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Maximizing Turfgrass Irrigation Efficiency

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Fresh water available for human consumption, recreation activities, agricultural production, and industrial uses accounts for only 1% of all water on the earth. The remaining 99% is salt water and polar ice. Water is a particularly precious resource in the arid Southwest where average annual rainfall is approximately 10 inches. This is insufficient for plant needs, such as tall fescue (*Festuca arundinacea*), which comprises 70-80% of the sod industry in the state of California. Tall fescue is also a popular turfgrass species in other regions of the USA. In Riverside, CA, tall fescue requires an average of 46 inches of water annually while a typical warm-season turfgrass requires 35 inches of water each year. As might be expected, plant water needs are greater in the arid West vs. the humid East.

Irrigation is a necessary component of typical landscape maintenance in the Southwest, and is becoming commonplace in landscapes countrywide. The

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demand for water is accentuated by growing urbanization, multiple years of drought, and reduced recharge of water supplies (aquifers, mountain snowpack). An example of growing urban demand is that approximately 30% of all water delivered by the Metropolitan Water District of Southern California is applied to landscapes. In response to this, local water districts have published recommendations for efficient landscape water application and some have initiated active conservation programs. One of their conservation goals is to reduce the amount of water being applied to landscapes and thus defer the need for more aqueducts and support facilities.

Turf and landscape managers are finding that acceptable aesthetic standards can be sustained with less water. It is in their best interest to employ irrigation practices that result in water conservation and monetary savings. A fine-tuned irrigation program is essential to maintain the aesthetic quality of turf while using limited water resources wisely. A companion article by Richard Hull (*TurfGrass Trends* 10: 1996) discussed management of turfgrass for minimum water use. This article will focus on managing turf and landscape irrigation practices toward the same end.

How Much Water Should Be Applied?

The first questions asked about turfgrass irrigation often relate to the quantity of water used, such as, "How much water needs to be applied to maintain acceptable aesthetic quality?" University research over the past two decades has established 80% of ETo, or reference evapotranspiration, as the recommended irrigation replenishment for cool-season turfgrasses in the Southwest, including tall fescue. This recommendation does not take into account the additional water required to compensate for a lack of irrigation uniformity. With typical irrigation uniformities of 60 to 80%, between 100 and 120% ETo may need to be required to maintain uniform and acceptable tall fescue quality, especially during the hot summers. To replace water used by a warm-season turfgrass, 60% ETo is generally required.

ETo is an estimate of the amount of water used by a healthy 4 to 6 inch-tall stand of cool-season grass. Reference ET values can be obtained from several sources. The California Department of Water Resources maintains the CIMIS (California Irrigation Management Information Service) program to aid irrigation managers. This program uses daily weather data and a modified Penman model to calculate (estimate) ETo values, which are retrieved by a manager using a modem. A similar program (AZMET) is available in Arizona. Managers of large turfgrass areas (golf courses, for example) may also employ Maxicom (RainBird, Azuza, CA) and similar weather-monitoring Penman systems to provide on-site ET-based irrigation programming. (See "The Use of Weather Stations," on page 10, for a golf course superintendent's experience with his weather station.) Historical ETo records in tabular form also are available for locations throughout the United States.

Besides using empirical equations, reference evapotranspiration can also be estimated from pan evaporation and atmometers. Doorenbos and Pruitt (1975) provide a thorough discussion of ETo and pan evaporation (Epan) using a USDA Class A pan. Listed below (Table 1) are coefficients (Kp) which are used to convert values of Epan to ETo (ETo = Epan x Kp) under different environmental conditions. Simonne et. al. (1992) discuss using containers other than a standard Class A pan for measuring reference evaporation and scheduling irrigation. Qian et. al. (1996) estimated turfgrass evapotranspiration using pan evaporation, atmometers (C and M Meteorological Supply, Colorado Springs, CO), and the empirical Penman-Monteith equation and found that atmometers (Bellani plate) correlated most closely with measured turf ET in relatively humid eastern Kansas. Whatever source is employed to estimate baseline turf water use, the first step to maximizing irrigation efficiency is to know the quantity of water to apply.

University Research Findings

The University of California, Riverside has conducted several precision-irrigation studies on tall fescue during the past 16 years. These studies were made possible primarily through several research grants from the Metropolitan Water District of Southern California. The more recent studies were conducted on precision-irrigation plots in Riverside, and involved irrigating tall fescue at approximately 80% ETo during the summer and fall months. The 80% irrigation system uniformity (see below) of our research plots is probably 25% more-uniform than those of most general turfgrass areas. The summer season is the most difficult time to maintain quality tall fescue at 80% ETo because of the hot dry conditions typical during these

Table 1. Pan coefficients (K_p) for Class A pan in different ground covers and levels of mean relative humidity and 24 hours wind. (Adapted from Doorenbos and Pruitt, 1975)

Class A Pan	*Case A: Pan surrounded by short green crop*				*Case B[z]: Pan surrounded by dry fallow land*			
Mean % Relative Humidity		Low < 40	Medium 40-70	High >70		Low < 40	Medium 40-70	High >70
Wind run (km/day)	Upwind distance of green crop (m)				Upwind distance of dry fallow (m)			
Light <175	0	.55	.65	.75	0	.70	.80	.85
	10	.65	.75	.85	10	.60	.70	.80
	100	.70	.80	.85	100	.55	.65	.75
	1,000	.75	.85	.85	1,000	.45	.55	.70
Moderate 175-425	0	.50	.60	.65	0	.65	.75	.80
	10	.60	.70	.75	10	.55	.65	.70
	100	.65	.75	.80	100	.50	.60	.65
	1,000	.70	.80	.80	1,000	.45	.55	.60
Strong 425-700	0	.45	.50	.60	0	.60	.65	.70
	10	.55	.60	.65	10	.50	.55	.65
	100	.60	.65	.70	100	.45	.50	.60
	1,000	.65	.70	.75	1,000	.40	.45	.55
Very Strong >700	0	.40	.45	.50	0	.50	.60	.65
	10	.45	.55	.60	10	.45	.50	.55
	100	.50	.60	.65	100	.40	.45	.50
	1,000	.55	.60	.65	1,000	.35	.40	.45

z For extensive areas of bare-fallow soils and no agricultural development, reduce Kpan values by 20% under hot windy conditions, by 5-10% for moderate wind, temperature and humidity conditions.

months. Research findings from the more recent Riverside studies show that when summer conditions are mild, quality tall fescue can be maintained when irrigated at 80% ETo and managed under the conditions of our research plots.

When summer conditions are more severe, minimally acceptable tall fescue can be maintained when irrigated at 80% ETo and managed under conditions of our research plots. These findings suggest that more irrigation water may be needed during the summer. Future research on tall fescue will be designed using 80% ETo over 12 months. To achieve this, more water may be applied during the summer and less water will be applied during the fall through spring season.

From Recommendation to Practice

A series of calculations are required to convert recommended quantity of water to an actual run time on an irrigation controller. The first step in this calculation is to determine how many inches of water need to be applied by multiplying ETo by the crop coefficient (Kc) for the turfgrass of interest.

The Kc appropriate for the region of interest and for the time increment desired, such as a month or quarter (irrigation schedules are not usually altered more frequently than this) must be selected. If irrigating tall fescue or other cool-season grasses, Kc = 0.8. A Kc of 0.6 is used for warm-season grasses. Crop ET is then equal to ETo x Kc . The resulting number is then divided by the irrigation system uniformity, or DU, which will be calculated below. This 'depth' of water is converted to an actual run time (minutes) for the period by dividing it by the system delivery rate (inches per hour) and then multiplying by 60.

The final step is to calculate run time (minutes) per irrigation event by dividing run time for the period (month or quarter) by the number of irrigation events for that period. Following is an example calculation for the city of Los Angeles for the month of July.

Historical ETo = 6.2"
Kc = 0.8 (80% ETo for cool-season grass)
DU = 0.6 (60%, typical for many systems)
System Delivery Rate - assume 1.5 inches/hour for an average rotor-type head

$$\frac{\text{ETo x Kc}}{\text{DU}} = \frac{6.2\text{" x } 0.8}{0.6} = 8.3 \text{ inches of water}$$

Depth of Water = 8.3 inches water

$$\text{Run time} = \frac{8.3 \text{ inches}}{1.5 \text{ inches per hour}} = 5.54 \text{ hours}$$

5.54 x 60 = 332 minutes run time for July

Two variables not previously discussed are required for this calculation. These are system uniformity (DU) and system delivery or precipitation rate, which are both calculated by performing a "catch can test." Six or more straight-sided cans (such as tuna cans) are placed in a grid within the irrigated area. The more cans that are used, the better the information derived from the test. After arranging the cans, sprinklers are run for 15 minutes (one quarter of an hour so that hourly precipitation rate is easily calculated by multiplying by 4) after which the depth of water in each can is measured with a ruler. If 15 minutes is not enough time, run sprinklers longer to collect a measurable depth of water and multiply accordingly.

Precipitation rate (inches/hour) is the average depth of water collected in all of the cans multiplied by 4. If the average measured depth is .25", then the system precipitation rate would be 1 inch per hour. Alternatively, precipitation rate can be calculated using the following equation, where the value 96.25 converts gallons delivered per minute per square foot to inches per hour:

$$\frac{\text{gpm(one head) x } 96.25}{\text{head spacing x row spacing (ft)}} = \text{precipitation*}$$

* precipitation in inches per hour

System distribution uniformity (DU) is determined by calculating the average amount of water in 25% of the cans that accumulated the least amount of water during the test divided by the mean depth of water in all cans.

Distribution Uniformity is calculated as follows:

$$DU = \frac{\text{Mean of the low quarter (volume or depth)}}{\text{Overall mean (volume or depth)}}$$

Here is an example. A catch can test is performed with 20 cans, spaced 5 feet apart. Measuring the depth of water in each can, the average depth in the 5 lowest cans is found to be 0.22 inch. The average depth of all 20 cans is 0.35 inch. Precipitation rate for this system is 0.35 x 4 = 1.4 inch per hour. DU is 0.22/0.35 = 0.63.

The next step in developing an efficient irrigation program is to calculate run time per irrigation event. This requires knowledge of the number of irrigation events per time period (month or quarter, for example). In the following example it will be assumed that the manager wants to irrigate twice each week (an assumption based on UCR research). Looking at a calendar, this translates into 9 irrigation events for an average month, or 35 irrigation events for a quarter. Total run time for the period needs to be divided by this many irrigation events. Continuing with the preceding example for Los Angeles:

$$\frac{\text{Run time per month (332 minutes)}}{\text{\# irrigation events per month (9)}} = 37 \text{ minutes}$$

37 minutes per irrigation event (Monday, Thursday for example).

This is the amount of time for each irrigation event that will actually be programmed into the irrigation controller to apply 80% Eto.

Why is a twice per week irrigation schedule used in the preceding example? Turfgrass managers are aware that light, frequent irrigation encourages shallow roots and weed growth. Therefore, their recommendation for many years has been to water turf just often enough to avoid visual drought symptoms by deep and infrequent watering (Grau and Ferguson, 1948; Hagan, 1955). Such infrequent scheduling may conserve water by reducing evaporation associated with irrigation events (Hagan, 1955), discourage weed growth, stimulate deeper rooting, and produce turf better able to withstand drought (Youngner, 1985).

Other recommendations for application frequency are based on replenishing soil moisture to a predetermined desirable level. Such scheduling requires knowledge of the soil's plant available water content and the rate of turf water use. The purpose of recent research at UCR was to find an optimum irrigation frequency for tall fescue in Southern California. Specifically, the objective was to determine if tall fescue performance, when irrigated at 80% crop ET (ETo x Kc for tall fescue x 0.8) in Southern California, could be improved by altering irrigation frequency, cultivar, selection and mowing height.

Results from this study showed advantages to watering tall fescue relatively infrequently (two times per week). Turfgrass color and visual quality, and soil moisture were highest when the turf was irrigated twice per week compared to three or four irrigations per week. Fewer irrigation events may have resulted in less evaporative water loss associated with wet turf and soil and deeper penetration of water into the active root zone resulting in improved plant water status. The bottom line is that the same amount of water applied less frequently results in more water per application and deeper penetration. Deeper water penetration encourages deeper turfgrass rooting and discourages surface rooting of trees and shrubs growing within the turf. Research continues to determine the influence of irrigation frequency on warm-season turf performance.

Optimizing Irrigation Application: Water Penetration

Regardless of how much irrigation water is applied to tall fescue, or how often it is applied, what is important is that the water must reach the root

Table 2. Comparison of two irrigation systems.

	System 1	*System 2*
Irrigation System Uniformity	80%	50%
Inches water applied	6.2	9.9
Total minutes	248	397
Minutes per run event	28	44
Gallons applied [z]	12400	19850
Cubic feet applied [z]	1662	2660

z Assuming an irrigation system using 50 gallons per minute and a precipitation rate of 1.5 inches per hour.

zone to be available for uptake by the plant. If the precipitation rate is greater than the soil infiltration rate, runoff will occur. Proper management can ensure maximum water penetration into the soil.

First of all, determine how long sprinklers can run before water begins to pool and run off. Irrigation run times should be shorter than this amount of time. Several sequential 'cycles' may be needed to apply enough water to meet plant needs. The 37 minute run time in the above example may need to be cycled into two 19 minute runs, three 12 -13 minute runs or four 9-10 minute runs (allowing soak-in time between runs) to ensure that all water delivered in 37 minutes reaches the root zone. Some irrigation controllers offer cycle repeat features which simplify this operation and preclude the need for multiple start times.

The second step an irrigator can take to increase water penetration or infiltration is to reduce irrigation system delivery rates. Reducing precipitation rates does not change the rate of soil infiltration, but provides a longer time period for the water to soak into the soil. When possible, this can be accomplished by designing systems with rotor-type heads instead of spray heads. A spray head may demand the same gallonage as a rotor head, but only cover 1/4 the area of the rotor head. Thus more water is applied per square foot using the spray head Also using smaller nozzle sizes on rotor heads (which can provide the same coverage radius) will deliver less water per square foot covered. Micro spray systems, some of which adapt to existing spray heads, can also be employed. Consult a professional irrigation supplier to see what is available. Although not a common practice in southern California, core cultivation or aerifying (punching holes in the soil surface) can be performed to increase water infiltration and reduce runoff.

Optimizing Irrigation Application: System Uniformity

Maximizing irrigation system uniformity is one of the most important steps an irrigator can take to optimize irrigation efficiency. Returning to the preceding example of applying 80% July ETo in L.A., a comparison of two systems with different distribution uniformities is instructive:

Notice how much more water must be applied with System 2 to achieve a similar result (9.9 inches vs. 6.2 inches). The less uniform a system is (the lower the DU), the longer the sprinklers will have to run to produce a uniform turf appearance over the entire irrigated area.

Irrigation system uniformity can be improved in many ways. The first is to ensure that system operating pressure is within the manufacturer's recommended range for the heads being used. Sprinkler heads are often sold with a specification sheet which includes the recommended operating pressure. Manufacturer's catalogues also list optimum operating pressures for specific heads. Higher than optimum pressure causes atomization and loss of fine droplets to wind, not to mention unnecessary wear on system piping and equipment. Lower than optimum pressures cause insufficient interfacing of sprinkler spray patterns, and dry 'donut' areas are the result. Operating pressure can be measured with a gauge affixed to a shrader-type valve on the solenoid valve (pressure regulating valves have these), or installed somewhere in the system. Pressure can also be measured on rotor or impact-type heads with a pitot tube held where water leaves the nozzle.

If system pressure is too high, it can be regulated with an adjustable pressure regulator or a pressure regulating solenoid valve. Pressure regulators are often located after the backflow device and regulate pressure on all systems downstream. (Note: before performing any alterations, an irrigation designer should be consulted. Higher pressures may be required for certain systems downstream, e.g., systems at higher elevations). One can also use a pressure regulating master valve which is actuated by the irrigation controller to supply water to all systems. All systems will therefore be supplied with the same operating pressure from the master valve. Pressure regulating valves can also be installed on each irrigation system. This provides the greatest flexibility by allowing adjustment of each system to an optimum operating pressure. Pressure regulation at the sprinkler head itself is also possible with products now available on the market. Spray head nozzles can be obtained with pressure compensating devices (PCD's) or pressure compensating screens (PCS's) which reduce operating pressure to an ideal range for a specific nozzle and thereby eliminate fogging. One manufacturer also has recently marketed a pop-up spray head with a built-in stem pressure regulating feature.

System uniformity also can be adversely affected by low operating pressures. Although sometimes more difficult to remedy than high pressure, several steps can be taken to increase a low operating pressure. The first step is to install a booster pump to increase system pressures. This can be a costly remedy and require considerable work. Another solution is to divide large systems into multiple smaller systems, reducing the gallonage demand, and increasing the operating pressure available to each smaller, individual system. This procedure will require the installation of more valves and may be complicated by the need for more wiring and additional controller stations. An easier solution may be to install smaller nozzles on rotor heads. Smaller nozzles can often provide sufficient radius for head-to-head coverage, while reducing the gallonage demand of the system. Finally, irrigation should occur when supply pressure (city water) is at its maximum, usually early morning.

Assuming system operating pressure is within the recommended range, system uniformity often can be improved further. Typically, rotor or impact-type heads provide superior uniformity to spray heads and should be used whenever possible. When using rotor heads, nozzles should be selected carefully to balance precipitation. For example, a rotor head with a 180-degree arc takes twice as long to cover its area as a head with a 90-degree arc. Therefore, a nozzle supplying approximately twice the gallonage of water should be used in the 180∞ head. A nozzle supplying four times the gallonage should be used in a 360-degree head. More specifically, if a corner head with an arc of 90-degree has a 1.5 gpm nozzle, an adjacent head operating with a 180-degree arc should have a 3.0 gpm nozzle. A full circle head on this system would then need to be equipped with a 6.0 gpm nozzle.

Heads should be checked periodically for vertical alignment to make sure they are as near to vertical as possible (assuming level ground). Head spacing and proper nozzle size should also be monitored to ensure head-to-head coverage. System operating condition should be checked routinely to ensure that all heads are functioning properly and that there are no clogged nozzles or streams. Finally, irrigation should be performed when wind is at a minimum, such as evening or morning. Early morning is generally recommended to reduce disease occurrence.

Optimizing Irrigation Application: Final Considerations

A few more considerations can help to optimize irrigation application. First, irrigation controllers should be rescheduled as frequently as possible. The above example assumes a monthly reschedule. Time permitting, run times could be changed weekly or biweekly. At the very least, irrigation controllers should be reprogrammed quarterly to compensate for seasonal climatic changes. Water budget or global adjust features on many controllers can simplify rescheduling by allowing the operator to 'dial in' an irrigation level as a percentage of a seasonal maximum. Remote control of irrigation, where programs can be changed via modem or radio, is becoming increasingly popular. Such features encourage frequent controller updating because irrigation control can be changed and monitored from one's home or office.

An irrigation system should be designed with hydrozones in mind. Water requirements of trees and shrubs differ from those of turf because the former have deeper and more extensive rooting patterns and can be watered more infrequently. Trees, shrubs, and turf constitute different hydrozones and if possible, separate systems should be used for each. Furthermore, shaded areas require less water than sunny areas, so ideally, separately valved systems should be in operation for these two zones. Irrigation on slopes may need to be cycled more frequently than systems on level land and therefore may constitute a unique hydrozone.

The use of rain switches can also prevent irrigation during rain events. Many new controllers have terminals into which a rain switch can easily be installed. Soil moisture sensors, such as Watermark sensors (Irrometer Co., Riverside, CA), also can be used to prevent irrigation when soil moisture is adequate for plant needs. Such sensors operate by opening valve circuits (preventing irrigation) when soil moisture is higher than a preset required level.

Terms to Know

- Crop Coefficient - Kc
- Crop or turfgrass water use, turfgrass evapotranspiration - ET_{crop}
- Distribution Uniformity - DU
- Historical ET_o
- Irrigation
- Irrigation Efficiency
- Plant Factor
- Precipitation Rate
- Turfgrass Water Requirement
- Turfgrass Irrigation Requirement
- Reference Evapotranspiration - ET_o
- Water Conservation

Conclusions

Applying an amount of water which just replenishes turf and landscape water use (ET) is a realizable goal which can result in significant water and monetary savings. ET-based irrigation scheduling seeks to prevent over-irrigation which leads to runoff or leaching into potable water sources. The goal is to irrigate plant materials at a recommended percentage of ETo as infrequently as possible. University research has shown that applying 80% ETo to tall fescue twice per week can result in improved turfgrass color and visual quality. The irrigator should keep in mind that with longer run times associated with less frequent irrigation, water infiltration becomes a consideration and multiple cycles or lower precipitation rates may need to be used. Acceptable turf quality can best be maintained when irrigation system uniformity is optimum. Recommendations for improving system uniformity included checking and adjusting operating pressures, selecting appropriate heads and nozzles, checking head alignment and operation, and irrigating at times when wind is minimal. Finally, nothing is more important than personal observation. The turf manager should visually inspect turf areas and irrigation systems on a regular basis (see article by Dave Shaw and Paul Zellman in *Turf Tales* Magazine, Winter, 1996, for an irrigation system walk-through checklist). If dry areas are apparent in spite of proper system operation, controller programs should be adjusted accordingly. With an efficient irrigation system and frequent controller program updates, landscape managers should begin to see improved plant quality with water and monetary savings.

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References

Beard, J.B., 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs, NJ.

Doorenbos, J. and W.O. Pruitt. 1975. Guidelines for predicting crop water requirements. FAO irrigation and drainage paper 24.

Grau, F.V. and M.H. Ferguson. 1948. Pointers on making good lawns. pp. 302-307 In A. Stefferud (ed.) Grass, The Yearbook of Agriculture. USDA.

Hagan, R.M. 1955. Watering lawns and turf and otherwise caring for them. pp. 462-467 In A. Stefferud (ed.), Water, The Yearbook of Agriculture. USDA.

Hartin, J., R.L. Green, and V.A. Gibeault. 1995. Scheduling turfgrass irrigations. *Turf Tales*. 2(2):8-11.

Hull, R.J. 1996. Managing turf for minimum water use. *TurfGrass TRENDS*. 5(10):1-9.

Qian, Y.L., J.D. Fry, S.C. Wiest, and W.S. Upham. 1996. Estimating turfgrass evapotranspiration using atmometers and the Penman-Monteith model. Crop Sci. 36: 699-704.

Shaw, D., and P. Zellman. 1996. Landscape irrigation system evaluation and scheduling for southern California. *Turf Tales*. 3(1):7-8.

Simonne, E., H. A. Mills, and D. A. Smittle. 1992. A simple method to measure on-farm pan evaporation for scheduling irrigation. Hort Technology. 2(3): 392-393.

Youngner, V.B. 1985. Physiology of water use and water stress. p. 37-43 In V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation. Univ. of California Publ., Oakland.