SDSU Extension

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BEST MANAGEMENT PRACTICES

Chapter: 32

The Management and Identification of Saline and Sodic Soils in the Northern Great Plains

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Salt-affected soil is a serious problem in the northern Great Plains. If high salt concentrations exist, then the problem's type and magnitude must be accurately diagnosed. The objective of this chapter is to discuss diagnosis and remediation of South Dakota's saline and saline/sodic soils. Key terms used in this chapter are provided at the end of the chapter. Clay dispersion can occur when the soil electrical conductivity (EC) is less than 2 dS/m and % sodium on the exchange sites is greater than 4%.

Basic Information

Due to increased rainfall, changing land uses, and that many of South Dakota's soils were developed over marine sediments, the amount of land impacted by high salt concentrations has been increasing. High salt concentrations have a staggering impact on crop yields. For example, the NRCS reported that in Beadle, Brown, and Spink counties, high soil salt concentrations have resulted in an annual economic loss of over $26 million.

Figure 32.1 A northern Great Plains dispersed soil. (Courtesy Cheryl Reese, SDSU)

South Dakota soils affected by saline and sodium (Na^+) are separated into three groups: saline (high total salts), saline/sodic (high total salts and Na^+), and sodic (high Na^+). The classification of a salt-affected soil into one of these groups is based on the soil electrical conductivity (EC, reported as dS/m) and the amount of Na^+ on the cation exchange sites. The soil cation exchange capacity (CEC) is the capacity of the soil to retain positively charged cations. Common cations include Ca^{2+}, Mg^{2+}, NH_4^{1+}, K^{1+}, Fe^{3+}, and Na^{+1}. The CEC helps the soil retain these nutrients from one year to the next. Because anions (negatively charged ions), such as nitrate (NO_3^{1-}), chloride (Cl^{1-}) or sulfate (SO_4^{2-}) are repelled by the soil's negative charges, anions are more rapidly lost with water percolating through the soil than cations.

Sodic soils have high Na^+ concentrations, which can result in soil dispersion, decreased water infiltration, and increased erosion. Saline/sodic soils have high EC and high Na^+ concentrations. Yields in these soils are reduced by the combined impact of high salt and Na^+ concentrations. In South Dakota, soil clay dispersion (Fig. 32.1) can occur when drainage is placed under soils with an EC value < 2 dS/m and when the percentage of Na on the cation exchange sites is greater than 4.

Saline Soils

Diagnosis of Saline Soils

Climatic records indicate that spring temperatures and rainfall have increased in the northern Great Plains (Hatfield et al., 2011; Schrag, 2011), and these land use changes have resulted in higher water tables and the subsequent transport of subsurface salts to the soil surface.

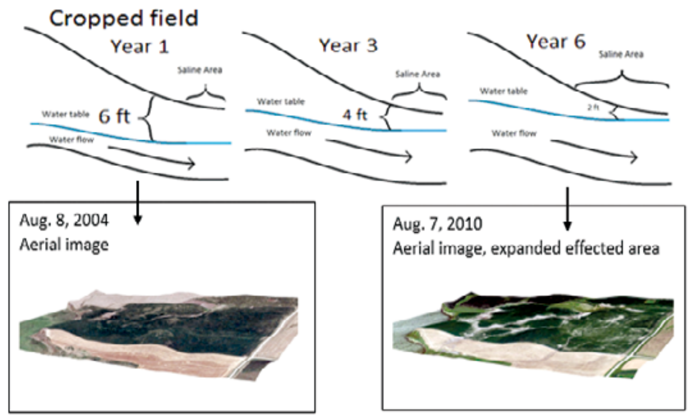

Figure 32.2 A schematic showing the relationship between water-table depth, increasing rainfall (from year 1 to 6), and salt accumulation. In the aerial image the salt-affected soils appear white. (Courtesy of SDSU)

Soils with salt problems can result from the natural weathering of soil and geologic parent materials, management, or a combination of both. Throughout South Dakota there are landscapes and geographic locations with naturally occurring high soil salinity levels. Within a field, salts have the potential to accumulate in some areas and not others. Generally, poorly drained footslope areas have higher salt contents than well-drained areas (Fig. 32.2). Problems often occur when the water table rises. In many South Dakota fields, salt accumulation is not a problem if irrigation water is not applied or if the water table is at least 6 feet below the soil surface.

To interpret the reported values from a soil testing laboratory, the test results and remediation techniques must be based on a standard analysis method. Many soil testing laboratories report EC values based on a 1:1 soil-to-water solution ratio, whereas the historical remediation techniques were based on the EC value measured using a saturated paste technique. Unfortunately, EC values from the two techniques are NOT equivalent, with the 1:1 method having a much lower value than the saturated paste method, thus underestimating the problem. Therefore, EC values from a 1:1 technique need to be converted to the saturated paste equivalent value, with the 1:1 values multiplied by 2.14, the relationship shown in Figure 32.3.

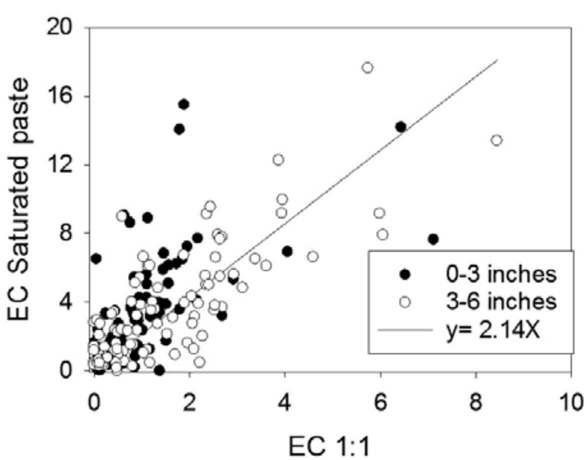

Figure 32.3 Relationship between EC values of a saturated paste and 1:1 (ECsaturated paste vs. EC1:1) solution. This South Dakota research data shows the relationship between EC used for remediation (EC saturated paste) and that reported by the commercial soil testing laboratories (EC 1:1). (Courtesy of SDSU)

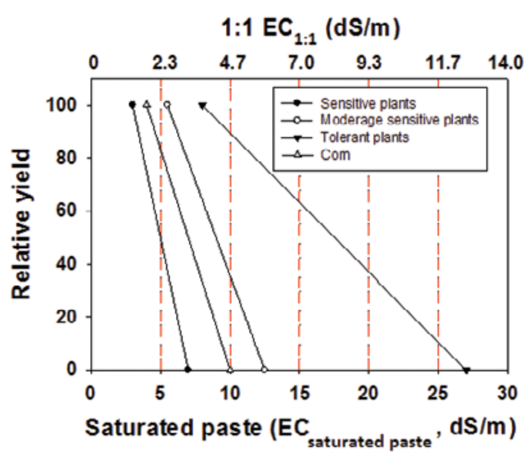

Figure 32.4 The relationhips between the EC values measured multiple ways and relative yield. The conversion of EC 1:1 to EC saturate paste was based on Figure 32.3. Note: The values of dS/m are identical to mmhos/cm. (Courtesy of SDSU)

Table 32.1 Sensitive, moderately sensitive, moderately tolerant, and tolerant plants. The 1:1 values were based on relationship shown in Figure 32.2. The units dS/m are identical to mmhos/cm. (Modified from the Food and Agriculture Organization of the United Nations, http://www.fao.org/DOCREP/005/Y4263E/y4263e0e.htm, accessed 6/1/2016)

	Max. EC without loss		% loss above crit. value			Max. EC without loss		% loss above crit. value	
Sensitive plants	1:1	Sat. paste	1:1	Sat. paste	Moderate Sen. Plants	1:1	Sat. paste	1:1	Sat. paste
	dS/m	dS/m	%loss/ dS/m	%loss/ dS/m			dS/m	%loss/ dS/m	%loss/ dS/m
Beans	0.47	1	38.5	19	Turnip	0.42	0.9	19.3	9
Carrot	0.47	1	30.0	14	Radish	0.56	1.2	27.8	13
Strawberry	0.67	1	70.6	33	Lettuce	0.61	1.3	27.8	13
Onion	0.56	1.2	34.2	16	Clover	0.70	1.5	25.7	12
Rice	1.4	3	25.7	12	Foxtail	0.70	1.5	20.5	9.6
Corn (sweet)	0.79	1.7	27.8	13	Orchard grass	0.70	1.5	13.3	6.2
Timothy	0.93	2	36.4	17	Corn (field)	0.79	1.7	25.7	12
					Flax	0.79	1.7	25.7	12
					Potato	0.79	1.7	25.7	12
					Alfalfa	0.93	2	15.6	7.3
					Cucumber	1.17	2.5	27.8	13
					Tomato	1.17	2.5	21.2	9.9
Mod Tol. Plants		dS/m		%loss/ dS/m	Oat	1.12	2.4	18.0	7.4
Wild rye	1.26	2.7	12.8	6	Sorghum	3.18	6.8	34.2	16
Sudan grass	1.31	2.8	9.2	4.3	**Tolerant Plants**		dS/m		%loss/ dS/m
Crested wheatgrass	1.64	3.5	8.6	4	Tall wheatgrass	3.50	7.5	14.8	6.9
Fescue, tall	1.82	3.9	11.3	5.3	Barley	3.74	8	10.7	5
Soybean	2.34	5	42.8	20	Canola or rapeseed	5.14	11	27.8	13
Birds foot trefoil	2.34	5	31.4	10	Cotton	3.59	7.7	11.1	5.2
Perennial ryegrass	2.62	5.6	16.3	7.6	Durum wheat	2.76	5.9	8.1	3.8
Durum wheat	2.66	5.7	11.6	5.4	Forage rye	3.55	7.6	10.4	4.9
Forage barley	2.80	6	15.2	7.1	Sugar beet	3.27	7	12.6	5.9
Wheat	2.80	6	15.2	7.1	Crested wheat grass	3.50	7.5	14.6	6.9
Asparagus	1.92	4.1	4.3	2					

High salt areas can be identified by conducting a visual survey of the area, conducting an apparent electrical conductivity (EC_a) survey using a Geonics EM 38 (Mississauga, Ontario, Canada) or the Veris Soil EC Mapping System manufactured by Veris technologies (Salina, Kansas), tracking changes in yield over multiple years, and collecting and analyzing soil samples for electrical conductivity (EC).

Remediation of Saline Soils

Managing High Salts

In saline soils, the high concentrations of soluble cations (Ca^{2+}, Mg^{2+}, Na^{1+}, K^{1+}) and anions (SO_4^{2-}, NO_3^{1-}, Cl^{1-}) reduce seed germination and plant growth. One of the first steps in remediating a salt problem is seeding salt-tolerant (preferably, perennial) plants in the saline and adjacent areas (Table 32.1). For example, alfalfa grown in adjacent areas may help lower the water table, which helps prevent the expansion of the affected soil. If the saturated paste soil EC1:1 is less than 0.5 dS/m, corn can be seeded (Fig. 32.4).

Table 32.2 Do's and Don'ts when managing saline soils:

<u>Things to do</u>

1. Identify the problem and map its extent. High salinity is often a symptom of a high water table, and soil layers with low water permeability.
2. Drainage reduces salinity risks. On average, the soil EC value will decrease 0.5 dS/m for every 6 inches of water that percolates through the soil. Drainage details are in Chapter 30.
3. Prevent expansion of the problem. Expansion can be slowed by establishing deep-rooted, salt-tolerant (preferably, perennial) vegetation within the saline area.
   a. If the area is poorly drained, dormant seeding tall wheatgrass into frozen soil can be used to establish a crop in the area.
   b. Alfalfa directly adjacent and above the salt-affected area can intercept water moving into the saline area.
   c. Cover crops seeded in the fall may reduce water flow into the affected area. Lowering the water table reduces capillary rise and provides the opportunity to leach salts deeper in the profile.
   d. Techniques that reduce surface-soil evaporation, such as no-till and minimum till may be useful.

<u>Things not to do</u>

1. Deep tillage, ripping, and spring tillage should be used with caution because tillage can bring salts back to the soil surface. No-till seeding has been used to overcome this risk.
2. For sodic or saline/sodic soil (soils with high sodium content), tile drainage can worsen the problem.

Over winter, salts can be transported out of the surface soil with percolating water. Tillage will bring these salts back to the soil surface, and in many situations dormant seeding is effective because the lowest EC values are observed in the spring following snowmelt.

A partial list of techniques to reduce salt problems is provided in Table 32.2. Once a high salt area is identified, an interceptor or tile drainage can be used to lower the water table (Note: Tiling should be done ONLY if sodium is NOT a problem in the soil). See Chapter 30 for details.

Sodium and Saline/Sodic Soils

Diagnosis of Saline/Sodic soils

The common Na-containing salts with South Dakota's soils are sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3). Managing for Na is important because the sodium cation disperses soil aggregates, slows water infiltration, and increases erosion (Fig. 32.1). High Na can also result in high soil pH, which can reduce the availability of some nutrients (N, P, Fe, Mn, Cu, and Zn). If tile drainage is installed the EC can decrease gradually until the tipping point is reached and the soil disperses (Fig. 32.5). As demonstrated in Figure 32.5, a flocculated soil may have > 4% of the bases extracted being Na if the EC is high. However, as the EC decreases the risk of soil dispersion increases. In northern Great Plains dryland agriculture, tile drainage of soils with % Na extracted with ammonium acetate greater than 4 can result in problems.

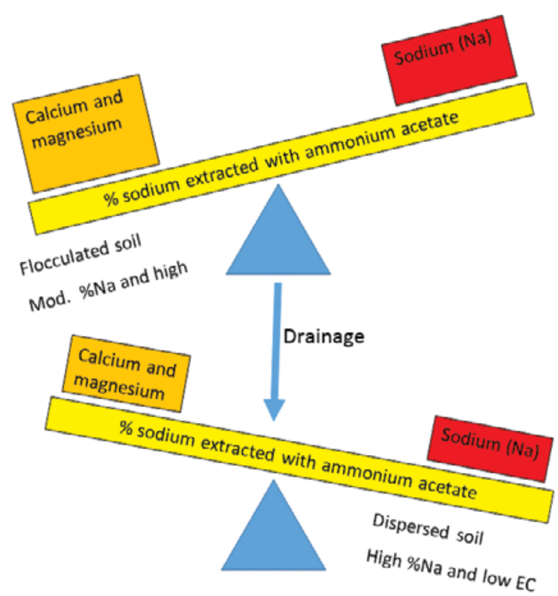

Figure 32.5 The influence of drainage on the relative amount Na extracted with ammonium acetate. Drainage results in a decrease in the soil EC and the concentrations of calcium, magnesium, and sodium (Na). However, the percentage of Na as a function of all cations increases, which results in soil dispersion.

Diagnosis involves collecting and analyzing soil samples from the problem areas. The sampling depth depends on the magnitude of the problem. If the goal is to install tile drainage, the soil sample should be collected from the soil surface for a salt

Table 32.3 Example of soil test laboratory report from a submitted sample.

% Na extracted with ammonium acetate

Sample Id	**Soil pH (1:1)**	**EC or sol. salts (1:1)**	**Nitrate**	**P**		**Ammonium acetate**			**Sum cations**	**% Bases**			
		mmhos/ cm	lbs/acre	ppm	K ppm	Ca ppm	Mg ppm	Na ppm	me/100 g	K	Ca	Mg	Na
2275	7.5	0.57	45	22	1037	2273	236	20	16.1	17	70	12	1

assessment and from the surface 3 feet for a drainage assessment. Each sample should contain at least 3 pounds of moist soil collected with a soil probe from at least 10 areas within the problem area. These soil samples should be sent to a laboratory to determine the EC and percent Na extracted by ammonium acetate. Examples for determining sodium risks are provided in Examples 32.1 and 32.2.

In soil testing reports, the sodium risk is the ratio between amount of Na in the soil and the sum of the cations extracted by the ammonium acetate solution (Table 32.3). [It is important to note that some laboratories refer to the sum of the cations as the cation exchange capacity (CEC)]. The percent sodium extracted with ammonium acetate is 100 times the ratio between Na and the sum of the cations (Table 32.3).

If the soil has a Na risk, the long-term goal should be to prevent further degradation. In South Dakota, installing drainage systems in saline/sodic soils can result in serious problems within a few years.

Example 32.1 Sample calculations for determining the percent of Na extracted with ammonium acetate.

A soil sample is sent off for laboratory analysis. In this analysis, ammonium acetate is used to extract Na, Ca, Mg, and K. The sample contains 2136 ppm Na^{1+}, 2181 ppm Mg^{2+}, 3198 ppm Ca^{2+}, and 200 ppm K^{1+}. Calculate the % Na extracted by ammonium acetate. In this calculation 1ppm = 1 mg/kg.

Note: When doing this calculation it is important to know that Na has a valance of +1, Ca has a valance of +2, and Mg has a valance of +2. In addition, the molecular weight of each cation is needed. Na = 23 mg/mmol; Mg = 24.3 mg/mmol; Ca = 40 mg/mmol; and K = 39 mg/mmol. The valances and molecular weights are used to convert mmol to mmolc.

Step 1. Convert ppm for each cation to mmolc/kg. For this conversion 1ppm = 1mg/L

$$\frac{2136\ \text{mg Na}}{\text{kg}} \times \frac{\text{mmol Na}}{23\ \text{mg Na}} \times \frac{\text{cmol}}{10\ \text{mmol}} \times \frac{1\ \text{cmol}_c\ \text{Na}}{1\text{cmol Na}} = \frac{9.29\ \text{cmol}_c\ \text{Na}}{\text{kg}}$$

$$\frac{2181\ \text{mg Mg}}{\text{kg}} \times \frac{\text{mmol Mg}}{24.3\ \text{mg Mg}} \times \frac{\text{cmol}}{10\ \text{mmol}} \times \frac{2\ \text{cmol}_c\ \text{Mg}}{1\text{cmol Mg}} = \frac{18.0\ \text{cmol}_c\ \text{Mg}}{\text{kg}}$$

$$\frac{3198\ \text{mg Ca}}{\text{kg}} \times \frac{\text{mmol Ca}}{40\ \text{mg Ca}} \times \frac{\text{cmol}}{10\ \text{mmol}} \times \frac{2\ \text{cmol}_c\ \text{Ca}}{1\text{cmol Ca}} = \frac{16\ \text{cmol}_c\ \text{Ca}}{\text{kg}}$$

$$\frac{200\ \text{mg K}}{\text{kg}} \times \frac{\text{mmol K}}{39\ \text{mg K}} \times \frac{\text{cmol}}{10\ \text{mmol}} = \frac{0.5\ \text{cmol K}}{\text{kg}}$$

The sum of cations (sometimes called bases) is (9.29+18.0+16+0.5) = 43.8 cmol_c/kg.

The % sodium extracted by ammonium acetate = 100× [total cmol_c NA/total sum of cations) or for this problem:
100 x (9.29/43.8) = 21.2%

Based on this analysis, the soil contains a high relative amount of Na^{1+} compared to the total cations in the soil. Therefore, tile drainage of this soil would NOT be recommended, as tiling may result in soil aggregate dispersion and an associated loss of productivity.

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Example 32.2 Estimating % sodium extracted by ammonium acetate.

The sum of bases or cations can be calculated using the following steps. First, use ammonium acetate to extract the soil cations. Determine the concentrations of Na^{1+}, Ca^{2+}, Mg^{2+}, and K^{+1} in the soil and the sum of the cations. In this example, the sum of the cations is 26 cmolc/kg or 26 meq/100 g and Na is 692 ppm.

Note: The sum of cations and the Na value are given in different units. Therefore, the common unit of $cmol_c$/kg (or meq/100 g) must be determined for the Na value to determine the % Na in the soil. For this calculation 1 ppm = 1 mg/kg.

On the soil testing laboratory reports, Na^{1+} is listed as ammonium acetate extractable and the units are ppm. For these calculations ppm must be converted to meq/100 g or $cmol_c$/kg.

Convert Na in ppm to $cmol_c$/kg.

$$\frac{692 \text{ mg Na}}{\text{kg}} \bullet \frac{\text{mmol}_c \text{ Na}}{23 \text{ mg Na}} \bullet \frac{1 \text{ cmol}_c \text{ Na}}{10 \text{ mmol}_c \text{ Na}} = \frac{3 \text{ cmol}_c}{\text{kg soil}}$$

The sum of the bases (provided in above example) is $\frac{26 \text{ cmol}_c}{\text{kg}}$

then

$$\% \text{ Na} = \frac{3 \text{ cmol}_c / \text{kg soil}}{26 \text{ cmol}_c / \text{kg soil}} \bullet 100\% = 11.5\%$$

This analysis indicates that 11.5% of the ammonium acetate extractable bases are Na^{1+}. This soil has a very high Na concentration. Caution should be used in this soil's management.

Adding Organic Matter

A relatively inexpensive approach to improve the soil structure is to apply low Na-containing manure or apply crop residues to problem areas. The organic matter in these materials can help stabilize and improve soil structure. It must be pointed out that not all manures have low Na concentrations. Manure from animals that have high concentrations of NaCl in their rations to meet animal nutritional requirements may not be desirable for soil applications.

Reseeding to Perennial Plants

Returning saline and sodic soils to deep-rooted, salt-tolerant perennial plants and grasses appears to reduce salt problems. These perennial plants can lower the water table and provide the roots needed to stabilize the soil aggregates.

Adding Chemical Amendments

Another Na remediation approach is to replace the sodium on the soil exchange sites with calcium. In most situations, the least expensive amendments are either gypsum or elemental sulfur. The oxidation of sulfur reduces soil pH and, if free lime is present, Ca can be released. If the soil contains high sulfate or gypsum concentrations, then the addition of gypsum may not be effective (Skarie et al., 1987). In soils containing high sulfate or gypsum, elemental S may be more effective than gypsum. However, for elemental S to work, the soil must contain free lime. To increase the effectiveness of elemental S, the appropriate amount should be mixed into the soil. Theoretically, 1 ton of gypsum is replaced by 380 lbs of elemental S (0.19 ×2000 lb/ton = 380 lbs Sulfur).

Mitigating Sodium Risks with Tile Drainage

If % sodium extracted by ammonium acetate is greater than 4 (example calculations shown above), installing tile drainage can result in soil dispersion and the loss of productivity if the water percolating through the soil is rainwater. This dispersion is the direct result of a gradual decrease in the soil EC. Chemical remediation can be used to reduce this risk. The amount of chemical to apply depends on the

Example 32.3 Determine how much gypsum is needed. In this calculation, remember that 1 $mmol_c$/100 g = 1 $cmol_c$/kg. In this soil, the soil sum of bases (cations) is 20 $cmol_c$/kg soil or 20 mmolc/100 grams, and the % Na^{1+} extracted by ammonium acetate was 15%. The goal is to reduce the surface 6 inches % Na extracted to 5%. In this calculation assume that the weight of the soil in the surface 6 inches is 1,850,000 lbs.

1. Calculate the amount of Na that must be exchanged to reduce from 15% to 5%.

$$15\% = 100 \times \frac{\text{Na}}{\text{CEC}}$$

in this example CEC is estimated to be 20 $mmol_c$/100 grams.

$$0.15 \times \frac{20\ \text{mmol}_c}{100\ \text{g}} = \text{Na} = 3\ \text{mmolc/100g}$$

at 5% Na, the amount of Na on the exchange sites is 1 $mmol_c$/100 g (i.e. 0.05*20)

To reduce Na from 3 to 1 $mmol_c$ /100g, then 2 $mmol_c$ /100g of Na must be replaced with Ca^{2+}.

2. Determine the amount of gypsum to apply. This calculation assumes that 1 mole of gypsum will replace 2 moles of Na. Gypsum is used in this calculation because it contains Ca^{2+} which replaces Na^{1+} on the exchange sites. This assumption is based on Ca having a 2+ valance and Na having a 1+ valance and gypsum having a molecular weight of 172.2 g.

$$\frac{1{,}850{,}000\ \text{lbs soil}}{\text{acre}} \times \frac{2\ \text{mmol Na}}{100\ \text{g}} \times \frac{1000\ \text{g}}{\text{kg}} \times \frac{1\ \text{kg}}{2.20\ \text{lbs}} \times \frac{\text{mole}}{1000\ \text{mmol}} \times \frac{1\ \text{mole CaSO4} \bullet 2\text{HO}}{2\ \text{moles Na}}$$

$$\frac{172.2\ \text{g}}{1\ \text{mole gypsum}} \times \frac{\text{kg}}{1000\ \text{g}} \times \frac{2.21\ \text{lbs}}{1\ \text{kg}} \times \frac{\text{ton}}{2000\ \text{lbs}} = 1.59\ \text{tons of gypsum}$$

Based on this calculation 1.59 tons of gypsum are needed if the surface 6 inches/acre weighs 1.85 million pounds. If the soil weighs 2 million pounds, then 1.72 tons of gypsum are needed [e.g. (2 million/1.85 million) x 1.59 tons] (Table 32.6).

Example 32.4 The soil test reports that the sample contains 2273 ppm Na^{1+}, 1037 ppm K^{1+}, 236 ppm Mg^{2+}, and 2273 ppm Ca^{2+}. Convert these ppm values to meq/100 g soil.

Solution

Note: When doing this calculation, it is important to know that K has a valance of 1+, Na has a valance of 1+, Ca has a valance of 2+, and Mg has a valance of 2+. Note: In these calculations, the answer has the units meg/100 g. The 100 g in the denominator by dividing by 10 g not 1000 g.

$$\frac{2273\ \text{mg Na}}{\text{kg soil}} \bullet \frac{\text{mmol Na}}{23\ \text{mg Na}} \bullet \frac{1\ \text{meq Na}}{1\ \text{mmol Na}} \bullet \frac{1\ \text{kg soil}}{100 \bullet 10\ \text{g}} = \frac{9.88\ \text{meq Na}}{100\ \text{g soil}}$$

$$\frac{1037\ \text{mg K}}{\text{kg soil}} \bullet \frac{\text{mmol K}}{39\ \text{mg K}} \bullet \frac{1\ \text{meq K}}{1\ \text{mmol K}} \bullet \frac{1\ \text{kg}}{100 \bullet 10\ \text{g}} = \frac{2.66\ \text{meq K}}{100\ \text{g soil}}$$

$$\frac{236\ \text{mg Mg}}{\text{kg soil}} \bullet \frac{\text{mmol Mg}}{24.3\ \text{mg Mg}} \bullet \frac{2\ \text{meq Mg}}{1\ \text{mmol Mg}} \bullet \frac{1\ \text{kg}}{100 \bullet 10\ \text{g}} = \frac{1.94\ \text{meq Mg}}{100\ \text{g}}$$

$$\frac{2273\ \text{mg Ca}}{\text{kg soil}} \bullet \frac{\text{mmol Ca}}{40\ \text{mg Ca}} \bullet \frac{2\ \text{meq Ca}}{1\ \text{mmol Ca}} \bullet \frac{1\ \text{kg}}{100 \bullet 10\ \text{g}} = \frac{11.4\ \text{meq Ca}}{100\ \text{g}}$$

2. Determine the sum of cations
   = (9.88+2.66+1.94+11.4) meq/(100 g soil) = 25.85 meq/100 g soil

3. Determine the % Na extracted with ammonium acetate
   %Na = 100% × 9.88/25.85 = 38.2%

Based on this value 38% of the total cations extracted were Na.

incorporation of the selected chemical. For example, if no-tillage is used in the field, then treating the top 2 inches may be necessary, whereas if the soil is plowed then an 8-inch profile should be treated. Tables 32.4, 32.5, 32.6, and 32.7 can be used to simplify these calculations.

Mixing Chemical Treatments with Soil

When applying an amendment, incorporate the amendment with a tillage operation (even in no-till). Chemical treatments are most effective when they are incorporated into the soil. If the subsoil contains gypsum, tillage can be used to transport subsurface gypsum to the surface (Sandoval and Jacober, 1977).

Economic Analysis

The costs of different chemical treatments are provided in Table 32.7. Before selecting a product, check with a local provider about availability and cost.

Summary

In the northern Great Plains saline and sodic soils are serious problems. The management of salt-affected soils includes diagnosis, prevention, and remediation. Diagnosis involves collecting a soil sample from the problem area, which must be correctly interpreted. Many soil testing laboratories use different methods to determine the soil EC and sodium risk. For example, Midwest Laboratories Inc. and Ward Laboratories Inc. report the EC of 1:1 solution to soil ratios, whereas the historical technique was to determine the EC using a saturated paste. The EC value of a 1:1 is converted to EC of a saturated paste by multiplying the value by 2.14.

Even though many soil testing laboratories report sodium and cation exchange capacity (CEC) values, they may not be labeled as such. For example, in the Ward Laboratories report and Table 32.2, CEC is listed as Sum of Cations, while on the Midwest Laboratories report, CEC is listed as CEC. AgLab Express, located in Sioux Falls, SD, reports CEC and ESP, while Agvise reports CEC and % base saturation. A more complete listing of soils laboratories is available in Chapter 21. In this document, these values are reported as % Na extracted by ammonium acetate.

Prevention and remediation involve planting something at the site. In sodic soils, a common remediation approach is to add Ca [elemental S; solubilizes $CaCO_3$ to release Ca; gypsum, and $CaSO_4$]. Gypsum additions may not be effective if the soil contains high concentrations of gypsum or SO_4-S. Under these conditions, elemental sulfur may be useful.

Table 32.4 The approximate amount of gypsum in tons/acre required to convert the soil surface 6 inches with a specified % Na extracted with ammonium acetate to a soil with a % Na of 5. The soil's cation exchange capacities are shown on the y-axis. This calculation assumes that the surface soil weighs 2 million pounds/acre. However, many soils weigh slightly less than this value. The weight of soil for 1 acre that is 6 inches deep is approximately 1.7×10^6 if it has a bulk density of 1.25 g/cm^3. If the bulk density is 1.45 g/cm^3, then the weight is approximately 2 million pounds. To convert from 2 million to 1.7 million pound multiply the gypsum needed by 0.85 (1.7 million pounds/ 2 million pounds).

Sum of bases	Initial % Na					
	10	15	20	25	30	35
	Tons gypsum/acre					
10	0.5	1.0	1.5	2.0	2.5	3.0
15	0.75	1.5	2.25	3.0	3.75	4.5
20	1	2.0	3	4.0	5.0	6.0
25	1.25	2.5	3.75	5.0	6.25	7.5
30	1.5	3.0	4.5	6.0	7.5	9.0
35	1.75	3.5	5.25	7.0	8.75	10.5

Table 32.5 The relationship between tons of gypsum and lbs of elemental sulfur required for the surface 6 inches as influenced by desired change in Na^{1+}. This calculation assumes that the surface soil weighs 2 million pounds/acre. If less than the 6 inches is treated, use the appropriate ratio. For example, if only 2 inches are treated divide the tons of gypsum by 3.

Desired change in %Na meq/100g	Tons gypsum 6 inches	Lbs of elemental S 6 inches
0.5	0.43	190
1.0	0.86	380
1.5	1.29	570
2.0	1.72	760
2.5	2.15	950
3.0	2.58	1,140
3.5	3.01	1,330
4.0	3.44	1,520

Table 32.6 The relationship between different chemical treatments and amount of gypsum needed.

Chemical	Chemical formula	Ton equivalent to 1 ton of gypsum
Gypsum	$CaSO_4 \bullet 2H_2O$	1.0
Elemental S	S	0.19
Sulfuric acid	H_2SO_4	0.57
Calcium Chloride	$CaCl_2 \bullet 2H_2O$	0.86
Limestone	$CaCO_3$	0.58

Table 32.7 2015 estimated costs for Na-affected soil remediation with chemical additives:

Cost of the chemical additives
- Elemental S at $720/ton
- Calcium chloride ($CaCl_2 \bullet 2H_2O$) at $740/ton
- Gypsum ($CaSO_4 \bullet 2H_2O$) at $240/ton

To reclaim a soil needing 1 ton equivalent gypsum
- Gypsum: 1 ton × $240/ton = $240
- $CaCl_2$: 0.86 ton × $740/ton = $636
- Elemental S: 0.19 ton × $720/ton = $137

Table 32.8 Key terms used in this chapter.

Key terms	Definition	Units
CEC	Cation exchange capacity, number of exchangeable cations that the soil is capable of holding.	meq/100 g = $cmol_c$ /kg
EC	Electrical conductivity, used to measure salts.	dS/m = mmol/cm
Sum of bases	Value reported on soil test results≈ CEC, may be identical to sum of cations.	meq/100 g = $cmol_c$ /kg
Sum of cations	Value reported on soil test results≈ CEC, may be identical to sum of bases.	meq/100 g = $cmol_c$ /kg
mmhos/cm	units used to measure salts.	identical to dS/m
dS/m	units used to measure salts.	identical to mmhos/cm
ESP	Exchangeable sodium percent.	% Na/CEC
SAR	Sodium adsorption ratio.	$=Na^{1+}/(0.5 \times (Ca^{2+}+Mg^{2+})^{0.5}$
Saline soil	Soil containing high salt concentration, based on EC.	Historically EC > 4 dS/m
Sodic soil	Soil containing high sodium concentrations,	
Based %Na/CEC.	Track when ESP > 4	
ppm	The number of parts per million	
meq/100 g	The millequivalents per 100 grams of soil	meq/100 g = $cmol_c$ /kg
$cmol_c$ /kg	The centamole of charge of an ion per kg of soil	

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