rich shale bedrock. Weathering of the soil parent material and the underlying shale releases salts and Na^+ into the groundwater.

In lower field areas (**Figure 1**), shallow groundwater depths (**Figure 2, Page 2**) can bring excessive salts and Na^+ to the surface (**Figure 3, Page 2**) or they can accumulate below the surface in the plant rooting zone (**Figure 4, Page 2**). Through time, water evaporates from the soil surface, leaving behind an accumulation of excess salts and Na^+ . Soils with groundwater depths within 6 feet of the surface (shallower than 2 meters) are highly susceptible to developing salinity or sodicity problems (Seelig, 2000).

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Figure 2. The groundwater table is at the soil surface at this site in Cavalier County, North Dakota. Evaporation of water from the standing water and the soil surface causes water and salts to wick upward and leave salts behind, resulting in salts accumulating at the soil surface. (N. Kalwar, NDSU)

Figure 3. This is an unproductive saline-sodic soil with a visible salt crust in Towner County, North Dakota, but it lacks obvious sodicity symptoms. Note the susceptibility of soil particles to movement by wind due to a lack of plant cover. (L. Berg, NDSU)



Figure 4. This subsoil has a visible accumulation of salts in the crop rooting zone below the soil surface in Sargent County, North Dakota. (N. Kalwar, NDSU)

The combination of shallow groundwater and high soil salt and Na⁺ results in moderate to severe crop yield losses. These factors provide the impetus for many farmers and landowners to install subsurface (tile) drainage systems.

During wet weather and with good soil water infiltration, tile can drain excess water in a timely manner. Properly functioning tile systems maintain groundwater depths at desired levels and allow for leaching and removal of water-soluble salts.

In addition, soils with good drainage show improved soil productivity and crop yields. Other advantages of drainage include lower crop production risks, more water and cropping management options, reduced seasonal wetness and improved timeliness of field operations

On the other hand, the cost of installation and maintenance, wetland determination issues, outflow management, need for water in dry seasons and strained relationships with neighbors may be disadvantages associated with tile drainage.

Although tile drainage is usually successful, instances may occur where the tile functions properly when first installed, but within a few growing seasons, areas in fields may not drain as expected. This situation may develop because of changes in soil chemistry due to the removal of salts and resulting soil swelling and dispersion rather than improper installation of the tile drains. Due to the high cost of tile installation, poor subsurface drainage

performance can have a significant economic impact on a farming operation.

The loss of subsurface drainage effectiveness may be partially due to the tile being placed in or below a zone of sodic or saline-sodic subsoils or below restrictive clay layers (**Figure 5**). The sodic or saline-sodic characteristics are often not readily noted at the soil surface. Characteristics of saline, sodic and saline-sodic soils are shown in **Table 1**.

Tile installed in soils or subsoils that are sodic or saline-sodic often will function normally for a time period after installation because these soils often contain divalent (2+ charged) calcium (Ca²⁺) and magnesium (Mg²⁺) salts that keep the soil in an adequately flocculated state (maintain soil structure) under natural moisture conditions. But when the soils are drained and excess water is removed, the divalent salts also are removed, with the water leaving

Table 1. Characteristics of saline, sodic and saline-sodic soils (from USDA Handbook No. 60).

Soil Type	pH	Electrical Conductivity (EC) [†]	Exchangeable Sodium Percentage (ESP)	Sodium Adsorption Ratio (SAR)
		mmhos/cm	%	
Saline	<8.5	>4	<15	<13
Sodic	>8.5	<4	>15	>13
Saline-sodic	≤8.5	>4	>15	>13

[†] mmhos/cm – millimhos per centimeter; 1 mmhos/cm = 1 deci-Siemen per meter (dS/m)



Figure 5. This NDSU Langdon Research Extension Center (LREC) tiled research site shows poor soil water infiltration due to high sodicity levels starting from the topsoil with standing water on Sept. 13, 2019. The site received no rain from Sept. 3 to 8, but received 1.51 inches between Sept. 9 and 13. (NDAWN LREC Data) (N. Kalwar, NDSU)

the soil material above or around the tile line saturated with monovalent (1+ charged) sodium (Na^+).

When this occurs, the soils lose their natural structure and become dispersed. This can cause sealing of the soil above and/or around the tile lines, resulting in ineffective drainage. In addition, if sodicity starts from the surface layers/topsoil, it will further reduce the soil water infiltration, resulting in increased runoff or rainwater standing in a low spot despite tile installation (**Figures 5 and 6**).

Reduced drainage performance is more likely to occur in fine-textured (silty or clayey) soils and to a much lesser extent in coarser-textured (sandy) soils or where subsurface layering of soils occurs of different soil textures (**Figure 7**). Once drainage performance is reduced, little can be done economically to restore the effectiveness of the drainage system.

However, producers can take precautions prior to tile installation on soils where drainage performance may be affected. These precautions include: (1) examining the characteristics of the soil series (soil types) in the field under consideration for drainage, (2) evaluating the soil chemical characteristics for each of the soils mapped in the field, (3) evaluating the soil properties for suitability to install tile and (4) verifying soil types and chemical characteristics (items 1 and 2 above) by deep soil sampling and testing. Using these precautions can help avoid installation of tile in areas where poor subsurface drainage performance is likely.

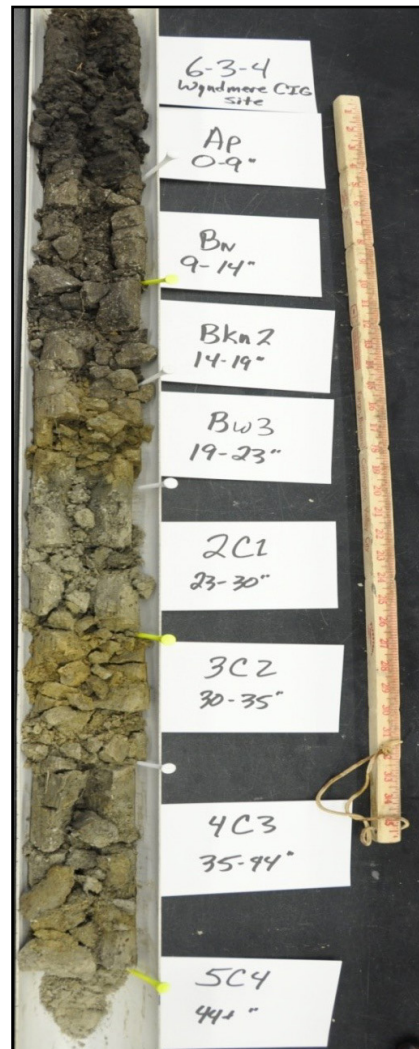


Figure 7. The soil profile of an Exline-type soil shows alternating clay and fine sand-textured layers. This layering will inhibit normal water percolation through the soil and may result in poor tile drainage performance due to tile lines normally being installed at the bottom of the soil profile below the layering.

Notable horizons:
 B_n – sodic horizon;
 B_{kn2} – saline and sodic horizon;
 $2C_1$ – silty clay texture;
 $3C_2$ – loamy fine sand texture;
 $4C_3$ – silty clay texture;
 $5C_4$ – fine sand texture.
 (L. Cihacek, NDSU)

Figure 6. This submersible pump at the NDSU Langdon Research Extension Center's tiled research site is not pumping water despite standing water at a low spot on Sept. 13, 2019, due to the poor soil water infiltration resulting in reduced drainage performance. The main drain is indicated by the arrow. (N. Kalwar, NDSU)



Knowledge of Soil Series

The occurrence of a specific soil series, types or map units on a parcel of land under consideration for tiling can be obtained from a county soil survey map or online from the U.S. Department of Agriculture-Natural Resources Conservation Service's Web Soil Survey (<http://websoilsurvey.nrcs.usda.gov>). The soil series listed in **Table 2 and Table 3** are soils that are most likely to have dispersion problems when drained.

Also, soils with the greatest probability of drainage problems are those soils with pH values greater than 8.5 in the surface or subsurface zones. A pH greater than 8.5 often indicates high sodium (Na⁺) saturation, which could lead to tile sealing when salts are leached out of the soil above the tile line. If any of the soils listed in **Tables 2 and 3** occur in the parcel of land to be drained, the soil chemical characteristics need to be evaluated.

Most drainage system designers and installers evaluate soil texture in a field as a part of the system design process. However, soil chemical characteristics are not normally part of this process. Preliminary evaluation of soil chemical characteristics can be accomplished by utilizing soil chemical data embedded in the Web Soil Survey. In addition, a soil drainage suitability rating for North Dakota soils is available in the Web Soil Survey.

Using the Web Soil Survey

The Web Soil Survey is an internet-based digital product provided by the USDA-Natural Resources Conservation Service at <http://websoilsurvey.nrcs.usda.gov> (**Figure 8**). Most soils in North Dakota can be evaluated from maps and information contained in the Web Soil Survey (**Figure 9, Page 6**). The following illustrations are an example of how to access this information from a personal computer or other device with internet access.

Table 2. Soil series with sodium-affected subsoils.

Aberdeen	Ferney	Manfred	Playmoor
Camtown	Harriet	Mekinock	Ranslo
Cathay	Heil	Miranda	Ryan
Cavour	Larson	Nahon	Stirum
Cresbard	Lemert	Niobell	Totten
Daglum	Letcher	Noonan	Turton
Easby	Ludden	Ojata	Uranda
Exline			

Table 3. Soil series with the potential for sodium-affected subsoils.

Antler	Glyndon	Moritz
Arveson	Grano	Nielsville
Augsburg	Grimsted	Northcote
Bearden	Gunclub	Putney
Bohnsack	Hamerly	Regan
Borup	Hedman	Reis
Clearwater	Hegne	Rockwell
Colvin	Holmquist	Roliss
Cubden	Huffton	Rosewood
Divide	Karlsruhe	Thiefriver
Eaglesnest	Kratka	Ulen
Elmville	Koto	Vallers
Enloe	Lamoure	Viking
Fargo	Lowe	Wheatville
Fossum	McKranz	Winger
Fram	Mantador	Wyndmere
Gilby	Marysland	Wyrene



Figure 8. Access to the Web Soil Survey (<http://websoilsurvey.nrcs.usda.gov>) is started by clicking on the large green "START WSS" button near the top of the page.

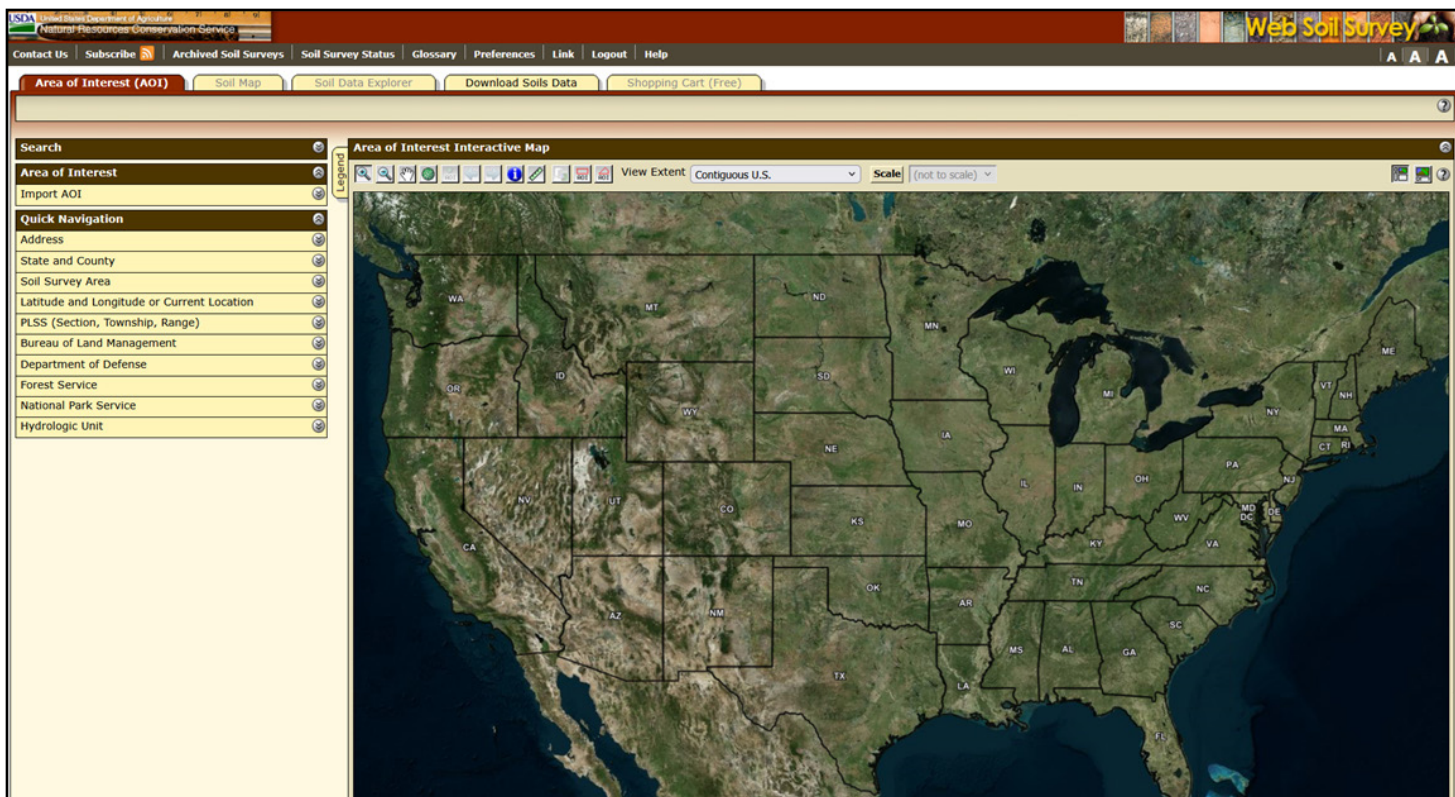


Figure 9. This is the Web Soil Survey navigation page. Note the 10 different “Quick Navigation” methods to get the parcel of land of interest. Another method is to use the mouse to repeatedly draw a rectangle around the area of interest until the field of interest is highlighted.

Evaluation of Soil Chemical Characteristics

Soil chemical properties can be evaluated utilizing the “Soil Data Explorer” tab in the Web Soil Survey. Once a parcel of land is selected (**Figure 10, Page 7**), choosing the “Soil Chemical Properties” menu within “Soil Data Explorer” provides options for soil evaluation that will bring up a menu of several chemical characteristics that can be evaluated (**Figure 11, Page 8**).

For this soil evaluation, the characteristic of interest is “Sodium Adsorption Ratio” (SAR). Clicking on “Sodium Adsorption Ratio” will bring up an interactive area where depths to be evaluated can be specified in inches or centimeters (cm). A general evaluation of SAR to a depth of 5 feet (150 cm) can provide a realistic evaluation of soil chemical properties. However, for greater accuracy, the evaluation should be carried out for successive 1-foot increments to a minimum depth of 5 feet or at least 2 feet below the deepest depth of the drain line.

For each increment, a colored field map will appear over the photo base map showing the level of hazard related to each soil type (**Figures 12a-d, Page 9**). A table with an interpretation and average electrical conductivity (EC) or SAR values accompanies the map and interpretative information. Within this evaluation, red, green and yellow generally indicate lower hazards, while blues indicate higher hazards. Dark blue indicates the highest hazard.

Maps for each depth increment can be printed for reference. The information contained in these evaluations is generalized for each soil series or map unit based on the total composition of the map unit. The data for each map unit is populated with chemical and physical property information that is aggregated from various soil laboratories and the National Soil Survey Laboratory.

This information may change from time to time as the database is updated. Also, colors indicating the degree of hazard may vary from county to county within the Web Soil Survey.

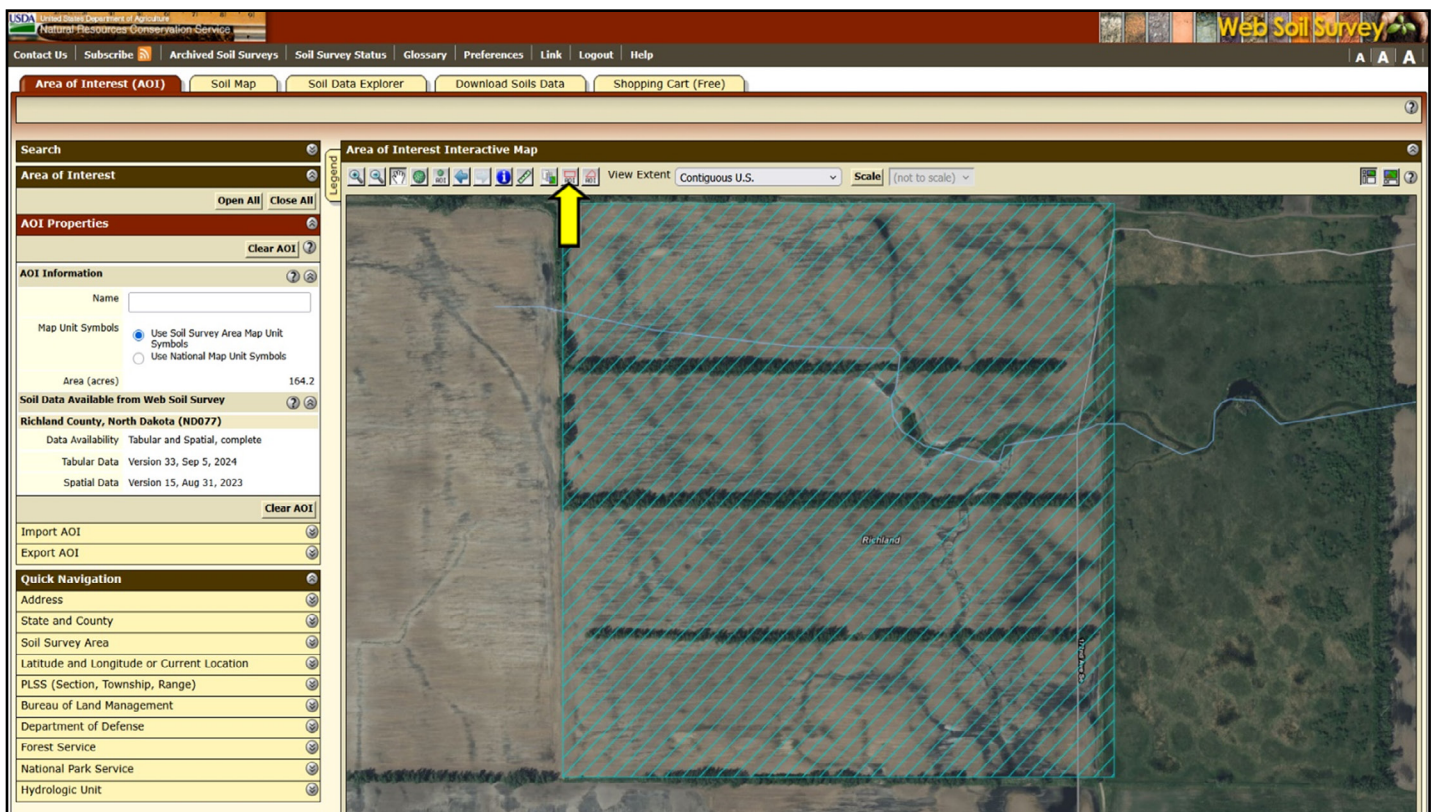


Figure 10. The land parcel can be delineated by clicking on one of the two AOI (Area of Interest) buttons (yellow arrow) on the interactive map. Selecting the left button allows you to put a rectangle around the AOI, and the right button can be used for irregular-shaped parcels. Selection of the AOI allows the Web Soil Survey to access soil survey information specific to that parcel of land.

You have four options for evaluating the soil layers in each mapping unit. Because each soil mapping unit includes small areas of varying sizes of soils that may not be suitable for drainage, the worst-case scenario should be utilized to identify soils that can contribute to problems with subsurface drainage.

The four choices for soil map unit evaluation are the following: (1) evaluation of all soil components, (2) evaluation of dominant soil components, (3) evaluation of dominant soil condition and (4) evaluation of a weighted average of all soil components. **Figures 12a-d** illustrate the comparison of these four choices for a general evaluation of the 5-foot (150 cm) depth zone of an actual parcel of land with sodium-affected subsoils. The numerical ratings for the field shown in **Figures 12a-d** are shown in **Table 4, Page 8**.

As shown in Table 4, evaluating the soil map units on the basis of all components will give the ratings for the most limiting soils within the map unit and provide for identification of the highest risk (or worst case) scenarios.

Data embedded in the Web Soil Survey is based on typical characterization sites across the normal geographic range of the occurrence of a specific soil type. Due to natural variability, the soils in the parcel of interest may vary from the “typical” map unit of the soil designated when the soil survey was conducted.

In addition, detailed variability and small inclusions within a soil map unit are difficult to show at the scale of typical soil surveys. Thus, a more detailed survey of the field to be drained will be useful for determining whether problems with subsurface drainage may exist.

All soils with an SAR value of 6 to 12 should be sampled for detailed chemical characterization. A qualified professional soil scientist or classifier should be consulted when making these evaluations.

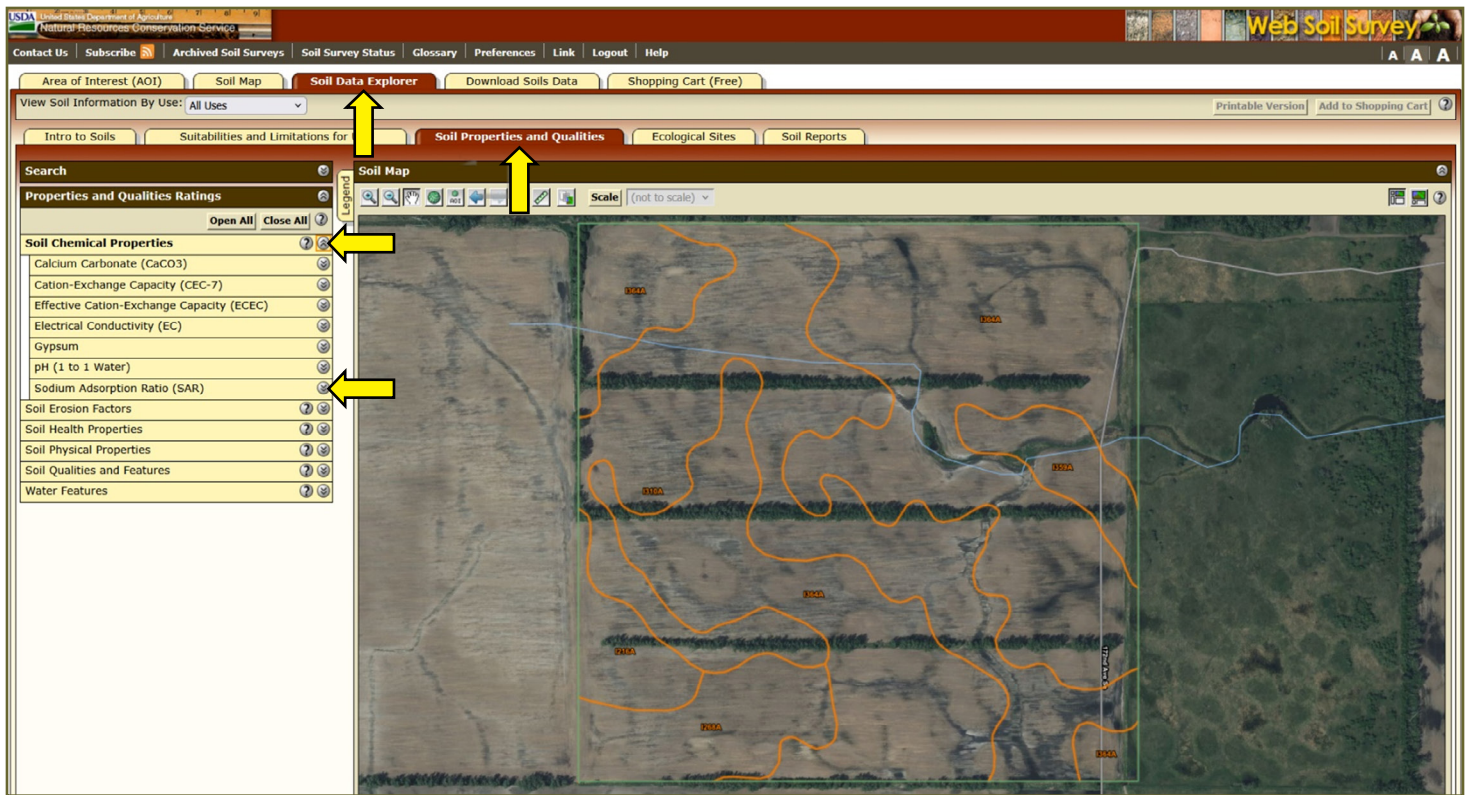


Figure 11. Accessing the evaluation data: Once the soil map is retrieved from the database, click on the Soil Data Explorer tab near the top of the page (yellow arrow No. 1). Then click on the Soil Properties and Qualities tab below the Soil Data Explorer tab (yellow arrow No. 2). From the menu to the left of the map, select Soil Chemical Properties (yellow arrow No. 3) and Sodium Adsorption Ratio (yellow arrow No. 4). This will lead to a refreshed map with SAR ratings for each soil series mapped on the parcel.

Table 4. The soil SAR ratings for the field shown in Figures 12a-d based on soil chemical data from the Web Soil Survey.

Map Unit Symbol	Map Unit Names	Web Soil Survey SAR Rating			
		All Components [†]	Dominant Component [‡]	Dominant Condition [§]	Weighted Average of All Components [¶]
I216A	Wyndmere fine sandy loam, 0-2% slopes	7.3	4.3	4.3	3.9
I268A	Foldahl loamy fine sand, 0-2% slopes	0.8	0.0	0.0	0.0
I310A	Arveson fine sandy loam, 0-1% slopes	7.8	0.8	0.8	1.0
I359A	Hamar loamy fine sand, 0-1% slopes	0.2	0.0	0.0	0.0
I364A	Hecla-Garborg-Arveson complex, 0-2% slopes	7.8	0.0	0.0	0.3

[†] All soils normally occurring in a map unit.
[‡] The major soil(s) making up a map unit.
[§] The usual state of the soil chemistry of the major soil(s) in a map unit.
[¶] The average rating based on the normal relative proportions of all soils in a map unit.

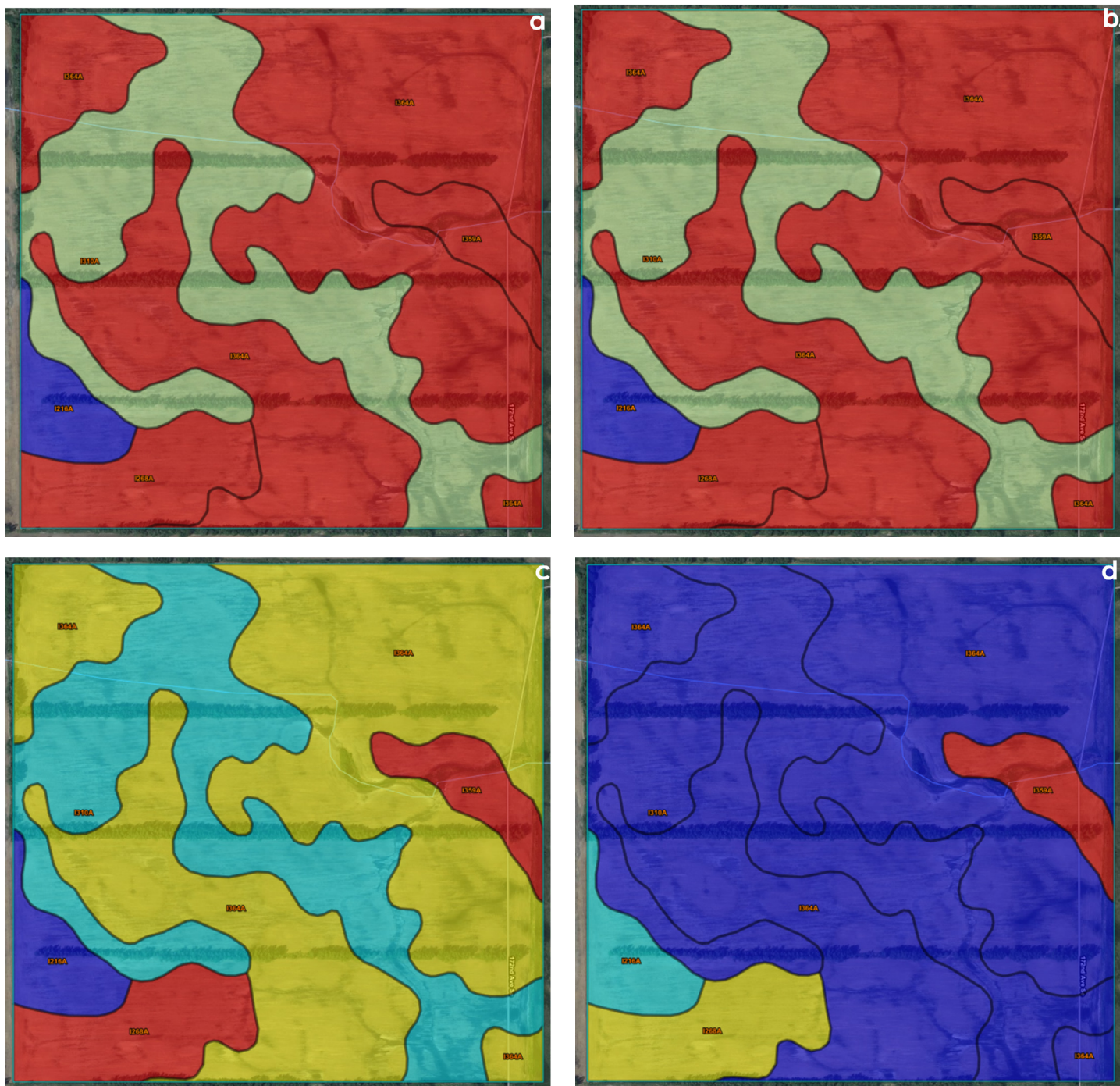


Figure 12. General evaluation of soil SAR in the 5-foot depth zone: (a) evaluation of dominant component, (b) evaluation of dominant condition, (c) evaluation of weighted average of all components and (d) evaluation of all soil components in each map unit. Evaluation of all components within each map unit provides the most stringent information regarding soil SAR conditions. In these images, dark blue indicates a high degree of SAR hazard. (See Table 4 for SAR ratings)

Subsurface Soil Drainage Suitability Rating

A soil drainage suitability interpretation has been incorporated into the Web Soil Survey. This rating evaluates all soils in a soil mapping unit using three criteria: installation, performance and tile water outflow quality. The information used for the evaluation of each criterion is shown in **Table 5**.

The suitability rating provides a scale of 0 to 1 for each of these criteria and provides a weighted rating based on the components of a soil map unit. A rating near 0 indicates no limitations for subsurface drainage, while a rating near 1 is very limited.

Soils with a rating greater than 0.15 for SAR performance should be subject to verification by soil sampling and testing. The SAR suitability ratings for soils based on the soil chemistry evaluation described above are shown in **Table 6**.

This tool may give limitation ratings for multiple factors for each soil in a mapping unit. While most limiting factors are based on soil properties that do not change with drainage or management, soil SAR and EC factors are subject to change as soils are drained. However, other limitations identified by using this tool may respond to modifications in design and installation.

What the soil drainage suitability rating *will not provide* is a comprehensive site evaluation, determination of wetlands and flooding issues or soil productivity or design information, and it will not address social or environmental issues.

The soil drainage suitability rating is not designed to tell the landowner, land manager or tile installer that a field should or should not be drained. The rating is mainly designed to present information that a decision maker can use in making a decision whether drainage is a suitable option as a land treatment.

Table 5. Criteria evaluated in subsurface drainage suitability ratings for subsurface water management in the Web Soil Survey.

Installation	Performance	Outflow Quality	Agronomic Concerns
Depth to bedrock or cemented pan	Presence of dense layers in soil	Soil salinity	Plant establishment
Stability of excavations	Soil permeability	Pesticide and nutrient potential	Plant growth
Amount of soil clay	Flooding	Soil cracking potential	Soil erosion
Presence of stones	Surface pH		Physical limitations
Slope gradient	Soil sodium content Soil gypsum content Soil subsidence Sedimentation		Pesticide and nutrient management

Table 6. Interpretation of soil SAR values and subsurface drainage suitability ratings for suitability of soils for drainage.

SAR Values [†]	Drainage Suitability Rating [‡]	Interpretation
< 6	<0.15	No limitation
6-10	0.15-0.80	Somewhat limited
>10	>0.80	Very limited

[†] Based on data from Springer (1997).

[‡] Based on Web Soil Survey

Verification of Soil Properties by Soil Sampling and Soil Testing

Once soil areas that have a moderate or severe SAR hazard are identified, these areas should be sampled to the proposed depth of the tile line in 1-foot increments. The soils should be sampled at a minimum of three locations within each soil map unit where an SAR hazard has been identified.

Samples from these locations can be composited into one sample for each depth increment. A minimum of one composite soil sample should be submitted for each five acres of a soil map unit in question.

Each soil depth increment should be analyzed for electrical conductivity (EC) and SAR using standard soil saturation paste extracts for the evaluation. This allows for making direct comparisons with the information contained in the Web Soil Survey database to verify the suitability for subsurface drainage.

If the soil analyses indicate that the SAR values are lower than the values shown in **Table 6**, then the soil is likely suitable for subsurface drainage. If soils are rated unsuitable for tile drainage, then alternatives such as leaving the soil area undrained or placing the area into permanent cover (by establishing perennial vegetation) should be considered. Utilizing registered professional soil scientists or NRCS soil scientists can assist in making decisions about alternatives to subsurface drainage.

The ratings shown in **Table 6** are only guide for drainage suitability. Dispersion of the soils under subsurface drainage conditions depends on several factors, including the composition of soil minerals, soil texture, composition of shallow groundwater and composition of soil salts. You also should recognize that soils subject to dispersion may be localized or only be a small proportion of the soils in the field or land parcel to be drained.

Evaluating soils for subsurface drainage suitability prior to installation can reduce the incidence of poor tile performance and unrecoverable installation costs. If soils susceptible to poor drainage are identified prior to tile installation, then alternatives to drainage can be considered and implemented. Once soils disperse due to subsurface drainage, attempting to remediate the soils to near their original internal drainage condition is extremely difficult and costly.

Additional Considerations for Tiling

Cost and environmental suitability are major considerations when deciding to install drain tile systems. The following questions should also be considered when considering when deciding to install tile drain systems:

1. Is water standing in fields due to a high shallow water table, or is it due to poor permeability of the soil?

Tile drains are usually installed at a 3-4 ft. depth below the soil surface. A tile drain can lower a shallow water table near the soil surface. However, if water infiltration or soil permeability is low, surface water may not be able to reach the soil zone within which the tile drain is installed.

In other words, tile drainage does not improve soil permeability because that is a natural property of the soil.

2. Are there enough rain events each year that create saturated soil conditions and lead to high shallow ground water tables during planting, crucial plant growing stages and harvest times on a consistent basis (e.g., every year versus two or three times in 10 years)?

Necessity versus convenience needs to be considered when making decisions of cost-effectiveness of tiling systems.

3. Is soil sodicity (high SAR) present in soil depths above or around the deepest depth proposed for fields in consideration for tiling?

High sodicity at these depths are extremely difficult to amend due to the large quantities of amendment needed to effectively treat the volume and quantity of soil affected. If soil permeability is highly restricted by sodium or high soil clay, normal surface applications will leach into the soil at a very slow rate at which the remediation may take decades to be accomplished.

Using the information available in Web Soil Survey as described in this bulletin can help provide answers to these questions. Many North Dakota soils are favorably suited for tile drainage. However, some soils will not react well to being drained. A thorough evaluation of a soil's suitability for drainage can prevent expensive mistakes.

Related NDSU Extension Publications

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The original publication was authored by Larry J. Cihacek, professor, Soil Science; Dave Franzen, Extension soil specialist; Xinhua Jia, professor, Agriculture and Biosystems Engineering; Roxanne Johnson, former Extension water quality associate; and Tom Scherer, Extension agricultural engineer, 2012.

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