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Plant Irrigation Requirements

This chapter introduces the relationships between the turfgrass plant, the host soil, and the irrigation water, which are key to proper irrigation design and management. It provides information on water movement through different soils and water uptake by plant roots. It discusses the concept of evapotranspiration (consumptive use) and its role in the calculation of water requirements. The chapter also includes information on various turfgrass types, their water requirements, and their relative drought tolerances.

SOIL-WATER-PLANT RELATIONSHIPS

Irrigation concerns the relationship between how a soil holds and stores water and how a plant uses water. Although you do not need to know a great deal about soil physics or plant physiology for proper irrigation, you do need to have a general knowledge of soils and to be familiar with how a plant, in this case turfgrass, uses water and uptakes it from the soil. There are a number of terms and concepts you should be familiar with in order to understand the soil-plant-water relationship.

Soils

A soil is made up of various amounts of sand, silt, clay, and organic material, as well as pore space. The pore space is filled with either air or water. The ideal mixture is 50 percent soil, 25 percent water, and 25 percent air. Under these conditions the turf expends a minimal amount of energy to uptake water and nutrients.

Texture is defined as the relative proportions of sand, silt, and clay in a soil. Texture cannot be changed or destroyed. Using an estimate of the percentage of each type, a soil can be classified in one of the 11 categories shown in the textural triangle in Figure 1.1. For example, as indicated in the textural triangle, a soil consisting of 50 percent sand, 30 percent clay, and 20 percent silt would be classified as a sandy clay loam.

The structure of a soil is defined by the arrangement of the various components that make up the soil texture. There are many types of soil structures, each with a specific name for its formation. In irrigation, a structure that allows for a high water-holding capacity is preferred. This structure is one that has medium-size pore spaces that

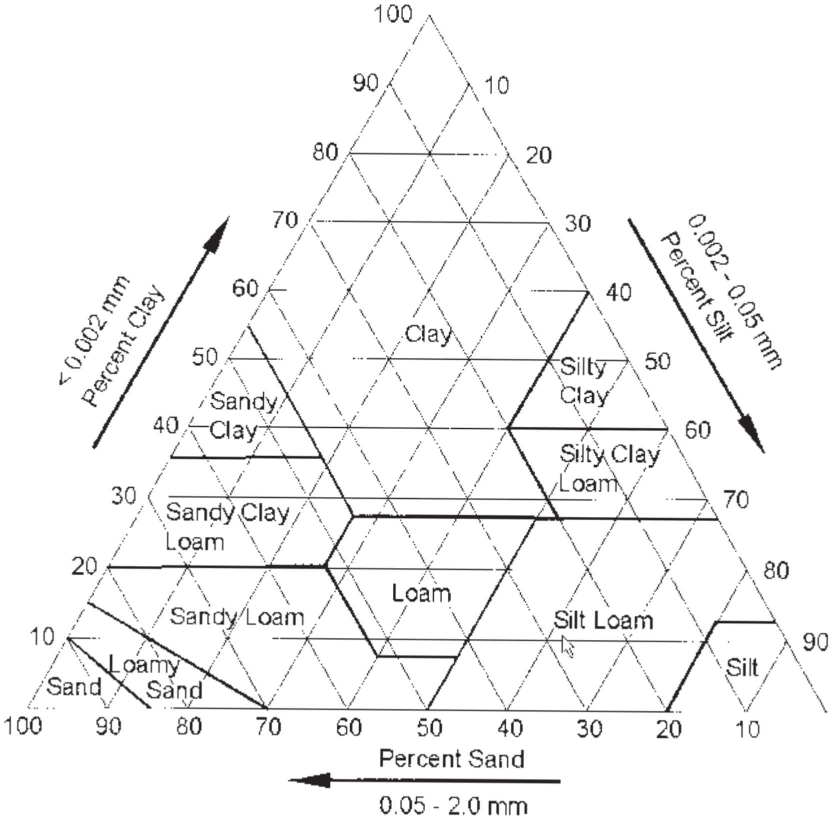

FIGURE 1.1

A textural triangle is used to generalize soils based on the percentages of silt, clay, and sand contained in the soil.

(Courtesy of the Irrigation Association.)

allows for some drainage but does not hold the water too tightly to the soil particles, such as clays. The structure of a soil can be easily changed with the use of various types of mechanical equipment such as rototillers, aerifiers, or bulldozers.

If you were to dig a deep hole in the ground with a backhoe and then jump into the hole, you could see how a soil consists of different layers. Each time the soil changes color, structure, texture, or other characteristics, there will be a distinct layer. These layers are called soil horizons. The makeup of all of the horizons in a soil create the soil profile. In a soil profile, the top layer, the soil growing the turf, is the first, or A, horizon. A small difference in the soil characteristics may make it the A1, A2, or A3 horizon. A significant change in the soil will change it to the B horizon. The C horizon is usually the parent material from which the upper horizons descended. In an undisturbed soil these horizons can be very old and quite consistent over large areas. On a golf course, significant grading has probably taken place as well as substantial amount of cutting and filling. As a result, the soil profile has been manipulated and the sequencing of the horizons disturbed. It is not uncommon to have the C horizon on top, with the original A horizon buried and the new A horizon probably brought in from another area of the site or imported onto the site. In dealing with a manipulated soil, it is important to figure out how the soil characteristics change with depth. On golf courses it is not uncommon to have a highly compacted impermeable layer of soil beneath the topsoil, or the A horizon, causing some irrigation and drainage problems.

Intake Rate

A soil's intake (infiltration) rate is a measure of how fast the soil will take in water, measured in inches per hour. In a dry, bare soil, the soil intake rate will initially be very high, but it slowly decreases to a point where it becomes consistent over time. Although the rate will be high at the beginning, in irrigation it is the leveled-off or basic intake rate that is of interest. Ideally, an irrigation system would never apply water at a rate greater than the intake rate of the particular soil being irrigated. On a United States Golf Association (USGA) regulation green, this ideal is easily obtainable, as the intake rate is significantly higher than the precipitation rate of the sprinklers. On a push-up green (constructed simply by shaping the existing soil—no drainage, gravel layer, or soil amendments are installed), however, the precipi-

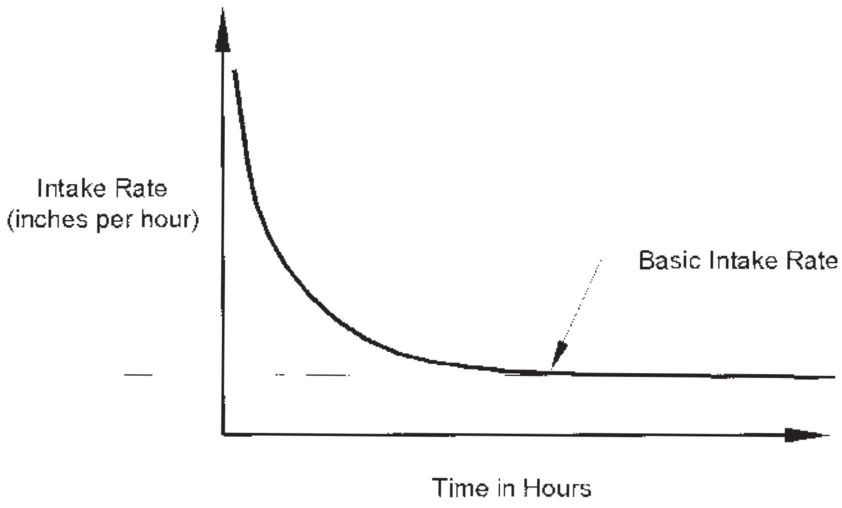

FIGURE 1.2
Generalized soil intake graph, intake rate versus time. *(Courtesy of the Irrigation Association.)*

tation rate may exceed the intake rate of the soil. To properly schedule irrigation and prevent runoff and puddles, the intake rate of the soil must be considered (Figure 1.2). If the precipitation rate of the irrigation system exceeds the soil intake rate, cycle and soak scheduling may be necessary to apply the required water efficiently.

Turf cover, compaction, and thatch all decrease the soil's intake rate. Compaction during construction, or even by the sprinklers operating at a pressure that is too low, will influence the intake rate over time. Thatch buildup will decrease the intake rate, as may the long-term use of effluent water, depending on its quality. If you have identified your soil type from the textural triangle, then a water intake rate can be estimated from information provided in a textbook on soils.

Soil Water Storage and Movement

The storage and movement of water in a soil is of great importance in scheduling irrigation efficiently and effectively. As the soil goes from wet to dry, the relationship of the water to the soil changes, as well as the type of movement and amount of storage (Figure 1.3). If you were to start with a dry soil and then irrigate it until it puddles or runoff occurs, the soil would have all its pore space filled with water and the soil would be saturated. If you stopped irrigating, the soil pore spaces would start to drain over the next 24 to 48 hours, and all of the water movement would be gravitational. At some point in time, the gravitational movement and drainage would slow to a very

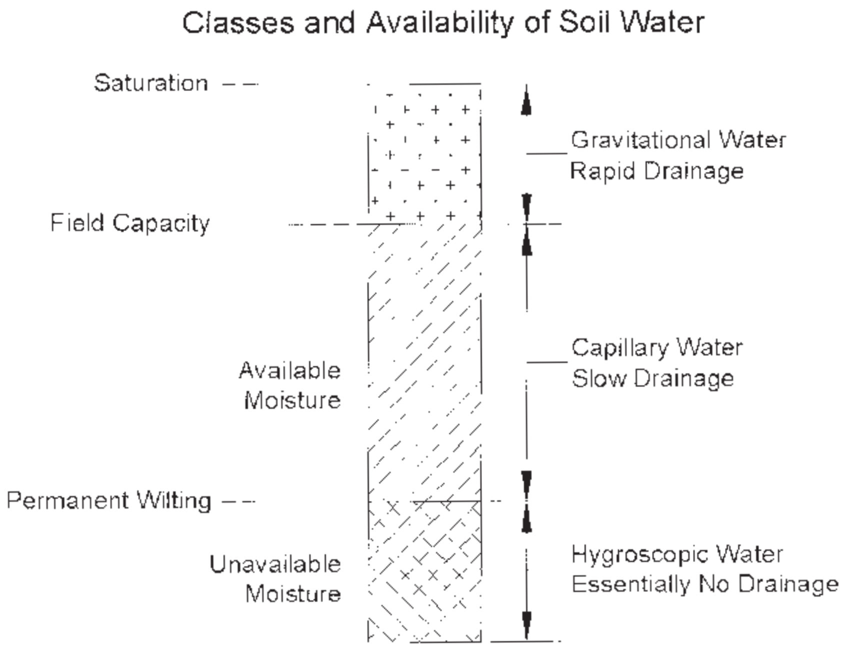

FIGURE 1.3
Soil moisture movement terms. *(Courtesy of the Irrigation Association.)*

low rate. At this point the soil pore space would be approximately 25 percent water and 25 percent air. The soil particles would be holding the water to them with adhesive forces (soil to water), thus keeping the pore spaces from draining any further. At this point the soil is said to be at field capacity. Field capacity in regard to soil moisture can be defined as the point where water is most available to the plant. Because the turf consumes water between irrigation or rainfall events, the amount of water available to the plant continues to decrease. The movement of water at this stage is caused by capillary action. The cohesive (water-to-water) forces move the water from the soil pore spaces to the roots for uptake by the turf. This will occur for some time, with the turf having to exert more and more force to pull the remaining water away from the soil particles as the soil dries out. This process will continue until the soil reaches the permanent wilting point. At this point, the soil moisture will be severely depleted and the turf can no longer exert enough energy to pull the water away from the soil. At the permanent wilting point there is still water in the soil, but it is held so tightly by the soil that the plant cannot use it. The remaining moisture is hygroscopic water, which can be removed only by applying heat to force drying (i.e., "oven dried" soils).

Water-Holding Capacity

Between field capacity and permanent wilting point is the available water-holding capacity of the soil. Again, if you have generalized the type of soil from the textural triangle, a soils text or Internet site can provide information on the particulars of a soil's water-holding capacity in either inches of water per foot of soil or inches of water per inch of soil. For example, a sandy clay loam may hold 1.6 in. of water per ft of soil. Although this is the total amount of water held between field capacity and permanent wilting point, all this water may not be available to the plant. It is difficult for plants to obtain water below the root zone, so root zone depth is an important consideration in irrigation scheduling, as it severely limits water availability and thus dictates the irrigation interval.

By relating the root zone depth to the available water-holding capacity of the soil, the amount of water available to the turf can be determined. For example, if the turf has a 6 in. root zone and the sandy clay loam (mentioned earlier) has a capacity of 1.6 in. per ft, the available water-holding capacity would be 0.8 in. (1.6 in./ft × 0.5 ft). A 3 in. root zone would have half the available water-holding capacity of a 6 in. root zone, or 0.4 in. (1.6 in./ft × .25 ft).

Irrigation Interval

In scheduling irrigation frequency, it is best to replenish the available water supply before reaching the permanent wilting point. Target levels have been identified for different crop types, including turfgrass. A target level is referred to as management allowable depletion (MAD). It is a management decision as to how much of the available water should be depleted before the next irrigation occurs. For turfgrass, the MAD has been determined to be about 50 percent by most agronomists. For example, applying a MAD of 50 percent to 0.8 in. of available water at field capacity results in a target of 0.4 in. of water being extracted by the turfgrass (0.8 in. × 0.50) before the next irrigation event. The next irrigation will be a net water application of 0.4 in. to fully refill the root zone. The time (days) it takes the turfgrass to consume the target MAD of 0.4 in. of water is referred to as the irrigation interval.

EVAPOTRANSPIRATION

Water evaporates from soil and transpires from plant leaves. Together, these two phenomena are referred to as evapotranspiration (ET). There are several methods used to estimate the *ET* rate or value. For research purposes, a weighing lysimeter has been used to measure the loss of water from turfgrass plots. Typically, soil is placed in a box that is supported beneath by a weighing scale. Turfgrass is planted on the soil surface, well irrigated, and properly maintained. The surface area of the planted turfgrass and the change in weight due to evapotranspiration (water use) are measured. These two measurements form the water use requirements. These measurements are usually expressed in fractions of an inch of water consumed per day, or daily *ET* rate.

Lysimeters are too complex and expensive for normal water management, so weather conditions, such as wind speed, temperature, sunlight intensity, humidity, and other parameters are often measured to calculate the amount of *ET* or plant water use. Researchers, such as Penman (1948), developed formulas from their investigations to estimate potential crop water use based on changing weather conditions. A modified Penman equation is currently used by most publicly accessible weather stations in California to estimate crop water demand.

There are several variations of the *ET* definition or measurement that may be available. They all have slightly different meanings. ET_c or *ET* crop is the water use rate of the crop (turf) that is being scheduled or managed. ET_c is the amount of water that evaporates from the soil surface and transpires from the leaf surface to the atmosphere.

Calculating the *ET* of turf for an irrigation schedule usually begins with the acquisition of a reference *ET* value. Reference ET_o, as defined by Doorenbos and Pruitt (1975), denotes the "the rate of evaporation from an extensive surface of green grass cover, of uniform height, actively growing, completely shading the ground, and not short of water." This is the most common example of the use of the Penman equation to calculate evapotranspiration for a specific reference plant cover. Other examples often available are ET_p and sometimes ET_r. These are modifications of the Penman equation that calculate *ET*'s for reference crops other than turf. The Irrigation Association website includes an extensive list of *ET* sources for the United States.

Such calculations are widely used in the western United States by the U.S. Bureau of Reclamation to estimate agricultural crop water use requirements. This measurement is based on work developed by Jensen et al. (1970), in which ET_r "represents the upper limit or maximum evapotranspiration that occurs under given climatic conditions with a field having a well-watered agricultural crop with an aerodynamically rough surface, such as alfalfa with 12 in. to 18 in. of top growth." The ET of the plant cover being managed (ET_c) is related to the various ET's (ET_o, ET_p, ET_r) by a value known as the crop coefficient (K_c). The mathematical relationship is defined as:

$$K_c = ET_c/ET_o \text{ or } ET_r$$

where:

K_c = crop coefficient
ET_c = evapotranspiration of the crop or turf being managed
ET_o = evapotranspiration—grass-based
ET_p or ET_r = evapotranspiration—alfalfa-based

However, because ET_o uses grass as a basis, versus ET_r, which uses alfalfa, the resultant crop coefficients can vary considerably. That is why it is critical to match the proper reference ET with the correct K_c adjustments. Using ET_o-based K_c's with ET_r reference values, or vice versa, can result in significant errors in water use estimates.

Crop coefficients are seasonally adjusted values that take into account the crop type, stage of growth, and crop cover. For example, the difference in K_c between a Bermudagrass and a tall fescue grass could be substantial. The K_c developed during April for Bermudagrass is 0.72 or 72 percent of ET_o. For tall fescue during April, the K_c is 1.04 or 104 percent of ET_o. This is a potential difference of 30 percent for applied water. Other months vary to a lesser degree. Also note that the K_c values used in the preceding example apply to southern California geographic conditions. These values or coefficients are developed for specific regions, so be sure to select the appropriate references.

TURF TYPES

A key component in determining the plant water requirement is identification of the species and variety (cultivars) of the turfgrass. For new construction, the type of plant material must also be identified to estimate water requirements in the irrigation design phase.

Of the more than 1200 different turfgrass species available, only 20 to 25 are suitable for the golf industry. The reason is that most of these plants do not meet the requirements of heavy traffic, low cutting heights, disease tolerance, leaf texture, seedling vigor, and drought tolerance. There is a large ongoing effort to breed new turfgrasses that require less water, have deep root systems, and demonstrate improved salt tolerance.

Water has several key functions in a plant. It acts as a nutrient carrier within the plant; as a solution carrying nutrients in the soil to the roots; and, in the plant leaves, as a temperature regulator. Water is also required for absorption by seeds during germination. Of all the water consumed by a plant, only about 2 percent is used for metabolic purposes. The rest is used for cooling and respiration.

Excessive moisture levels can have detrimental effects on turfgrass, such as oxygen deficits and the unnecessary leaching of nutrients from the root zone. The available water must be managed in the root zone between the MAD and field capacity.

Generally, turfgrasses are grouped into two basic categories: warm-season grasses and cool-season grasses. The temperatures in which they thrive and length of growing season classify these two groups. Warm-season grasses are most active when temperatures are between 80°F and 90°F and will go dormant in cool winter months. Cool-season turfgrasses prefer 60°F to 75°F and will stay green year-round. In terms of plant water use, cool-season grasses tend to consume more water than warm-season grasses under similar weather conditions.

Although turfgrasses are classified into cool- and warm-season categories, each species and cultivar may have particular behavioral characteristics. Factors that influence behavior include soil type, shade conditions, air and soil temperatures, water quality, mowing heights, and other cultural practices.

The following guide can be used for estimating relative plant water use requirements:

Relative Drought Tolerance—Cool-Season Turfgrass

Bluegrass	Low to medium
Annual bluegrass	Low
Fescue	High
Ryegrass	Medium
Creeping bentgrass	Low

Relative Drought Tolerance—Warm-Season Turfgrass

Bermudagrass	High
Zoysia	High
Carpetgrass	Medium
St. Augustine grass	Medium
Buffalograss	High

Fescues tend to have the greatest tolerance for drought as cool-season grasses, primarily because of their rolled leaf structure, which protects the stomates from exposure during stress. The warm-season Bermudagrass tends to have an extensive, deep root system that aids it in extracting water from the soil.

Excellent sources for regional information on appropriate turfgrasses are local experiment stations and university programs. In addition, the National Turfgrass Evaluation Program (NTEP) can be contacted for information on regional turfgrass trial data at www.ntep.org.

Water Use Calculations

Reference ET values can be obtained from several sources. The most effective is a weather station located on or near the golf course. There are specific siting requirements for weather stations, but they generally include an unobstructed area around the station, irrigated and maintained turfgrass, and available power. Too many sites are located next to equipment yards where buildings interfere with wind measurements and heat is radiated from asphalt and concrete areas. Automated weather stations that read directly to a desktop computer are available with software that will calculate a reference ET. Be sure to get K_c values that match the particular reference ET calculated by your specific weather station.

Other sources of ET values are government-sponsored weather stations and local weather reporting. Some of these sources are available through the Internet. For example, WateRight.org provides ET values and matching crop coefficients and calculates irrigation requirements.

The procedure for estimating crop water requirements in "real time" is sometimes explained as the checkbook method. The analogy is that you start with a balance of money in your account; as you write checks and deduct the amounts from your balance, there is less money available in the account. From time to time money must be deposited back into your account or the account will become overdrawn. And just like you, a turfgrass will experience stress when the account (of water) is overdrawn.

In determining irrigation amounts and frequencies, the available water in the root zone should be considered as the bank account. Each day the grass extracts water (writes a check) from the available water account. The amount of water taken from the root zone (size of the check) is determined by the weather conditions (ET) and turf type

(K_c). The soil's water-holding capacity and depth of root zone determine the amount of water available (the size of the initial balance). The grass cannot withdraw more water than it has available, or it will die.

Calculating the size of the daily *ET* is the most difficult part of the process. Generally, water use calculations begin with a reference turf *ET* value for the local area. Next, the correct K_c value must be identified and used for the *ET* value (crop, period, and reference). *ET* values are usually expressed for a period of time (e.g., day, week, or month). Weekly *ET* values are normally sufficient to track seasonal changes in water use. There is typically enough water storage in the root zone to accommodate daily swings in *ET* during the week. However, using a monthly average may put the crop health in danger because of extended weather fluctuations.

The calculation is

$$K_c \times ET \text{ reference} = \text{crop water requirements for the calculated period of time.}$$

A more specific example is the use of a reference ET_0 (grass-based) value of 1.8 in. per week for a week in May, say the first through the seventh. The calculated K_c value for Bermudagrass in May is 0.79 for a particular area. To estimate the crop water use for this first week in May, the following calculation is performed:

$$\text{Net water requirement expressed in inches for that week } (1.42) = K_c\ (0.79) \times ET_0\ (1.8) \text{ in./week}$$

where

K_c = crop factor for selected crop (Bermudagrass), time of year (May), and geographic region (Arizona)

ET_0 = measured grass-based evapotranspiration for period of time (in./week)

The next week the weather could change and the ET_0 could be higher or lower, but the calculation would be the same. If the calculation were performed for the last week in April instead, you would use a slightly lower K_c value, 0.72, to multiply by the estimated ET_0 value for that week.

In summary, know your reference *ET* (grass- or alfalfa-based), identify the correct crop coefficients, time of year, and geographic region. The total calculated turf *ET*s since the last irrigation will be the amount to use when determining the total net water requirement for the next irrigation schedule.

Remember, the estimated crop water usage is not the amount of water you need to apply. System uniformity must also be accounted for in the total water application amount, along with any leaching fraction.

Leaching Fractions

Leaching fraction or requirement (Lr) is the amount of additional irrigation water required to move salts out of the root zone to maintain a healthy growing environment. The amount is dependent on numerous factors, including the salinity of the soil, soil type, water quality, rainfall, drainage, and crop tolerance. Probably the single most important factor is the quality of the water. This is especially true for golf courses that use effluent water supplies. The water quality sets the lower limit for the minimum salinity that can accommodate turfgrass growth. The water quality is usually expressed as the electrical conductivity (EC) of the water.

When plants extract water from the soil, salts are left to accumulate in the soil. Over time the level of salinity can build up to the point where it is toxic to the plant. Excess irrigation or rainfall will push the accumulated salts below the root zone, maintaining a healthy growing environment for the turfgrass.

In areas of limited summer rainfall, irrigation water is used to leach or "push" salts out of the root zone. With sufficient flushing, the EC of the soil will approach the EC of the water. The challenge is to determine exactly how much overirrigation to apply. The process starts with knowing the salt tolerance of the plant or turfgrass; this sets the minimum salinity level that can be used without damaging the turfgrass. Obviously, the EC of the irrigation water must be equal to or less than the tolerance limits of the crop.

In developing an irrigation schedule when salinity is a concern, it is important to make an estimate of the minimum quantity of water required to move excess salts out of the root zone. This quantity or leaching requirement may be estimated by using the salt balance equation developed by Hoffman and Van Genuchten (1983):

$$\mathrm{Lr} = \frac{\mathrm{EC_I}}{\mathrm{EC_D}}$$

where

Lr = leaching requirement, the percentage of the irrigation that should pass through the root zone

EC_I = electrical conductivity of the irrigation water (dS/m) being applied

EC_D = electrical conductivity of drainage water above which turf damage occurs

In managing conditions of high salinity, the uniformity of the sprinkler system is extremely important. To meet the leaching requirement of the driest coverage areas (10 or 20 percent), a tremendous amount of water is wasted in the wetter areas in the form of overirrigation with nonuniform systems. Because the leaching requirement is only an estimate, periodic monitoring of the salinity in the root zone is highly recommended to maintain the appropriate salt balance.

Maintaining the appropriate salt balance is critical for several reasons. These include the health of the plant and the need to minimize the cost of water and energy wasted through overirrigation. But perhaps most important, when overirrigation occurs, it moves fertilizers and chemicals with the water toward underground aquifers. The intended efficacy of these materials is lost when they are moved below the root zone. Moreover, many of these underlying aquifers are close to cities and homes that use this water source for human consumption. If contaminants show up in public water supplies, and can be traced to mismanagement at the golf course, fines and/or litigation are likely to follow.

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