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SUCCESSFUL RESTORATION OF SEVERELY DISTURBED WYOMING LANDS: Reclamation on salt/sodium-affected soils

This bulletin provides general information especially relevant to MLRA (Major Land Resource Area) 32, 34,58, and 67 ecological sites in Wyoming (plains, desertic basins, and plateaus).

Part of a series by the University of Wyoming Extension and Wyoming Reclamation and Restoration Center (WRRC) that describes specific strategies for restoring ecological functions to disturbed Wyoming lands. All the bulletins can be downloaded from the WRRC (http://www.uwyo.edu/wrrc/bulletins.html) and CES (http://ces.uwyo.edu/) websites.

For this series, **reclamation** means **restoration** of components that support desired ecological functions, such as livestock grazing, wildlife forage and cover, water quality protection, and aesthetic values.

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Summary

Reclaiming severely disturbed soils with elevated levels of salt, sodium, or both is difficult. Undisturbed topsoil is often less than 3 inches thick, but soil salvage operations usually scrape soils to a standard 6-inch depth. This mixes surface soils with materials from deeper in the soil profile that may contain higher salt and/or sodium levels or other toxic materials that inhibit plant growth. Once concentrations in surface soils are elevated, returning them to levels suitable for plant growth can be challenging. Several chemical amendments used in agricultural applications work well when irrigation water is available to dissolve the amendments and leach the salts and sodium below the root zone. This approach is not feasible in semi-arid regions like much of Wyoming. Research around the world has demonstrated that adding organic amendments (compost, manure, or biosolids) to saline/sodic soils can facilitate reclamation of disturbed sites. In this bulletin, soil amendments and their use in arid environments are examined, and recommendations are provided.

Introduction

Most soils in semiarid regions, including much of Wyoming, are naturally "salt-affected" and these salts dominate soil properties and shape native plant communities. Though most Wyoming rangelands are dominated by plant species tolerant to salts to some degree, development and reclamation activities can increase salt content in surface soils to levels even the most tolerant upland native plants can't survive.

Salts are soluble combinations of positively charged cations, such as calcium, potassium, magnesium, sodium, and others, with negatively charged anions like carbonate, sulfate, and chloride. These materials weather from soil parent materials and accumulate near the surface in regions where evaporation exceeds precipitation, which is a definition of semiarid. Surface soils typically have slightly lower salt concentrations than subsoils if seasonal precipitation is sufficient to leach (move) salts down through the soil profile, and soil organic matter from decomposing plants accumulates near the surface, diluting salt content and offsetting some of the detrimental effects.

Though some cations in salts are essential plant nutrients, excess amounts can have toxic effects or can impact soil properties in ways that impede plant growth. This bulletin addresses problems associated with elevated salt contents and methods to improve reclamation on these sites.

How do salts affect soils?

Positively charged cations react with negatively charged surfaces on clay particles to bring particles together, or flocculate them, to form aggregates. But salts have high affinity for water and in high concentrations can prevent plant water uptake. Sodium has unique properties that make it especially problematic at high concentrations. Sodium has a weak positive charge but is especially attractive to water molecules. Its large ionic radius in water increases electronegativity that drives soil particles apart, or disperses them, destroying soil structure and porosity.

Types of salt-affected soils

Figure 1 shows relationships among electrical conductivity (EC), which is a measurement of total salt content, and sodium adsorption ratio (SAR), which is the ratio of sodium to calcium and magnesium. Three categories of salt-affected soils have been identified for management purposes:

- Saline soils. Salt problems in general: EC > 4 dS/m
- Sodic soils. Sodium problems: SAR ≥ 13 or ESP ≥ 15.
- Saline-sodic soils. Problems with sodium *and* other salts: EC > 4, SAR > 13

Saline soils: Salt problems in general: EC > 4 dS/m

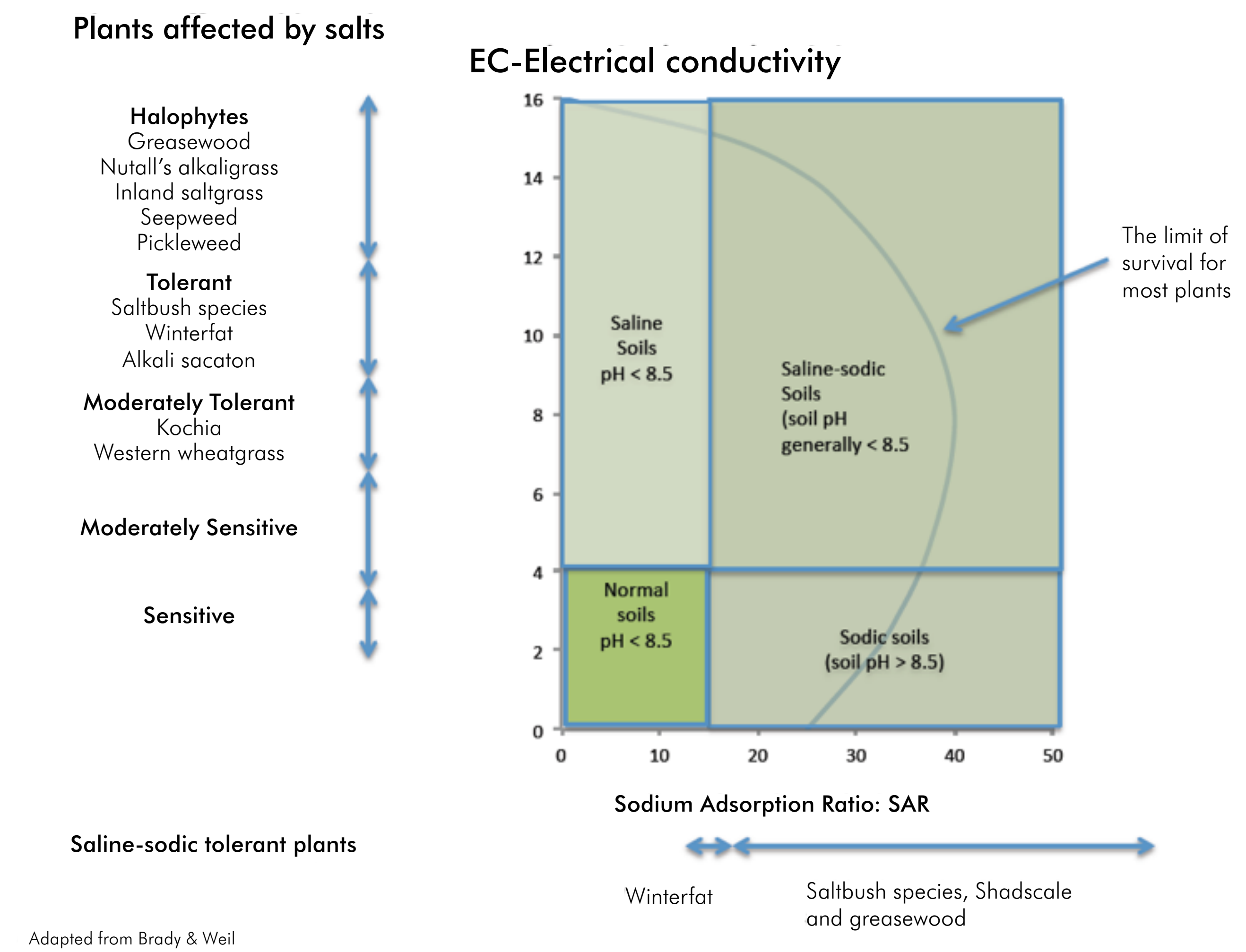
The predominant exchangeable cations in saline soils are calcium and magnesium. Saline soils commonly have visible salt deposits on the surface and are sometimes called white alkali soils. High concentrations of salts in solution increase EC, which is used as an index of salt content. EC is measured using a meter either in the field or in a laboratory.

Most salts have a positive effect on fertility, soil structure, and water infiltration. While water penetration is not a major concern with saline soils, excessive salt content in the root zone can make extracting water from the soil difficult for plants. Salts increase soil water osmotic potential, causing water to move from areas of lower salt concentration (plant tissue) into the soil where the salt concentration is higher, actually pulling water out of plants. High salt concentration in the soil can cause plants to wilt even when soil moisture is adequate. Saline soils in Wyoming often are often dominated by *Atriplex gardneri* (Gardner saltbush), which can tolerate EC levels between 4 and 12 dS/m. Saline soil may be present in areas within sagebrush communities.

Sodic soils: Sodium problems: SAR ≥ 13 or ESP ≥ 15.

Sodic soils are high in sodium relative to calcium and magnesium. Exchangeable Sodium Percentage (ESP) is

Figure 1



Adapted from Brady & Weil

Run-on area Gardner saltbush

Preventing salt problems in reclamation:

Since remediating salt problems to support restoration of native plant communities is extremely difficult, the best approach is to carefully identify the potential for problems and then plan development and reclamation activities to avoid them. This starts with careful inventory of the pre-disturbance plant communities and identification of the depth of soil that is suitable for use in re-establishing it (See University of Wyoming Extension bulletin B-1212). For Wyoming saline/sodic ecological site descriptions (ESDs), refer to Table 1.

another common measurement of sodium contents. EC is generally less than 4 dS/m and often less than 2 dS/m. Soil pH is greater than 8.5 and, in some case, as high as 10. The dispersion of soil particles in sodic soils destroys structure and porosity, which inhibits water movement into and through the soil by clogging pore space and can also cause severe crusting on the surface.

Severely sodic soils can have a black color due to the dispersion of organic matter, as well as a greasy or oily-looking surface with little or no vegetative growth. These soils in Wyoming are often referred to as black alkali soils or slick spots and may be occupied by greasewood (*Sarcobatus vermiculatus*) or Gardner saltbush communities, which can tolerate high sodium levels (SAR >14-40) in the soil. These communities occupy low-lying depressions in landscapes that receive run-on moisture.

Saline-sodic soils: Problems with sodium *and* other salts: EC > 4, SAR > 13

Saline-sodic soils are high in sodium and other salts. The EC is greater than 4 dS/m and SAR > 13. The pH may be above or below 8.5. Water moves throughout the soil profile indicating good soil structure but crusting may be an issue. These soils may exhibit saline or sodic characteristics depending on the dominant element in the soil: sodium or calcium. These sites are also dominated by either greasewood or Gardner saltbush. Saline-sodic conditions usually result from natural events, including weathering, parent material characteristics, and erosion by wind or water. They are often in areas with a shallow water table (2-4 feet below the surface) and occur in low-lying areas or in depressions where runoff concentrates.

Identifying potential problems

By definition, salt-tolerant native plants can handle salt-affected soils, but improper reclamation that mixes subsoil with surface soil can push salt and sodium levels above the tolerance level of even the toughest plants. Some species, like Gardner saltbush, can tolerate very high salt concentrations in their root zones but need surface soils with lower concentrations in order to germinate and establish (Roundy, 1987). Table 2 lists the salt tolerance of some Wyoming native plants. Crucial soil tests for determining suitable soils for salt-tolerant plant communities include pH and EC and SAR. Soil EC and pH can be done with relatively inexpensive field meters while SAR must be done in a soil-testing laboratory.

Table 3 provides values of these parameters and their interpretations for reclamation. High salt concentrations (EC > 4 dS/m) may reduce plant germination and growth. With high concentrations of sodium (SAR > 13) and low salt concentrations, soil structure deteriorates, soils become dispersed, and infiltration is reduced. Very high sodium concentration can be toxic to plants. The pH of the soil becomes problematic at 8.5 because soil micronutrients, like iron, manganese, and others, can become fixed to particles and are unavailable for plant uptake. A pH above 8.5 may indicate potential sodic soil with little or no structure.

Remediation with organic amendments

The addition of organic material increases soil microbial respiration, which reduces pH by organic acid production during decomposition (Chorum and Regasamy, 1997) in non-calcareous soils. Soil microbial activity is crucial for remediation for degraded soils that contain high salt/so-

Determining rates of organic amendments

You'll need to know the organic matter content of the pre-disturbance soils, the post-disturbance soil, and the organic amendment to be applied. You also need to know that the top 3 inches of soil weighs around 1 million pounds (or 500 tons) per acre. Use this formula to calculate the amount of SOM to be added to bring the upper 3 inches back to near its original organic matter content:

500 tons x (original SOM% - disturbed SOM%) = tons of SOM to be replaced

Tons SOM to be replaced ÷ %SOM in amendment = tons of amendment to be added.

For instance, if a soil has 1.5% SOM in the top 3 inches before disturbance and 0.5% afterwards, then 1% must be replaced to begin remediation processes:

500 tons x (1.5% - 0.5%) = 5 tons of SOM per acre to be replaced.

A source of composted cattle manure might have about 40% organic matter, so:

5 tons ÷ 40% = 12.5 tons of the composted cattle manure per acre incorporated to 3 inches.

dium, heavy metals, or bare ground containing little organic matter. When soil organic matter is drastically reduced, the microbial population decreases and respiration levels fall. Upon addition of a substrate (organic matter food source), the microbial population multiplies, which promotes soil aggregation, structure, stability (through chemical reactions), and provides a steady supply of nutrients into the soil.

Organic amendments vary in origin and types. They differ from mulch in that mulch is applied to the surface primarily to reduce erosion and conserve moisture, while amendments are incorporated into the soil to improve soil quality and fertility for plant establishment and growth. The most effective amendments are naturally occurring root exudates and biomass from a thriving plant community, both of which provide energy to the microbial biomass in the soil. For reclamation, the goal of amending soils with organic material is to speed recovery of plant communities that will sustain soil organic matter. Use of organic amendments is usually a one-time effort. Sources of organic material for reclamation include fresh or composted farmyard/feedlot manure, composted municipal yard and tree waste, sewage sludge, and wood chips from forest fuel reduction activities. Sewage sludge can be an excellent organic amendment, but care should be taken to avoid sources that contain heavy metals, which is relatively rare in today's biosolids. Composted manure is much preferred to fresh manure because it is drier and therefore lighter to transport, weed seeds have been killed during the composting process, and it has much lower salt content. The carbon in compost is more stable in the soil than carbon from fresh manure. Woody materials can have very high carbon-to-nitrogen ratios, which can temporarily tie up soil nutrients. Ideally, organic amendments will have carbon-to-nitrogen ratios of 30:1 or less.

Benefits of adding composted organic materials for remediation of salt-affected soils have long been recognized. Myers (1937) concluded that organic matter improves soil structure by interacting with the sodium to prevent swelling and dispersion. Organic matter provides an energy source for the microbial population in the soil, which can promote stable aggregation of soil particles. Meyer and Sims (1979) concluded that compost additions to the soil add organic compounds that bind soil particles, improving structure, porosity, soil water retention, and oxygen supply.

Recent research has shown that organic amendments have long-lasting positive effects on severely salt-affected soils. Tejada et al. (2006) observed steady declines in salt and sodium content, along with marked increase in plant cover and soil porosity, over a five-year period after adding compost and poultry manure to a saline-sodic soil in the semiarid desert region of Spain. The application of compost and poultry manure accelerated sodium leaching and reduced EC, which increased water-holding capacity and soil aggregate stability (El-Shakweer et al., 1998).

Avnimelech et al. (1994) concluded that the addition of compost to a sodic soil seems to be long lasting, as it effectively dissolves the native calcium carbonate ($CaCO_3$) resulting in the replacement of sodium with calcium, which improves soil structure and water infiltration and significantly reduces SAR. Pascual et al. (1999) observed that addition of municipal solid waste compost (MSW) to the soil improves soil quality for a long period (eight years) after application; therefore, it is a suitable technique for the regeneration of soils in semiarid regions.

Smith et al. (1987) state that applications of organic matter can improve site and soil quality as it usually improves infiltration, reduces evaporation, and improves drainage in fine- textured soils and encourages robust root systems. This can improve water availability and water use efficiency of the plants. They recommend addition of organic matter on reclaimed sites at a rate that will restore the soil organic matter (SOM) level to pre-disturbance levels.

Chemical amendments for remediation

Chemical amendments are often used to decrease soil sodium content in agricultural settings, especially when combinations of drainage and irrigation are available to facilitate leaching. Chemical methods are less effective in reclamation situations because, while the chemical reactions

mobilize salts and sodium after precipitation, there is usually not enough precipitation in semi-arid climates to leach salts out of the root zone. The benefits can be short-lived, and the amendment is just adding more salt to the problem. A common chemical amendment is soluble calcium added to the soil as gypsum ($CaSO_4 \cdot 2H_2O$). With adequate moisture, it dissolves calcium from gypsum and replaces sodium on clay surfaces, which flocculates soil particles to increase infiltration and reduce crusting. For sodic soils already high in calcium, acidifying amendments (sulfuric acid, elemental sulfur) that dissolve native calcium carbonate are used to reduce sodium levels. For recommended application rates, see Table 4.

Chemical applications do not add organic matter or stimulate microbial respiration or enzymatic activity in the soil. Although they may improve soil structure, the effects are temporary in reclamation situations because moisture is generally inadequate to leach salts below the root zone. Since gypsum is a salt, it can make the soil more saline unless it can be leached from the root zone (Table 5).

Scholl and Miyamoto (1984) found that applications of sulfuric acid (5mt/ha or 2.2T/ac) on sodic mine spoils in northwestern New Mexico improved the infiltration rate and reduced surface crusting of reclaimed soils. These applications lowered the pH and SAR on both the sandstone and shale spoils. The acid treatments showed promise, but gypsum has limitations because of low solubility; it requires approximately 20 cm (8 inches) of water to dissolve 5 tons of gypsum.

Combination of organic and chemical amendments

Bjugstad et al. (1981) found that mulching, fertilization, gypsum application, and physical amendment application (sawdust, straw, perlite, and vermiculite) all helped in promoting plant establishment on a saline-sodic bentonite spoil. The researchers found that the organic amendments provided rapid improvements in soil physical conditions often unattainable with chemical amendment only.

The addition of organic matter in conjunction with gypsum has been successful in reducing adverse soil properties associated with sodic soils. Vance et al. (1998) found that the addition of organic matter and gypsum to the surface soil decreased dispersion and reduced EC in surface soils more effectively than gypsum alone. Wong et al. (2009) determined that the addition of organic material increased soil microbial biomass while added gypsum decreased pH. Chorum and Rengasamy (1997) found a larger decrease in pH in highly alkaline soil with the combined addition of gypsum and green manure, compared to the addition of green manure or gypsum alone. Wong et al. (2009) conclude that there is often a dormant population of salt- tolerant microorganisms in degraded soils and can multiply rapidly when substrate is made available. The large increase in EC with the addition of gypsum does not appear to affect microbial respiration rates. Decomposition processes in their study were apparently limited by microbial substrate (food source) rather than poor, salt-affected soil conditions.

Conclusion

Saline, sodic, or saline/sodic soils are problematic for reclamation in semi-arid areas where evaporation rates exceeds precipitation. Chemical treatments, including additions of sulfur or gypsum, can be effective for agriculture because they require moisture to activate the chemical processes that can reduce sodium levels, or leach salts from the root zone. However, organic amendment applications are the best for reclamation because they alleviate problems associated with excessive salts or sodium without supplemental irrigation.

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Table 1. Dominant plant communities found on saline rangeland ecological sites of Wyoming. From Natural Resources Conservation Service (NRCS) soil characterization data and Ecological Site Descriptions (ESDs).

MLRA zone	Ecological site name	Depth inches	Surface subsurface		Dominant plant spp.
			SAR	EC	
58B Northern Rolling High Plains, Southern Part 10-14″	Saline Lowland		**6** **12**	**3.4** **5.2**	Thickspike wheatgrass, alkali sacaton, greasewood, fourwing saltbush and forbs.
	Saline Subirrigated		No data		Alkali sacaton, Nutall's alkaligrass, greasewood, plains cottonwood, and forbs
	Saline Upland	0-9.35 9.35-14.9	**22** **14**	**7.8** **11**	Gardner saltbush, winterfat, thickspike wheatgrass, and forbs
58B Northern Rolling High Plains, Southern Part 15-17″	Saline Lowland	0-2.28 2.28-6.24	**6** **12**	**5.6** **6.9**	Rhizomatous wheatgrasses, alkali sacaton, greasewood, and forbs
	Saline Subirrigated		No data		Alkali sacaton, Nutall's alkaligrass, greasewood
	Saline Upland		No data		Gardner saltbush, winterfat, rhizomatous wheatgrasses
34A Cool Central Desertic Basins and Plateaus (Green River and Great Divide Basins) 7-9″	Saline Lowland	0-2 2-10.6	**5** **4**	**1** **0.6**	Alkali sacaton, greasewood, and forbs
	Saline Lowland Drained		No data		Indian ricegrass, greasewood, and forbs
	Saline Subirrigated		No data		Alkali sacaton, basin wildrye and forbs
	Saline Upland	0-1 1-2	**8** **16**	**1.6** **0.9**	Gardner saltbush, Indian ricegrass, bottlebrush squirreltail
34A Cool Central Desertic Basins and Plateaus (Foothills and Basins West) 34A 10-14″	Saline Lowland	0-3.84 3.84-13	**3** **13**	**1.2** **0 .7**	Alkali sacaton, greasewood, and forbs
	Saline Lowland Drained		No data		Indian ricegrass, greasewood, and forbs
	Saline Subirrigated		No data		Alkali sacaton, basin wildrye, and forbs
	Saline Upland	0-3.84 3.84-13	**3** **13**	**1.2** **0.7**	Gardner saltbush, Indian ricegrass, and forbs
34A Cool Central Desertic Basins and Plateau (High Plains Southeast) 10-14″	Saline Loamy		No data		Rhizomatous wheatgrasses, birdfoot sagebrush, and forbs
	Saline Lowland		No data		Alkali sacaton, greasewood, and milkvetch
	Saline Subirrigated		No data		Alkali sacaton, basin wildrye, arrowgrass, and greasewood
	Saline Upland		No data		Gardner saltbush, Indian ricegrass, and Sandberg bluegrass
67A Central High Plains, Northern Part (SE Wyoming) 15-17″	Saline Lowland		No data		Alkali sacaton, western wheatgrass
	Saline Subirrigated		No data		Alkali sacaton, western wheatgrass, and inland saltgrass
	Saline Upland	0-1 1-5.4	**9** **17**	**0.9** **1.2**	Western wheatgrass, blue grama, and fourwing saltbush

Table 1. Dominant plant communities found on saline rangeland ecological sites of Wyoming. From Natural Resources Conservation Service (NRCS) soil characterization data and Ecological Site Descriptions (ESDs). (continued)

MLRA Zone	Ecological site name	Depth inches	Surface subsurface		Dominant plant spp.
			SAR	EC	
32X Northern Intermountain Desertic Basins (Big Horn Basin) 5-9″	Saline Lowland		No data		Alkali sacaton, inland saltgrass, greasewood <25%
	Saline Subirrigated		No data		Alkali sacaton and Nutall's alkaligrass
	Saline Upland	0-1 1-5	**3** **1**	**1.2** **0.47**	Gardner saltbush = 40%, Indian ricegrass and bottlebrush squirreltail
32X Northern Intermountain Desertic Basins (Wind River Basin) 5-9″	Saline Lowland		No data		Alkali sacaton, basin wild rye, greasewood <20%
	Saline Subirrigated		No data		Alkali sacaton and Nutall's alkaligrass
	Saline Upland		No data		Gardner saltbush = 40% Indian ricegrass and bottlebrush squirreltail
32X Northern Intermountain Desertic Basins (East Precipitation Zone 10-14″	Saline Lowland				Basin wildrye and cottonwoods
	Saline Lowland Drained		No data		Inland saltgrass, basin wildrye, and alkali sacaton
	Saline Subirrigated		No data		Alkali sacaton and Nuttall's alkaligrass
	Saline Upland		No data		Gardner saltbush, Indian ricegrass, and bottlebrush squirreltail
43B Central Rocky Mountains (Foothills and Mountains West) 15-19″	Saline Subirrigated		No data		Alkali sacaton and basin wildrye

Species listed are Historic Climax Plant Community, additional species and states may be present, go to http://esis.sc.egov.usda.gov/ for complete listing.

Table 2. Salt tolerance of common plants that grow on salt-or saline-sodic affected soils

Common name	Scientific name	Tolerance level
Black greasewood Nuttall's alkaligrass Inland saltgrass Beardless wildrye Shore arrowgrass Red glasswort Seepweed Pickleweed	Sarcobatus vermiculatus Puccinellia nuttalliana Distichlis stricta Leymus triticoides Triglochin maritime Salicornia ruba Suaeda depressa Salicornia ruba	Very high 20-30 dS/m
Alkali cordgrass Slender wheatgrass Saltbush species Winterfat Alkali bluegrass Alkali sacaton Foxtail barley Cinquefoil species	Spartina gracilis Elymus trachycaulus Atriplex spp Krascheninnikovia lanata Poa juncifolia Sporobolus airoides Horedeum jubatum Potentila spp	High 16-19 dS/m
Curly dock Povertyweed Kochia Plains bluegrass Western wheatgrass Thickspike wheatgrass	Rumex crispus Iva axillaries Kochia scoparia Poa arida Pascopyrum smithii Elymus lanceolatus	Moderate 10-15 dS/m

TN Plant Materials NO. 9A USDA-Natural Resources Conservation Service October 2009

The values in the table; personal communication with Dan Ogle, NRCS plant materials specialist, Idaho, NRCS, and author of TN Plant materials NO. 9A.

Table 3. Soil test interpretation

Soil test measurement	Low	Medium	High	Problem
Electrical Conductivity (EC):dS/m	Below 0.75	0.75-4.0	Above 4.0	EC is an indicator of dissolved salts. High salt concentrations may reduce germination and plant growth.
Exchangeable Sodium Percentage (ESP)	Below 5%	5-15%	Above 15%	As ESP (sodium) increases, soil structure decreases, infiltration and water movement through the soil may be reduced. Sodium levels may be toxic to plants.
Sodium Adsorption Ratio (SAR)	Below 5	5-13	Above 13	Same as ESP.
pH	Below 7.5	7.5-8.5	Above 8.5	Soil iron, manganese, and other micronutrients are less available for plant use. Careful monitoring of soil SAR and ESP is necessary.

From Horneck et al., 2007.

Table 4. Amendment Rates of gypsum/elemental sulfur needed to reclaim sodic soils.

Exchangeable Na to be replaced by Ca (meq Na/100 g soil	Gypsum (ton/acre) 12 inches	Gypsum (ton/acre) 6 inches	Elemental S[a] (ton/acre) 12 inches	Elemental S[a] (ton/acre) 6 inches
1	1.8	0.9	0.32	0.16
2	3.4	1.7	0.64	0.32
4	6.9	3.4	1.28	0.64
8	13.7	6.9	2.56	1.28

[a] Elemental sulfur does not supply calcium but will dissolve calcium-bearing minerals present in some alkaline soils.

From Horneck et al., 2007

Table 5. Reclamation failures: When only part of a reclamation problem is considered, amending soils or leaching can make a situation worse. Consider the whole system. Drainage, pH, salts, and sodium are the main concerns. Examples of situations to avoid include the following.

Goal	Action	Unrecognized problem	Unforeseen outcome
Solve problem of excess sodium in soil.	Add gypsum	Salts can’t be leached from the root zone.	Gypsum (a salt) accumulates. Soil becomes more saline.
Solve problem of excess sodium in a calcareous soil.	Add elemental sulfur	Salts can’t be leached from the root zone.	Gypsum (a salt) accumulates. Soil becomes more saline
Remove salts from a saline soil that contains a significant amount of sodium.	Irrigate with clean (low EC) irrigation water to remove salts.	Soil also contains high levels of sodium.	As salts are removed, the remaining sodium causes soil aggregates to disperse, sealing the soil surface, reducing infiltration and increasing runoff.

From Horneck et al., 2007.

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