Soil & Water MANAGEMENT MODULE 2

MONTANA STATE UNIVERSITY EXTENSION SERVICE

SALINITY & SODICITY MANAGEMENT

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Introduction

This is the second module within the Soil and Water (*SW*) Management series provided by the Montana State University Extension Service and Rocky Mountain Certified Crop Adviser (CCA) program. Used in conjunction with the Nutrient Management (*NM*) modules, this series is designed to provide useful, applicable information for Extension agents, CCAs, consultants and producers within Montana and Wyoming on practices used to effectively manage soil and water resources. To enhance the learning objective and provide CCAs with continuing education units (CEUs) in Soil and Water Management, a quiz accompanies this module. Also, realizing there are many other sources of information pertaining to salinity and sodicity management, we have included an appendix at the end of the module listing additional resources and contacts. This module includes concepts from the following Rocky Mountain CCA Soil and Water Management Competency Areas: water and solute movement in soils, plant/water relations, and water quality.

Objectives

After reading this module, the reader should be able to:

- Understand how salt-affected soils develop
- Recognize properties of saline, sodic and saline-sodic soils
- Determine the relative difference of plant tolerances to salts
- Describe appropriate management plans for prevention and reclamation of salt-affected soils
- Understand the impacts of methane gas production on soil and water quality in Montana and Wyoming

Background

The term, 'salt-affected' refers to soils with substantial enough salt concentrations to affect plant health, soil properties, water quality and other land and soil resource uses. Many soils in the northern Great Plains are affected by salts, both natural and human-induced. Since salt-affected soils can substantially reduce land value and productivity (Figure 1), learning how to identify and manage salt problems is important for many agricultural producers, consultants and land managers. A case study of the effects of methane gas production on soil and water quality is presented at the end of the module to shed light upon this current issue and its potential effects on agriculture in Montana and Wyoming.

SOIL & WATER MANAGEMENT

A self-study course from the MSU Extension Service Continuing Education Series

CCA 1.5 SW CEU

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Figure 1. Effect of salt-affected soils on a corn stand near Bridger, Montana.

Development of Salt-Affected Soils

What are salts and how do they accumulate in soil? A salt is a water-soluble compound that, in soil, may include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), bicarbonate (HCO_3^-), or sulfate (SO_4^{2-}). For example, Ca^{2+} and SO_4^{2-} form to make the salt gypsum ($CaSO_4 \cdot 2H_2O$). Salts in soil can develop from the weathering of primary minerals or be deposited by wind or water that carries salts from other locations. Salt-affected areas generally occur in semi-arid and arid climates where precipitation is not adequate to leach salts, causing them to remain in the soil profile. Salinization, the process of salt accumulation, most often occurs where surrounding soil or underlying parent material contains high levels of soluble minerals, where drainage through the soil is poor, where water ponds and evaporates, or where shallow water tables allow salty groundwater to move upward and deposit salts due to evaporation. Salinization can also occur when irrigation water containing high levels of soluble salts is applied to the land over a prolonged period. Additionally, certain fertilizers, amendments, and manure can contribute to salt accumulation in localized areas (covered in *Nutrient Management* (*NM*) *10* and *13*; see Appendix).

Saline Seeps

Many salt-affected soils in the northern Great Plains are the result of saline seeps. In general, saline seeps form when excess water, either from rainfall or irrigation, enters a recharge area (the area of the land that is the source of water for the seep), leaches salts downward, and meets an impermeable layer, such as bedrock. Since the salt-laden water isn't able to move downward any longer, it moves horizontally across the impermeable layer, and eventually resurfaces at a low-lying location (the discharge area) (Figure 2). Upon evaporation, salt is left behind to accumulate. Saline seeps are characterized by a build up of salt in localized places, poor plant growth, water ponding, and slow water infiltration. The formation and growth of saline seeps can be influenced by agricultural practices that alter water movement, specifically converting perennial grasslands to cultivated land and introducing crop-fallow systems. Fallow periods with little or no vegetation allow excess soil water carrying salts to either evaporate or move through the profile, causing a saline seep to form. Other factors such as heavy precipitation, poor surface drainage, snow accumulation, and gravelly or sandy soils that allow more free water drainage can heighten the formation of saline seeps (Troeh et al., 1999).

Table 1. Conversion factors used in measuring salinity and sodicity.

Multiply	by	To Get
µmhos/cm	0.001	mmhos/cm
mmbos/cm	1	dS/m
ppm	1	mg/L
EC (mmhos/cm) EC (µmhos/cm)	640 0.64	TDS (mg/L) (approximated value)
ppm	Element valence number/atomic weight	mg/L

Measuring Salinity and Sodicity

The presence of salts in soil and water can be assessed by measuring salinity, the concentration of soluble salts in a soil, and sodicity, the relative concentration of Na^+ compared to Ca^{2+} and Mg^{2+}. Salinity is most commonly measured with an electrical conductivity (EC) meter that estimates the concentration of soluble salts in a soil slurry or water solution by how well an electrical current passes through the medium. The ability of a solution to conduct electricity increases with increasing salt content; therefore, a high EC value corresponds with high amounts of soluble salts, and vice versa. EC values can be expressed in micromhos/cm (μmhos/cm), millimhos per centimeter (mmhos/cm), or deciSiemens per meter (dS/m) (Table 1). In seep discharge areas, soil samples should be taken from the 0-6 inch and 6-12 inch depths to determine at what EC vegetation might be planted (and what species). In the recharge areas, a 6-12" sample should be sufficient. Samples in non-seep areas should include the 0-6" depth, and possibly a 6-12" sample, which will provide additional information for conditions within the rooting zone. In addition to EC, water salinity can be quantified in terms of total dissolved solids (TDS). TDS can be determined in a laboratory or estimated from EC, as shown in Table 1.

Sodicity is measured by calculating the exchangeable sodium percentage (ESP) and/or the sodium adsorption ratio (SAR). ESP is the percentage of soil exchange sites occupied by Na^+, and is calculated by dividing the concentration of Na^+ cations by the total cation exchange capacity (CEC; *SW 1*). Units of concentration for ESP are milliequivalents per 100 g (meq/100g). SAR, on the other hand, expresses the proportion of Na^+ relative to the proportions of Ca^{2+} and Mg^{2+}, where cation concentrations are in milliequivalents per liter (meq/L) (Calculation Box #1). EC, ESP, and SAR are routine analyses for most soil or water testing laboratories, with the exception of ESP, which is not analyzed for water samples. Soil sampling depths for ESP and SAR are the same as for EC and should be taken from the 0-6 inch and/or 6-12 inch profile depths.

Properties of Salt-Affected Soils

Salt-affected soils can be broken into three classes based on general EC, SAR, ESP, and pH guidelines: saline, sodic and saline-sodic (Table 2). Properties of each of these soils are discussed below.

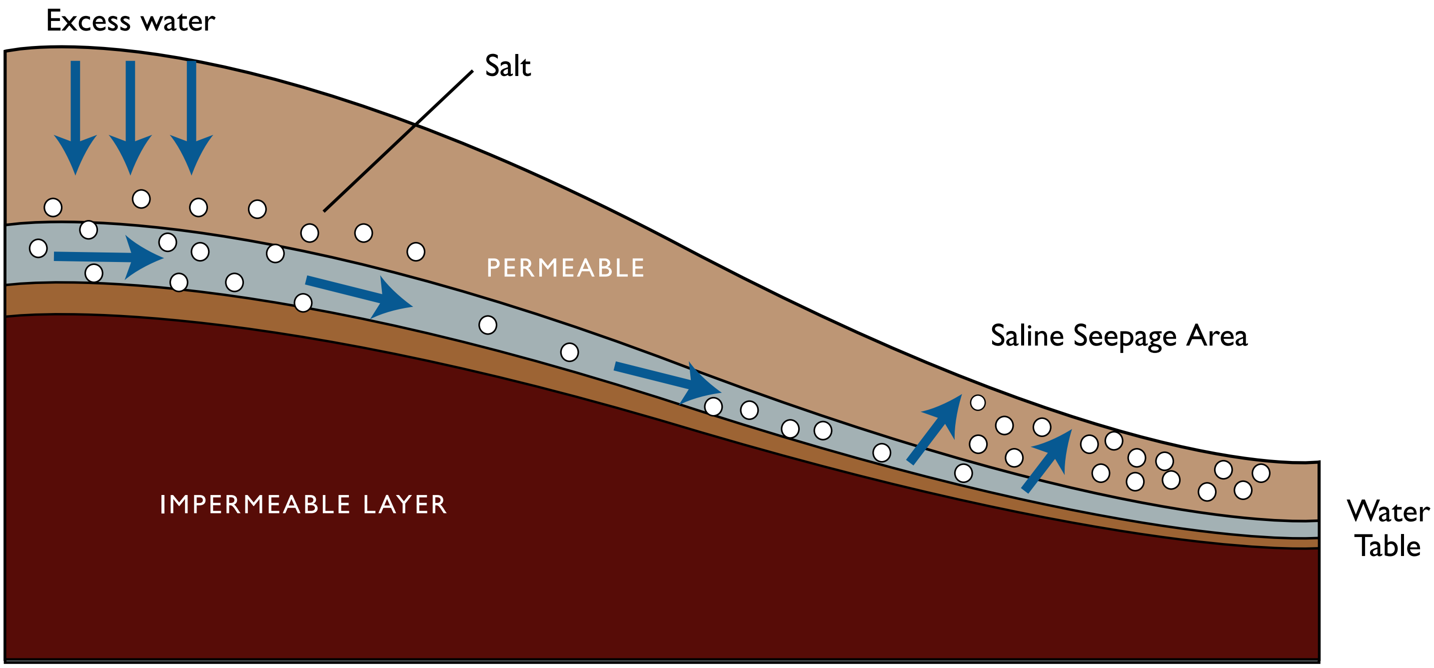


Figure 2. General diagram of saline seep formation.

Calculation Box #1

A soil sample contains 60 meq Na^+/L, 20 meq Ca^{2+}/L, and 12 meq Mg^{2+}/L.
What is the SAR of this soil?

Equation: $$SAR = \frac{[Na^+]}{\sqrt{([Ca^{2+}] + [Mg^{2+}]) \div 2}}$$, where units of concentration are meq/L.*

Calculation: $$SAR = \frac{60}{\sqrt{(20 + 12) \div 2}} = \frac{60}{\sqrt{16}} = \frac{60}{4}$$

$SAR = 15$ Since SAR is a ratio, it has no units.

*To convert ppm to meq/L, multiply ppm by the element's valence number, and then divide by the element's molecular (atomic) weight: meq/L = ppm x valence number ÷ molecular weight.

Table 2. Salt-affected soil classification. (from NRCS guidelines)

Soil Classification	EC (mmhos/cm)	SAR	ESP	pH
Saline	> 4.0	< 12	< 15	< 8.5
Sodic	< 4.0	> 12	> 15	> 8.5
Saline-sodic	> 4.0	> 12	> 15	< 8.5

Saline Soils

Saline soils contain excessive concentrations of soluble carbonate, chloride and sulfate salts that cause EC levels to exceed 4 mmhos/cm. Although relatively insoluble salts such as Ca and Mg carbonates do not cause high EC levels, they are often present in saline soils and may result in the formation of a white crust on the soil surface. The primary challenge of saline soils on agricultural land is their effect on plant/water relations. Excess salts in the root zone reduce the amount of water available to plants and cause the plant to expend more energy to exclude salts and take up pure water (Figure 3). Additionally, if salinity in the soil solution is great enough, water may be pulled out of the plant cell to the soil solution, causing root cells to shrink and collapse (Brady and Weil, 2002). The effect of these processes is 'osmotic' stress for the plant. Osmotic stress symptoms are very similar to those of drought stress, and include stunted growth, poor germination, leaf burn, wilting and possibly death. Salinity can also affect vegetation by causing specific ion effects (i.e., nutrient deficiencies or toxicities; *NM 9*), or salt itself can be toxic to plants at elevated concentrations (Balba, 1995). Thus, any increase in salinity can be at the expense of plant health, and decreases in crop productivity and yield are likely to occur with increasing salinity.

Although excessive salts can be hazardous to plant growth, low to moderate salinity may actually improve some soil physical conditions. Ca^{2+} and Mg^{2+} ions have a tendency

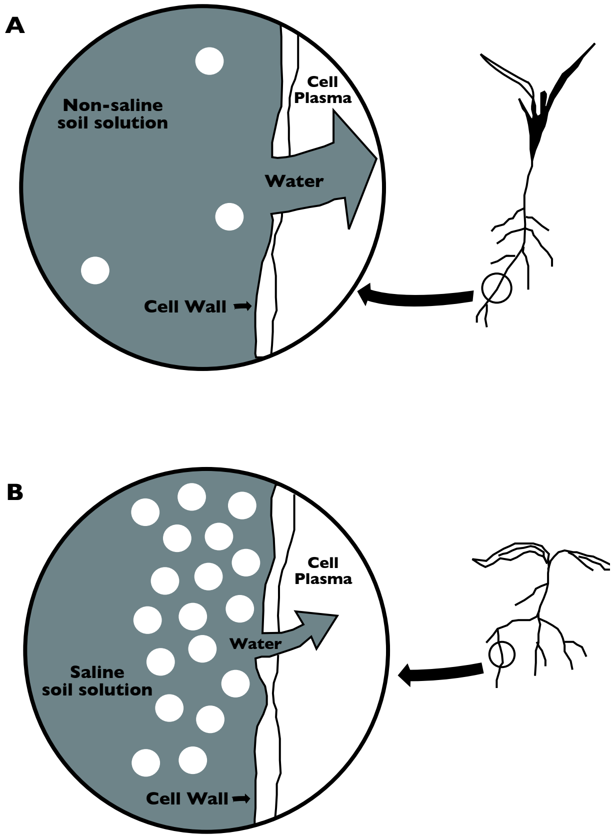


Figure 3. Effect of salts on water uptake by plants. Water uptake by a plant in a non-saline soil (A), and uptake in a saline soil (B). (Figure from Seelig, 2000)

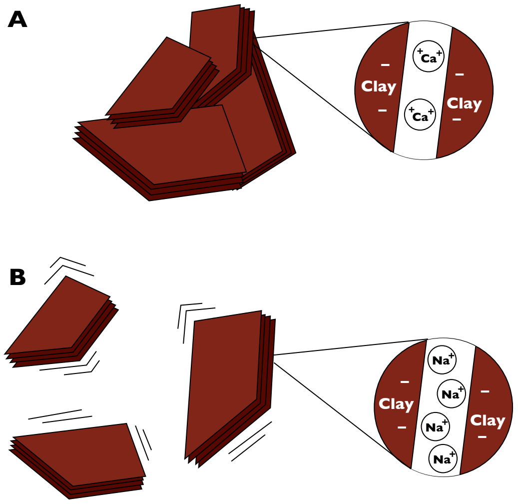


Figure 4. Role of Ca^{2+} and Na^{+} in flocculation and dispersion of clays, respectively. (Brady and Weil, 2002)

to 'flocculate' (clump together) soil colloids (fine clay and organic matter particles), thus, increasing aggregation and macroporosity (Figure 4A). In turn, soil porosity, structural stability and water movement may actually be improved in saline soils. However, benefits of structure improvement are likely to come at the cost of reduced plant health.

Sodic Soils

In contrast to saline soils, sodic soils have a relatively low EC, but a high amount of Na^{+} occupying exchange sites, often resulting in the soil having a pH at or above 8.5 (Q & A #1). Instead of flocculating, Na^{+} causes soil colloids to disperse, or spread out, if sufficient amounts of flocculating cations (i.e., Ca^{2+} and Mg^{2+}) are not present to counteract the Na^{+} (Figure 4B). Dispersed colloids clog soil pores, effectively reducing the soil's ability to transport water and air. The result is soil with low water permeability and slow infiltration that causes ponding and then crusting when dry. These conditions tend to inhibit seedling emergence and hinder plant growth. Sodic soils are also prone to extreme swelling and shrinking during periods of drying and wetting, further breaking down soil structure (Figure 9 in *NM 10*). The subsoil of a sodic soil is usually very compact, moist and sticky, and may be composed of soil columns with rounded caps (Figure 5). Fine-textured soils with high clay content are more prone to dispersion than coarser textured soils because of their low leaching potential, slow permeability and high exchange capacity. Other symptoms of sodic soils include less plant available water, poor tilth and sometimes a black crust on the surface formed from dispersed organic matter.

Q & A #1

Why do sodic soils generally have high pH values?

Sodium on clay (Na-clay) and carbonate (CO_3^{2-}) ions, which are elevated in sodic soils, react with water to produce hydroxide ions (OH^-) via the following reactions:

$$\text{Na-clay} + H_2O \rightarrow \text{H-clay} + Na^+ + OH^-$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$$

The resulting increase in OH^- ions causes pH to increase. As a result of a higher pH, nutrient availability and microorganism activity may be hindered in sodic soils (*NM 8, SW 1*).

Figure 5. White, rounded caps observed in the B horizon of a sodic soil. (Photo from Brady and Weil, 2002)

Saline-Sodic Soils

Saline-sodic soils are soils that have chemical characteristics of both saline soils (EC greater than 4 mmhos/cm and pH less than 8.5) and sodic soils (ESP greater than 15). Therefore, plant growth in saline-sodic soils is affected by both excess salts and excess Na^{+}. Physical characteristics of saline-sodic soils are intermediate between saline and sodic soils; flocculating salts help moderate the dispersing action of Na^{+} and structure is not as poor as in sodic soils. The pH of saline-sodic soils is generally less than 8.5; however, this can increase with the leaching of soluble salts unless concentrations of Ca^{2+} and Mg^{2+} are high in the soil or irrigation water (Brady and Weil, 2002).

Managing Salt-Affected Soils

The first step in managing salt-affected soils is to determine the problem and identify its cause or source. If salt problems are suspected or likely, soil and water samples should be collected on an annual basis and analyzed for EC, ESP and/or SAR, and pH. Other parameters, such as percent organic matter, clay content, CEC, and presence of lime, may also be useful (Schafer, 1982). Identifying the cause or source of the salt problem can be somewhat difficult, especially if multiple factors are involved. Therefore, it's useful to gather and observe as much information about the affected area as possible. Information should include historical and recent land use, local geology, location of the problem with respect to the surrounding landscape (i.e., at the top of a hill or in a low-lying area), and the origin of any applied water.

After determining the problem and its cause, the second step is to determine a management plan. Choosing how to manage a salt problem and which techniques to employ will depend on a number of factors, including cropping systems, availability of water, and cost. If salinity/sodicity is not severe enough to significantly reduce yields, reclamation efforts are not likely to be economical. Thus, learning ways to prevent further salinization and managing soils "as is" with salt-tolerant crops or different land uses may be the best choice. The following provides methods to aid in managing and reclaiming of salt-affected soils.

Managing Saline Soils

Reclaiming Saline Soils

For saline soils with high enough salt levels to significantly damage plants and reduce growth, reclamation with excess water is recommended, provided there is enough good quality water available and adequate drainage. Reclamation should be done in the fall or spring, prior to planting. Water can be applied via sprinkling or flooding, and is more effective when the soil moisture content is unsaturated than saturated, to allow drainage rather than potential runoff (Balba, 1995). To maintain unsaturated conditions and ensure salts are being leached through the profile, water should be applied in a series of applications and allowed to drain after each application. Thus, sprinkling or intermittent ponding is usually more effective than continuous ponding. The quantity of water needed will depend upon initial and desired salt levels, water quality, application methods and soil texture (Lamond and Whitney, 1992). Figure 6 shows the depth of leaching water per unit depth of soil required to remove a certain percentage of 'initial salts' (salts in solution). In general, it requires about 1 foot of flood irrigation to remove 75% of the solution salts in 1 foot of soil (Chhabra, 1996). Sprinkling may reduce the amount of water needed to 8 to 10 inches for 1 foot depth. Finer soils will likely require more leaching water than coarser soils because of their increased ability to retain water. To be certain adequate leaching of salts is occurring, periodic soil testing should be done. Saline soils cannot be reclaimed with amendments, conditioners, fertilizers or manure.

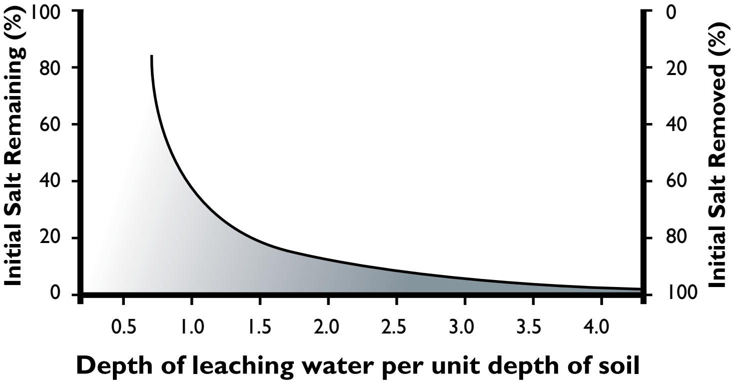


Figure 6. **Percentage of salt remaining/removed from a soil with different amounts of leaching water applied per unit depth of soil.** For example, a half foot depth of leaching water per 1 foot depth of soil would equal 0.5. (From Chhabra, 1996).

Controlling Salinity with Irrigation Water

Where applicable, irrigation water can be used to maintain soil salinity at levels where maximum crop yields can be obtained by applying excess water to drain through the root zone and leach salts. For any given water, the lower the fraction of applied water that becomes drainage water, the higher the average root zone salinity. The amount of excess drainage water required to maintain salinity at sustainable levels is the leaching requirement (LR). LR can be estimated by the following equation:

$$LR = \frac{EC_{iw}}{(5 \times EC_{t} - EC_{iw})}$$

Table 3. General ECt values for common crops and forages in Montana and Wyoming.[1] (Ayers, 1977)

Crop	ECt (mmhos/cm)
Alfalfa	2.0
Barley[2]	8.0
Beans	1.0
Corn	1.7
Flax	1.7
Potatoes	1.7
Safflower	5.3
Soybeans	5.0
Sugar beets[2]	7.0
Wheat[2]	6.0

[1] *These values should only be used as guidelines for use in the LR equation. Yields may be reduced at or below the ECt level stated, which is dependent upon soil, plant and water conditions.*

[2] *These species are less tolerant to salt at germination and seedling stage and ECt values should be lowered to 4-5 mmhos/cm for wheat and barley, and near 3 mmhos/cm for sugar beets.*

where EC_{iw} is the EC of the irrigation water and EC_t is the soil EC that should not be exceeded in order to minimize yield loss (Table 3). After determining LR, the total amount of water required (WR) by the crop can be estimated by knowing the crop's evapotranspiration (ET) rate: WR= ET/ (1-LR). ET rates for common Montana and Wyoming crops can be found at www.usbr.gov/gp/agrimet/ or by contacting a local county Extension office. Calculation Box #2 shows an example for determining LR and WR. The previous equations do not take into account rainfall that contributes to some of the water used by the crop. Therefore, if rainfall is a contributing factor in crop water usage, one should use a weighted average salinity of the irrigation water and rain water (EC = 0) for EC_{iw}. Additionally, EC_{iw} will likely change throughout the irrigation season, and the leaching requirement may need to be adjusted accordingly. Because EC_t levels are only a guideline value, more water than calculated can be applied to ensure the desirable quantity of salts is leached.

Salt-Tolerant Plants

In areas in which leaching salts with water is not feasible or economical, planting crops or forages that are able to grow under low to moderate saline conditions may be an economically viable option. As previously discussed, any increase in soil salinity is at the expense of plant health; however, some plants are better able to tolerate salinity than others. Salt tolerance is not an exact value, but rather depends upon many factors, such as salt type, climate, soil conditions, and plant age. Table 4 shows a qualitative value of salt tolerance for common crops and forages grown in Montana. In general, perennial plants, especially some grass forages, possess the highest tolerance to salts, while legumes are typically the most sensitive to salts. In using Table 4, it is important to note that although plants listed as tolerant can tolerate a higher EC than those listed as sensitive, plant health and yields, regardless of tolerance, will likely be reduced with increased salinity. For example, a study by the Bridger Plant Materials Center (2001)

Calculation Box #2

The EC_{iw} of a farmer's irrigation water is 3 mmhos/cm and it is being used to grow sugar beets which have a EC_t of 7 mmhos/cm. How much total water is required in order to maintain productivity? Assume sugar beets have a seasonal water requirement of 30 inches for ET and rainfall does not contribute to crop water use.

Calculations: $LR = \frac{EC_{iw}}{(5xEC_t - EC_{iw})}$ and $WR = \frac{ET}{(1 - LR)}$

$$LR = \frac{30}{(5x7 - 3)} = 0.09$$

$$WR = \frac{30}{(1 - 0.09)} = 33$$

The total water required throughout the season is 33 inches. Three inches of excess water becomes drainage, and the ratio of drainage water to the total applied water is 3/33 or 0.1.

Table 4. General tolerance of various crops and forages to saline conditions. (Hansen et al., 1999)

	Tolerant	Moderately Tolerant	Moderately Sensitive	Sensitive
Crops	Barley Sugar beet Triticale	Oats Safflower Sorghum Soybean Wheat	Corn Potato Flax	Field Bean Lentil Pea
Forages	NewHy wheat grass Tall wheat grass Altai wild rye Slender wheat grass Western wheat grass Russian wild rye	Barley (forage) Beardless wild rye Bird's foot trefoil Crested wheat grass Tall fescue Yellow sweetclover	Alfalfa Cicer milkvetch Meadow Foxtail Orchardgrass	Alsike clover Ladino clover Red clover White clover

found five salt-tolerant forages to establish and survive in soils with EC levels greater than 20 mmhos/cm, yet yield decreased steadily with increasing salinity for all species and establishment was significantly hindered as EC neared 30 mmhos/cm (Figure 7). Thus, despite a plant being able to tolerate high salinity levels, its health and yield will likely be influenced by salts at even very low EC values. For highly saline soils, some degree of reclamation is needed prior to the planting of salt-tolerant plants to ensure successful establishment and productivity.

Another important factor to note in selecting salt tolerant plants is that a plant's tolerance to salts is not constant and can differ throughout the growing season or under periods of stress. For example, sugar beets, alfalfa and barley are all sensitive to salt during emergence, yet become more tolerant by maturity. In general, germination rates are poorer in salt-affected soils than non-affected soils and seeding rates in saline soils should be increased accordingly (USDA-SCS, 1983). Light irrigation in early spring may also improve germination and emergence rates. The optimum time to seed a forage or cover crop in saline soils is late fall or during a snow-free period in the winter so that the seed can take advantage of lower salt concentrations during germination due to the diluting effect of early spring moisture (Plant Materials Center, 1996). Salinity effects on nodulation of legumes by N-fixing bacteria will likely depend on the plant's tolerance to salt rather than the bacteria's tolerance (Rao et al., 2002).

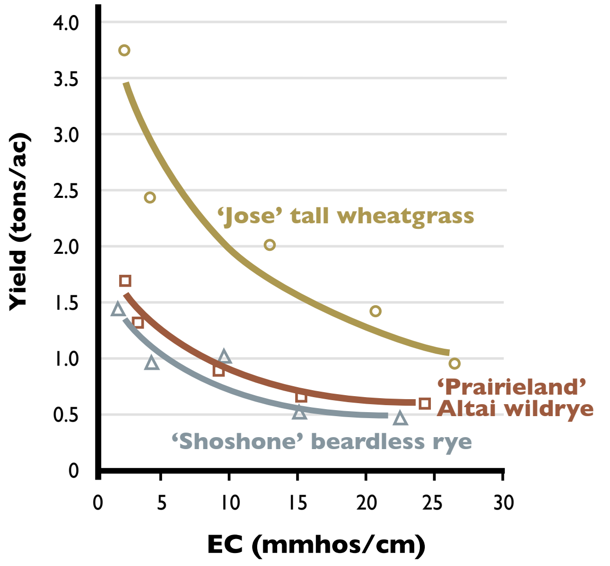


Figure 7. Average annual effect of increasing salt gradient on yield of three salt-tolerant forages over a four year period. Forage yields for 'NewHy' hybrid wheatgrass and 'Pryor' slender wheatgrass (data not shown) had yield curves similar to 'Prairieland' and 'Shoshone', respectively. (Adapted from Bridger Plant Materials Center, 2001).

Managing Saline Seeps

Since saline seeps are underlain by a relatively impermeable layer, leaching salts with excessive water may only make the salinity problem worse. Thus, rather than adding water, the first step in reclaiming saline seeps is to decrease the amount of water going into the recharge area. This can be done by adjusting irrigation rates, choosing crops that will take up more water, converting crop-fallow systems to annual cropping systems, or possibly returning cropland to perennial vegetation under the Conservation Reserve Program (CRP) (*SW 3*). Deep rooted plants in the recharge area can help take up excess water in the soil, allowing little water to drain through and reversing the water flow. For recharge areas with deep soil, alfalfa has been shown to be the most efficient at lowering the ground water levels (Dodge et al., 1983), although other deep rooted grasses and legumes may also work well. The implementation of an annual, flexible cropping system helps control saline seeps by eliminating the fallow period, the period in which the majority of water leaching in a crop-fallow system occurs (*NM 15*). In the discharge area, the establishment of salt tolerant plants may help improve infiltration and soil structure in these salt-affected soils.

The management of saline seeps will depend on the size of the recharge/discharge areas (e.g., large watershed or localized seep) and land ownership. If both the recharge and discharge area are owned by the same person, individual methods, such as planting alfalfa in the recharge area, can be used. However, if the recharge area is owned by one or more land owners, it may be necessary to implement a large-scale watershed approach in which a number of land owners and organizations are involved. Please see Appendix for a listing of organizations that work on salinity issues and options for managing saline seeps.

Managing Sodic and Saline-Sodic Soils

Reclamation

Reclaiming sodic and saline-sodic soils requires a different approach than saline soils and can be considerably more costly. Prior to leaching, excess Na^+ needs to be replaced from the exchange site by another cation, namely Ca^{2+} or Mg^{2+}. This is done by adding an amendment that either directly or indirectly releases exchangeable Ca^{2+} or Mg^{2+}. Because Ca^{2+} and Mg^{2+} have a stronger charge than Na^+, they will replace Na^+ on exchange sites, causing Na^+ to be released to the soil solution and be susceptible to removal by leaching. Amendments used to correct sodicity include gypsum ($CaSO_4 \cdot 2H_2O$), lime ($CaCO_3$), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), sulfur and sulfuric acid materials (Q & A #2), and organic amendments. The most common and economical amendment used on sodic soils is gypsum, which can be applied dry or with irrigation water. Gypsum is slow reacting, but will react in the soil for a long period of time. Fine gypsum (passing through a 60 mesh) should be used to maximize reactivity and effectiveness. Adding gypsum or lime to a soil that already has gypsum and/or lime present will not increase Ca^{2+} solubility, an outcome that could potentially limit their effectiveness as amendments (Wienhold and Trooien, 1995). Please see *NM 10* for more information on sodic soil amendments and their use.

For amendments to be effective, water needs to be applied to leach the Na^+ that is pushed off exchange sites by Ca^{2+}. Leaching and drainage in sodic soils can be slow due to poor structure and limited water movement associated with sodic soils. For sodic soils with low EC, saline water may be appropriate for the initial stages of reclamation to provide additional Ca^{2+} to promote flocculation, and thus increase permeability (Troeh et al., 1999). Tillage may help break up surface crusts and increase water infiltration into the soil (*SW 4*). Establishing a salt-tolerant crop or forage shortly after reclamation has begun will also increase the effectiveness of reclamation efforts.

Saline-sodic soils should be amended by first addressing the excess Na^+ problem and then the excessive salt problem. If soluble salts are leached prior to the removal of Na^+ from exchange sites, sodic soil properties, such as dispersion, can result. Therefore, a Ca^{2+} amendment should be applied to replace Na^+, and then excessive water applied to leach the Na^+ and other salts.

Q & A #2

Elemental sulfur and sulfuric acid don't contain Ca^{2+} or Mg^{2+}. How can they reduce sodicity?

Elemental sulfur (S^0) and sulfuric acid (H_2SO_4) reduce sodicity by indirectly supplying Ca^{2+} to the soil solution. Through bacterial action, S^0 can be oxidized to sulfuric acid (H_2SO_4), which, in soils already containing Ca^{2+}, can release tied up Ca^{2+} and increase its solubility. However, because these amendments are more costly and may require special handling, they may have limited value in the management of sodic soils.

Salinity and Sodicity in Irrigation Water

Irrigating with saline or sodic water on soils with inadequate drainage will ultimately cause soil salinization to occur, although salt effects may not be readily apparent. How rapidly salinization from irrigation water occurs, and its subsequent effect on plant growth and soil properties, depends on the quantity and quality of the water, how the water is applied and soil properties, such as texture. Table 5 gives general guidelines for irrigation water quality for different soil textures. As previously discussed, EC and SAR values can be higher for water applied via sprinklers rather than flooding because sprinklers allow the soil to remain unsaturated, which results in a more complete removal of salts than flooding, which saturates the soil (Schafer, 1982).

Similar to soil, irrigation water should be analyzed for salinity and sodicity on an annual basis to determine proper application and management. In general, water quality in Montana and Wyoming streams and rivers deteriorates as the irrigation season progresses (i.e., as stream flow decreases), so time of testing should be considered. Recycled irrigation water will also be higher in salts as the season progresses.

Table 5. Suggested guidelines of EC and SAR for irrigation water for a variety of soil textures. (Schafer, 1982)

Soil Texture	EC Range (mmhos/cm)		SAR	
	Flood	Sprinkle	Flood	Sprinkle
Very Coarse (sands, loamy sands)	0-4	0-5	<18	<24
Coarse (sandy loam)	0-3	0-4.5	<12	<15
Medium (loams, silt loams)	0.2-2.5	0-3	<12	<15
Medium Fine (clay loam, sandy clay loam)	0.3-2.5	0.2-3	<8	<12
Fine (silty clay loam, clay, sandy clay, silty clay)	0.5-2	0.3-2.5	<6	<9

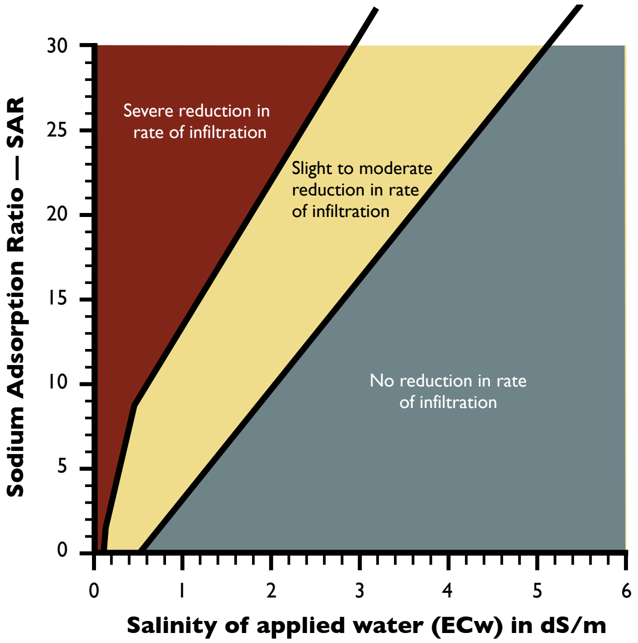


Figure 8. Interaction between EC and SAR on infiltration rates of irrigation water. Relationship independent of soil texture. (Ayers and Westcot, 1985)

EC-SAR Interaction

The effect of Na$^+$-induced dispersion on soil properties and water transport largely depends on the relationship between EC and SAR. The EC-SAR interaction is based on a higher concentration of Ca^{2+} and Mg^{2+} being able to counteract the dispersive nature of Na$^+$, thereby reducing dispersion effects on soil structure (Figure 8). Infiltration rates are severely reduced when EC is very low (less than 1 dS/m), even though SAR may not be excessively high. On the other hand, there may be less of a reduction in infiltration rates when sodicity is coupled with high salinity. This interaction between EC and SAR is important in determining management techniques. For instance, if rain or diluted/non-saline irrigation water is applied to a soil previously irrigated with saline-sodic water, soil EC could drop more quickly than the SAR, and infiltration and structure could be worsened (Mace and Amrhein, 2001). One note of caution in utilizing the EC-SAR interaction is the negative impact of high EC on plant health. Regardless of improved infiltration, plant establishment and growth will be poor if EC levels are too high. Thus, when determining the effect that Na$^+$ will have on infiltration and other soil properties, EC and all of its associated effects should be taken into consideration.

A Case Study: Effects of Methane Production on Soil and Water Quality

A regional issue that has received attention in recent years due to its potential influence on water and soil quality, particularly with regard to salts, is the extraction of methane gas. Methane can exist in the seams of coal beds or be held in porous (non-coal) formations. Within the northern Great Plains region, the extraction of methane from coal beds, referred to as coal bed methane (CBM), is primarily occurring in the Powder River Basin (PRB) of northern Wyoming and southeastern Montana, whereas extraction of methane from non-coal formations is mainly happening in western Wyoming. Extraction of CBM (Figure 9) and non-coal methane has increased substantially in recent years, triggering many agencies, organizations and consultants to become involved in its development and regulation. The following case study looks at the effects of methane production on soil and water quality and some of the techniques currently being used in its management.

The Problem

Coal Bed Methane

Although drill pads, extraction wells, pipelines and roads do cause some land degradation, the majority of controversy surrounding CBM production is its product water. CBM extraction results in large quantities of groundwater being removed and brought to the surface (Q & A #3). For example, in September 2004, each CBM well in the PRB removed an average of 4,800 gallons of water per day (WOGCC, 2004), equating to about 60 million gallons of water per day being extracted from the basin. Primary concerns regarding this large amount of water are its quality and subsequent disposal. Water produced with CBM is dominated by Na^+ and bicarbonate (HCO_3^-) ions, and typically has high sodicity and varying levels of salinity (Van Voast, 2003; Q &A #4). These characteristics can limit its beneficial use in some areas and, depending on the method of disposal, possibly degrade water and land quality. A decrease in water quality can adversely affect crop and forage productivity downstream, especially for land under irrigation, as well as alter habitat for aquatic species, vegetation and wildlife.

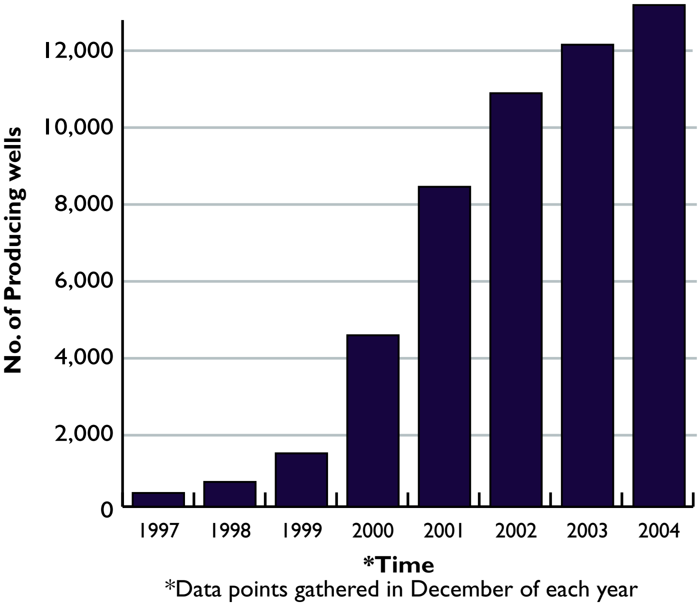


Figure 9. **Number of CBM producing wells in the Wyoming portion of the Powder River Basin from December 1997 to March 2004.** (Wyoming Oil and Gas Conservation Commission (WOGCC), 2004)

Current disposal methods of CBM water in the PRB include discharge into surface waters (rivers and streams), containment in impoundment ponds, application to land via irrigation, and formation of supplemental water sources for livestock and wildlife. Re-injection of removed water back into the original aquifer is a possibility and is currently being used in the PRB on a limited basis. Advanced technologies may increase the amount of water re-injected to aquifers in the future.

Non-coal Methane

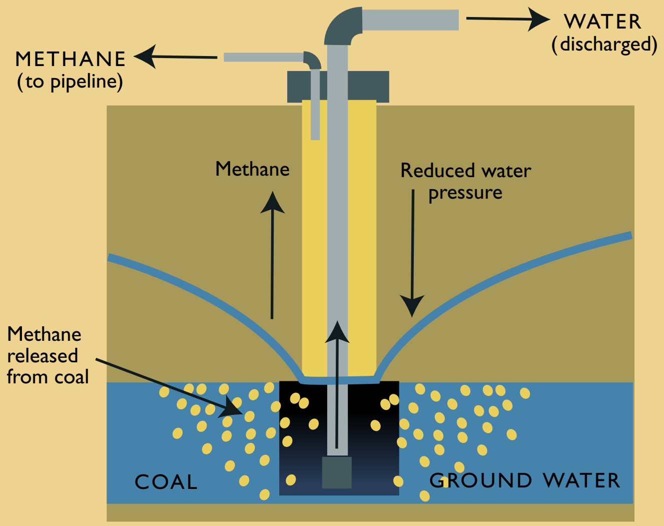
Unlike CBM, the main problem associated with the extraction of non-coal methane is not product water (water is produced, but not nearly on the scale it is from CBM extraction), but rather the effects of drill pads and extraction wells on soil quality after the well is discontinued and the land is put back into production. Non-coal methane wells are very deep and require the construction of large drill pads to support them. Due to the size of these pads, outside soil material is often brought in to construct them. Depending on the source, this soil can be high in salts and other constituents that may be unsuitable for proper plant growth, resulting in potential yield reductions and land degradation for agricultural producers (Dollhopf, pers. comm.).

Q & A #3

How is coal bed methane (CBM) extracted?

CBM is held in coal seams under the pressure of water. To extract CBM, a well is drilled into the seam aquifer and groundwater is removed, allowing methane to flow with the decrease in pressure. Since methane has very low solubility in water, it will separate from the water and rise. As the coal seam is dewatered, both methane and water are brought to the surface. In the early stages of production, large volumes of water are brought to the surface with relatively less methane. However as the seam is further dewatered, less water and more methane is produced. (Figure from Montana Bureau of Mines and Geology)

CBM Well Construction



Use of CBM Water in Agriculture

The use of CBM water for either irrigation or livestock water is dependent upon the quality of water, conditions of the receiving area, soil mineralogy and texture, and plant/animal tolerance to salts (U.S. DOE, 2004). The quality of CBM discharge water varies substantially throughout the PRB. For example, a USGS study found sodicity and salinity levels of water co-produced with CBM to range from 6-32 for SAR and 270-2010 mg/L for TDS (approximate EC of 0.5-3.1 dS/m), respectively (Rice et al., 2000). And, in general, SAR and TDS values increase from south to north and east to west within the region (Regele and Stark, 2000). Water with SAR and TDS levels in excess of acceptable values (actual values dependent on soil, water and plant conditions) should not be used for irrigation. Considering that many soils within the PRB have high amounts of clay and silt, applying irrigation water with even low to moderate sodicity/salinity could cause plant damage and changes in soil structure to occur. Water quality parameters for livestock are not well researched and depend on numerous factors such as type of animal, age and diet. General guidelines discourage using water for livestock when EC values exceed 11-16 mmhos/cm and Na^+ levels are in excess of 600-800 mg/L (Puls, R., 1994). Well water that could potentially be contaminated by CBM water should be monitored carefully to avoid toxicity to humans and domestic animals.

Management Techniques and Potential Solutions

At this time, there is no widely used solution or technique used to manage the effects of methane gas production on water and soil quality, yet research is underway to find ways to minimize its effects. One technique being used in the PRB is to treat CBM discharge water prior to disposal. Possible methods for this include salt precipitation, reverse osmosis, and a water treatment system. Another method being researched and applied in some PRB locations is the addition of gypsum to soils irrigated with sodic water. The amount of gypsum added is dependent upon the SAR and EC of both the soil and irrigation water. A potential problem that can arise with gypsum application is that Ca^{2+} can quickly combine with excess CO_3^{2-} in the water, causing $CaCO_3$ to precipitate and effectively reducing Ca^{2+} in solution and on exchange sites. This problem may be remedied by coupling the addition of gypsum with direct acidification, which will lower CO_3^{2-} levels and increase Ca^{2+} in solution, thus lowering the SAR. Gypsum solubility can limit this process, though, and it is not likely to be effective when SAR exceeds 15. Previously discussed methods, such as leaching salts with excess water or growing salt-tolerant plants, may also be successful in some areas.

In western Wyoming, one of the best options for reclaiming land affected by methane production is to remove the drill pad soil and replace it with better quality soil; however, this process can be quite expensive and labor intensive. Producers, gas companies and law makers are currently discussing ways to improve extraction methods and reduce its impact on the soil and land.

Q & A #4

Why is CBM water high in Na^+ and HCO_3^-?

The occurrence and production of methane in coal seam aquifers is very specific to areas where Na and HCO_3^- dominate the water chemistry. The source of the HCO_3^- is from the coal itself and certain biological processes associated with the production of methane, specifically the reduction of sulfate (SO_4^{2-}) by microorganisms. Cations, such as Ca^{2+} and Na^+, are present in the underlying, depositional material. As HCO_3^- levels increase, Ca^{2+} and Mg^{2+} levels are depleted due to less solubility in HCO_3^- enriched environments and Na+ becomes the predominant cation in solution. Exchange of Na^+ by Ca^{2+} or Mg^{2+} on clay surfaces may also contribute to more Na^+ in solution. (From Van Voast, 2003).

Conclusion

Soil and plant health can be adversely affected by the presence of excessive salts in soil. Understanding how salt-affected soils develop and identifying their characteristics is crucial to managing areas with salt problems. Choosing which management techniques to employ to salt-affected soils will depend on the nature and extent of the problem, cost and available resources. If productivity is severely restricted, reclamation methods should be considered, however problems are likely to reappear if changes in cropping systems or water usage do not occur. Other techniques, such as growing salt tolerant crops and forages or by controlling salinity levels with excess irrigation water, can be very useful for systems that are marginally to moderately affected by salts to maintain or improve plant growing conditions. Ultimately, however, salinity and sodicity are best managed prior to declines in productivity. Recognizing early symptoms of salt-affected soils and where potential problems could occur and making appropriate adjustments in land and water usage can prevent severe salt problems from occurring.

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Appendix

Books

Management of Problem Soils in Arid Ecosystems. A.M. Balba. 1995. CRC Press. 250 p. Approximately $110.

Soils in Our Environment, 10th Edition. D. Gardiner and R. Miller. 2004. Prentice Hall. Upper Saddle River, New Jersey. 656 p. Approximately $110.

Extension Materials

The following Extension materials are available and can be obtained at the address below. (Shipping rate varies depending on quantity, see http://www.montana.edu/publications/)

MSU Extension Publications
P.O. Box 172040
Bozeman, MT 59717-2040

Managing Dryland Sodic Soils. 1983. MT198381AG. Free

Saline and Sodic Soils in Montana. 1982. 2B1272. Free

Saline Seep Control With Alfalfa. 1984. MT198323AG. Free

Salinity Control Under Irrigation. 1983. MT198382AG. Free

Salt Tolerant Forages for Saline Seep Areas. 1983. MT198321AG. Free

Salty Soils and Saline Seep—Definitions Identification. 1978. 2C1166. Free

Nutrient Management Modules (1-15). 4449-(1 to 15). Can be obtained from Extension Publications or on-line in PDF format at www.montana.edu/wwwpb/pubs/mt4449.html. Free

Soil and Water Management Modules (1-3). 4481-1, 4481-2 and 4481-3 can be obtained from Extension Publications or on-line in PDF format at www.montana.edu/wwwpb/pubs/4481.html/. Free

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Web Resources

Montana Salinity Control Association, a satellite organization of Montana's conservation districts that helps producers manage saline seeps and other salinity problems. http://www.dnrc.state.mt.us/cardd/consdist/salinity.htm

Water Quality and Irrigation Management site (Montana State University) site with information, resources, and research on salinity, sodicity, and CBM. http://waterquality.montana.edu/

NRCS Salinity Management homepage. http://www.wcc.nrcs.usda.gov/salinity/

USDA "Salinity Laboratory" homepage. http://www.ussl.ars.usda.gov/

Wyoming CBM Clearinghouse page. Includes information on product history, development, recent news, events, and contacts. http://www.cbmclearinghouse.info/

Montana DEQ website listing laws, regulations, and permits regarding CBM development and discharge. http://www.deq.state.mt.us/coalbedmethane/Laws_regulations_permits.asp

Wyoming DEQ's Water Quality website with information on CBM permitting, applications, water quality standards, and contact information. Provides links to NPDES program for CBM water. http://deq.state.wy.us/wqd/index.asp

Alberta, Canada Agriculture, Food, and Rural Development website with detailed information on types and causes of dryland saline seeps. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex167?opendocument

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