ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA
College of Agriculture and Life Sciences
AZ1527 August 2010

Factors Contributing to Development of Salinity Problems in Turf

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Introduction

Professional turfgrass managers in many parts of Arizona are confronted with a growing number of management challenges related to excess levels of salinity and/or sodium in soils. The consequences of excess salinity and/or sodium are poor turf performance, reduced water infiltration and the appearance of a new turf disease, rapid blight (*Labyrinthula terrestris*). Salinity related problems could be attributed to factors such as limited water duties or the use of reclaimed water; however, a detailed assessment of the current situation suggests that several factors contribute to the current problems. This report reviews several of the more important factors contributing to salinity related problems in Arizona turfgrass systems, and then concludes with a brief discussion of possible solutions to these problems.

Causes of Salinity Related Problems

There are two main causes of salt problems in turf production systems: 1) inadequate leaching and 2) inherited salinity. Inadequate leaching is responsible for the majority of salinity problems (Fig. 1). Irrigation continually adds salts to soils, and salts will accumulate to damaging or toxic levels if a process referred to as leaching does not remove them. Leaching occurs when a portion of applied water (precipitation or irrigation water) percolates below the root zone and thus is no longer available for plant uptake. This leachate carries away the detrimental salts. When the water supply for irrigation is insufficient to support proper leaching, salinity levels rise and eventually turf performance and/or soil structure declines.

Inherited salinity problems typically arise when construction activities such as excavation and soil transport/replacement (e.g., for golf courses or adjacent buildings) bring high salinity soils to the surface where they serve as the root zone for turfgrass (Fig. 2). Managers of such facilities are confronted with high salinity conditions almost immediately. Inherited salinity problems are most prevalent in turf facilities constructed on former agricultural soils where past irrigation leaching activities resulted in salty subsurface soil horizons.

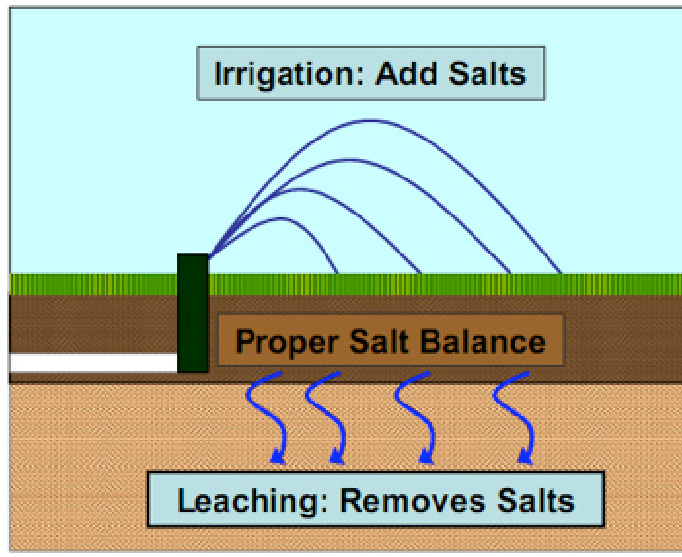


Figure 1. Water management regulates the salt balance of soils supporting turfgrass. Irrigation water continually adds salts to soil. Water in excess of evapotranspiration is required to facilitate deep percolation or leaching which removes excess salts, helping to maintain the proper salt balance in the root zone.

Figure 2. Golf course construction activities can unearth and bring to the surface salty subsoils leading to immediate salinity related problems.

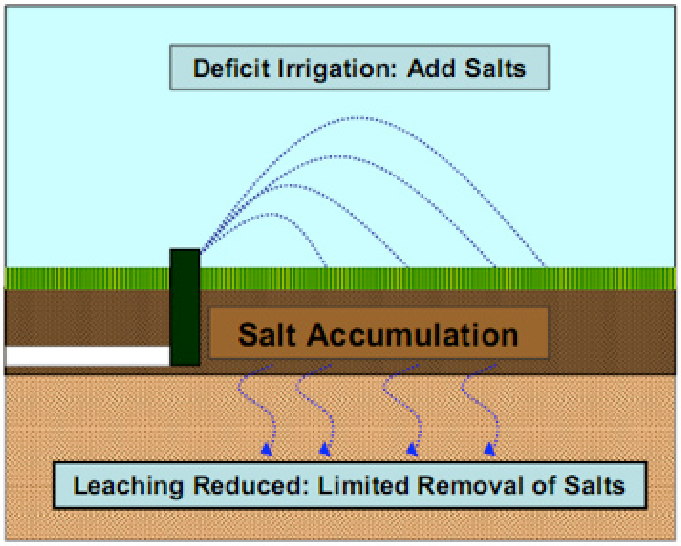


Figure 3. Deficit irrigation regimes develop when the amount of water received from irrigation and precipitation is insufficient to facilitate the level of leaching required to keep salinity levels at acceptable and stable levels in the root zone. Salts accumulate in the root zone and eventually reduce turf performance and damage soil structure.

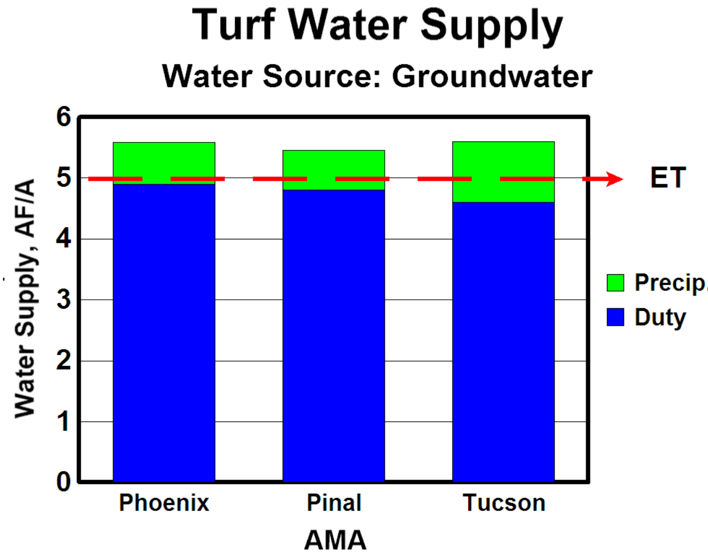


Figure 4. Potential water supply for turf irrigated with groundwater in the Phoenix, Pinal and Tucson Active Management Areas (AMA). Water supply consists of the water duty (amount of groundwater that can be used for irrigation; blue bar) and the average precipitation (green bar) for each AMA. Evapotranspiration (ET) of year round turf (red arrow) is similar in each AMA and exceeds the water duty.

Factors Contributing To Salinity Related Problems

Deficit irrigation is the cause of most salinity related problems in the Arizona turf industry. A deficit irrigation regime is defined as one in which water applied to turfgrass via irrigation and precipitation is inadequate to maintain soil salinity at levels that support optimal turf performance (Fig. 3). Key factors contributing to the development of deficit irrigation regimes include water supply limitations (quantity and quality), irrigation system design and management, drought, and soil infiltration problems. Each of these factors is discussed in brief below.

Water Supply Limitations

For more than 20 years the Arizona Department of Water Resources (ADWR) has limited the supply of water for large turf facilities (> 10 acres of turf) using groundwater. These usage caps, referred to as water duties, are set at or below turf evapotranspiration (ET), forcing facilities that overseed to manage irrigation very carefully (Fig. 4). University of Arizona research indicates the present system of water duties may force turf facilities in the Phoenix area to utilize deficit irrigation regimes when factors such as precipitation, runoff and irrigation efficiency are properly considered (Brown, 2006).

Water Quality

Water quality issues add further to the potential for deficit irrigation. Turf facilities are being asked or mandated to use lower quality water. Lower quality water includes reclaimed water that generally carries higher levels of salinity and selected groundwater sources with salinity levels in excess of 1000 ppm. Turf facilities that use lower quality water must irrigate more heavily to ensure leaching is sufficient to maintain soil salinity at proper levels. There is a well established body of science that quantifies the amount of leaching required based on the salinity of the water supply and the salinity tolerance of the turfgrass species (e.g., Ayers and Westcot, 1989; Mass, 1984; Carrow and Duncan, 1998). For most low desert turf facilities, an additional three to six inches of water in excess of ET is required on an annual basis to accomplish leaching (Table 1). ADWR water duties increase if the salinity of the groundwater exceeds 1000 ppm, or if turf facilities blend reclaimed water with groundwater. Turf facilities must then determine how to apply this extra water in a manner that optimizes the functionality of the turf for recreational use.

Irrigation Management

Irrigation management clearly plays a role in the development of salinity related problems. Professional turf managers are continually adjusting irrigation regimes to meet the water needs of the turf while providing a functional or playable surface. Golf course superintendents and sports turf managers try to limit water applications to avoid excessive wetness and improve playability, which amplifies the impact of irrigation non-uniformity (Fig. 5), a key factor contributing to the development of salinity problems. Reducing irrigation rates to address the wet side of the precipitation distribution may produce deficit irrigation regimes in areas associated with the dry side of the distribution. Turf quality in the dry areas may improve and brown areas be avoided through hand watering or temporary use of portable sprinklers (Fig. 6), but adequate leaching may not be achieved.

Two other irrigation related factors that can lead to deficit irrigation regimes are: 1) not adequately understanding or knowing the local ET rate and 2) inaccurately estimating irrigation system precipitation rates. Many turf facilities have on-site weather stations to provide local ET information. These weather stations generate an estimate of environmental evaporative demand known as reference evapotranspiration

Table 1. Leaching requirements in inches/year for bermudagrass overseeded in winter with ryegrass and irrigated with water carrying the indicated level of salinity. Salinity is presented both in terms of electrical conductivity (ECw) and total dissolved salts (TDS). Assumes annual ET from year round turf is 60 inches/year.

Water Salinity		Leaching Requirement	Water Salinity		Leaching Requirement
ECw (dS/m)	TDS (ppm)	(in/yr)	ECw (dS/m)	TDS (ppm)	(in/yr)
0.2	140	0.4	2.2	1540	5.1
0.4	280	0.9	2.4	1680	5.6
0.6	420	1.3	2.6	1820	6.1
0.8	560	1.8	2.8	1960	6.7
1.0	700	2.2	3.0	2100	7.2
1.2	840	2.7	3.2	2240	7.7
1.4	980	3.2	3.4	2380	8.3
1.6	1120	3.6	3.6	2520	8.9
1.8	1260	4.1	3.8	2660	9.4
2.0	1400	4.6	4.0	2800	10.0

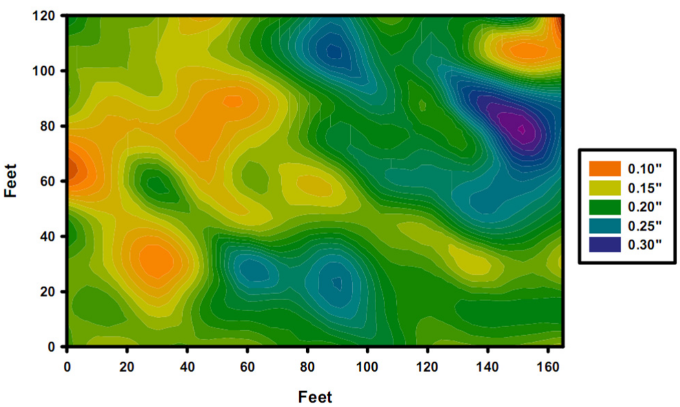


Figure 5. Map showing the distribution of water applied (in inches) on a fairway during a single irrigation event. Leaching may be insufficient to prevent the accumulation of salinity in areas that are chronically under watered as a result of non-uniform irrigation.

Figure 6. Portable, temporary sprinklers are commonly used to address dry areas in turf settings.

(ETos); University of Arizona research indicates that turfgrass uses between 80 and 83% of weather station ETos (Brown, et al., 2001). Managers providing significantly less than this amount may be imposing a deficit irrigation regime.

Many irrigation control systems estimate sprinkler precipitation rates using mathematical computations based on system pressure, head spacing, and nozzle size. Most independent evaluations reveal that computed precipitation rates overestimate the amount of water reaching the turf surface due to system leaks (e.g., around heads or connections), evaporation as water moves from the head to the turf, and spray drift caused by wind. Research is presently underway to quantify these irrigations losses for Arizona turf systems. In the interim facility managers should realize that computed precipitation rates are probably higher than the actual amount reaching the turf. The accuracy of computed precipitation rates can be assessed by using catch cans to capture the

Figure 7. Catch cans (lower right) are graduated plastic containers used to quantify the amount of irrigation. Photo shows catch cans set out in an array to assess the amount and uniformity of an irrigation event.

water applied in a timed irrigation event (Fig. 7). Multiple tests should be conducted to thoroughly compare and assess the computed precipitation rates which may change due to seasonal changes in wind, temperature, humidity, and system operating pressure.

Drought

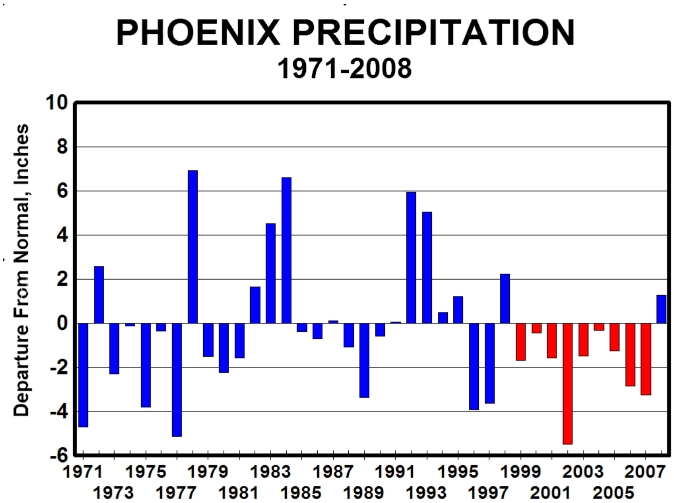
Arizona has been experiencing an extended drought during much of the current decade (Fig. 8a). In addition to reducing precipitation which lowers the available water supply for turf, drought also produces extended periods with lower humidity and less cloudiness. This can increase turf water use, making the water supply issue even more challenging. Rainfall, while quite variable over small distances, applies water more uniformly than most irrigation systems, so rain can generate a more uniform leaching event than an irrigation system. A key feature of the current drought is a reduction in the number of leaching months – months where precipitation exceeds ET. Winter is an efficient time to leach a turf facility because ET rates are low, and an ideal environment for leaching develops when precipitation exceeds ET for an extended period (e.g., a week or a month). Meteorological records show that Phoenix experienced only three "leaching months" during the past decade compared to four and ten in the previous two decades, respectively (Fig. 8b). It is very possible that the recent rise in salinity related problems in turf can be attributed in part to the current drought.

Infiltration

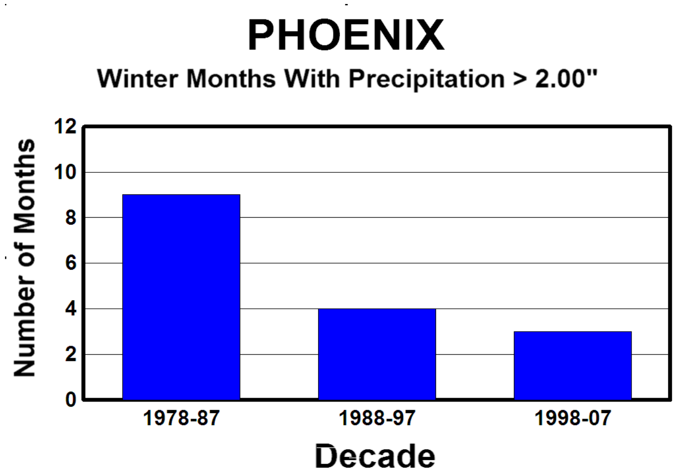
Deficit irrigation may also develop with properly designed irrigation regimes if applied water runs off due to poor infiltration. Factors that contribute to poor soil infiltration include compaction caused by traffic, soil type, poor soil structure, water quality, and irrigation rates that exceed the steady state infiltration rate of the soil. Most modern irrigation systems can implement "cycle soak" regimes wherein the day's required runtime is divided into several shorter periods that are separated in time. "Cycle soaks" help minimize runoff by ensuring that the irrigation rate never exceeds the infiltration capacity of the soil. Infiltration rates can also be improved by using a combination of traffic control, cultivation (e.g., aeration), and soil/water amendments. Common soil amendments include gypsum and sulfur, primarily used to adjust the ratio of calcium to sodium (Sodium Adsorption Ratio; SAR) in soils, which improves soil structure. The most common water amendments acidify or lower the pH of the irrigation water (e.g., sulfurous acid from sulfur burners or sulfuric acid injection), thereby reducing bicarbonate levels that reduce the level of free calcium in soil. Water with a lower pH increases the levels of exchangeable calcium in soils by dissolving calcium carbonate, a resident component of most desert soils.

Solutions To Salinity Related Problems

Increasing the amount of water available for turf irrigation is one means of addressing salinity related problems. This additional water requirement for salinity management must be properly addressed by ADWR when formulating future water duties for turfgrass. Cooperation on the part of the turfgrass industry and ADWR will be required to develop the data sets necessary to accurately adjust water duties in future management plans. However, in the interim period the turf industry must implement other measures to address salinity related problems. Two options for increasing water supply include: 1) applying for the ADWR leaching allotment if the salinity level of your water exceeds 1000 ppm and 2) blending effluent and groundwater (effectively increasing a facility's water supply due to ADWR effluent incentives). A third possible option for enhancing water supplies is to collect runoff from structures, parking lots, and fairways in lakes or irrigation reservoirs for more efficient use of rainwater. For



(a)



(b)

Figure 8. (a) Annual precipitation in Phoenix presented as departure from normal (average) for the period 1971-2008 (left). In recent years drought has reduced the water supply available for turf and increased the likelihood of deficit irrigation regimes (red bars). (b) Number of winter months in each of the past three decades with precipitation in excess of 2.0" in Phoenix.

example, over the past decade 41% of the annual precipitation at Encanto Park in Phoenix has occurred on days when rainfall exceeded 0.75". Relatively intense rainfall events generate runoff from fairways and hardscapes, water that cannot be used unless it is collected and stored. One critical reason for setting water duties at or below ET is the expectation that turf facilities can effectively utilize rainwater. With more than 40% of the rainfall vulnerable to runoff, water harvesting may be necessary for a turf facility to utilize a high fraction of the annual rainfall.

Another effective means of increasing the water supply for leaching is to reduce the amount of area in turf – either permanently or seasonally. The annual ET of an acre of year round turf ranges between 4.5' and 5.0'/yr. Permanent removal of turf would conserve 5.5-6.0 acre feet/acre after accounting for the leaching requirement and irrigation efficiency/non-uniformity (both of which increase irrigation requirement). Seasonal reductions in turf area are accomplished by reductions in overseeding (Fig. 9). The potential water savings, while significant, is not as great as many believe. Water use during the four coldest winter months is relatively low and winter rainfall can approach 30 to 50% of ET. University of Arizona research indicates the true water savings associated with not overseeding turf would be less than 18" for most turf facilities. Using this estimate, a 90-acre turf facility in need of an additional four inches of water for leaching could achieve that savings by not overseeding 20% of the facility.

Weather stations used to provide ET values for irrigation management software can contribute to problems with deficit irrigation. Weather stations estimate ET from measurements of air temperature, wind speed, relative humidity and solar radiation. Failure to perform proper weather station maintenance will lead to inaccurate measurements of these meteorological parameters and declining ET values over time (Brown and Russell, 2001). Siting of weather stations represents another possible factor that can impact ET values. Weather stations should be installed over turf in shade-free areas, and away from parking lots that generate excessive heat or walls and other structures that can block wind flow. The University of Arizona publication AZ1260 entitled "Siting and Maintenance of Weather Stations" provides guidance on this issue (available at http:/ag.arizona.edu/pubs/water/az1260.pdf)

Management activities that improve irrigation application uniformity will limit the amount of area that is chronically under-watered. Factors contributing to poor uniformity include sprinkler head spacing, inadequate pressure regulation, nozzle size, topography, and local wind conditions. A formal irrigation audit can help identify areas with poor uniformity and provide management options for alleviating uniformity problems. Audits are both time-consuming and expensive; auditing activities should therefore be targeted to areas with known uniformity problems.

Improving infiltration by using cultivation and chemical remediation can minimize problems with deficit irrigation. Low infiltration rates resulting from poor surface soil structure can lead to standing water in level or depressed areas and runoff in areas with sloping topography. Water that runs off is effectively lost and can contribute to deficit irrigation. Standing water negatively affects playability and is commonly addressed by cutting back on irrigation – again leading to a deficit irrigation regime. Cultivation is a mechanical process that loosens soil and reduces compaction and thatch by slicing or creating holes in the surface soil (Fig. 10). Core aerification is an effective cultivation practice that removes a core of soil from the turf. Hollow metal times measuring up to one inch in diameter can penetrate to a depth of three to four inches. Solid tines can penetrate deeper to 10-inch depths without removing soil cores. A cultivation operation that produces holes on a two inch by two inch spacing with a 0.625-inch hollow core tine can affect up to 25% of the surface area. Aerification holes or slices serve as tiny reservoirs that collect and store the applied water until the infiltration process is complete, greatly reducing the chances for runoff.

Tillage, alone, may not eliminate poor infiltration rates if the structure of the surface soil has been damaged by sodium accumulation. Sodium in irrigation water is applied

Figure 9. Water saved through reductions in overseeded winter turf may provide sufficient water to meet the leaching requirements of a turf facility.

Figure 10. Tillage operations that create holes or slits in the surface soil can greatly improve infiltration and reduce the level of runoff. Deficit irrigation regimes can develop in areas prone to runoff, leading to poor turf quality and the accumulation of salts and sodium.

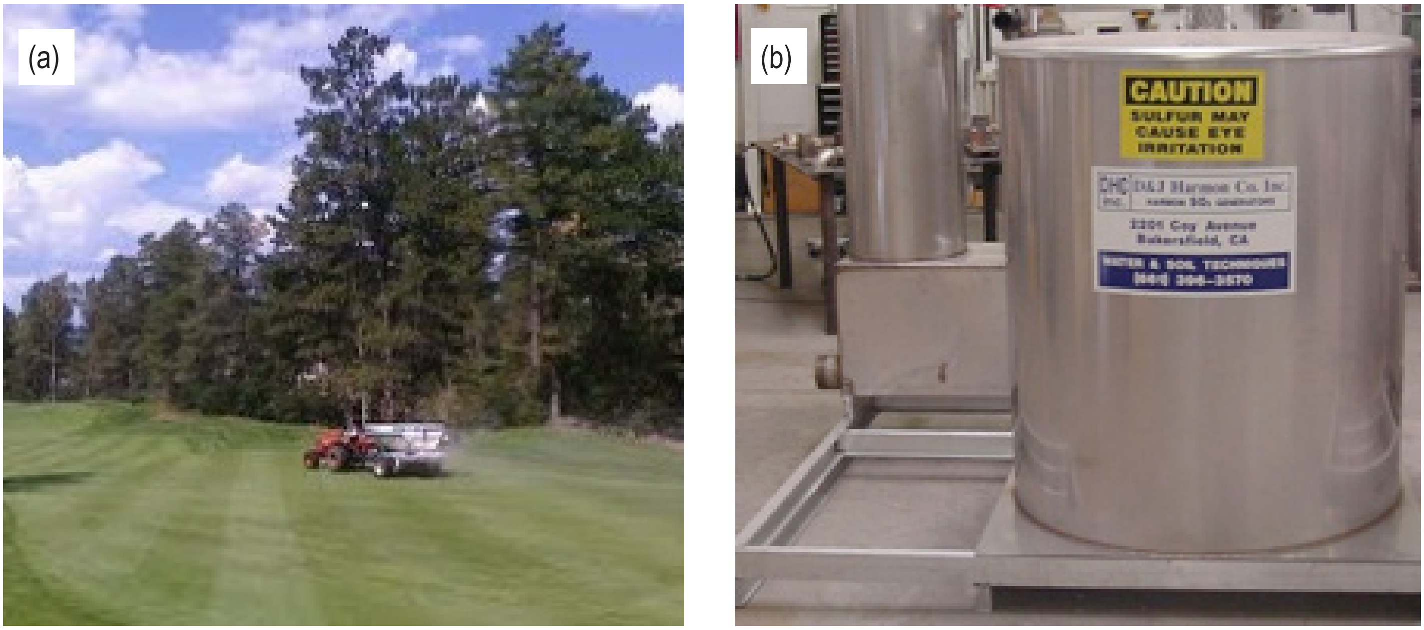


Figure 11. Applications of gypsum (a) can be used to increase the ratio of calcium to sodium in soils and thereby improve soil structure and infiltration. Lowering the pH of the irrigation water through the use of sulfur burners (b) or acid injection reduces the level of bicarbonate in the irrigation water which also improves the ratio of calcium to sodium in the soil.

to the soil with each irrigation. When sodium accumulation exceeds certain thresholds, soil aggregates disperse, leading to a breakdown in soil structure (Walworth, 2006b). Structure can be improved by replacing exchangeable soil sodium with soluble calcium. This is accomplished by first applying calcium, usually in the form of gypsum (Fig. 11a), and then applying excess water to remove the sodium. Gypsum application rates depend on soil texture and the level of sodium in the soil (Walworth, 2006a). The University of Arizona publication number AZ1413 "Using Gypsum in Southwestern Soils" (http://cals.arizona.edu/pubs/garden/az1413.pdf) can help turf managers determine the proper rate of gypsum for their facility. Sulfur may also be added to soils to improve soil structure. Sulfur is converted into sulfuric acid by soil microbes and will acidify the soil, dissolve calcium carbonate, and increase exchangeable calcium levels.

Amendments may be added directly to the irrigation water to address infiltration problems. Water tests that measure SAR, salinity (ECw) and bicarbonate concentration are used to assess whether a given water supply will negatively impact infiltration (Tables 2 & 3). Acidification of irrigation water through the use of sulfur burners or acid injection will reduce the levels of bicarbonate in the water (Fig. 11b). Bicarbonate added in high pH irrigation water reacts with soil calcium,

Table 2. Infiltration is impacted by both the sodium adsorption ratio (SAR) and the salinity (ECw) of the irrigation water source. For a given SAR value, infiltration improves with increasing ECw. The table below provides the expected impact on infiltration of water sources with the indicated ranges of SAR and ECw.

SAR	Resulting Reduction in Infiltration for Indicated Values of ECw[1]		
	None	Slight to Moderate	Severe
0-3	>0.7 dS/m	0.7-0.2 dS/m	<0.2 dS/m
3-6	>1.2 dS/m	1.2-0.3 dS/m	<0.3 dS/m
6-12	>1.9 dS/m	1.9-0.5 dS/m	<0.5 dS/m
12-20	>2.9 dS/m	2.9-1.3 dS/m	<1.3 dS/m
20-40	>5.0 dS/m	5.0-2.9 dS/m	<2.9 dS/m

[1]Adapted from University of California Committee of Consultants, 1974

Table 3. High concentrations of bicarbonate in irrigation water can negatively impact infiltration. Bicarbonate reduces the level of free calcium in the soil solution, leading to an increase in sodium adsorption ratio and an eventual decline in soil structure.

Use Restriction: Irrigation Waters With Indicated Bicarbonate Concentrations[1]		
Low	Slight to Moderate	Severe
<1.5 meq/l	1.5-8.5 meq/l	>8.5 meq/l

[1]Adapted from University of California Committee of Consultants, 1974

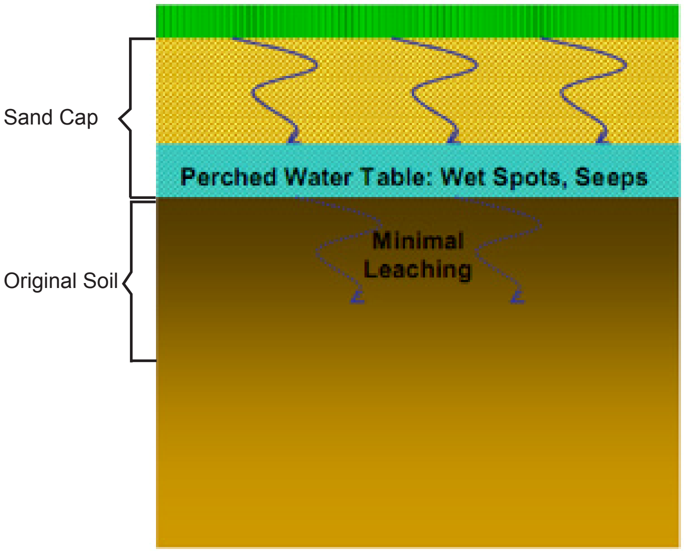


Figure 12. Capping poor infiltration soils with sand has been proposed as one means of improving infiltration rates. However, failure to improve the infiltration of the original soil surface (through chemical or mechanical means) prior to capping may result in the accumulation of water at the interface between the cap and the original soil surface. This accumulation of water is referred to as a perched water table and can lead to wet spots, seeps and the accumulation of salts in the sand cap.

converting it into insoluble calcium carbonate. This reaction reduces the level of exchangeable soil calcium and can lead to poor soil structure. Water with a low pH, on the other hand, will dissolve the calcium carbonate that is present in most desert soils. The soluble calcium released by this reaction displaces sodium from soil exchange sites, improving soil structure over time.

Capping golf course fairways with sand has been utilized as an alternate means of improving water infiltration. Capping will improve surface infiltration rates, but the procedure effectively buries the old turf surface with poor infiltration characteristics. Water will be perched at the interface between the sand and the old soil if nothing is done to improve the infiltration capacity of the old soil turf surface (Figure 12). Salts will accumulate above this interface if the perched water is not removed through some means of drainage. Cultivation and/or chemical remediation of the old surface soil or installation of a drainage system may be warranted before installing the sand cap.

Concluding Remarks

Salinity related problems are becoming more problematic on many golf courses and sports turf facilities in the low desert. In most cases these problems have been years in the making and thus will require time, patience, and additional budget outlays to remedy. This report has summarized the factors contributing to the development of salinity related problems in turfgrass facilities and offers some possible solutions. University of Arizona research is continuing to address salinity monitoring and assessment, cultivation practices, chemical remediation, salinity tolerant turfgrasses, and irrigation efficiency. Results and solutions to these practical problems will be transferred to professional turf managers at the conclusion of these important research studies.

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