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SALT-AFFECTED SOILS: THEIR CAUSES, MEASURE, AND CLASSIFICATION

The effect of high-salt soils upon conservation and landscaping projects in the northern Plains and Rocky Mountains is impressive. It is estimated that 300,000 acres in Montana alone have been removed from production because of increased salinity. Even soils classified as "slightly saline" are marginally acceptable for many crops. Before installing salt-tolerant plants or reclaiming a salt-affected site, it's important for landowners and managers to have good analytical information available in order to formulate a strong conservation plan. Professionals and landowners need to understand 1) the causes of salt-affected soils, 2) the various tests used to measure saltiness, and 3) the various classifications or types of salt-affected soils.

The main source of salts in our Region is the weathering of primary minerals. Parent materials high in sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), nitrate (NO_3^-), and chloride (Cl^-) weather to release these ions to form salts directly, or influence soil chemistry in ways that result in salt accumulation. In arid regions like the northern Plains, limited rainfall results in minimal leaching of bases and salts under non-irrigated conditions, so soluble salts of Ca, Mg, and Na remain in high concentrations in the soil. There is typically a zone in the lower profile where these bases accumulate that is often higher in base concentration than the parent material from which it was derived. This zone typically remains in the lower profile under native range conditions in arid locations. The weathering of minerals in a localized site seldom results in a highly salty soil. High accumulations typically require the movement of salts, carried by water from adjacent areas, to markedly increase the salt concentration of a given site. This recharge with soluble salts is an important management consideration because the source of recharge may be from adjacent land under different ownership. In most cases, this funneling and build-up of water results from an elevation gradient and/or an impervious soil layer. A plow pan, hard pan, sand lens, or rock layer often restricts the movement of water through the profile, allowing capillary movement of water and dissolved mineral salts upwards to the soil surface and into the rooting zone. Where the salt layer resides in the profile is important, since it influences whether a seeding verses a planting is appropriate, the type of site preparation needed, whether to use bareroot or container planting stock, which corrective measures to implement, and the likelihood of success. Crop-fallow systems to encourage soil moisture storage can also lead to a localized salt accumulation. Prolonged irrigation with salty water also increases soil saltiness and will be the topic of a future HortNote. Infrequently, excessive fertilization can lead to localized increases in soil salinity in our region.

To verify a potential salt problem, soil analyses are needed to determine the level of saltiness and the type of ions involved. Testing begins with a thorough sampling of the site. In some cases, county soil survey data may be sufficient for large-scale management. For intensively managed sites, such as ornamental landscapes, commercial nurseries, and other high-end crops, supplemental testing is advisable. There is often resistance to adequate soil testing because of the cost involved. Analytical costs represent a minimal percentage of the total cost of reclaiming a salty site. Proper sampling requires collecting specimens across the surface of the site as well as at varying depths within the profile.

There are several tests to quantify or qualify soil saltiness. It's important to understand the differences among these tests because each provides a specific type of information that may or may not help us determine best management. It's also valuable to be able to understand the results, although soils experts can assist with interpretation. **Electrical conductivity (EC)** describes the amount of electrical current conducted by a saturated soil extract at a fixed temperature. The more salts in solution, the greater the EC reading, and the greater the toxicity to plants. This test does not distinguish between one type of salt and another; it simply provides an overall measure of water-soluble salts (see table 1). Units of measure include decisiemens per meter (dS/m or dS m^{-1}) and millimhos per centimeter (mmhos/cm or mmhos cm^{-1}), which are synonymous (1dS m^{-1} = 1mmhos cm^{-1}). **Total dissolved solids (TDS)** provides similar information as EC, but is based on an evaporative test and has been largely replaced by the EC test. TDS results are expressed in milligrams per liter (mg/l or mg l^{-1}) or parts per million (ppm), the two units being equal. (You can approximate TDS by multiplying the EC[dS m^{-1}] of lesser saline samples by 640 or the EC of very saline samples by 800.) Since Na toxicity to plants is severe, and the effects of Na on soil pH and structure are significant, two tests have been devised to describe the relative amounts of Na present in the soil. The **exchangeable sodium percentage (ESP)** provides a measure of the amount of exchangeable Na relative to the total cation exchange capacity of the soil expressed as a percentage. As the ESP goes up, more exchangeable Na is available, and the greater the potential for negative plant and soil impacts. The **sodium adsorption ratio (SAR)** describes the ratio of Na relative to Ca and Mg - two cations that moderate the adverse effects of Na. The greater the SAR, the more Na relative to Ca and Mg, the greater the toxicity to plants. **Soil pH** is another important soil measure even though it does not directly measure saltiness. It is a measure of the hydrogen ion concentration in soil solution - an important indication of the chemical status of the soil. Since soluble salts affect soil pH and vice versa, it is often included in evaluations and discussions of soil saltiness. A main implication of changing the soil pH is plant nutrient availability, which is often a secondary response to microbial activity levels responding to changing soil pH. As soil pH climbs, elements such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), phosphorus (P), and boron (B) become limiting. The soil pH scale ranges from 0 to 14, with <7 considered acidic, 7 neutral, and >7 alkaline or basic (see table 2). Each whole number represents a ten-fold change in both H concentration and OH, or a 100-fold change in the concentration of H relative to OH (since there is an inverse relationship between the two: as one increases the other proportionally decreases). Most arable soils in our region have a pH in the range of 7 to 9.

It's important to distinguish between the different types of salt-affected soils because the individual ions involved vary, as do their modes of action, and prescribed treatment. There are three soil classifications used to describe salt accumulation in soils. **Saline** soils typically measure >4 dS m^{-1} of EC, have an ESP <15%, a pH below 8.5, and an SAR of 0-12. These soils are sometimes referred to as *alkali* or *white alkali* to describe the white incrustation that develops at the soil surface. **Saline-sodic** soils also have an EC >4 dS m^{-1}, and a pH below 8.5, but have an ESP >15% and SAR >12. Leaching in this case is risky because the exchangeable sodium readily hydrolyzes, increasing the hydroxyl ion concentration and raising the soil pH. Both neutral soluble salts and sodium can be toxic to plants, the high soil pH results in limited availability of plant nutrients, and mineral colloids are dispersed creating a hard, impervious soil structure. **Sodic** soils contain few neutral soluble salts, the ESP is >15%, the EC is <4 dS m^{-1}, and the pH above 8.5. The result of these conditions is Na and hydroxyl ion (OH^-) toxicity to the plant, very high pH with a commensurate decrease in nutrient solubility and availability, and very poor physical properties of the soil - none of which are good for plant growth.

Most soil analyses provide only absolute values for each test, with no indication of the significance of the measure. In some cases, unit conversion may be necessary. Landowners and managers will need correlation information to make sense of test results. As an example, a soil test indicating an EC of 8 dS m^{-1} is meaningless to the average cooperator or landowner. What is of value is data that correlates plant tolerances to various levels of salinity (ECs). The next HortNote will provide information and references on this subject.

So, how exactly does soil salt level influence plant survival and growth? Water is absorbed into plants because of a gradient that exists between the soil solution and the cell sap of the interior root cells (both passive and active systems are involved). As the concentration of neutral salts such as sodium chloride and sodium sulfate increases in the soil solution, its water potential becomes more negative, making water movement to the root cells more difficult. If the soil solution potential becomes negative enough, water may actually migrate out of the plant cells and into soil solution. There may be ample available soil moisture for plant growth; it's just that the plant cannot extract it because of the strong negative potential. The effect is essentially the same as drought - the plant can't get enough water to maintain proper growth, or it takes so much plant energy extracting the water that growth suffers. The situation is exacerbated under water stress conditions, particularly on fine-textured soils where it takes more "pull" for the plant to remove water at a given soil moisture level. In addition to the osmotic effect, certain ions are directly toxic to plants. Also, ions such as Na can influence soil chemistry and biology to such a degree as to limit plant nutrient availability as previously described. Lastly, certain ions negatively influence soil structure and permeability characteristics, thereby retarding plant growth.

Here are a few handy tables and conversions for interpreting soil analysis results:

Table 1. Soil Salinity Classes

Salinity Class	EC (electrical conductivity)
	dS m^{-1} or mmhos cm^{-1}
Nonsaline	0-2
Very slightly saline	2-4
Slightly saline	4-8
Moderately saline	8-16
Strongly saline	>16

Table 2. Soil pH Classes

pH Class	pH
Ultra acid	<3.5
Extremely acid	3.5-4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	>9.0

Handy Unit Conversions:

Milligrams per liter (mg/l or mg l^{-1}) equals parts per million (ppm).
Example: 125 mg l^{-1} = 125 ppm.

Percentage multiplied by 10,000 equals parts per million (ppm) or conversely, parts per million (ppm) divided by 10,000 equals percentage (%).
Example: To convert 2% (0.02 x 100) to ppm, multiply 2 times 10,000 to get 20,000 ppm. Do not confuse the fraction 0.02 with 2 percent when converting. If, however, the percentage were actually 0.02% (0.02/100 or 0.0002), then the conversion would correctly be 0.02 x 10,000 = 200 ppm. Keep your fractions and percentages straight.

Milligrams per liter (mg l^{-1}) = parts per million (ppm).
Example: 20 mg l^{-1} = 20 ppm.

Electrical Conductivity (EC) x 640 = Total dissolved solids (TDS) of lesser saline soils
Electrical Conductivity (EC) x 800 = Total dissolved solids (TDS) of highly saline soils
Example: the TDS of a very slightly saline soil with an EC of 2.5 dS cm^{-1} can be approximated by multiplying 2.5 X 640 = 1,600 ppm or 0.16 percent or 0.0016.

References:

Soil Salinity Management-Nonirrigated, USDA-NRCS Conservation Practice Standard, Code 571, Jan. 2002.
Brady, N. 1984. The Nature and Property of Soils, Ninth Edition.
Tanji, K (ed.). 1990. Agricultural Salinity Assessment and Management, American Society of Civil Engineers.
Majerus, Mark. 1996. Plants for Saline-Alkaline Soils, USDA/NRCS, Technical Notes, Plant Materials No. 26 (revised), Bozeman, MT.