Leaching for Salinity Management on Turfgrass Sites

Where salts are a problem, leaching is the answer.

by R. N. CARROW, M. HUCK, and R. R. DUNCAN

Well water can vary greatly and change over time. Regular monitoring of well water is necessary to prevent undesirable contamination. Here brine has entered the water supply through a damaged well casing.

"SALINITY MANAGEMENT" *is synonymous with leaching of salts.* Leaching is the single most important management practice for alleviating or preventing salt stresses on turfgrass sites. Especially when the irrigation water contains appreciable salts, turfgrass managers must operate from a mindset of "*keep the salts moving downward!*"

Although the principle is simple, achieving an effective leaching program that keeps salts moving past the rootzone is complex. Salinity management is influenced by: salt type, soil factors, water quality/quantity, rainfall, turfgrass species and varieties, and time of year.[1,4,9] The approach in this article is to discuss each of these factors, using typical field situations as practical examples.

Which Salt Problem?

1. *High total salinity is the most common and injurious salt problem* (i.e., saline or saline-sodic soil). It is measured as electrical conductivity (EC) of irrigation water (EC_w) or within soils (EC_e, from a saturated paste extract)[1,3,4]. When the total soluble salt level in the rootzone becomes excessive, turfgrass water uptake is reduced, a situation often referred to as *physiological drought*. This salt-induced drought stress causes typical drought symptoms, including wilting and reduced growth rate, even though soil moisture may appear to be adequate. As the stress continues, grasses often start to exhibit chlorosis and decline in quality.[1,9] These symptoms are often mistaken for disease injury.[9]

Leaching of excessive soluble salts is the easiest of the various salt problems to alleviate. Since the salts are soluble and the majority are in solution when the soil is well irrigated, removal of these salts requires the least quantity of water and time. *Only sufficient water applications are needed; amendments will not improve salt movement unless* *other specific problems exist with the soil or water.* With sufficient water moving through the soil, leaching may require 1 to 4 weeks for reclamation purposes. However, accumulation of excessive soluble salts can rapidly reappear due to high salt additions from irrigation water not followed by ample leaching, as well as from soluble salts moving by capillary rise from below the rootzone up into the root area.

2. *Excessive sodium (Na) levels within the soil* can lead to specific ion toxicity to root tissues *and* to deterioration of soil structural (i.e., sodic or saline-sodic soil).[1] The latter condition is evaluated by the soil SAR (sodium adsorption ratio), the SAR_w (SAR of irrigation water), and RSC (residual sodium carbonate) value of irrigation water.[3]

The effects of sodium ion toxicity on root tissues of grasses and high total salinity result in greater expression of drought stress symptoms. Soil structure deterioration from excess Na^+ on soil colloid (clays, colloidal organic matter) exchange sites causes: a decline in water infiltration/percolation/drainage; low soil O_2, which further limits rooting; waterlogged and poorly drained soil; and, sometimes, black layer symptoms.

Leaching of Na^+ requires addition of a relatively soluble Ca^{+2} source to displace the Na^+ from the soil cation exchange sites. When this happens, the Na^+ goes into solution and can be leached.[1] *It is important that a soluble Ca^{+2} source be added whenever leaching with a Na-laden irrigation water source is conducted. If not, the Na problem can be compounded by the leaching of all remaining Ca^{+2}, allowing replacement with Na supplied by Na-laden leaching water, and causing a complete sealing at the soil surface.*

Compared with the removal of high total salts, a much longer time period is required and more water must move through the soil profile. Generally, for the reclamation of a Na-affected site, a year or more may be required to alleviate the Na-induced structural problem, though only 1 to 4 weeks are needed to alleviate the specific ion toxicity threat. Obviously, preventing a sodic condition from forming is very important and is much easier than reclaiming a sodic soil.

3. *Toxic soil levels of the salt boron (B)* is another salt-related problem that requires leaching. Since B is adsorbed to soil particles, two to three times the leaching water volume is necessary compared to the quantity needed for removal of total soluble salts. *In conjunction with leaching, collection and off-site disposal of clippings can assist in reducing B since it is accumulated in turfgrass leaf tips. This strategy can also be used with total salt and sodium problems as a supplemental method of salt reduction.*

Salt Factors

A number of soil characteristics influence salt and water movement/retention and, therefore, leaching practices. Major differences in soil properties are especially apparent when comparing *sandy soils* (i.e., sands, sandy loams, loamy sands) *to fine-textured types* (i.e., containing appreciable

A distinct layer in the profile is inhibiting water movement, resulting in black layer development near the surface. Frequent core cultivation is needed to keep water and salts moving down through the profile.

amounts of silt and clay). Sandy soils are typical of high-sand-content greens, while fine-textured types are representative of pushup greens (native soil greens), fairways, and many tees.

1. *Cation exchange capacity (CEC)*, the ability of a soil to retain cations, is much higher for fine-textured soils than with sands. As a result, less total soluble salts, Na^+, or B are required before CEC sites of sands are adversely affected compared to fine-textured soil CEC sites, and these salts start to accumulate in the soil solution where they are more active. Although salts reach adverse levels more rapidly in sands, removal by leaching is also more rapid.

2. *Macropores*, soil pores with a diameter > 0.12mm, are much more prevalent in sands than fine-textured soils. Macropores are critical for rapid water movement into the soil surface (*infiltration*), through the rootzone (*percolation*), and beyond the rootzone (*drainage*). Effective leaching cannot be accomplished without macropores, and macropores must be present throughout the soil profile.

Even a thin zone or layer with few macropores within a soil profile will both limit water movement and result in salt accumulation above this layer. Any soil layer or horizon that inhibits water movement will be a major hindrance to effective leaching — whether it is at the surface (surface compaction) or subsurface (e.g., B horizon, cultivation pan, buried layer from flood deposition of fines, etc.). Cultivation operations that enhance infiltration and percolation (deep cultivation techniques) are done essentially to create temporary macropores. If the cultivation holes are filled with sand, the macropores remain for a longer period of time. Thus, turfgrass managers must be familiar with the entire soil profile and should "visualize" whether macropores exist for effective leaching down to the deep subsoil or to drain lines.

3. *Clay type* has a significant influence on water movement. Non-shrink/swell clays (kaolinite, Fe/Al oxides) are called *1:1 clay types*, and these do not crack when dry or seal by swelling when wet. The benefits of cultivation generally last longer on 1:1 clays than the *2:1 types* discussed below. Also, a higher level of Na^+ is required on 1:1 CEC sites before soil structure begins to deteriorate, usually at > 24% Na saturation compared to > 9% Na for many 2:1 types (montmorillonite, illite). Generally, 1:1 clays are more resistant to soil compaction than 2:1 clays. Because 1:1 clays evolve in humid, high-rainfall areas, they often exhibit a B horizon where clay content is higher due to downward movement of particles over many years. For example, many Piedmont red clays (1:1 types) contain 40% to 50% clay in the B horizon versus 15% to 25% in the surface A horizon, and water movement is slower across the B horizon.

In arid and semi-arid climates, where salt problems occur most often, 2:1 clays predominate. Nevertheless, they can be present in most climatic zones. When drying, 2:1 types are "self-cultivating" because cracks form. Unfortunately, under well-watered to saturated moisture conditions, these clays swell and most macropores are lost. When total salinity problems develop on these soils, deep cultivation and filling the cultivation holes with sand or sand plus gypsum (sodic sites) is necessary to maintain a sufficient number of macropores to at least the depth of cultivation. In contrast, deep cultivation operations are effective for longer time periods on 1:1 clays even without filling holes with sand.

4. *Good soil structure* on fine-textured soils is important for maintaining macropores. As aggregates are formed, macropores are developed between aggregates or structural units. Soil compaction from recreational traffic destroys many of the macropores in the surface 3-inch zone, but a well-structured soil will usually have some macropores deeper in the profile. The 2:1 clays are much more prone to soil compaction than the 1:1 types.

Sandy soils with > 85% sand content exhibit sand particle-to-particle contact, which creates many macropores and gives the soil good resistance to compaction. If excessive fines are added to the soil or excessive organic matter fills most of the macropores, infiltration rates can decline, but generally, sands have high infiltration rates conducive to leaching of salts. Although high Na^+ content does not cause "structural breakdown" of single grain sand particles, it does cause any colloidal particles (clay or organic matter in nature) to be dispersed and become susceptible to particle migration. Pond, lake, or river water with high turbidity can contribute fines during irrigation. Often, these fine particles accumulate at the normal depth of irrigation water penetration and can cause a layer and eventually may induce black layer formation. This sequence of events would then inhibit salt leaching.

As noted previously, high levels of Na^+ cause structural deterioration of fine-textured soils. This is especially serious on 2:1 clays, since they often exhibit poor drainage even under low Na^+ due to their swelling/sealing nature. High Na^+ content further decreases water movement throughout the whole soil profile.

5. *Capillary rise* of the soil solution and any dissolved salts in the solution occurs in the *micropores* (pores of < 0.12mm diameter) and can result in major redistribution of salts within the soil profile. When ample water is applied to cause net downward leaching of salts, salinity near the surface is similar to the initial irrigation water salinity level, but salinity then increases with depth. Under high evapotranspiration (ET) conditions, salts may start

Table 1
Evapotranspiration averages by environment for turfgrasses under well-irrigated conditions for different climate conditions

Climate Situations	Average Evapotranspiration* (inches per day)
Cool humid	0.10 to 0.15
Cool dry	0.15 to 0.25
Warm humid	0.15 to 0.20
Warm dry	0.20 to 0.25
Hot humid	0.20 to 0.25
Hot dry	0.25 to 0.35

*The actual ET varies with grass species/cultivar, wind speed, management level, etc., but these values provide "ballpark" estimates. Also, as soil moisture level declines, ET decreases dramatically.

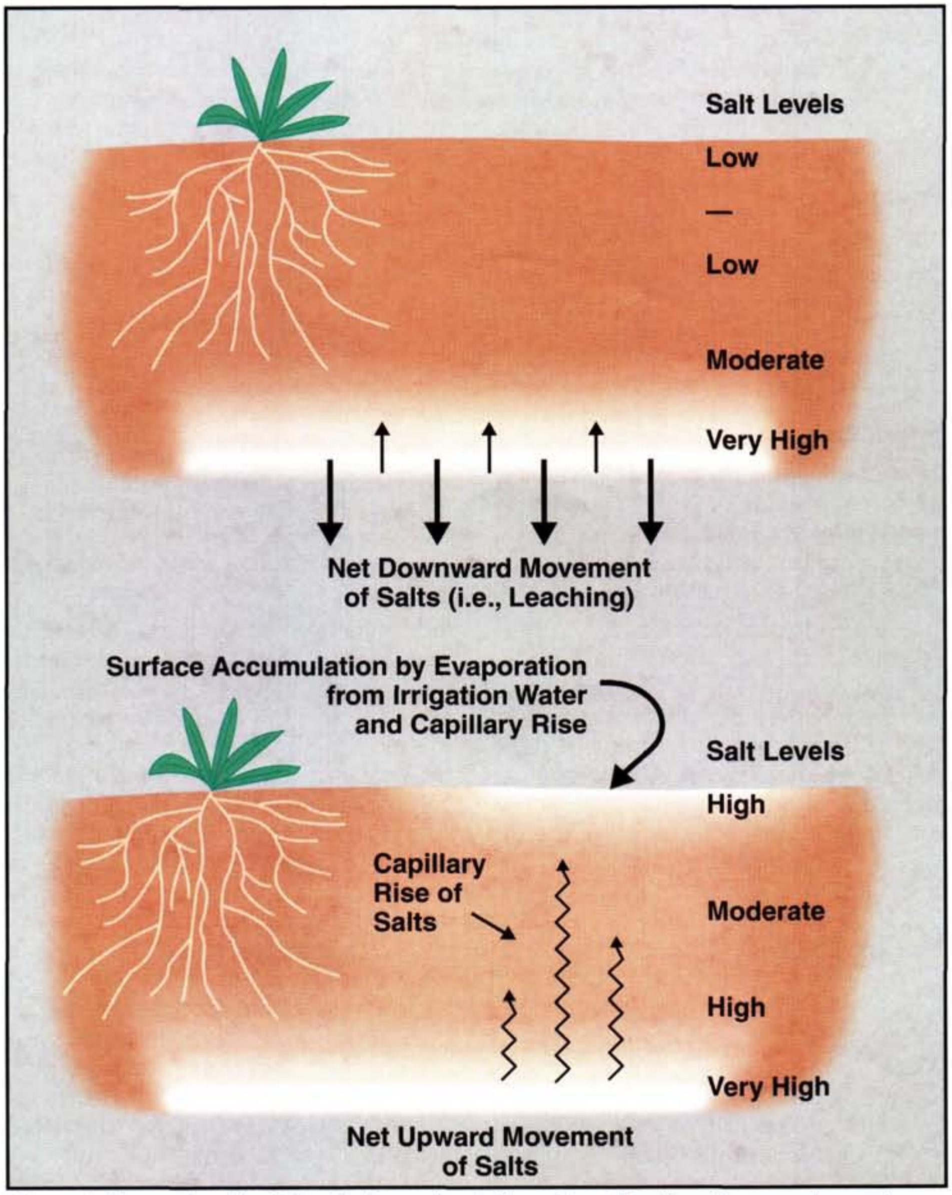


Figure 1. Examples of salt levels throughout the soil profile. Top: Represents good leaching conditions with adequate leaching requirement (LR) applied. Bottom: Represents what happens when insufficient water is applied in midsummer with high evapotranspiration (ET) conditions.

to rise by capillary action and by plant transpiration if the leaching fraction is less than ET (Table 1). Salts then will move back into the rootzone and start to accumulate near the surface (Figure 1).

Capillary rise of salts will be more rapid on fine-textured soils than sands because fine-textured soils contain more micropores. Other factors that increase capillary rise of salts are low leaching rates, high ET conditions, and a high water table.

6. *Water table location* is another soil factor that influences salinity control. Turfgrass soils often contain a layer in the profile that inhibits water percolation or drainage. This can create a temporary *perched water table* as water flow is slowed or stopped when the wetting front reaches this layer. Salts then will accumulate above the layer and can rise to the surface whenever low leaching rates and/or high ET occurs. The quantity of water needed to cause net salt leaching in low-ET conditions may not be adequate for leaching under hot, dry situations (Table 1).

Subsurface layers that are 1 to 3 feet below the surface are often overlooked in arid or semi-arid regions where heavy rainfall events that are sufficient to pond water up to the soil surface are rare. But, these *hidden layers* can contribute to major salt accumulation so that when conditions favor capillary rise, the resulting water has very high salinity.

In many turfgrass soils, the layer that limits water percolation/drainage has few macropores. Cultivation depth must penetrate completely through the layer to be very useful for maintaining water flow when excess water application occurs by irrigation or rainfall.

Another type of *perched water table* is found in many high sand content constructed profiles, such as those built with the USGA green construction method. In this case, ample macropores are present but sufficient water is required to break the perched water tension and to initiate rapid drainage or *flushing* of the rootzone. During summer months when ET is high, salts above the perched water table zone may start to rise toward the roots and soil surface if thorough leaching is not practiced. Prolonged drought, high temperatures, and dry, windy conditions can escalate this capillary rise of concentrated salts.

In addition to perched water tables, sometimes the *natural water table level* is near the surface. The *capillary fringe* of semi-saturated water conditions above a free water table is usually 2 to 8 inches for sands and 8 to 12 inches for fine-textured soils. However, high ET conditions and limited leaching can cause salts to rise well above these distances over time. Capillary rise on fine-textured soils is still strongly controlled by climatic conditions (i.e., ET) at a depth of 2.5 to 3.0 feet and possibly down to about 5.0 feet.

Another problem with a water table relatively near the surface occurs when poor irrigation water quality requires a high leaching fraction. Over time, the water table may rise even higher and cause massive salinization of the rootzone. On sites where shallow water tables may rise, the turf manager should investigate means to lower the water table.

7. *Total pore space (pore volume, PV)* of a soil also influences salt leaching. Soils with higher PV require more water to leach the same quantity of salts.[7] The PV range of sands, loams, and clays is about 35% to 40%, 40% to 50%, and 45% to 55%, respectively. For a soil depth of 12 inches, 1 PV of applied water would represent 4.6 to 4.8 (sands), 4.8 to 6.0 (loams), and 5.4 to 6.6 (clays) inches of irrigation. Thus, more water is required to leach fine-textured soils than sands.

Water and Irrigation Factors

1. *Irrigation water quality* strongly influences the quantity of water needed to leach salts, with more water required as water salinity level increases. The *leaching requirement (LR)* is the minimum amount of water that must pass through the rootzone to keep salts (i.e., keep salts moving) within an acceptable range. Thus, LR is used for *maintenance leaching* where sufficient water is applied to maintain soil salinity at an acceptable level.

Several methods are used to determine the LR[1]. The method of Rhoades[6] provides a good approximation and is based on the irrigation water salinity level (EC_w, dSm^{-1}) and grass salinity tolerance using the *threshold* EC_e (the soil salinity, EC_e, at which growth declines compared to growth under non-saline conditions), where (see Table 2):

$$LR = \frac{EC_w}{5EC_e - EC_w} = \text{percent extra water above ET to leach salts}$$

Assuming the initial rootzone salinity level is acceptable, *when the LR is not sufficient to maintain salt leaching, two adverse salt responses occur:* a) first, salts applied in the irrigation water start to accumulate within the surface few inches, and b) capillary rise of salts from deeper in the soil and beyond the rootzone starts to bring salts back into the rootzone (Figure 1). Oftentimes, this zone of accumulated salts has a very high EC_e and upon reaching the lower rootzone can induce rapid salinity stress. When this happens, alleviating salinity stress (physiological drought with reduced water uptake for transpirational cooling) now requires much more applied water than the LR amount because it is a reclamation problem (as well as a serious threat to job security).

This scenario is most often observed on high sand bentgrass/*Poa annua* golf greens irrigated with water of medium to high salinity. In addition, turf managers who apply water with relatively low total salt levels (500 to 600 ppm) may experience this situation under extreme environmental conditions. The turf manager may be achieving adequate leaching in the spring and early summer using ample irrigation or rainfall. However, by midsummer, three events can impede leaching: a) hot, dry weather increases the ET and increases the quantity of irrigation needed just to maintain soil moisture (Table 1); b) turf roots start to die back; and c) turf managers shift to light, more frequent irrigation which does not supply sufficient water for leaching. The process depicted in Figure 1 (bottom) is initiated.

Light, frequent irrigation increases salt accumulation in the surface zone, where most of the roots are located. Also, salts rise by capillary action into the rootzone from: a) a high salt zone common in pushup greens, or b) the perched water of a USGA green that is not adequately flushed. Injury normally appears on the most elevated, open, and exposed greens where high ET conditions prevail due to high solar radiation and wind movement. Since the bentgrass/*Poa annua* is now under high temperature stress, the salt-induced drought is a serious additional stress.

By being aware of this sequence of events, the turf manager can apply an extra leaching irrigation every 1 to 4 weeks to avoid salt accumulation. The frequency between leaching events will vary depending upon water quality, rootzone depth, and the threshold EC of individual turfgrass varieties. The leaching frequency and threshold EC can be accurately determined by use of an inexpensive portable EC meter.[10] *EC at the soil surface and throughout the profile can be monitored regularly (daily if necessary) and, as the threshold EC is reached, leaching can be initiated to purge the perched water table.*

A practical method to assure that the perched water table has been completely purged is to locate the outflow drain line exiting the green cavity and install an inspection port. Drainage flow can be observed, and samples collected and tested with the portable (EC) meter. Once the EC of the drainage water is at or near the EC of the irrigation water, then leaching has been completed. Although native soils may require 1 to 4 weeks to reclaim, well-drained sand constructed putting green rootzones with perched water tables can often be reclaimed in 1 to 3 days.

Between leaching events, additional irrigation may be needed on a light, frequent basis until turf roots regenerate, which may not occur on bentgrass/*Poa annua* greens until cooler weather arrives.

2. *Reclamation leaching* differs from the previous maintenance LR concept, which focused on maintaining salinity levels at an existing acceptable level. In reclamation, a higher quantity of water is required to decrease rootzone salinity to acceptable levels. Once this acceptable level is achieved, the LR irrigation approach (maintenance leaching) can be used, since it requires less extra water. The reclamation approach occurs in two primary situations in turfgrass management: a) when a seriously salt-affected soil (e.g., highly saline and/or sodic condition) must be leached of excess salts before grass can be established, and b) when a turf manager has not main-

Table 2
Determination of the Maintenance Leaching Requirement (LR) (after Rhoades[6])

Concept: Once the soil salinity level in the turfgrass rootzone is at an acceptable or desirable level, the leaching requirement (LR) approach is used to maintain this level. The "leaching requirement" (LR) is the minimum amount of water that passes through the rootzone to control salts within an acceptable range. A good formula to determine LR is:

$$LR = \frac{EC_w}{5EC_e - EC_w}$$

where EC_w = irrigation water salinity (dSm^{-1})
EC_e = threshold soil salinity at which growth starts to decline for the turfgrass on the site. Carrow and Duncan[1] has an extensive listing.

Example: For turfgrass with a threshold EC_e of 6 dSm^{-1} and irrigation water that has an EC_w = 2 dSm^{-1}.

$$LR = \frac{(2)}{5(6) - 2} = 0.0714$$

which means that the LR is 7.1% more irrigation water volume than that needed to meet ET needs. Thus, if irrigation of 0.50 inches of water is required to replace soil moisture lost by ET, an additional 7.1% or $(0.50 \times 0.07) = 0.035$ inches of water would be required for a total of 0.535 inches to maintain a particular salinity level. It should be noted that a *more saline irrigation water* with higher EC_w or a *less-salt-tolerant grass* would *increase the LR*.

tained an adequate LR and the rootzone has increased in salinity to severe levels. This latter situation is most likely to occur during hot, dry summers when ET rates have increased, but the total water applied for ET + LR has not been adjusted to keep up with actual ET. Cool-season turfgrasses subjected to this sudden and intense salinity shock (a combination of drought, high temperature, and greater wear stresses from slower growth, all induced by salts) often do not survive. The take-home lesson for this type of stress is *prevention* by adequate, continual application of sufficient LR water to keep salts moving downward and away from the turf root system.

Reclamation leaching needs can be estimated by the procedure presented by Rhoades and Loveday[7] (Table 3). This procedure takes into consideration: depth of leaching, desired EC_e, current or initial EC_e leaching water quality, and soil type.

Once the depth of water (D_w) required for leaching is determined in terms of "inches of water to apply," then *the influence of rainfall* can be factored into the situation. For example, in Table 3, the situation indicates that 10.4 inches of water would be required for reclamation where the leaching water has an $EC_w = 1.5$ dSm^{-1}. If an EC_w of 0.10 dSm^{-1} is used for rainfall, then the $D_w = 3.32$ inches of rain to achieve the same degree of leaching as 10.4 inches of $EC_w = 1.5$ dSm^{-1} irrigation water.

When comparing the D_w leaching needs using an irrigation water with $EC_w = 1.5$ dSm^{-1} quality versus rainfall (Table 3), it is clear that water quality has a similar important influence on reclamation leaching and on maintenance LR. A second implication is that turfgrass managers should use their rainfall periods to maximize leaching. For example, following a good rainfall period when substantial salt leaching has occurred and has adequately leached salts below the rootzone, do not stop a maintenance LR program to conserve water. Instead, the LR fraction should be continued to prevent salts from rising back into the rootzone. If resalinization of the rootzone is allowed to occur, a reclamation leaching with substantially more water is required to achieve what the rainfall event had accomplished.

In the previous discussions on maintenance LR and reclamation leaching needs, the emphasis has been on total soluble salts and their removal. Normally, a site contains an array of soluble salts. However, if the water quality test and soil tests indicate that Cl is the dominant salt ion, the amount of water required for leaching this ion is less than for other total soluble salts due to the high mobility of Cl. As an approximation, leaching needs could be reduced by about one-third for a trial period and then readjusted based on the results. Reduced leaf tip burn symptoms on landscape plants would be a good indication of your leaching success.

A second means of estimating reclamation leaching is noted in Table 4. This method considers soil type, percent of total salts to be leached, and depth of leaching. It does not, however, take into account leaching water quality.

3. *Irrigation scheduling for effective leaching.* A highly efficient, well-zoned irrigation system is a priority for effective leaching of salts. The method of water application, even with a well-designed system, though, influences the quantity of water required for effective

Table 3
Determining Reclamation Leaching Needs
(adapted after Rhoades and Loveday[7])*

The following equation is used:

$$D_w = k \times D_s \times \frac{EC_{eo} - EC_w}{EC_e - EC_w}$$

where: D_w = depth of water to apply for leaching (feet)
D_s = depth of soil to be reclaimed or leached (feet)
EC_e = final soil salinity desired. *This value is usually the threshold EC_e for the turfgrass being used or somewhat less than the threshold EC_e*
EC_{eo} = initial or original soil salinity
EC_w = salinity of irrigation water used for leaching
k = factor that varies with soil type and water application method (efficiency of irrigation system)

For sprinkler irrigation applied by pulse irrigation to allow drainage ranging from 1 to 2 hours (sands) to 2 to 8 hours (fine-textured soils) between a pulse irrigation event until the total quantity of water is applied:

$k = 0.05$ for high sand content each with > 95% sand content (i.e., < 5% silt + clay content)

$k = 0.10$ for all other soils

For continuous ponding or continuous sprinkler irrigation applied to keep the soils saturated during leaching:

$k = 0.45$ for organic soils

$k = 0.30$ for fine-textured soils

$k = 0.10$ for sandy soils

Example: A high-sand-content golf green with an initial soil EC = 8.0 dSm^{-1} (i.e., EC_{eo}) and the turf manager desires a final soil EC = 2.0 dSm^{-1} (i.e., EC_e). The irrigation water used for leaching has an EC_w of 1.50 dSm^{-1} and the desired leaching depth (D_s) is 16 in. to reach the drain tile, where 16 in. = 1.33 ft.

$$D_w = k \times D_s \times \frac{EC_{eo} - EC_w}{EC_e - EC_w}$$

= 0.86 ft. of leaching water

= 10.4 inches of water

- *If the leaching water quality was better* (for example, $EC_w = 1.0$ dSm^{-1}), then: *$D_w = 5.6$ inches of water.*
- *If the final salinity level (EC_e) was higher* because of a more salt-tolerant grass (for example, $EC_e = 4.0$ dSm^{-1}), then: *$D_w = 2.6$ inches of water.*
- *If the green was a pushup green* with < 95% sand where k = 0.10, then: *$D_w = 20.7$ inches of water.*

*Adjustments in the k value for high-sand-content greens are based on experience of Carrow, Huck, and Duncan.

Table 4
Estimated Reclamation Leaching Needs Based on Soil Type*

An alternative to determining "Reclamation Leaching Needs" by the methods of Rhoades and Loveday[7] presented in Table 1 is based on the soil total pore space or pore volume (PV)

Basic Relationships:

Soil Type	PV (%)	Inches of Water Per 12 Inches Soil to Fill PV
Sand (< 95% sand content)	35	(.35)(12) = 4.20
Loamy sand	38	4.56
Sandy loam	42	5.04
Loams	45	5.40
Clays	50	6.00

PV Equivalent of Water Required to Leach 70% of Total Soluble Salts:

Sand (< 95% sand content)	= 0.70
Loamy sand	= 1.00
Sandy loam	= 1.00-1.25**
Loams	= 1.50-2.50**
Clays	= 2.50-4.00**

Example: A high-sand-content golf green with leaching desired to a depth of 16 in. to reach the tile lines. PV = 35% = 4.20 in. of water per 12 in. of soil depth, thus for 16 in.:

(4.20 in. of water) $\times \frac{16}{12}$ = 5.60 in. of water to fill the PV to 16 in.

For a high-sand-content green (> 95% sand), a PV equivalent of 0.70 is used to achieve approximately 70% leaching of total soluble salts, therefore:

(5.60 in. of water)(0.70) = *3.92 in. of water should be applied to achieve 70% leaching of salts across the 16 in. soil depth*

If only 50% salt leaching is required, adjust the PV equivalent, for example:

(5.60 in. of water)$(0.70 \times \frac{50\%}{70\%})$= 2.80 in. of water

If a pushup green is present, then PV equivalent becomes 1.25 (assuming a sandy loam, 2:1 clay) and the inches of water per 12 in. soil depth is 5.04 in. Then, for 70% leaching of salts:

(5.04 in. of water) $\times \frac{16}{12}$ = 6.72 in. of water to fill the PV to 16 in.

(6.72 in. of water)(1.25) = *8.4 in. of water* applied

*Rhoades and Loveday[7]. PV equivalent values are adjusted by Carrow, Huck, and Duncan based on experience.

**For 2:1 shrink/swell cracking clays, use the higher value, and for 1:1 non-cracking clays, use the lower value.

leaching.[4,7] Potential means to apply water for reclamation or maintenance LR needs are:

• *Heavy continuous water application by sprinklers* where the soil is essentially saturated or near saturation throughout the leaching period. This would be similar to soil conditions that could occur from *heavy rainfall* or *continuous ponding* of water above the soil surface. Water application by any of these methods requires the most water to achieve leaching, especially on fine-textured soils. Under *saturated flow* or near-saturated conditions, water flow is primarily through the larger macropores, and water does not effectively leach between the macropores, i.e., within soil aggregates or micropore areas. On high sand content soils, which do not form aggregates but are more single grain sand in structure, saturated flow works better than on fine-textured soils.

• *Pulse irrigation* occurs when water is applied in increments of 0.20 to 0.33 inches, with a time interval before the next pulse, and this cycle is repeated until the desired quantity of water is applied. Runoff from the soil surface is minimized. Generally, the time interval between pulses is ½ to 1 hour (sands), 1 to 2 hours (loamy sands, sandy loams), 2 to 4 hours (loams), and 3 to 6 hours (clays). A good surface cultivation program, to maintain adequate water infiltration without runoff, will reduce the time required between irrigation pulses.

With this type of irrigation, water flow within the soil is primarily *unsaturated flow,* which moves as a more uniform wetting front downward through the soil profile. Water movement occurs more in the micropores than in the macropores; therefore, leaching is more effective. Wetting agents often aid in maintaining a more uniform wetting front for leaching. In fact, one-third to one-half the water is required for pulse irrigation versus heavy continuous irrigation. A *light, continuous rainfall* can simulate pulse irrigation as long as the rainfall rate is less than the saturated water hydraulic conductivity of the soil (i.e., the infiltration rate when the soil is saturated).

On *high sand content greens*, the surface 1- to 2-inch zone is where the water movement rate generally is the lowest. If a good maintenance LR program is followed, such that salts have not been allowed to accumulate in the surface, periodic surface cultivation to keep vertical "macropores" or holes open across this zone is beneficial to allow rapid water infiltration during heavier rains. Also, maintaining high infiltration rates across the surface zone makes irrigation programming easier, and a pulse approach may not be necessary under these conditions.

If salts are allowed to accumulate at the surface, however, due to insufficient LR, then a pulse approach is necessary. Attempting to implement a heavy leaching event will result in most of the water flowing through the cultivation holes that penetrate through the salt-troubled surface zone. A pulse approach is better because it allows leaching between holes where salt has accumulated.

4. *Irrigation scheduling to avoid soggy soils is a challenge, especially for fine-textured soils.* When salts accumulate in the surface zone and/ or deeper in the rootzone to a point where reclamation leaching is required: a) a good surface cultivation program is necessary to allow rapid infiltration; b) deep cultivation is needed to allow water percolation. Also, this will allow better water penetration during heavy rains, and c) additional drainage, such as tile lines, may be needed to keep the salts moving away from the rootzone.

Reclamation leaching will normally result in temporary soggy conditions for fine-textured soils due to the intensive nature of leaching. Thus, the best way to avoid soggy soils is to avoid being in a reclamation condition. This is achieved by a good routine maintenance LR program that continuously keeps salts leached out of the rootzone. Maintenance LR programs require much less water than reclamation situations and therefore are less likely to create waterlogged or soggy soils.

Following are guidelines for scheduling routine irrigation events on fine-textured soils that include the LR as well as ET replacement components.

• When the irrigation water is moderate to high in salinity, *schedule irrigation so that the bottom one-third of the rootzone is subjected to only moderate moisture stress.* Grasses extract water primarily from the surface two-thirds of their rootzone until the moisture in this zone becomes limited. Since salts concentrate in the soil solution with soil drying, sites irrigated with saline water should be irrigated more frequently (i.e., with less dry-down to induce moisture stress) than non-saline sites. Thus, if a non-saline area would receive irrigation every 7 days with water to replace the 7-day ET loss, then a saline site may need to be irrigated on day 5, with the 5-day ET replacement water plus the additional LR.

• *When irrigation is applied, pulse scheduling is preferred to achieve better leaching and avoid soggy soils.* The interval between irrigation pulses was noted previously as 2 to 4 hours (loams) and 3 to 6 hours (clays), with the longer interval required on compaced sites or Na^+-affected soils (i.e., sodic soils or soils starting to become sodic). Such intervals may only allow 2 to 3 pulse applications per evening at 0.20 to 0.33 inches per application. Thus, it may require two or more consecutive evenings to apply sufficient total water (i.e., ET + LR). Another possibility is to schedule pulses during the daytime when the golf course is closed (often Mondays) as well as during the evenings. For example, from Sunday evening through early Tuesday morning would provide a 32-hour period for pulse irrigation. Consideration for traffic restrictions (golf cars and maintenance equipment) in fine-textured soil areas (fairways and roughs) may be necessary for 1 to 3 days following a heavy leaching.

• *The use of the LR fraction as part of normal irrigation should be a continuous, routine practice,* especially: a) when the irrigation water quality is high in total soluble salts or Na, b) on fine-textured soils but particularly 2:1 clay types, and c) on any sodic or presodic soil. A common reason for resalinization of rootzones or ineffective leaching of total salts/Na is the elimination of the LR application after a rainfall period, followed by redistribution of salts.

• *Application of the LR should start early in the growing season,* if soil salinity is at an acceptable level.[9] If not, then reclamation leaching should be instituted until the soil salinity level becomes acceptable. Thereafter, the LR application should be initiated and maintained. This will prevent the advent of salts accumulating to harmful levels during high-ET summer months when reclamation leaching is very difficult.

5. *Irrigation water quantity* obviously influences leaching effectiveness. Up to this point, we have noted that the *Irrigation Quantity (IQ)* for routine irrigation consists of replacement of soil moisture lost by evapotranspiration (ET) plus LR. However, a third factor influences total irrigation needs. This factor is nonuniformity (efficiency) of the irrigation system. Water application rate must be increased by a *Scheduling Coefficient (SC)* to account for nonuniform water application. Thus, total irrigation quantity required includes:

$$IQ = SC(ET + LR) = \text{inches of irrigation water to apply}$$

where the SC may be a factor such as 1.1 to adjust for nonuniformity of the irrigation system.

On turfgrass sites receiving saline irrigation water, identifying a correct IQ and adjusting the value as the weather changes is essential for good salinity management and high turfgrass performance. *Once an acceptable soil salinity has been achieved, the primary cause of resalinization is inadequate water application (i.e., IQ).* Turfgrass managers are strongly encouraged to think in terms of *quantity of water applied* rather than *minutes of irrigation time.* Salt leaching requires an adequate quantity of water and only by monitoring the quantity of applied water can there be confidence of achieving long-term maintenance leaching.

Huck[5] presents an excellent discussion on *irrigation system efficiency* and design considerations. Nonuniformity of water application may result from several factors, including: a) improper sprinkler head spacing for wind and water pressure conditions, including hydraulic losses from friction and elevation differences; b) incorrect sprinkler or nozzle selection; and c) poor system maintenance such as leakage, sprinkler/nozzle wear, and mixing of nozzles. Adjustments in these factors during design and, if necessary, after installation can improve delivery efficiency and enhance leaching of salts.

Where irrigation uniformity is lacking and cannot be improved due to a poor irrigation system, the use of portable hose-end sprinklers can be an effective method to apply additional water in areas lacking coverage. Ultra-low precipitation rate models are most effective. They are normally placed in the problem area and allowed to operate from dusk until dawn.

Site-specific water management is important for salinity management and to avoid waterlogged areas. Some examples are: a) dual irrigation systems for greens and the surrounds. The ideal system would include the ability to irrigate greens with a different, higher-quality water source, but dual systems, even with the same water source, allow for better scheduling. b) Mounds, berms, bunker tongues, and steep slopes present a problem. West- and south-facing exposures in the northern hemisphere are especially vulnerable to high-ET losses and salt accumulation. On facilities with highly saline irrigation water, irrigation designers should consider how to effectively irrigate water on these peripheral areas. c) On fairways with south-facing slopes where ET is normally greater, zones should be designed to accommodate this need. Portable sprinklers can also be used effectively to specifically leach putting green surfaces and avoid flooding bunkers or saturating green surrounds during the leaching process.[11]

6. *Infiltration, percolation, and drainage of applied water is essential for salt leaching.* The soil profile on each site on a golf course should be assessed in terms of any barriers to water movement, starting with infiltration. Carrow and Duncan[1] present the most common soil physical problems on sandy and fine-textured soils that impede water movement downward through the whole profile. Appropriate cultivation, soil modification, and drainage operations should be conducted to ensure that water (and salts) are able to move downward. Drainage and salt disposal options should also be considered as part of an overall water management plan.[1]

7. *Water and soil amendments* need to be considered to ensure good water infiltration and to facilitate alleviation of sodic conditions on sodic sites. The various situations requiring irrigation water treatment have been discussed by Carrow et al[2] and Carrow and Duncan[1]. Proper amendment selection (for water and soil), application method, and rates are all very important, especially when sodic conditions might occur or are already present. Due to the detailed nature of these subjects, they are beyond the scope of this article. However, treatment of irrigation water or the soil with amendments will be ineffective for alleviating salt problems unless a good leaching program is followed.

Grass Type

Salinity management is influenced by the type of grass, salt types present, soil factors, and water/irrigation factors.

1. *Salinity tolerance of the grass is the most important influence of grass species/cultivar in salinity management.* As demonstrated in the example in Table 1, the LR is influenced by the salinity level the grass can tolerate. The threshold EC_e is used as a guide and is defined as the soil salinity at which growth starts to decline compared to a nonsaline condition.[1] Grasses with moderate to very high salinity tolerance can be irrigated to maintain the soil salinity at greater than the threshold EC_e, perhaps at EC_e of 25% or 50% growth reduction. The grass vigor and ability to withstand wear from traffic should be considered in selecting the appropriate maintenance EC_e.

2. *Turfgrass rooting depth impacts salinity management.* Provided that adequate soil moisture is present in the lower one-third of the root system to avoid salt concentration (i.e., soil moisture is about field capacity in this zone), turfgrass growth is related to average rootzone EC_e, regardless of the salt distribution with in the rootzone. Thus, when monitoring soil EC_e by depth within the rootzone, the average EC_e is the value used to compare with the turfgrass salinity tolerance level selected, such as EC_e for 25% growth reduction.

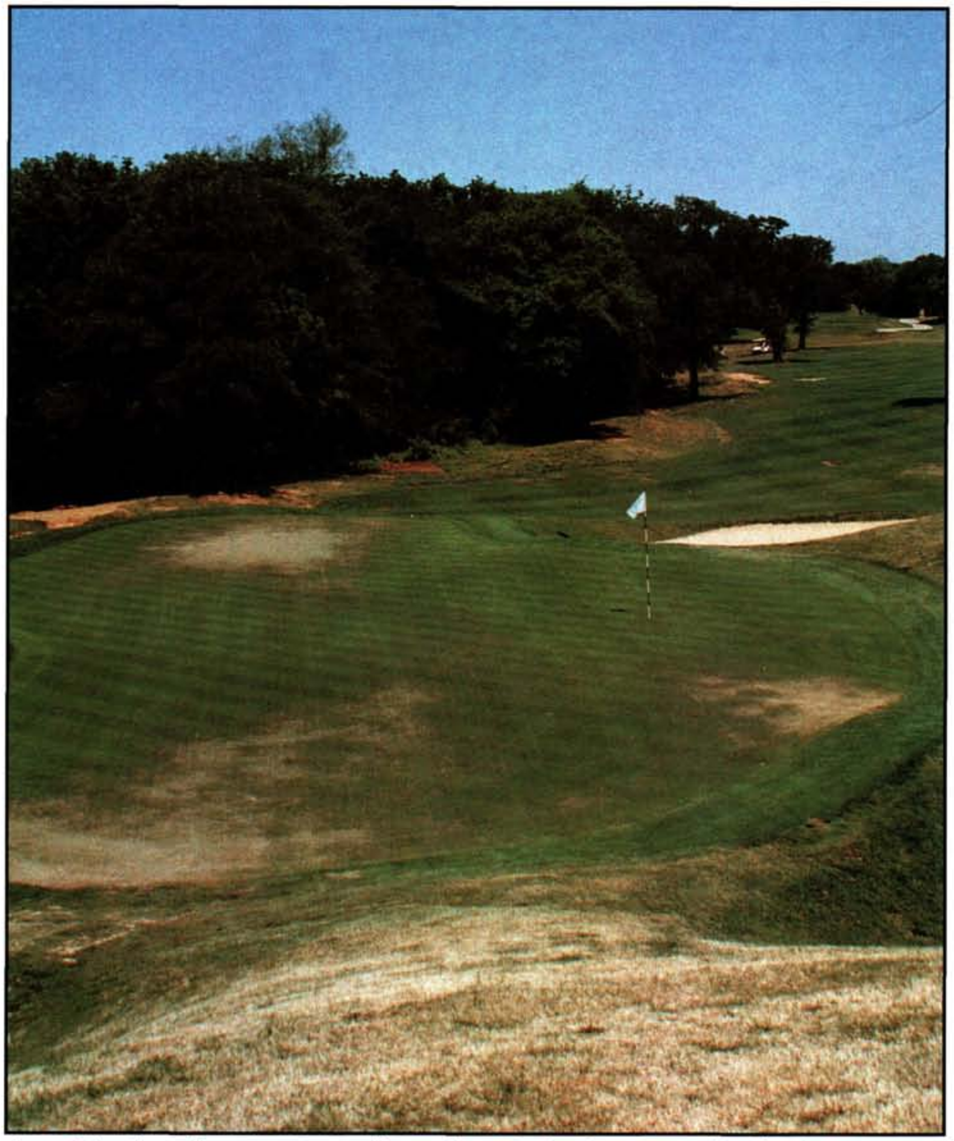
The effects of high salt levels in the irrigation water are obvious on this pine tree.

Especially with high-saline irrigation water, irrigation events should be scheduled to avoid depletion of soil moisture within the lower one-third of the rootzone. Otherwise, serious salt stress will occur. Irrigation events need to be scheduled more often than on a similar nonsaline site, with the IQ dependent on ET losses since the last irrigation plus the LR. Also, a deep-rooted turfgrass will allow for more days between irrigation events than a shallow-rooted grass.

Rooting depth determines the rootzone that must be leached by the LR. This is the D_s (depth of soil) to be reclaimed or leached in Table 2 and the leaching depth in Table 3.

Monitoring Soil Salinity

Monitoring soil salinity by soil depth is critical for assessing the success of a salinity management program.[1,4] The *soil depth* for monitoring is determined by the rootzone depth. Soil EC_e values within the surface one-third and bottom one-third of the rootzone are the most important. Soil sampling procedures and methods for monitoring field salinity are given by Carrow and



A combination of poor water quality and poor irrigation system distribution has caused severe salt stress injury on this green and surrounds.

Duncan[1] and Hanson et al.[4] On sites with an ongoing salinity problem, obtaining instruments to determine soil salinity in-situ should be considered. J. D. Rhoades of the U.S. Salinity Laboratory has developed two procedures[4]: a) the four-electrode salinity probe, which can be used to measure salt levels at different depths, and b) the electromagnetic conductivity meter for rapid surface measurement, including down to a depth of 3 to 4 feet. Vermeulen[10] also discusses an inexpensive conductivity meter useful for both monitoring drainage water and soil salinity in the field.

Summary

Development of a salinity management program requires the consideration of a number of soil, water, and grass factors. *Leaching of salts is the most important component of any salinity management program.* Unless salts are consistently leached from the rootzone, resalinization will occur from irrigation salt additions and capillary movement from below the rootzone. The peak time of year for massive resalinization and the accompanying decline of turf performance is often mid- to late summer. This is the least favorable time to experience salinity stress and the most difficult time to institute reclamation leaching. *The best option for managing salinity is a continuous, routine maintenance leaching program using an adequate LR.* The most common reason for not applying sufficient irrigation water volume for leaching of salts is underestimating the daily ET requirement for replacement of soil moisture lost by ET, rather than underestimating the LR fraction of total irrigation needed.

Also, understand that many of the scientific principles outlined in this text were first researched and developed for agricultural crop production situations, where daily equipment and pedestrian traffic, as well as maintaining a playing surface, can be controlled or are not of concern! Therefore, golfers need to understand that in implementing a salinity control program, playing conditions will need to be compromised from time to time.

References

[1]Carrow, R. N., and R. R. Duncan. 1998. Salt-affected turfgrass sites: assessment and management. Ann Arbor Press, Chelsea, Mich.

[2]Carrow, R. N., R. R. Duncan, and M. Huck. 1999. Treating the cause, not the symptoms: irrigation water treatment for better infiltration. USGA Green Section Record. 37(6): 11-15.

[3]Duncan, R. R., R. N. Carrow, and M. Huck. 2000. Understanding water quality and guidelines to management. USGA Green Section Record. Vol. 38(5):14-24.

[4]Hanson, B., S. R. Grattan, and A. Fulton. 1999. Agricultural salinity and drainage. Div. of Agric. and Nat. Res. Pub. 3375. Univ. of Calif., Davis, Calif.

[5]Huck, M. 1997. Irrigation design, rocket science, and the SPACE program. USGA Green Section Record. 35(1):1-7.

[6]Rhoades, J. D. 1974. Drainage for salinity control. *In* J. van Schilfgaarde (ed.). Drainage for Agriculture. Agronomy Monograph No. 17. Amer. Soc. of Agron., Madison, Wis.

[7]Rhoades, J. D., and J. Loveday. 1990. Salinity in irrigated agriculture. *In* B. A. Stewart and D. R. Nielson (eds.). Irrigation of Agricultural Crops. Agronomy No. 30. Amer. Soc. of Agron., Madison, Wis.

[8]Skaggs, R. W., and J. van Schilfgaarde (eds.). 1999. Agricultural Drainage. Agronomy No. 38. Amer. Soc. of Agron., Madison, Wis.

[9]Yenny, Reed. 1994. Salinity management. USGA Green Section Record, Vol. 32(6): 7-10.

[10]Vermeulen, P. H. 1997. Knowing when to over-irrigate. USGA Green Section Record. Vol. 35(5):16.

[11]Gross, P. 1999. Flood your greens — not your bunkers. USGA Green Section Record. Vol. 37(3):26.

DR. RON R. DUNCAN *(turfgrass genetics/breeding, stress physiology) and* DR. ROBERT N. CARROW *(turfgrass stress physiology and soil physical and chemical stresses) are research scientists in the Crop and Soil Science Department, University of Georgia, Georgia Experimental Station at Griffin.* MIKE HUCK *is an agronomist with the USGA Green Section Southwest Region.*