Turf Irrigation Series No. 2

Drought Resistance and Efficient Irrigation for the Cool-Humid Region

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Water Conservation

When rainfall is insufficient and water resources become limited, supplemental irrigation needed to sustain landscape plantings such as turf is often the first to be placed on water use restrictions. Under such restrictions professional turf managers and homeowners are forced to maintain turf function and acceptable turf quality with less water applied as irrigation. In some cases when no irrigation is permitted, turf consumptive water use must be met by natural precipitation events as rainfall. However, if turf water use requirements are to be met by precipitation events alone they must be distributed to conform to turf needs, which do not necessarily correlate in dry summers.

In such cases, water conservation strategies and efficient irrigation practices are needed to maintain turf; these practices may include:

- incorporating water-use-efficient plant material into the landscape
- implementing water conserving management practices, and
- maximizing irrigation efficiency by controlling leaching, pooling or ponding of irrigation water, and surface water as runoff.

Even in areas where water shortages are rare events, judicious and careful planning in anticipation of drought is extremely important. Planning and implementation of water conservation strategies are not necessarily practices that provide immediate results but rather may take significant time and continued effort before measured water savings are achieved.

Alternatively, over-use of water as supplemental irrigation must be avoided in summer because over-watering can have adverse impacts on turf function and environmental health, which may include:

- diminished rooting, and water and nutrient acquisition
- higher potential for leaching and mobility/movement of water and contaminants into ground water
- increased soil compaction tendencies and higher lateral transport of water and contaminants to surface water
- increased and elevated shoot (tissue) water content that inhibit the turfgrass' tolerances to physiological stress (heat, cold or drought) and wear (traffic)
- greater leaf wetness and the resulting increased potential for disease occurrence and severity, particularly for those diseases which are active in summer when supplemental irrigation is used

- higher evapotranspiration (ET) rates and greater soil moisture depletion rates in summer
- diminished drought resistance caused by elevated ET and shallow rooting
- the need for more water as irrigation in both the amount applied and the frequency of irrigation, and
- increase irrigation system maintenance and the cost of water due to higher water usage.

Meeting but not exceeding the water use requirements of turfgrass is important, and irrigating with less water is always preferred to over-watering. In addition, allowing for natural rainfall (as precipitation) to meet some of the turfgrass' water use requirements can help to replace in part the need for supplemental irrigation. Rainfall precipitation rates, duration, and frequency can vary from location-to-location but these additions of water are "free" and of good quality and therefore must be taken into account when scheduling irrigation in order to conserve water applied as supplemental irrigation. Natural precipitation events are not necessarily effective in meeting some fractional level of the turf's water use requirement because some rainfall as precipitation may exceed soil infiltration rates and may be sufficient to cause runoff while other events may exceed rooting depth and cause leaching.

Both runoff and leaching reduce "*precipitation efficiency*" because these additions do not provide any value for turf use and in turn, increase the need for supplemental irrigation. Precipitation efficiency can be defined as the relative amount of water in the foliage and root zone utilized by the turf and is available as ET following rainfall or irrigation. All turfgrass systems from high-maintenance turf under irrigation to lower value turf without irrigation can benefit from increased precipitation efficiency.

Precipitation efficiency = The proportion of precipitation (rainfall) available for turf evapotranspiration. Any conditions or practices that promote runoff or leaching from the turf system reduces precipitation effectiveness and increases supplemental irrigation requirements. Adjusting irrigation requirements by correcting (subtracting) rainfall amounts from ET-based irrigation is a form of enhancing precipitation effectiveness because such adjustments diminish leaching.

Precipitation efficiency as rainfall or as supplemental irrigation can be increased by ensuring the following:

- maintain good turfgrass cover to reduce runoff and increase soil infiltration
- maintain good turfgrass cover and soil shading to reduce evaporative water loss
- control weeds that compete with desirable turfgrass for water
- increase soil moisture retention of droughty root zones with additions of appropriate peat moss or other organic amendments to amend sandy soils
- increase surface and internal drainage of poorly drained root zones with additions of appropriate amendments and establishment of proper surface grades to avoid surface water runoff
- maintain ET rates of turfgrass using ET replacement with sufficient soil drying between intervals to allow soil moisture depletion and to promote higher soil-water storage capacity to utilize precipitation; i.e., avoid turf dormancy

- maintain deeper rooting to allow for higher soil-water storage capacity to utilize precipitation; i.e., avoid turf dormancy
- alleviate and control for high soil compaction tendencies to promote rooting and increase soil infiltration rates
- alleviate and control for high thatch tendencies to promote rooting and to increase soil infiltration rates
- use multiple cycling under irrigation on soils with low infiltration rates
- adjust irrigation to correct for rainfall, and
- use wetting agents to promote uniform wetting and increase soil infiltration rates.

These strategies that are targeted at increasing precipitation efficiency help to lengthen the days between supplement irrigation. Moreover, they increase the storage capacity of the plant-available soil-water reserve or facilitate recharge and therefore increase the likelihood of rainfall as "free water" to meet the water use requirements of turf.

How much water is enough?

The irrigation of turf using ET replacement is effective in preventing leaching losses and therefore eliminates potential sources of waste, which is an important water conservation strategy. However, repeated and daily use of irrigation applied as ET replacement is a form of over-use of water because daily watering diminishes rooting depth by inhibiting the turfgrass' ability to effectively redistribute deeper rooting into the soil profile. The scheduling of irrigation using ET replacement helps to quantify water in terms of the "*amount*" in inches to be applied to turf. Scheduling of irrigation using ET rates is highly variable (see *Turf Irrigation Series No. 1* entitled "*Use of Meteorological Data to Estimate Irrigation Requirements of Recreational Turf*: *Evapotranspiration and Crop Coefficients for the Cool-Humid Region*") and is just one factor among several that must be taken into consideration in developing an effective irrigation program.

In addition to the amount applied as ET replacement, the scheduling of irrigation is also determined by the "*timing*" of an irrigation event such as "*days between irrigation*". The scheduling of irrigation as a timing event is highly variable because the days between irrigation are affected by precipitation efficiency described above. In addition, conditions and practices that increase precipitation efficiency help to lengthen the irrigation cycle and therefore decrease irrigation frequency. Decreasing the irrigation frequency is equivalent, for example, to adjusting from irrigating daily using a 1-day cycle (high frequency) to irrigating on a 7-day cycle (low frequency), which allows for greater soil drying between cycles.

Soil drying between irrigation events promotes the following:

- decreases soil compaction tendencies under traffic
- diminishes shoot water content and increases physiological stress tolerance
- reduces leaf wetness and disease severity
- allows for greater soil-water recharge potential with less water loss as runoff
- promotes greater rooting depth with less water loss as leaching, and

- increases precipitation efficiency.

The frequency of irrigation also decreases with the following practices and conditions:

- Lower ET rates promoted by
  - use of slow release N or no nitrogen in summer
  - spoon-feeding with foliar N
  - regular mowing according to the 1/3 rule
  - use of appropriate height of cut (see Figure 1)
  - use of appropriate PGRs in summer
  - use of wilt-based irrigation in summer
  - correcting for soil potassium (K) deficiencies, and
  - use of deficit irrigation (applying less than 100% ET replacement).

- Deeper rooting promoted by
  - alleviating excessive thatch and soil hardness as compaction
  - correcting for strongly acidic soil pH
  - maintaining 100% grassy cover and soil shading
  - use of slow release N or no nitrogen in summer
  - spoon-feeding with foliar N
  - use of appropriate height of cut (see Figure 2)
  - use of wilt-based irrigation in summer (see Figure 3)
  - maintaining ET rates using ET replacement in summer to promote heat transfer and soil and plant cooling
  - avoiding excessively close HOC causing turfgrass thinning, and
  - use of deficit irrigation (applying less than 100% ET replacement).

Lower ET and deep rooting are plant factors associated with superior drought resistance. These plant characteristics lengthen the time between irrigation events and increase precipitation efficiency. As such, the twenty or more conditions or practices outlined above and presented in Table 1 and which are associated with increased drought resistance and precipitation efficiency, indicate that there are numerous opportunities for turf managers to increase water conservation.

The irrigation "timing interval" can be highly variable because drought resistance and precipitation efficiency vary from site-to-site. In addition, the greater the number of drought resistance and precipitation efficiency practices that are implemented and incorporated into the turf management program, the greater the water savings and the greater the interval (in days) between irrigation events. Poor practices will shorten the irrigation cycle (interval) while appropriate practices, including both their quality and numbers will lengthen the irrigation cycle. For example, irrigating at early symptoms of leaf dehydration (i.e., 50% wilt, leaf-fold and leaf-roll) is a timing event that is appropriate for turf. However, the benefit of "wilt-based irrigation" and its capacity to increase rooting depth requires repeated exposures to wilt in

> **Wilt-based irrigation** = Wilting tendency is a timing variable for initiating irrigation while tracking daily ET is the amount applied as irrigation. Allowing for wilt (mild plant dehydration) encourages greater soil drying and promotes less runoff and leaching that increases precipitation effectiveness.

order for drought resistance benefits to fully develop (see Figure 3).

Deficit irrigation = Is a variation on ET replacement where some fractional level of irrigation is applied at less than 100% of ET. Irrigation amounts (ET replacement) computed using weather stations are adjusted down to save water but also promotes greater soil and plant water deficits that lower turf quality and function. Actual deficit replacement levels (90, 80, or 70% of ET) and the timing of irrigation are dependent on numerous factors related to turf drought resistance and moisture retention of the site.

In turf areas where lower turf quality and turf function are acceptable, the practice of deficit irrigation replacement may be implemented. Deficit irrigation replacement recommends applying some fractional level of actual turf ET, where actual turf ET is derived using the expression:

$$\text{Turf } ET_T = ET_o \times K_c \quad \text{[Eq. 1]}$$

Turf ET_T is the amount of water lost from the turf system (as evaporative water loss from the soil surface plus transpirational water loss from associated leaf surfaces) and is the amount applied as irrigation. ET_o is the reference ET (prediction) calculated by a nearby weather station using meteorological data, and K_c (crop coefficient) is the appropriate correction factor to adjust reference ET_o to match actual turf ET_T. For greater detail and discussion of Eq. 1 please see *Turf Irrigation Series No. 1* entitled "*Use of Meteorological Data to Estimate Irrigation Requirements of Recreational Turf*: *Evapotranspiration and Crop Coefficients for the Cool-Humid Region*".

Turf ET_T estimated using Eq. 1 applies irrigation at 100% of ET replacement. Deficit irrigation is used to adjust actual turf ET_T down (i.e., deficit replacement) by applying irrigation at some fractional level less than 100% of ET. In deficit irrigation, actual turf ET_T calculated using Eq. 1 is applied at some deficit irrigation replacement level (i.e., < 1 or < 100%) according to the expression:

$$\text{Deficit irrigation} = \text{Turf } ET_T \times \text{Deficit replacement (0.90 or 0.80 or lower)} \quad \text{[Eq. 2]}$$

substituting Eq. 1 into Eq. 2

$$\text{Deficit irrigation} = (ET_o \times K_c) \times (0.90 \text{ or } 0.80 \text{ or lower}) \quad \text{[Eq. 3]}$$

Deficit irrigation replacement will allow for greater water savings because less water is applied (i.e., 0.70 vs. 0.80 vs. 0.90) relative to 100% of turf ET_T replacement. For example, if the reference ET_o computed by a nearby weather station since the last irrigation of a golf course fairway turf is 0.80 inch, and the appropriate K_c value for the golf fairway is 0.95, then according to Eq. 1:

$$\text{Turf } ET_T = 0.80 \text{ inch} \times 0.95 = 0.76 \text{ inch}$$

It would follow that irrigation of the golf fairway turf using 0.80 inches as ET replacement (i.e., 100% of ET replacement) could be applied. Using deficit irrigation replacement level of 80% of actual turf ET_T (i.e., 20% water savings relative to 100% of turf ET_T), further adjustments could be made using Eq. 2 (or equivalently Eq. 3) as:

$$\text{Deficit irrigation} = 0.76 \text{ inch (from Eq. 1)} \times 0.80 \text{ (deficit level)} = 0.61 \text{ inch}$$

After adjusting actual turf ET_T to 80% deficit irrigation replacement, 0.61 inch of water could be applied as irrigation with a resulting 20% water savings compared to 100% ET replacement (i.e., 0.61 vs. 0.76 inch applied as irrigation at 80 and 100% ET replacement, respectively).

It's important to note that crop coefficients (K_c values) adjust reference ET_o values (up or down) to account for specific maintenance practices and their effects on turf ET in order to compute (using Eq. 1) the most reliable (accurate) prediction of actual turf ET_T. Unlike crop coefficients, however, deficit irrigation replacement levels are adjustments to weather station computations of turf ET_T (calculated using Eq. 1) and are downward adjustments of turf ET_T (i.e., ET deficits).

Repeated use of deficit irrigation (using Eq. 2 or Eq. 3) provides additional water savings (conservation). However, when compared to 100% ET replacement (Eq. 1), long term water deficits may cause greater dehydration stress and the potential loss in turfgrass quality and function, and therefore should not be used on high priority areas such as golf greens and tees or sport grass under intense traffic (DaCosta and Huang, 2006). Lower deficit irrigation replacement levels (i.e., 70%, 80%, 90% of ET replacement) may be more appropriate where rapid growth for recovery under traffic are less important such as golf fairways and rough areas, and lawn turf.

However, using 100% ET replacement as the *amount* applied as irrigation along with wilt-based irrigation as the *timing* variable combines some of the benefits from soil drying (see above) along with the benefits of ET replacement (i.e., diminished leaching potential with soil and transpirational cooling). The proper deficit irrigation replacement level and the timing variable for your turf will vary with (i) the turfgrass species' and cultivars' capacity to tolerate the drought imposed by the specific deficit level, (ii) the factors affecting precipitation efficiency, and (iii) the factors affecting drought resistance immediately before and during implementation of deficit irrigation replacement.

Other Considerations

Soil water available for plant growth is highly variable because of the numerous factors affecting plant-available soil-water including rooting depth, soil texture, soil layering, soil infiltration rates, soil permeability rates, and soil moisture depletion rates (i.e., ET). Such variability is unknown even where uniform, artificial root zones are constructed. However, knowledge of the amount of soil water held in storage for plant use is not necessary when using ET replacement to schedule irrigation events. The practices outlined above that increase precipitation efficiency and drought resistance insure greater soil water available as ET. Therefore, estimating daily ET and tracking daily ET corrected for rainfall can effectively estimate *how much water* to apply while *when to water* may follow visual drought stress symptoms such as wilt or some other performance standard such as minimum turf quality or green cover (Hejl et al., 2016). Similarly, the timing event or the interval between irrigation will follow the precipitation efficiency and drought resistance aspects of the turf under irrigation (Table 1).

Implementing the appropriate water conserving practices allows turf managers to effectively schedule irrigation using less water by lengthening the irrigation cycle. To that end, (i) estimating ET using meteorological data collected by weather stations, (ii) improving the turfgrass' drought resistance capacity to maintain function with less precipitation (irrigation and rainfall), and (iii) improving the effectiveness of the site to capture and store precipitation are important and effective strategies. These water conservation strategies will also effectively address the many concerns expressed by advocates from the general public, as well as federal, state, and municipal regulators regarding the need to conserve water and to eliminate waste in turf systems.

References

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Table 1. Conditions and practices that increase precipitation efficiency (rainfall and irrigation) and the turf's capacity to store soil water for ET utilization.

By increasing rooting:	By decreasing leaching:	By decreasing runoff:
Appropriate HOC, irrigated	Avoiding turf dormancy	Appropriate surface drainage
Appropriate HOC, non-irrigated	Deeper rooting	Avoiding turf dormancy
Appropriate internal drainage	ET replacement	Controlling for thatch and soil compaction
Deficit irrigation replacement	ET replacement corrected for rainfall	Deficit irrigation replacement
Favorable soil pH	Increase soil water retention	Maintaining active turfgrass cover
Low N as spoon-feeding	Maintaining dense-active turf cover	Multiple cycling of irrigation
Low N as SRN		Use of wetting agents
Low soil compaction tendencies		Wilt-base irrigation
Low thatch tendencies		
Wilt-base irrigation		

Figure 1. The effects of height of cut (HOC) on evapotranspiration rate (ET) measured in summer under irrigation. Short grass turf (creeping bentgrass, CB) mowed at greens and fairway HOC use approximately 20% less water as ET compared to taller HOC turf (Kentucky bluegrass, KB, and perennial ryegrass, PR). No significant difference in ET rates between greens and fairway HOC are observed. Decreasing the HOC of taller grass from 2.50 to 1.25 inch significantly reduces ET rates by 7%. There is a 0.015 inch increase in weekly ET rates (and irrigation requirements) for each 0.10 inch increase in HOC. Vertical bars with the same letter are not statistically different. From Poro et al. (2017).

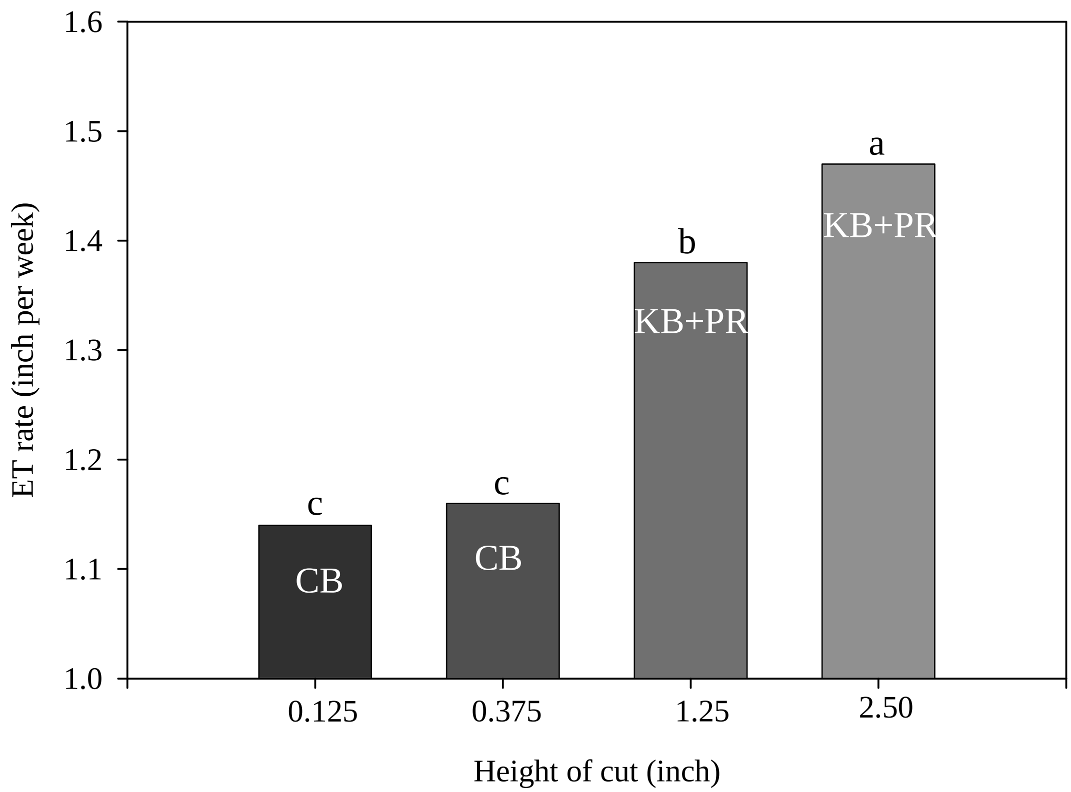

Figure 2. The effects of height of cut (HOC) on rooting density in the deepest portion of the soil profile (10 to 18 inch soil depth) measured in summer under irrigation. Deep rooting is especially sensitive to HOC and is important for acquisition of soil water under drought and irrigation. Short grass turf (creeping bentgrass, CB) mowed at greens and fairway HOC exhibited 60% less rooting density compared to taller HOC turf (Kentucky bluegrass, KB, and perennial ryegrass, PR). No significant difference in rooting density is observed between greens and fairway HOC or between taller HOC turf mowed at 1.25 to 2.50 inch. A decrease in HOC within the accepted range for the species does not necessarily diminish deep rooting in summer while lower ET rates may be observed under irrigation (see Figure 1). However, lower HOC in summer that cause significant grass thinning may inhibit rooting. Vertical bars with the same letter are not statistically different. From Poro et al. (2017).

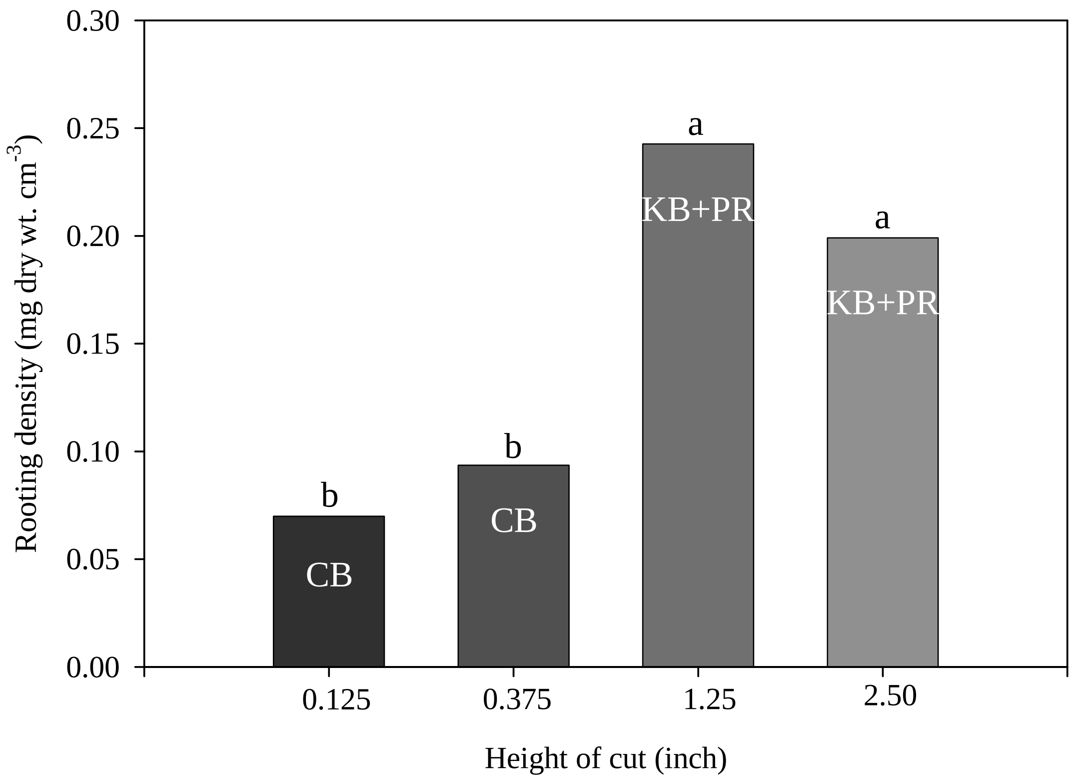

Figure 3. Wilt-irrigation comparing one wilt-event with six wilt-events and its effects on days-to-wilt (number) and changes in volumetric soil moisture content (VSMC). Irrigation was applied using 100% ET replacement when perennial ryegrass reached 50% wilt. Perennial ryegrass was mowed at 2.0 inch height of cut. Six wilt events added 2.5 days to the irrigation interval when compared to one wilt event. The added days-to-wilt using six wilt-events was due to the greater rooting density at the 14-inch soil depth indicated by greater soil moisture depletion (i.e., changes in VSMC). From Lanier et al. (2012).