TREATING THE CAUSE, NOT THE SYMPTOMS

Irrigation water treatment for better infiltration.

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Editor's Note: This article is the first in a three-part series on water quality issues.

SOME CONSTITUENTS found in irrigation water can influence water infiltration into the soil. Whether chemical treatment of the irrigation water is required depends on the specific problem. There are conditions where soil-applied treatments can be equally or more effective. The type of chemical treatment also is dependent on the nature of the problem. Four situations can occur that limit water infiltration into soils:

• **High Na, Low HCO$_3$/CO$_3$:** Irrigation water treatment is not necessary, but amendments to alleviate sodic conditions can be delivered through an irrigation system or they can also be directly applied to the turfgrass. Possible amendments for water treatment include gypsum, soluble Ca materials, or a S-based acid to combine with soil-applied lime to form gypsum.

• **High to Moderate Na, High HCO$_3$/CO$_3$:** Acidification of the irrigation water to remove excess HCO$_3$ is strongly preferred.

• **Ultra-Pure Water:** Gypsum injection is an option, and other soluble salts could be added to the irrigation water to raise EC$_w$. Or, salts can be directly applied to the soil. If soil application is the chosen method of treatment, a light and frequent approach is suggested to avoid leaching all the amendment beyond the surface and into the soil a few centimeters. This could result in the infiltration problem recurring at the surface.

• **High Ca/Mg, High HCO$_3$/CO$_3$:** If sufficient calcite forms at the surface to decrease infiltration rates, acidification of the irrigation water is an option. Cultivation, use of acid fertilizers, and direct S application to the turf can produce similar results.

These four situations are discussed in greater detail in the following sections:

Situation 1:
High Sodium, Low HCO$_3$/CO$_3$

Irrigation water high in sodium (Na) but low in HCO$_3$/CO$_3$ (bicarbonate/carbonate) content will create a sodic soil. In a sodic soil, Na causes the soil structure to deteriorate, resulting in poor water infiltration and percolation. To assess the potential for Na to cause soil structure deterioration and, therefore, low water infiltration, the sodium adsorption ratio is used (see glossary). The unadjusted SAR$_w$ (sodium adsorption ratio) will be high (>18) and adjusted SAR$_w$ (adj. SAR$_w$) would be similar to the unadjusted SAR$_w$ since few HCO$_3$/CO$_3$ ions are present in the water.

Sodium hazard (permeability) guidelines of irrigation water based on SAR$_w$ and adj. SAR$_w$ criteria. SAR$_w$ is preferred when HCO$_3^-$ (<2.0 meq L^{-1}, 120 mg L^{-1}) and CO$_3^{-2}$ (<0.5 meq L^{-1}, 15 mg L^{-1}) are low, but adj. SAR$_w$ should be used at higher HCO$_3^-$ and CO$_3^{-2}$ concentrations. Guideline ranges are the same for both SAR$_w$ and adj. SAR$_w$.

Na Hazard Classification	SAR$_w$ or adj. SAR$_w$ (meq L^{-1}) of water		Comments on Na Hazard
USSL Classification			
Low	<10		Can be used to irrigate almost all soils without structure deterioration. Salt-sensitive plants may be affected.
Medium	10-18		Appreciable Na permeability hazard on fine-textured soils with high CEC. Best used on coarse-textured soils with good drainage.
High	18-26		Harmful levels of Na accumulation on most soils. Will require intensive management-amendments, drainage, leaching.
Very High	>26		Generally not suitable for irrigation except at low to medium soil salinity levels. Requires intensive management.
Based on Clay-Type Classification (Ayers and Westcot)			
None	<6	Montmorillonite	Generally no Na hazard unless EC$_w$ is very low
	<8	Illite	
	<16	Kaolinite*	
Possible	6-9	Montmorillonite	Possible problem unless a Ca source and some leaching are used
	8-16	Illite	
	16-24	Kaolinite	
Probable	>9	Montmorillonite	Requires intensive corrective measures to use
	>16	Illite	
	>24	Kaolinite*	

*Also, kaolinite-like clays that are non-swelling such as Fe/Al oxides

Sodium hazard (permeability) of irrigation water based on RSC (residual sodium carbonate) guidelines (Eaton).

RSC Value (meq L^{-1})	Na Hazard
<0 (i.e., negative)	None. Ca and Mg will not be precipitated as carbonates from irrigation water; they remain active to prevent Na accumulation on CEC sites.
0-1.25	Low. Some removal of Ca and Mg from irrigation water.
1.25-2.50	Medium. Appreciable removal of Ca and Mg from irrigation water.
>2.50	High. All or most of Ca and Mg removed as carbonate precipitates leaving Na to accumulate. How rapidly Na buildup occurs depends on Na content of the water.

The RSC does not contain Na in its formula but is widely used as a measure of sodium hazard for irrigation water. If not reported on a water analysis report, it is easily calculated from Ca, Mg, CO_3, and HCO_3 content in meq L^{-1} units. For example:

Ca = 2.63 meq L^{-1} CO_3 = 0.25 meq L^{-1}

Mg = 1.72 meq L^{-1} HCO_3 = 9.83 meq L^{-1}

Na = 8.53 meq L^{-1}

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$
$$= (0.25 + 9.83) - (2.63 + 1.72)$$
$$= 5.73 \text{ meq } L^{-1}$$

In this situation, irrigation water treatment is an option, but not necessarily required since soil-applied amendments also can be an effective management program. Many turfgrass managers use the irrigation system as a means of adding amendments. Calcium (Ca) amendments applied into the irrigation water are most effective where the irrigation water SAR is high and/or the salinity is low to moderate (EC_w<1.0 dSm^{-1} — Electrical Conductivity of the irrigation water, a measure of total dissolved salts; see glossary). The Ca amendments in the irrigation water would increase EC_w while reducing SAR_w, which can favor better water infiltration. If water salinity is moderate to high (EC_w>1.0 dSm^{-1}) in addition to a high SAR, soil-applied amendments may be preferred and often are more effective (Ayers and Westcot, 1985).

If amendments are added through the irrigation system, the normal choices would be: (a) gypsum injected as a fine particle size in a suspension (sometimes other more soluble Ca materials are used in addition to the gypsum, such as $CaCl_2, Ca(NO_3)_2$ or other water soluble Ca forms); or (b) SO_4 as one of the acids or generated from a SO_3 generator. In this case, lime would need to be present at the soil surface to react with SO_4 to create gypsum. In either of these situations, high Ca levels result, replacing Na on the soil CEC sites. The Na is then leached as Na_2SO_4, a soluble salt.

Situation 2:
High to Moderate Na, High HCO_3/CO_3

High bicarbonate (HCO_3) or carbonate (CO_3) content in irrigation water reacts with Ca and Mg to precipitate insoluble lime ($CaCO_3$, $MgCO_3$). Even if the irrigation water contains little Ca or Mg, the HCO_3/CO_3 will react with any soluble Ca/Mg in the soil to precipitate lime. This greatly reduces the effectiveness of applied gypsum or S-source + lime (to create gypsum) by reacting with soluble Ca/Mg released from these amendments to form less soluble forms. This leaves excess soluble Na to increase the ESP (exchangeable sodium percentage) on the soil CEC sites without

soluble Ca or Mg available to inhibit this process.

Under these conditions, even moderate levels of Na can cause sodic soil formation with structure deterioration and, therefore, a reduced infiltration rate. Irrigation water would be characterized by: (a) a high adjusted SAR_w (adj. SAR_w) that would be considerably greater than the unadjusted SAR_w value (the adj. SAR_w takes into consideration the presence of HCO_3/CO_3, and when these are high the adj. SAR_w increases relative to the unadjusted SAR_w value); and (b) RSC (residual sodium carbonate) value would be > 1.25 meq L^{-1} (i.e. high). The RSC is a measure of whether Ca and Mg in irrigation water will react with HCO_3 and CO_3 to precipitate as insoluble lime.

Treatment of the irrigation water with acid to evolve the HCO_3 and CO_3 off as CO_2 gas plus water is highly desirable since: (a) it allows any Ca and Mg in irrigation water to remain soluble so they could displace Na from the soil CEC sites, and (b) it allows soil-applied amendments to be more effective in producing relatively soluble Ca, rather than being precipitated as lime.

When irrigation water is acidified with a SO_4-based acid or by SO_3 generators, it is important to effectively utilize the S to form gypsum. This can be achieved by adding lime to the soil surface periodically. Calcareous soils have free $CaCO_3$ that can serve as the lime source. However, over time the free $CaCO_3$ at the surface may become depleted, resulting in a reduction in water infiltration rate. In this situation, lime should be applied to the surface to maintain a Ca source at the soil surface to react with the S-source.

Reaction of the S-source plus lime creates gypsum ($CaSO_4$), which is beneficial for alleviating sodic conditions if leaching is sufficient to remove the Na in the form of Na_2SO_4. Approximately 100 lbs. of lime is needed to react with every 98 lbs. of H_2SO_4 applied. Thus, if 100 lbs. of H_2SO_4 were applied per acre-foot of irrigation water, 104 lbs. of $CaCO_3$ per acre would be required to react with the H_2SO_4 and form gypsum at about 136 lbs. per acre. This process not only makes positive use of any SO_4 used to treat the irrigation water, but also aids in decreasing the quantity of free SO_4 in the soil. If anaerobic (low soil oxygen) conditions occur, high levels of SO_4 could become reduced into FeS or MnS, which contribute to black layer development.

Situation 3:
Ultra Pure Water (EC < 0.50 dSm⁻¹)

Pure water usually originates from snowmelt sources or from continuous rains during monsoon season, but some groundwater sources may have low EC_w. Very pure irrigation water has a low electrical conductivity (EC_w) of <0.50 dSm⁻¹. Prolonged use of very pure water can strip cations and salts from the soil surface, usually a zone of less than 1 cm in depth. Regardless of SAR, this action results in crusting at the soil surface and reduced infiltration as clay particles become dispersed after drying. These problems are accentuated when electrical conductivity (EC_w) is extremely low, ≤0.20 dSm⁻¹.
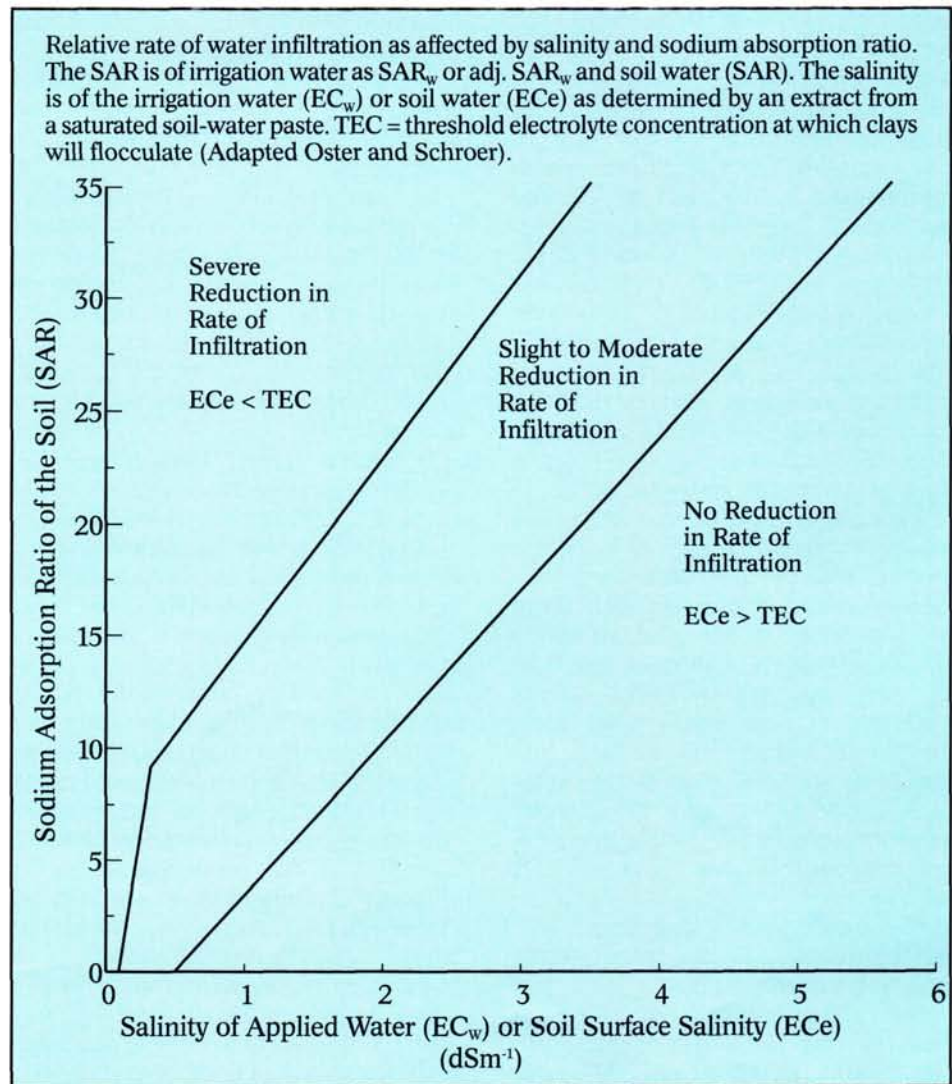
Reduced infiltration is especially noticeable on a site with limited turfgrass coverage, such as during establishment or on areas thinned by traffic, since direct raindrop or irrigation water impact enhances crusting. However, it can occur under a full turfgrass cover. The symptoms are greater runoff on sloped areas than would normally be expected, slower infiltration on level sites, and slower drainage of low areas.

The management choices for this problem are to: (a) increase the salt concentrations at the soil surface with soil application of gypsum, phosphogypsum, or a S-source plus lime (soil-applied treatments can be used on a trial area to determine if low water infiltration is due to ultra-pure water or from another cause like soil compaction); or (b) increase the salt concentration in the irrigation water to above 0.50 dSm⁻¹. Increasing dissolved Ca in low-salinity water by 1.0 to 4.0 meq CaL⁻¹ in turn also raises the EC_w by approximately 0.075 to 0.30 dSm⁻¹. This can increase soil infiltration significantly, by as much as 100 to 300 percent. Table 10.2 of Carrow and Duncan (1998) lists various materials that can be used, as well as equivalent rates for irrigation water treatment. For example, 234 lbs. of $CaSO_4 \cdot 2H_2O$ or 201 lbs. of $CaCl_2 \cdot 2H_2O$ added per acre-foot of water would increase the EC_w by 0.075 dSm⁻¹. These rates are equivalent to 1.0 meq Ca L⁻¹.

Situation 4:
High Ca/Mg, High HCO₃/CO₃

In this situation, the water contains unusually high Ca/Mg *and* HCO₃/CO₃ concentrations, but Na is absent or at low levels. As the HCO₃/CO₃ react with Ca/Mg, insoluble lime ($CaCO_3$, $MgCO_3$) precipitates, often at the sur-

face 1 cm of soil. Concentrations of these constituents in irrigation water usually are: 100 to 400 mg L⁻¹ (HCO_3^-), 0 to 5 mg L⁻¹ (CO_3^-) unless pH is > 9.5, 25 to 200 mg L⁻¹ (Ca), and 20 to 40 mg L⁻¹ (Mg). Wastewater normally has higher levels than domestic sources.

Since it is not unusual to add 25 to 50 lbs. of $CaCO^3$ (lime) per 1,000 sq. ft. to turfgrasses growing on acid soil, the question arises as to whether lime formation from irrigation water constituents (such lime is called calcite) really reduces infiltration and, if so, how. When limestone is applied, it is as discrete particles rather than as a sheet-like layer at the surface as occurs with irrigation water sources. Especially on sands, which have a low surface area, calcite coatings can form on particles and start to bridge between particles and fill the pores. This could create conditions where sealing of the surface would be possible and cause reduced water infiltration. Certainly, caliche

soils exhibit calcite layers where water movement is decreased, so a similar situation could occur over on a "micro" scale within the surface 1 or 2 cm.

To determine the quantity of calcite deposition, we can assume high concentrations of all components such as:

200 mg L⁻¹ Ca = 10.0 meq L⁻¹ Ca
40 mg L⁻¹ Mg = 3.3 meq L⁻¹ Mg
811 mg L⁻¹ HCO_3 = 13.3 meq L⁻¹ HCO_3

We also assume that all materials react to form $CaCO_3$ or $MgCO_3$. To calculate the quantity of Ca and Mg in an acre-foot of irrigation water, the quantity of each element in mg L⁻¹ (ppm) is multiplied by 2.72 (Table 5.8, Carrow and Duncan, 1998).

200 mg L⁻¹ Ca × 2.72 = 544 lbs. Ca/acre-foot of irrigation water

40 mg L⁻¹ Mg × 2.72 = 109 lbs. Mg/acre-foot of irrigation water

These values are equivalent to formations of 1,700 lbs. per acre-foot $CaCO_3$ (32% Ca), and 404 lbs. per acre-

Relative rate of water infiltration as affected by salinity and sodium absorption ratio. The SAR is of irrigation water as SAR_w or adj. SAR_w and soil water (SAR). The salinity is of the irrigation water (EC_w) or soil water (ECe) as determined by an extract from a saturated soil-water paste. TEC = threshold electrolyte concentration at which clays will flocculate (Adapted Oster and Schroer).

Severe Reduction in Rate of Infiltration

ECe < TEC

Slight to Moderate Reduction in Rate of Infiltration

No Reduction in Rate of Infiltration

ECe > TEC

Sodium Adsorption Ratio of the Soil (SAR)

Salinity of Applied Water (EC_w) or Soil Surface Salinity (ECe) (dSm⁻¹)

foot $MgCO_3$ (27% Mg). Combined, the total would be 2,104 lbs. $CaCO_3$+ $MgCO_3$ per acre-foot of water, or 48 lbs. per 1,000 sq. ft. per 12 in. irrigation water applied.

If we assume an arid climate where most water is by irrigation at 1.0 in. per week and a 12-month growing season:

1.0 in. × 52 weeks = 52 in. water = 4.3 acre-feet.

Thus, 4.3 acre-feet × 48 lbs. calcite per 1,000 sq. ft. per 12 in. irrigation = 206 lbs. calcite/1,000 sq. ft. deposited in the surface 0.25 in. per year. Actually, some would be expected to be precipitated deeper than at 0.25 in., but this illustrates a "worst-case situation."

Since an 8 in. acre-furrow slice of soil weighs 2,000,000 lbs., a 0.25 in. "slice" weighs 1,435 lbs. per 1,000 sq. ft. The 206 lbs. calcite would represent about 14% by weight of the total, assuming all calcite was within the surface 0.25 in. zone, but only 0.01037% of the 2,000,000 lb. acre-furrow slice. Thus, this is sufficient to cause at least some sealing of the surface. However, sufficient calcite to adversely affect water infiltration would accumulate primarily under a *combination of conditions* such as:

• Sand soils with limited particle size surface area would be more susceptible than fine-textured soils.

• Irrigation water with unusually high HCO_3 *and* high Ca/Mg concentrations.

• An arid climate where high water use would result in considerable annual additions of calcite.

• Reliance on light, more frequent irrigation rather than less frequent and deeper application. Light, frequent irrigation would favor deposition of the calcite at the surface under high ET conditions, while deeper but less frequent irrigation would favor calcite deposition near the depth of normal irrigation water penetration.

• A long growing season, including any winter overseeding period, that would result in high total water use over a year.

In humid regions, calcite buildup at the surface would be less likely because the rainfall (i.e. low HCO_3, Ca, Mg) would tend to dissolve the calcite or at least move it deeper and more dispersed throughout the soil profile. Also, annual additions of calcite would be less since irrigation would be less frequent.

When the above combination of conditions favors calcite accumulation within the surface zone, is acidification of irrigation water a solution? The answer is yes, but not necessarily the best choice. For example, often on a golf course only the sand-based greens may show a decrease in infiltration, while more fine-textured areas do not. Treating the irrigation water for the whole golf course would not be necessary. In contrast, the problem of high HCO_3 with high Na causes sodic conditions that adversely affect all soils. Therefore, acidification of the water for all areas of the golf course would be important for this problem. Additionally, a calcite layer is essentially a physical barrier to water infiltration; it could be broken by periodic cultivation. Or, the use of acidifying fertilizer such as $(NH_4)_2SO_4$ or applying elemental S to the turfgrass surface would aid in dissolving the calcite layer by changing it into more soluble and mobile forms such as gypsum $(CaSO_4)$ and $MgSO_4$.

Other Considerations

It is not implied and should not be assumed that water and soil treatments to improve infiltration can be substituted for core aeration. Core cultivation will need to remain an important part of the overall soil management program. Water and soil chemical amendment treatments are methods to improve infiltration where water quality problems cause soil structure deterioration. Whether irrigation water treatment is necessary or optional for improved water infiltration *and* the type of water treatment depend on the specific situation as identified by water chemistry analysis.

When water versus soil treatment is being considered, the pros and cons to take into account include those of costs, convenience, and safety. For example:

Pros

• Water treatment eliminates dust associated with granular soil applications of amendments such as lime, gypsum, or sulfur. This can be an important consideration where strict air quality regulations exist or residential developments surround a golf course.

• Water treatment can reduce labor requirements and eliminate course downtime when compared to granular soil applications.

• Water acidification can reduce the burn potential associated with soil sulfur applications, especially on low-CEC soils such as sands, lava rock, or decomposed granite.

Cons

• Pound-for-pound of active ingredient, liquid amendments generally cost more than dry products.

• Equipment for water treatment can be an expensive investment costing from $8,000 to $30,000, depending on

Saline-sodic soil with high total salts (whitish crust) and high Na causing a black appearance. This site had a soil ECe of 26 to 85 d Sm^{-1} and SAR 32 to 67.

This sulfurous generator burns elemental S to create SO_3, which reacts with water to form sulfurous acid, H_2SO_3.

Poor water infiltration into a sodic soil resulting in standing water in low areas.

the type of equipment and treatment necessary.

• Where acidification is required, products must be evaluated and selected carefully, as some options are dangerous to handle until diluted in the irrigation water.

• Application uniformity of water treatments is only as good as the distribution uniformity of the irrigation system.

Glossary

Acid Injection: Used to treat waters with high HCO_3 and CO_3 content. Adding an acid evolves the HCO_3 and CO_3 off as CO_2 and water.

Ca: Calcium, equivalent weight = 20. An essential plant nutrient and the cation responsible for good soil structure.

CaCl₂: Calcium chloride. A very soluble calcium salt that can be dissolved in irrigation water to lower the SAR or increase the EC_w.

CaCO₃: Calcium carbonate (lime). The insoluble form of calcium precipitated by waters high in Ca, HCO_3, and CO_3. Sometimes naturally occurring in calcareous/caliche soils in arid regions. Insoluble until reacted with an acid.

CaCO₃·MgCO₃: Calcium/magnesium carbonate (dolomitic lime). Insoluble calcium/magnesium combination precipitated from waters high in Ca, Mg, HCO_3, and CO_3. Sometimes naturally occurring in calcareous/caliche soils in arid regions. Insoluble until reacted with an acid.

Calcite: Lime precipitant from a water source.

CaNO₃: Calcium nitrate. A highly soluble source of calcium and nitrogen that can be dissolved in irrigation water to lower the SAR or increase the EC_w.

CaSO₄: Calcium sulfate, commonly referred to as gypsum. An amendment used to displace sodium at the soil exchange site or suspended in irrigation water to increase EC_w or the ratio of Ca/Na, thereby lowering SAR.

CEC: Cation exchange capacity. The sum total of exchangeable cations that a soil can absorb.

CO₃: Carbonate, equivalent weight = 30. Combines with Ca (calcium) and Mg (magnesium) to form $CaCO_3$ and $MgCO_3$ (cal-

cium carbonate and magnesium carbonate) forms of insoluble lime or calcite.

dS m⁻¹: Decisiemens per meter. The standard measurement used to report electrical conductivity of water (EC_w).

EC₆: Electrical conductivity of soil from a saturated paste extract.

EC_w: Electrical conductivity of irrigation water. This is a measure of the total salinity or total dissolved salts. 640 ppm TDS = 1.0 dS/m EC_w.

ESP: Exchangeable sodium percentage. Used to classify sodic and saline-sodic soil conditions. The degree of saturation of the soil exchange complex with sodium as compared to other exchangeable cations.

H₂SO₄: Sulfuric acid. Forms in soil when acidifying amendments/fertilizers are used such as soil sulfur (S), ammonium sulfate, etc., or is injected into irrigation water via a sulfurous generator or acid injection and products such as urea sulfuric acid (NpHURIC).

HCO₃: Bicarbonate, equivalent weight = 61. Combines with Ca (calcium) and Mg (magnesium) to form $CaCO_3$ and $MgCO_3$ (calcium carbonate and magnesium carbonate), forms of insoluble lime or calcite.

meq/l: Milliequivalents per liter. Parts per million (ppm) divided by equivalent weight equals milliequivalents per liter.

mg L⁻¹: Milligrams per liter. Equals parts per million.

Mg: Magnesium, equivalent weight = 12. An essential plant nutrient and cation associated with good soil structure, providing it is not available in excessive quantities in relationship to Ca.

MgCO₃: Magnesium carbonate. Insoluble form of magnesium precipitated by waters high in Mg, HCO_3, and CO_3. Sometimes naturally occurring in calcareous/caliche soils in arid regions. Insoluble until reacted with an acid.

Na: Sodium, equivalent weight = 23. Nonessential as a nutrient, a "small" cation with large hydrated size that disperses soils, thereby adversely affecting infiltration and soil aeration.

Na₂SO₄: Sodium sulfate. A soluble salt formed when gypsum is used to treat soils with high sodium content.

ppm: Parts per million. Milliequivalents per liter multiplied by equivalent weight = parts per million.

RSC: Residual sodium carbonate. Like the SAR_w, is used to determine whether Na in irrigation water will cause soil structure problems. The RSC compares the concentrations of Ca and Mg to HCO_3 and CO_3 and determines when calcium and magnesium precipitation can occur in the soil and result in additional sodium domination of soil cation exchange sites. RSC = $(CO_3 + HCO_3) - (Ca + Mg)$. This calculation is done with all measurements in meq/l.

RSC Value	Potential Irrigation Use
<1.25	Generally safe for irrigation
1.25 - 2.5	Marginal
>2.5	Usually unsuitable unless treated

S: Sulfur. A secondary plant nutrient used as a soil amendment to modify pH in alkaline soils. Also used in calcareous and caliche soils (containing high lime) to convert lime into gypsum.

SAR_w: Sodium adsorption ratio of irrigation water. SAR_w is used to determine whether sodium (Na) levels of water will cause soil structure to deteriorate. Unadjusted SAR (SAR_w) considers only Na^+, Ca^{+2}, and Mg^{+2}, while adjusted SAR (adj. SAR_w) also includes the influence of HCO_3^- and CO_3^{-2} on Na activity.

SO₃ Generator: Sulfurous generator, also known as a sulfur burner. Equipment used to treat irrigation water containing high carbonates and bicarbonates. Burns sulfur at high temperatures to produce sulfurous gas that, when combined with water, becomes sulfuric acid. This evolves the HCO_3 and CO_3 off as CO_2 and water. This is another method of acid injection.

SO₄: Sulfate, equivalent weight = 48. When combined with lime, while in an acid form, creates gypsum.

TDS: Total dissolved salts, normally reported as parts per million (ppm).

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