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Irrigation Water Quality

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Irrigation Water Quality: Part I. Salinity

With an ever increasing demand on drinking water supplies, golf course superintendents are frequently faced with utilization of poor quality irrigation water. Wells, ponds, streams, and waste treatment plants are common water sources for irrigation. Problem levels of salinity, sodium, carbonates, and pH can occur in any of these sources, especially near the seashore. The continued application of poor quality irrigation water and its detrimental effects on soil properties can reduce the quality and growth of turfgrass. However, with proper precautions and altered management practices, poor quality irrigation water may be used to produce high quality turf. In this newsletter we will discuss the effects of salinity on turfgrass growth and quality. Later newsletters will examine problems arising from sodium, carbonates, and pH.

SALINITY

High soil salinity may result from the application of saline irrigation water, insufficient rainfall and irrigation to leach excess salts, poor drainage, upward movement of leached salt from perched water tables, and/or salt water intrusion. Turf continually irrigated with high salinity water often becomes weak, eventually declining to a point of no longer being acceptable. Severe salinity stress will ultimately cause turf death, leaving a patchy, thin turfgrass stand, especially in areas of standing water. In severe cases a white crust develops in the bare spots as evaporation causes the salts to precipitate. Reduced turf quality, however, occurs well before such obvious symptoms of high salinity are evident.

Salts reduce turfgrass health mostly by an osmotic effect on the turfgrass plant. The more salt in the rootzone, the harder the plant must work to take-up water. The initial response of turfgrass to salinity stress is reduced shoot growth. Leaf blades become narrower and stiff, and can become dark green, or blue-green, in color. Salt-stressed turf also wilts faster than normal as a result of osmotic stress. Wilting due to high salt can occur even when the soil is moist. Leaf tipburn and a general thinning of turf develop at higher salinity levels.

Turfgrass species have varying levels of salt tolerance. Only a few species grow well under saline conditions. Zoysiagrass, seashore paspalum, bermudagrass, and St. Augustinegrass are the best warm-season turf species to grow if irrigation water is salty, whereas, alkaligrass, tall fescue, and perennial ryegrass are the best cool-season turfgrasses. Unfortunately, bentgrass only has a fair tolerance to salinity, and *Poa trivialis* and centipede have poor tolerance.

Salinity also slows seed germination. High salinity makes it more difficult for the seed to imbibe water and the germination rate is reduced. Unfortunately, this problem is accentuated with light frequent irrigations that are typically utilized during turfgrass establishment. Each light irrigation deposits salt in the seedbed and salinity can accumulate rapidly to levels that prohibit seed germination. It is important to periodically leach salts out of the seedbed when using saline irrigation water during seedling establishment.

Measuring and Classifying Irrigation Salinity

Salinity is determined by measuring the ability of water to conduct an electrical current. Salinity is expressed in two different ways, either as electrical conductivity (EC_w) or total dissolved salts (TDS). There are several units commonly used to express EC_w: deciSiemens per meter (dS/m), Siemens per meter (S/m), microSiemens per centimeter (µS/cm), millimhos per centimeter (mmhos/cm), or micromhos per centimeter (µmhos/cm). The relationship between these units is:

1 dS/m = 0.1 S/m = 1000 µS/cm= 1 mmhos/cm = 1000 µmhos/cm

Total dissolved salts are expressed in parts per million (ppm) or milligrams per liter (mg/L) and are generally not measured directly, but calculated from the EC_w measurement.

1 milligram/liter (mg/l) = 1 part per million (ppm)
EC_W (mmhos/cm or dS/m) x 640 = TDS (mg/l or ppm)

The ratio of total dissolved salt to EC_W of various salt solutions ranges from 550 to 700 ppm per dS/m. The most common salt in saline water, sodium chloride, has a TDS of 640 ppm at an EC_W of 1 dS/m. Most laboratories use this relationship to calculate TDS from EC_W, but some multiply by other factors. Water sample salinities are sometimes compared to those of seawater which has an average EC of 43 dS/m or about 32,000 ppm dissolved salts.

Irrigation water is classified into four categories based on salinity hazard which considers the potential for damaging plants and the level of management needed for utilization as an irrigation source (**Table 1**). Water with EC_w readings of less than 0.75 dS/m are generally suitable for irrigation without problems. Successful use of water with EC_w values above 0.75 dS/m depends upon soil conditions and plant tolerance to salinity. Generally, higher salinity levels can be used on sandy soils where salts can be easily flushed compared to similar values on poorly draining clay soils which may cause problems. Under typical summer stress growing conditions, EC_w of irrigation water should ideally not exceed 1.25 dS/m soluble salts. Salinity levels above 3.0 dS/m are unsuitable for any length of time as an irrigation source.

Many irrigation water samples we have seen from Coastal golf courses in South Carolina have salinities that range from 0.75 to 1.25 dS/m and salinities of 2 dS/m are not uncommon. These levels are sufficient to reduce the growth and quality of turf and necessitate additional management to produce high quality turfgrass.

Table 1. USDA Salinity Laboratory's classification of saline irrigation water based on salinity level, potential injury to plants, and management necessary for satisfactory utilization.

Salinity class	Electrical conductivity (dS/m)	Total dissolved salts (ppm)	Potential injury and necessary management for use as irrigation water
Low	<0.25	<150	Low salinity hazard; generally not a problem; additional management is not needed.
Medium	0.25 - 0.75	150 - 500	Damage to salt sensitive plants may occur. Occasional flushing with low salinity water may be necessary.
High	0.75 - 2.25	500 - 1500	Damage to plants with low tolerance to salinity will likely occur. Plant growth and quality will be improved with excess irrigation for leaching, and/or periodic use of low salinity water and good drainage provided.
Very High	>2.25	>1500	Damage to plants with high tolerance to salinity may occur. Successful use as an irrigation source requires salt tolerant plants, good soil drainage, excess irrigation for leaching, and/or periodic utilization of low salinity water.

Assessing Soil Salinity

Soils are a key to continued use of saline irrigation water. Good drainage is essential to leach soluble salts through the soil profile. The better the drainage, the better one can keep soluble salts in the rootzone within tolerable limits. Poorly drained soils accumulate salts due to poor drainage. Although sandy soils are usually best suited for saline irrigation because of easy drainage, soil moisture must be maintained near field capacity in order to prevent intolerable salinity levels from occurring.

Soluble salts are measured in soils by the same basic method as water samples. A conductivity instrument measures electrical conductivity (EC) either from a saturated paste extract or from a soil:water dilution ratio. Electrical conductivity readings from these two methods are not comparable. Using the saturated paste extract, soils with EC readings of 2.0 to 4.0 dS/m are considered to have low salt levels (**Table 2**). Soils with EC readings of 4.0 to 12.0 dS/m have medium levels. When soil readings are above 12.0 dS/m, soils are considered to have high salt levels and only salt-tolerant turfgrasses survive above 16 dS/m. Under well-watered conditions the EC of a saturated paste extract is approximately 1.5 times the electrical conductivity of the irrigation water.

Table 2. Classification of saline soils by saturated paste method.

Salinity Class	EC (dS/m) (saturated paste extract)	TDS (ppm)
low	2.0 to 4.0	1300 to 2500
medium	4.0 to 12.0	2500 to 7500
high	>12.0	>7500

Soil testing laboratories frequently use a 1:2 dilution method (one part dry soil:two parts water) because it is more rapid than obtaining a saturated paste extract. The Clemson University Agricultural Laboratory uses the guidelines in **Table 3** for interpretation.

Table 3. Classification of saline soils by 1:2 dilution method.

Probable relationship to plant growth	Soil Textural Classification			
	Sand (<15% clay)	Loams (15-20% clay)	Clay Loams (27-40% clay)	Clays (>40% clay)
Normal range	0.05 - 0.15	0.10 - 0.20	0.15 - 0.30	0.20 - 0.50
Salt buildup-Caution	0.15 - 0.30	0.20 - 0.50	0.30 - 1.00	0.50 - 2.00
Excessive salts	> 0.30	> 0.50	> 1.00	> 2.00

Substantial amounts of salt can accumulate in the root zone rapidly during periods of drought when saline irrigation water is the predominant source of water. The application of 1 inch of moderately saline irrigation water (1.0 dS/m) contributes approximately 3.3 pounds of salt per 1000 sq. ft. Since turf water use during peak demand is about 0.15 to 0.30 inches/day, this amount of salt can accumulate in the soil in three to seven days. Compare this amount of salt added via irrigation to routine fertilization which is usually less than 2 pounds of salt (fertilizer) per application, and is usually avoided when the weather is hot and dry.

MANAGING IRRIGATION WATER QUALITY PROBLEMS

Managing irrigation water high in salinity requires constant attention. Practices which aid in remedying salinity problems are:

(1) Diluting high salinity water with low salinity water
(2) Leaching excess salts from the soil with excess water

Blending Water Sources for Reducing Salinity

High salinity water that is unacceptable for use because of salinity only (does not apply if sodium is also high) can be made suitable as an irrigation source by dilution with low salinity water. Enough low salinity water must be available to create a mixed water of acceptable quality, e.g., do not end up making a less saline water that is still too salty to be used. The salinity of a high salinity water source should improve proportionally to the mixing ratio with a low salinity water. For example, a water source with an EC_w of 3 dS/m mixed equally with a source with an EC_w of 1 dS/m should result in a blend with a salinity of approximately 2 dS/m. A chemical analysis of the blend should be performed to confirm this. The salinity of the mixture can be calculated with this equation:

$$\frac{\text{gallons (water A) x ECw (water A) + gallons (water B) x ECw (water B)}}{\text{gallons (water A) + gallons (water B)}}$$

Mixing of irrigation sources can occur in irrigation ponds or within the irrigation system itself. When mixing water sources in irrigation ponds, the non-saline water should be added immediately prior to being used so as to reduce evaporative losses. Evaporation of surface water is not only an inefficient use of water, it also increases the salinity of the water remaining in the pond.

Leaching Soils to Remove Salts

Salt build-up from saline irrigation water occurs when rainfall is low and evaporative demand is high. This normally corresponds to mid-spring through early fall. As water evaporates from the soil surface, salts are left behind. Determining the electrical conductivity of the soil is the best way to determine the extent of salt accumulation. When the electrical conductivity exceeds the tolerance level of the turfgrass (**Table 4**), the soil should be leached to move the salt below the root zone.

Frequent flushing of the soil with good quality irrigation water or rainfall is the best method of preventing excessive salt accumulation. Unfortunately, low salinity irrigation sources are not always available and frequently saline irrigation water must be used to manage soil salinity. However, as long as the salinity of the irrigation water is acceptable (<2 dS/m-see Table 1), it can be used to leach accumulated salts from the turf root zone. The use of soil amendments, such as gypsum, should be considered in conjunction with leaching irrigation applications in soils that are also high in sodium. However, if excessive soil sodium and poor water drainage is not a problem the use of soil amendments should be avoided since they add to the salinity of the soil.

If saline water is used to reduce the salt level of the soil, irrigation must be applied at rates exceeding evapotranspiration to leach excess salts out of the root zone. To determine the amount of excess water required to leach salt below the rootzone, the following leaching requirement equation is often used.

Leaching requirement is the amount of extra water needed to leach salts from the rootzone and is defined as:

$$\text{Leaching Requirement} = \frac{EC_{iw}}{EC_{TS}} \times 100\%$$

EC_{iw} is the electrical conductivity of the irrigation water. EC_{TS} is the electrical conductivity of a saturated paste extract that can be tolerated by the turfgrass (see **Table 4** for tolerance levels of some turfgrasses). For example, an irrigation water source with a salinity (EC_{iw}) of 1.5 dS/m is used to irrigate creeping bentgrass with a tolerance (EC_{TS}) of 3 dS/m. The leaching requirement is (1.5 ÷ 3) x 100% or 50%. In this example, 50% more irrigation water than is needed to satisfy normal irrigation requirements is required to leach salt from the rootzone (e.g., 50% greater than 0.5 inch of water applied equals 0.75 inches). The leaching requirement increases with saltier irrigation water and/or less tolerant turfgrasses.

Table 4. Upper limit of tolerance to soil salinity of turfgrass species commonly grown in South Carolina. Tolerance is assessed by the electrical conductivity of a saturated paste extract (EC_{TS}).

Turfgrass	**Upper limit, EC_{TS} dS/m**
Bermudagrass, hybrid	10
Centipede grass	< 3
Creeping bentgrass	3
Perennial ryegrass	10
Poa trivialis	< 3
St. Augustinegrass	>10
Tall fescue	10

SUMMARY

Continued use of irrigation water with electrical conductivities exceeding 0.75 dS/m, or total dissolved salts greater than 480 ppm, may reduce the growth and quality of turfgrasses. Detrimental effects are greatest during prolonged droughts when irrigation water is the sole source of water and irrigation amounts typically do not exceed evapotranspiration. Creeping bentgrass, *Poa trivialis*, and centipede grass are the species most likely to show salinity damage. Periodic leaching of salts from the rootzone with irrigation amounts exceeding evapotranspiration are effective at reducing high soil salinity. Low salinity irrigation water or rainfall are preferred for leaching salts, however, irrigation water of <2 dS/m is generally acceptable for leaching purposes.

Irrigation Water Quality: Part II. Sodium, Carbonates, and pH

In Part I we discussed the effects of irrigation water salinity on quality and growth of turfgrass and the management necessary to produce high quality turf with salty water. In Part II we discuss two additional factors that may limit irrigation water utilization, sodium and carbonates.

High Sodium Reduces Water Infiltration and Soil Aeration

Irrigation sources high in sodium (Na) may lead to the deterioration of soil structure. High soil Na causes soil clays and organic matter to disperse or deflocculate. The clays and organic matter clog soil pores, reducing water infiltration and soil aeration. These problems are greater on fine-textured soils such as clays and loams than on sandy soils. Calcium (Ca) and magnesium (Mg) cause the soil to flocculate, and therefore counteract the negative effects of Na.

Assessing Irrigation Water for Sodium Problems

The potential for irrigation water to have poor infiltration properties is assessed by determining the sodium adsorption ratio (SAR) and the electrical conductivity (EC_w) of the water. The sodium adsorption ratio relates the concentration of Na to the concentration of Ca and Mg (See equation below). The higher the Na in relation to Ca and Mg, the higher the SAR, and the poorer the water infiltration. SAR is defined as:

$$SAR = \frac{[Na^{+}]}{\frac{\sqrt{Ca^{+2} + Mg^{+2}}}{2}}$$

Note: Ion concentrations must be expressed in milliequivalents per liter (meq/l) to calculate SAR using above equation. To convert parts per million (or mg/l) to meq/l use the following equation and equivalent weights for Na, Ca, and Mg of 23, 20, and 12.2, respectively.

$$\frac{\text{ppm (or mg/l)}}{\text{equivalent weight}} = \text{meq/l}$$

The effects of high SAR on irrigation water infiltration are dependent on the electrical conductivity of the water. For a given SAR the lower the EC_w the poorer the infiltration properties, the higher the EC_w the better the infiltration. For example irrigation water with an SAR=15 has poor infiltration properties if the EC_w = 0.5 dS/m but good infiltration properties if the EC_w = 2.0 dS/m. See **Figure 1** for the relationship between SAR and Ec_w. A good rule-of-thumb based on this figure is if the SAR is more than 10 times greater than the EC_w, then poor water infiltration is likely to occur.

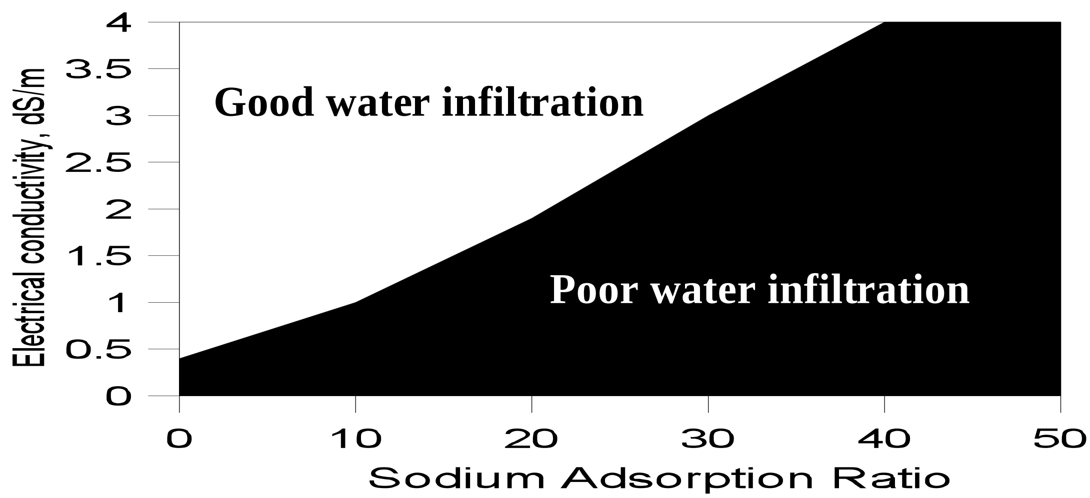

Figure 1. Water infiltration based on sodium adsorption ratio and irrigation water electrical conductivity.

General guidelines for precautions and management of irrigation water with various SAR values and an EC_w =1.0 dS/m are provided in **Table 1**. Fine textured soils such as clay can have permeability problems if irrigation water with SAR >9 is used over an extended period. Well-drained sandy soils, such as many modified golf greens, can tolerate higher SAR values. Note that some labs report adjusted SAR values instead of SAR. The adjusted SAR includes the added effects of the precipitation or dissolution of Ca in soils and related to carbonate and bicarbonate concentrations. Bicarbonates can interact with soil Ca and Mg to precipitate out lime ($CaCO_3$) or magnesium carbonate ($MgCO_3$), causing an increase in the SAR.

Table 1. Sodium adsorption ratio values (SAR), categories, and precautions for irrigation sources with electrical conductivity of 1.0 dS/m.

SAR	**Category**	**Precaution and Management Suggestions**
0 - 10	1 (low Na water)	Little danger.
10 - 18	2 (medium Na water)	Problems on fine texture soils and sodium sensitive plants, especially under low-leaching conditions. Soils should have good permeability.
18 - 24	3 (high Na water)	Problems on most soils. Good salt tolerant plants are required along with special management such as the use of gypsum.
>24	4 (very high Na water)	Unsatisfactory except with high salinity (>2.0 dS/m), high calcium levels, and the use of gypsum.

Assessing Soils for Sodium Problems

Two laboratory measurements are used to assess whether soils contain excessive Na levels and poor drainage and aeration are likely to occur. These measures are the exchangeable sodium percentage (ESP) and the sodium adsorption ratio (SAR). Exchangeable sodium percentage is the percentage of the soil cation exchange capacity occupied by Na:

$$ESP = \frac{\text{Exchangeable sodium (meq/100 grams)}}{\text{Cation exchange capacity (meq/100 grams)}} \times 100$$

Soil SAR is analogous to the irrigation water SAR discussed earlier (see equation in irrigation water section above). Soil SAR is calculated from soil-test extractable levels of Na, Ca, and Mg (expressed in meq/100 grams). An ESP>15% or a soil SAR>13 indicates that Na is likely to be reducing the permeability of the soil to water and air. Usually few or only minor problems occur at lower levels of ESP or soil SAR.

Carbonates Complicate Management of Sodium

Bicarbonate (HCO_3^-) and to a lesser extent carbonate (CO_3^{-2}) are found in high pH water and are collectively referred to as carbonates. Irrigation water containing high carbonates greatly complicate the management of excessive Na. When water containing carbonates dries at the soil surface, Ca and Mg carbonates (lime) are formed. Since Ca and Mg are no longer dissolved, they do not counteract the negative effects of Na, and problems related to high Na may occur. White lime deposits may also become visible on turf leaves during hot, dry periods as carbonates are deposited during evaporation.

There are two measurements used for assessing the carbonate level of irrigation water, the direct measurement of carbonate and bicarbonate and the residual sodium carbonate equation (RSC). Carbonate levels alone are sometimes used to assess potential limitations of an irrigation water source (**Table 2**). When the sum of carbonate and bicarbonate expressed as meq/l exceed 1.5 then problems related to calcium carbonate precipitation may occur. When carbonates exceed 8.5 meq/l these problems may be severe. Bicarbonate and carbonate are good indicators of hazard when irrigation water Ca and Mg concentrations are low, but the RSC equation should be utilized when water Ca and Mg are high.

Table 2. Potential limitation of irrigation water due to carbonate level.

Carbonates (meq/l)	Potential Limitation
<1.5	Generally safe for irrigation
1.5 - 8.5	Increasing problem
>8.5	Severe problem

The negative effects of bicarbonate and carbonate are negated by high levels of Ca and Mg. To take this into account, the RSC equation is used to indicate the potential for Ca and Mg precipitation at the soil surface and removal of Ca and Mg from the soil solution. High carbonate water can have good infiltration properties if Ca and Mg levels are also high. The RSC equation compares the concentration of carbonates to the concentration of Ca and Mg:

$$RSC = (CO_3^{-2} + HCO_3^{-}) - (Ca^{+2} + Mg^{+2})$$

(all ions expressed in meq/l)

Assessment for poor water infiltration due to high carbonates and low Ca and Mg as determined by the RSC equation is listed in **Table 3**.

Table 3. Potential for precipitation of calcium and magnesium at the soil surface by high carbonate and bicarbonate in the irrigation water as determined by Residual Sodium Carbonate (RSC) equation.

RSC Value (meq/l)	Potential Use
≤1.25	Generally safe for irrigation.
1.25 to 2.5	Marginal as an irrigation source.
>2.5	Usually unsuitable for irrigation without amendment.

If water high in RSC is repeatedly used, the soil becomes alkaline and is likely to become sodic over time if the water also contains appreciable quantities of Na. Normally, if irrigation RSC values are high but SAR values are low, insufficient Na is present to cause water infiltration problems. However, soil pH becomes too high as the soil becomes saturated with calcium carbonate.

Detrimental Effects of High Soil pH

Continued use of high bicarbonate water leads to a high soil pH. When Na is the predominant cation in the soil, pH may be as high as 9.5. However, when Ca predominates, soil pH generally stabilizes around 8.0. High pH can induce iron and manganese deficiencies by rendering these micronutrient unavailable to the turfgrass roots. High soil pH also favors the development of some diseases, such as take-all-patch and pink snow mold.

Counteracting Excess Soil Sodium with Soil Amendments

Several Ca containing soil amendments are used to replace Na in sodic soils in conjunction with leaching to remove salts from the rootzone. The amendments counteract Na by providing Ca either directly (contain Ca) or indirectly (provide acid to dissolve calcium carbonate present in the soil). Calcium arising from the soil amendments reacts with soil Na to displace it from the cation exchange sites on clay and organic matter particles. The released Na can then be leached out of the soil profile as sodium sulfate. The most commonly used amendments for the treatment of sodic soils are gypsum and elemental sulfur.

Guidelines for Application of Gypsum

Most commercial gypsum sources contain 50 to 90% $CaSO_4$. Application rates should be adjusted according to $CaSO_4$ content. Effectiveness of gypsum increases with fineness. Gypsum used on turfgrass should be fine enough so at least 80% passes a USA Standard No. 8 sieve. Large particles not able to pass a No. 8 sieve are too slow to dissolve, rendering them relatively ineffective. Fine particles will react faster and give better uniformity than large particles. However, excessively fine gypsum may be dusty and difficult to spread. Several irrigations are usually required to dissolve gypsum and leach Na. Gypsum is slow reacting and does not normally burn foliage, however, its wise to apply during mild temperatures (e.g., $\leq$80 °F). Due to is low water solubility, some time will be required before gypsum will disappear from the soil surface.

The amount of gypsum required to decrease soil Na is dependent on the ESP and the cation exchange capacity of the soil. The objective of adding gypsum is to lower the ESP level below 10%. Application rates typically range from 20 to 50 pounds per 1000 sq. ft., applied monthly if necessary. Light frequent applications are more effective than heavy infrequent applications, especially in sandy soils. Frequent soil testing should be used to monitor the effects of gypsum on ESP and plant available levels of potassium and magnesium. Gypsum will increase the leaching of potassium and magnesium, as well as Na, so levels of these nutrients should be monitored closely to avoid deficiencies.

Fall and winter applications of gypsum may be warranted even though irrigation is limited during these seasons because rainfall has poor infiltration properties due to its low salinity. Dissolution of gypsum at the soil surface with rainfall increases the salinity of the water, maintains soil aggregation, facilitates Na leaching, and improves water infiltration.

Amending Irrigation Water High in Sodium

Mixing high SAR water with water low in both Ca and EC_w does not reduce the Na hazard of the mixture, because the SAR does not change appreciably and the EC_w is reduced. High SAR water with low EC_w usually has worse infiltration properties than high SAR water with high EC_w. However, adding gypsum to water with high SAR is an effective method of increasing the suitability of irrigation water. Gypsum decreases the SAR and increases the EC_w, which increases the infiltration properties of the water. Applying gypsum via the irrigation system provides additional benefits of continual maintenance of Ca at the soil surface through light frequent application. No labor is needed for gypsum application via irrigation in contrast to traditional methods of application. However, specialized equipment is required for metering gypsum into the irrigation stream and a high purity and extremely fine gypsum must be used.

The impact of gypsum on irrigation water Ca and EC_w are listed in **Table 4**. Sodium adsorption ratio and EC_w for the water sample should be recalculated using the changes indicated. Adust the EC_w and SAR of the water with gypsum to produce a water that has sufficient EC_w and SAR to be considered acceptable as assessed by the criteria in **Figure 1** and **Table 2**.

Table 4. Changes in water calcium and electrical conductivity due to gypsum addition.			
Gypsum rate, lb/1000 gal	Gypsum added in acre-foot of water (lb/acre)	Ca added, meq/l	Increase in Ec_w, dS/m
0.72	234	1.0	0.1
1.44	468	2.0	0.2
2.16	702	3.0	0.3
2.88	936	4.0	0.4
3.60	1170	5.0	0.5
4.32	1404	6.0	0.6
5.04	1638	7.0	0.7

Sulfur and Other Acid Forming Amendments

Elemental sulfur and acid-forming fertilizers (Table 5) may be used to provide soluble Ca indirectly by lowering soil pH and dissolving calcium carbonate precipitated in the soil. If soil pH is only slightly elevated, routine applications of acid-forming N fertilizers containing or generating ammonium (NH_4^+) may be sufficient to maintain soil pH. Ammonium sulfate is considerably more acidic than other commonly used nitrogen fertilizers and is widely used as a primary nitrogen source where irrigation sources have moderate levels of carbonates.

Table 5. Commonly utilized acid-forming nitrogen sources.	
Nitrogen Source	Acidity, lb $CaCO_3$/lb N
Ammonium nitrate	1.8
Urea	1.8
Ureaformaldehyde	1.8
Sulfur coated urea	3.2
Ammonium sulfate	5.2

However, when irrigation sources have severe carbonate problems, elemental sulfur is the most frequently utilized acid forming amendment because it is more available and less costly than other amendments. Extreme care should be exercised when using sulfur to lower soil pH because it has a high potential to burn plant tissue and can lower soil pH excessively if used unwisely.

Sulfur is oxidized by soil bacteria to form sulfuric acid which is the substance that lowers soil pH. Sulfur oxidizing bacteria are most active in wet, warm, well-aerated soil. Limited activity occurs when soil temperatures are below 50 ^oF. Sulfur application, therefore, should be limited during cooler fall and winter months. Acidity equal to 30 pounds of limestone is generated by each 10 pounds of sulfur. The acidifying effects of elemental sulfur are slow to move into the soil when sulfur is surface-applied. Therefore, large decreases in pH may occur in the thatch layer and immediate soil surface with little initial impact on soil pH of the root zone. Application rates must be minimal to avoid damage to the crowns of the turfgrass plant. Rates applied to bermudagrass at fairway or rough height may be as high as 5 lb/1000 sq. ft., whereas applications to greens should not exceed 0.5 lb/1000 sq. ft.. Total annual applications should not exceed 10 lb/1000 sq. ft. on fairways. Plenty of irrigation water should be applied immediately after each application to wash the sulfur from the turfgrass leaves. Applications are best made when temperatures are warm enough for the bacteria to oxidize the sulfur (70 - 80 ˚F), but not hot enough to accentuate tissue burn. It is wise to check soil pH before re-application of sulfur to avoid over-acidification. Sulfur application coincident with core aerification minimizes the potential for tissue burn and accelerates the acidification of the root zone.

Commercial sulfur ranges in purity from 50 to 99%. Value of sulfur for reclamation depends on its purity and fineness. Like gypsum, the finer the material, the faster it is reacts in soil.

Amending Irrigation Water High in Carbonate and Bicarbonate

Carbonates in irrigation water can be decreased with sulfur dioxide, sulfuric acid, or other acidifying materials. This is accomplished by injecting the acidifying material into the irrigation system. This process requires specialized equipment and constant monitoring to ensure successful acidification of water without phytotoxic effects occurring to the turf.

Acidification of the irrigation water converts bicarbonate and carbonate to carbon dioxide and water, but does not affect the Na, Ca, or Mg content of the irrigation water. Generally, amendment rates are based on neutralizing only 75% of the carbonates in the irrigation water. This precaution is taken because once the carbonates are neutralized the pH of the water decreases precipitously with further additions of acid.

Summary

Irrigation water sources along the South Carolina coast are often plagued by high sodium and carbonate contents. Excess sodium causes soil dispersion, resulting in poor water infiltration and aeration and leading to declining turf quality. Calcium additions are needed to displace the sodium so it can be leached from the soil profile, allowing the soil to remain flocculated. Unfortunately, the concurrent occurrence of carbonates in the many water sources renders the calcium insoluble and ineffective. Therefore, acidity in the form of acid-forming nitrogen fertilizers and elemental sulfur applied directly to the turf or sulfur dioxide or sulfuric acid injected into the irrigation stream are also necessary. Judicious use of calcium and acidity in many instances results in excellent turf quality in spite of irrigation water tainted by sodium and carbonates.

Update from the 2001 Carolinas GCSA Annual Meeting