

Marshall, Aaron

From: Marshall, Aaron
Sent: Friday, February 05, 2010 3:13 PM
To: 'charles.e.brockway@brockwayeng.com'; 'erick.powell@brockwayeng.com'
Cc: Keen, Shelley
Subject: Irrigation System Efficiency Estimates

Gentlemen,

Attached are three publications providing information on turfgrass irrigation and irrigation system efficiency. The most readily useful information may be found in Table 2 of the document from the University of Arizona saved as "UA - irrigation system eff.pdf".

The following link provides additional information on irrigation efficiency. The link is for the abstract – I have not purchased and reviewed the entire report. The abstract indicates that measured "[i]rrigation efficiency values ranged from 83 to 98%."

<http://cedb.asce.org/cgi/WWWdisplay.cgi?0530398>

Based on this information, I agree with your conclusion in the revised narrative that explains, "If a more efficient method of irrigation such as "sprinkler irrigation" is employed, which is probable, then the irrigation efficiency would be raised to 75%..."

In my opinion, 75% is a reasonable estimate for total irrigation system efficiency ($T_{\text{eff}} = \text{conveyance eff.} + \text{application eff.}$) using a closed conduit sprinkler system.

Aaron Marshall
Senior Water Resource Agent
Idaho Department of Water Resources
P.O. Box 83720
Boise, ID 83720-0098
(208) 287-4943
aaron.marshall@idwr.idaho.gov



NC State -
turfgrass irrigatio...



UC - Managing
Turfgrass.pdf



UA - irrigation
system eff.pdf...



Determining the Amount of Irrigation Water Applied to a Field



Introduction

Critical to any irrigation management approach is an accurate estimate of the amount of water applied to a field. Too often, growers apply water to make the fields and rows “look good” (blacken-up the beds) or continue irrigating until the water reaches the end of every furrow. However, quite often they never realize just how much water they have applied. When growers do not take their system’s efficiency into account, they may apply too little or too much water. Too little water causes unnecessary water stress and can result in yield reductions. Too much water can cause water logging, leaching, and may also result in loss of yield.

The Irrigator’s Equation

How Much Did I Apply?

Estimating the amount of water applied to a field or to a set is fairly easy for surface systems. The Irrigator’s Equation, $Q \times t = d \times A$, can be used to estimate the depth of water applied. In the equation:

$$Q \times t = d \times A$$

Q is the flow rate, in cubic feet per second (cfs); t is the set time or total time of irrigation (hours); d is the depth of water applied (inches) and A is the area irrigated (acres).

If you are working with a pump, remember that 450 gallons per minute equals 1 cfs. Also, there are 40 miners-inches per 1 cfs. However, miners-inches change from region to region. Make sure you check which type of miners-inches you are working with. Table 1 has some useful conversions.

To determine how much water was applied, use the Irrigator’s Equation and solve for the unknown value, d , depth of water applied in inches. For example, suppose you irrigated a set 320 ft. wide (that’s 96 rows at 40 inches apart); 800 ft. long with a head of 6 cfs. Your set time was about 6.5 hours. How much water have you applied? First, calculate the area irrigated:

$$320 \text{ ft.} \times 800 \text{ ft.} = 256,000 \text{ ft.}^2$$

There are 43,560 ft.² in 1 acre, so:

$$256,000 \text{ ft.}^2 / (43,560 \text{ ft.}^2/\text{acre}) = 5.9 \text{ acres}$$

Now, using the Irrigator’s Equation we get:

$$6.0 \text{ (cfs)} \times 6.5 \text{ (hours)} = d \text{ (inches)} \times 5.9 \text{ (acres)}$$

Solving for d (depth of water applied) we get:

$$d \text{ (inches)} = (6 \times 6.5) / 5.9 = 6.6 \text{ inches}$$

The total amount of water applied to the field was 6.6 inches in depth.

How Long Should My Set Time Be?

The Irrigator’s Equation can also be used to estimate how long your set times should be. By choosing a target amount of water to apply, you can use the same equation but solve for time instead of depth of application.

For example, suppose you estimated that your soil-water deficit was 4.0 inches. You want to refill the soil and apply the full 4.0 inches. Your set size is 150 feet wide (that is 45 rows at 40 inches apart), 1100 feet long, and you are running 5 cfs. How long should your set time be?

Again, first calculate the total area to be irrigated. In this case, we have:

$$150 \text{ ft.} \times 1100 \text{ ft.} = 165,000 \text{ ft.}^2$$

To convert to acres:

$$165,000 \text{ ft.}^2 / (43,560 \text{ ft.}^2/\text{acre}) = 3.8 \text{ acres}$$

8/2006

AZ1157

Arizona Water Series No. 29

THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE
TUCSON, ARIZONA 85721

EDWARD C. MARTIN, Ph.D.
Extension Irrigation Specialist

This information has been reviewed by university faculty.
ag.arizona.edu/pubs/water/az1157.pdf

Table 1. Conversion from cubic feet per second (cfs) to gallons per minute (gpm) to Miners inches.

Flow Rate Conversion Table		
Cubic Feet per Second (cfs)	Gallons per Minute (gpm)	Miner's Inches
1	450	40
2	900	80
4	1800	160
6	2700	240
8	3600	320
10	4500	400

Now using the Irrigator's Equation, we get:

$$5.0 \text{ (cfs)} \times t \text{ (hours)} = 4 \text{ (in)} \times 3.8 \text{ (acres)}$$

Solving for t we get:

$$t \text{ (hours)} = (4 \times 3.8)/5 = 3 \text{ hours}$$

The set time should be three hours to apply 4.0 inches of water.

The Irrigator's Equation can be used to determine any of the four variables in the equation, providing you know the other three.

Don't Forget the Efficiency

The one factor in irrigation that is most often overlooked is the efficiency of the irrigation system itself. There are many different types of efficiency and many different ways to define it. Efficiency here refers to the overall system's ability to apply an equal amount of water to all parts of the field. A system with 100% efficiency would be able to apply the same amount of water to every inch of the field, head end, tail end, center, side, etc. No system is 100% efficient. Drip systems are the most efficient and they are usually near 95% efficient. Surface systems are notorious for inefficiency, but properly maintained fields can achieve efficiencies as high as some sprinkler systems.

Table 2 gives the range of efficiencies normally associated with different types of irrigation systems. In order to apply the proper amount of water to a field, first you must decide what efficiency to use in your calculations. The table gives a range of values for seasonal and peak use periods. These are provided because some systems are better equipped to handle large applications and during times of peak water use, when water demand is high, the system's efficiency is increased.

For example, all of the surface systems have an increase in their efficiency from seasonal to peak use periods because surface systems can apply large amounts of water more efficiently than smaller amounts. During the early part of the season, these systems are inefficient because they over-water. Overall, seasonal efficiency is relatively low compared to the efficiency during peak use. Sprinkler and drip systems (with the exception of the traveler sprinkler system), on the other hand, maintain their efficiencies regardless of seasonal or peak use periods. This is because these systems apply large and small quantities of water at about the same efficiency.

Taking the average of the ranges in Table 2 is probably a good start, although many surface systems operate at the very low end of the ranges given. Also, many sprinkler systems with LEPA (Low Energy Precision Application) systems and drop nozzles achieve even higher efficiencies than those given. You can contact your local Natural Resources Conservation Service office or local consultant who may be able to perform an analysis on your system to determine the irrigation efficiency. Once the efficiency has been determined, use that to adjust your irrigation amounts.

Let's take the second example where the grower was determining how long the set time should be to irrigate 4.0 inches. If he has a system that is 75% efficient, then the target amount would be increased from 4.0 inches to 5.3 inches. In order to account for the system's inefficiency, the efficiency must be divided into the targeted amount. In the example above, the efficiency of 75% (or 0.75) is divided into the target amount of 4 inches:

$$4.0/0.75 = 5.3$$

Table 2. Estimated seasonal average and peak water-use period irrigation efficiencies.*

Type of Irrigation System		Efficiency Range (%)	
		Seasonal Average	Peak Use Period
Surface	Furrow (without reuse)	55-77	77-80
	Border (without reuse)	63-84	77-87
	Basin	70-80	70-87
	Precision-leveled basin	77-84	80-87
Sprinkler	Moved lateral	70-80	70-80
	Traveler or boom	67-75	55-70
	Solid set	70-87	70-87
	Center pivot	80-87	80-87
	Lateral move	84-90	84-90
Drip	Point source	74-93	74-93
	Drip tape	85-95	85-95

* Modified from Hoffman et al. (1990)

This gives the actual amount of water that needs to be applied to assure that the entire field receives at least 4 inches of water. Of course, some of the field will receive more water, but that is the cost of the system's inefficiency.

To determine the set time for the example above, we use the Irrigator's Equation and calculate for 5.3 inches instead of 4.0 inches:

$$5 \times t = 5.3 \times 3.8$$

$$Q \times t = d \times A$$

Solving for t we get:

$$t = (5.3 \times 3.8) / 5 = 4 \text{ hours}$$

The set time should be four hours to assure that all parts of the field receive at least 4.0 inches of water

Proper calculation and keeping records of irrigation amounts and set times, as well as a realistic estimate of system efficiency, will help to assure that your crop receives all the water it needs.

The information provided in this bulletin is also available in an *Irrigation Slide Chart* (1999), which helps to determine set times and flow rates. The slide chart is written in both English and Spanish and is easy to use. The slide chart is available through your local Cooperative Extension office.

References

Hoffman, G.J., T.A. Howell and K.H. Solomon, eds. 1990. Management of Farm Irrigation Systems. Amer. Soc. Agric. Engr. ASAE Monograph No. 9. St. Joseph, MI 1040 pp.

Irrigation Slide Chart. 1999. The University of Arizona, Cooperative Extension, Pub. az1135, *Arizona Water Series*: Number 21. (English/Spanish)

For further information contact your local Cooperative Extension office.

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Managing Turfgrasses during Drought

M. ALI HARIVANDI, University of California Cooperative Extension Advisor, San Francisco Bay Area; **JAMES BAIRD**, Turfgrass Specialist, University of California, Riverside; **JANET HARTIN**, University of California Cooperative Extension Advisor, San Bernardino County; **MICHAEL HENRY**, University of California Cooperative Extension Advisor, Riverside County; **DAVID SHAW**, University of California Cooperative Extension Advisor, San Diego County

INTRODUCTION

Most of California has a Mediterranean climate characterized by long, hot, dry summers, and turfgrasses must be watered to survive under these conditions. Californians must learn how to use water more efficiently as demand and cost rise and drought conditions continue.

Warm-season and cool-season grasses are used as turfgrass in California, based on their climatic adaptability. The warm-season species include common and hybrid bermudagrasses, St. Augustinegrass, seashore paspalum, zoysiagrass, buffalograss, and kikuyugrass. These grasses are used in the San Joaquin Valley, southern California, and parts of the greater San Francisco Bay Area. The cool-season grasses include tall fescue, perennial ryegrass, Kentucky bluegrass, fineleaf fescues in mixes, and specialty grasses such as creeping bentgrass and rough bluegrass. Turfgrasses can be irrigated at different levels. The Optimum irrigation is the amount of water needed for the most efficient growth, maximum quality, and best appearance of the respective turfgrasses. Deficit irrigation provides sufficient water to maintain adequate turfgrass appearance with less growth. In contrast, survival irrigation provides only enough water to allow survival and potential recovery of the desired species when adequate water is again available. Under survival irrigation, growth and quality are drastically reduced.

Figure 1 presents the percentage of reference evapotranspiration (ET_o) obtained from the California Irrigation Management Information System, relative to the three irrigation levels for warm- and cool-season turfgrasses. Figure 1 also

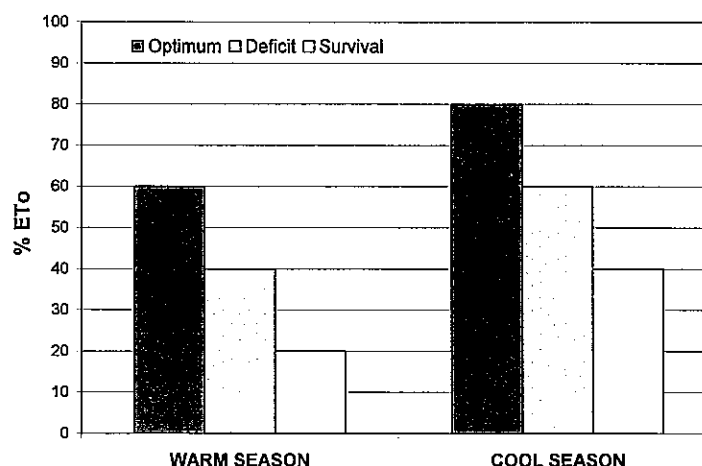


Figure 1. Turfgrass water requirements (as % of ET_o) at optimum, deficit, and survival levels of irrigation.

indicates that both cool-season and warm-season turfgrasses, when irrigated at deficit levels, can save at least 25 percent of irrigation water needed for optimum growth. Irrigation at a survival rate would be at 30 percent of optimum for warm-season turfgrasses and about 50 percent of optimum for cool-season turfgrasses.

If water rationing is needed, both cool-season and warm-season turfgrasses can be irrigated at less than optimum levels. Where possible, using warm-season turfgrasses can result in considerable water savings compared with cool-season turfgrasses.

BACKGROUND

Turfgrass directly affects the way most Californians live. It provides the play medium on many recreational facilities, cools the immediate environment, reduces reradiated heat, and provides an aesthetically pleasing and functional home landscape. In addition, the turfgrass industry has a significant direct economic impact on our economy and indirect impact on our tourist economy.

Many recreational facilities depend on uniform, vigorously growing, well-maintained turf that is able to recuperate from heavy use. These include soccer, baseball, and football fields, as well as golf courses, bowling greens, lacrosse and polo fields, general use and specialty parks, and school playgrounds. Turfgrasses provide a safety cushion that is especially beneficial in contact and physically intensive sports. Additionally, sites such as homes, industrial parks, cemeteries, greenbelts, roadsides, and dog parks can benefit from low-growing and traffic-tolerant green vegetation like turfgrasses.

Most Californians now live in urban and suburban centers where glass, steel, concrete, asphalt, buildings, and cars prevail; turfgrasses directly influence these immediate environments in positive ways. Actively growing turfgrasses reduce high summer ground surface temperatures due to transpirational cooling. Turfgrasses and other landscape plants reduce discomforting glare and noise. Soil erosion, dust, and fire danger are reduced or eliminated on turfed surfaces. Turfgrasses also increase infiltration of water into the soil profile and also enhance the quality of the water moving through or below the turfgrass system.

HOW TURFGRASSES USE WATER

Water enters a turfgrass plant through its root hairs, which are located near root tips. Water then moves

upward through the plant to the leaves. A very small amount of the water taken up is used for plant growth, and the rest of the water transpires out of the plant through the stomatal pores. Water can also be lost from the turfgrass site by evaporation from leaf or soil surfaces. The water use rate is the total amount of water lost by a plant through evaporation and transpiration and used for growth, per unit of time. Because the amount of water used by turfgrasses for growth is so small, the water use rate is usually calculated as the evapotranspiration (ET) rate, which is the total rate of water loss by evaporation plus the rate of water loss by transpiration.

ET is expressed in units of depth and time such as inches (in) or millimeters (mm) per day, per week, or per month. Turfgrass ET depends on temperature, solar radiation, day length, wind, relative humidity, and other environmental factors. However, the ET rate also varies by species and the cultural practices used in maintaining the turf.

Water use rates have been established for the most commonly used warm- and cool-season turfgrass species. Research at Texas A&M in the late 1980s evaluated comparative water use rates among turfgrasses commonly grown in the United States. The comparative water use rates for those grasses used in California are presented in table 1. In the northern part of California and in the mountain regions of the state, turfgrasses are exclusively cool-

Table 1. Evapotranspiration rates of turfgrasses commonly grown in California

Relative ranking	ET rate (in./day)	Cool-season turfgrasses	Warm-season turfgrasses
very low	< 0.24		buffalograss
low	0.24–0.28		bermudagrass zoysiagrass
medium	0.28–0.33	hard fescue Chewing's fescue red fescue seashore paspalum St. Augustine grass	
high	0.33–0.39	perennial ryegrass kikuyugrass	
very high	> 0.39	tall fescue creeping bentgrass annual bluegrass Kentucky bluegrass rough bluegrass annual ryegrass	

Note: 1 inch = 2.54 cm.

Source: Adapted from Beard and Beard 2004.

Table 2. Suggested Kc values (% of ETo) for irrigation strategies resulting in optimum, deficit, and survival performance levels for selected turfgrasses grown in California.

Turfgrass performance level	Cool-season turfgrasses	Warm-season turfgrasses
	Kc*	Kc
optimum	0.80	0.60
deficit	0.60	0.40
survival	0.40	0.20

Note: * Kc (crop coefficient) is a dimensionless number that is multiplied by the ETo value to arrive at an estimate of crop ET, or water requirement.

season species. In other areas of the state, warm-season turfgrasses are grown extensively, and they perform well particularly in warm inland climates and desert areas. Both cool-season and warm-season species are grown in major populated areas of the state. Differences in water use rates have been noted between cultivars within all turfgrass species. Currently, research is underway throughout the United States to develop species and cultivars that have low water use rates. The lower-water-use turfgrasses have a low leaf-blade area and include species with narrow leaves with slow vertical extension rates and grasses with high shoot densities and high leaf numbers.

Warm-season turfgrass species use significantly less water than cool-season species. This is because warm-season grasses are more efficient at photosynthesis and are able to continue high-level carbohydrate production even under mild water stress when their stomates are partially closed. By contrast, cool-season grasses use a less efficient photosynthetic process and cannot produce enough carbohydrate to maintain growth unless their stomates are nearly wide open. Thus, when water is limited, transpiration rates of cool-season turfgrasses are generally higher than those of warm-season turfgrasses.

The effects of irrigating several species of turfgrasses below their optimal levels were investigated at Irvine, California. Cool-season grasses tested were Kentucky bluegrass, perennial ryegrass, and tall fescue; warm-season turfgrasses were hybrid bermudagrass, zoysiagrass, and seashore paspalum. Irrigation regimes supplied 100, 80, or 60 percent of calculated ET for each species. For acceptable turfgrass quality, 36 percent less water was required by the warm-season species than by the cool-season species.

Similar irrigation regimes can be created for any area of the state using ETo information and

the crop coefficient (Kc) values (expressed as a percentage of ETo needed to satisfy water needs of a specific plant species) in table 2.

WATER USE VERSUS DROUGHT RESISTANCE

The ET of a turfgrass is not synonymous with its ability to resist drought. Drought resistance includes mechanisms of drought avoidance (i.e., of retaining moisture within the plant) and of drought tolerance (i.e., of minimizing the damage to tissues caused by water deprivation).

Plant characteristics that contribute to drought avoidance include deep root systems with high root hair length and density, rolled leaf blades, thick cuticle (or ability to quickly form a thick cuticle following water stress initiation), reduced leaf area, slow leaf extension rates, and leaf orientation and density. Examples of turfgrasses with good drought avoidance mechanisms are common bermudagrass and seashore paspalum (both warm-season species) and tall fescue (a cool-season species).

Turfgrasses can also tolerate drought by escape (e.g., buffalograss, which tolerates drought with a dormancy mechanism) or by high tolerance to tissue dehydration (e.g., St. Augustinegrass). Through these mechanisms, turfgrass species have different levels of drought resistance (table 3). Comparison of the water use rates (table 1) and drought resistance (table 3) gives insight into the performance turfgrass species. Several turfgrasses, such as bermudagrass, seashore paspalum, and buffalograss, have both low water use rates and high drought resistance mechanisms. Other turfgrasses, such as tall fescue, have high water use rates and medium drought resistance. Still others, such as the ryegrasses and bluegrasses, have high water use rates and fair or poor drought resistance.

Some turfgrasses and ground covers can survive with very little applied water, as evidenced by a research study conducted at the South Coast

Table 3. Drought resistance comparisons of turfgrasses commonly grown in California.

Relative ranking	Cool-season turfgrasses	Warm-season turfgrasses
superior	—	bermudagrass (common) bermudagrass (hybrid) buffalograss
excellent	—	seashore paspalum zoysiagrass
good	—	St. Augustinegrass kikuyugrass
medium	tall fescue	—
fair	perennial ryegrass Kentucky bluegrass creeping bentgrass hard fescue Chewing's fescue red fescue	—
poor	colonial bentgrass annual bluegrass	—
very poor	rough bluegrass	—

Field Station, Irvine, California, in which plants were irrigated at 60, 40, and 20 percent of calculated ET. Of the 27 plant species tested, common and hybrid bermudagrasses and seashore paspalum performed best under very low irrigation regimes. Buffalograss also produced comparatively good cover and quality.

IRRIGATION AND OTHER CULTURAL PRACTICES FOR TURFGRASS

Irrigation

The goal of irrigation management is to apply the correct amount of water at the correct time to optimize water uptake by the root system. It is also important to reduce the amount of water lost to runoff from the soil surface and deep percolation below the root zone. Regular water audits, ensuring that equipment is operating correctly, and using soil probes or soil moisture measuring devices help fine-tune irrigation schedules, promote healthy turfgrass, and decrease water waste.

Effective irrigation involves filling the root zone soil profile with each irrigation. This requires calculating the amount and frequency of water application based on weather data (used to estimate the ET of the turfgrass), the plant's rooting depth, and the water-holding capacity of the soil. These factors may also be used to plan deficit irrigation strategies.

Evapotranspiration and CIMIS

The California Irrigation Management System (CIMIS) provides irrigation managers, scientists, and water agencies with an accurate, site-specific means of estimating plant water demand based on the climatic parameters that drive evapotranspiration in plants. Reference evapotranspiration (ET_o) approximates the water use of an irrigated grass pasture. Water use (ET) by turfgrasses is estimated by means of a correlation factor, the crop coefficient (K_c), according to the formula

$$ET = ET_o \times K_c$$

Turfgrass K_c values fluctuate slightly during the season based on the percentage of plant cover, growth rate, root growth, stage of plant development, and turf management practices. For practical purposes, the K_c of cool-season turfgrasses is 0.8, and the K_c for warm-season turfgrasses is 0.6. Numerous CIMIS stations are located in varying climatic zones throughout California; daily water use information (i.e., ET_o) is accessible online for most areas of California at the CIMIS website, <http://www.cimis.water.ca.gov/cimis/welcome.jsp>.

Soil water availability

The amount of water available for use by turfgrasses varies by soil texture and pore size and by the rooting depth of the turfgrass. After soil is irrigated and free drainage has taken place, the soil is full of water, or at field capacity. As plants extract the water from the soil, eventually the soil will become so dry that plants cannot be sustained. At this point (often called the permanent wilting point or percentage) there is still water in the soil but it is tightly held by mineral and organic particles and is unavailable for plant use. The total amount of water a soil can hold and the amount of available water a plant can absorb and use differ with different soil textures (table 4). These data, in conjunction with root depth, give the approximate amount of water that is available to a turfgrass plant.

Root system

Turfgrass species differ in their rooting depth and density. Rooting depths vary from a few inches to many feet; they are also influenced by water patterns, soil characteristics, management practices such as mowing and fertilization, and by on-site compaction. The best method to determine root depth in a particular location is by digging into the

Table 4. Unavailable and available water for selected soil textures.

Soil texture	Total water (in/ft)	Available water (in/ft)	Unavailable water (in/ft)
sand	0.6–1.8	0.4–1.0	0.2–0.8
sandy loam	1.8–2.7	0.9–1.3	0.9–1.4
loam	2.7–4.0	1.3–2.0	1.4–2.0
silt loam	4.0–4.5	2.0–2.1	2.0–2.4
clay loam	4.2–4.8	1.8–2.1	2.4–2.7
clay	4.5–4.8	1.8–1.9	2.7–2.9

Note: 1 in/ft = 8.3 cm/m

soil and looking at the roots. Table 5 is a general guide to root depths. The available soil water is determined by multiplying the available water by the effective depth of the root system. Table 6 shows the amount of water available to turfgrasses growing in various soils at selected root system depths. Since proper irrigation should supply water to the root system, root depths and soil texture play an important role in both the amount of water applied and irrigation frequency.

Table 5. Approximate root depths of common California turfgrasses under normal use conditions.

Cool-season grasses	Root depth (ft)
Kentucky bluegrass	0.5–1.5
perennial ryegrass	0.5–1.5
tall fescue	1.5–3.0
creeping bentgrass	0.3–1.5
annual bluegrass	0.1–0.3

Warm-season grasses	Root depth (ft)
bermudagrass	1.5–6.0
buffalograss	1.5–3.0
St. Augustinegrass	1.5–5.0
seashore paspalum	1.5–5.0
zoysiagrass	1.5–2.5

Note: 1 ft = 0.348 m.

Irrigation frequency

For scheduling turfgrass irrigation, the suggested depletion of available soil water is 50 percent before applying irrigation. In other words, irrigation is needed when one-half the available water that is present in a root profile is depleted. This practice allows for adequate water to be available at all times. If more than 50 percent of the available water is depleted (i.e., irrigations are not frequent enough), the turf suffers water stress.

Fifty percent of the available water divided by the ET equals the number of days of sufficient supply, or the number of days between irrigations. For example, for a cool-season turfgrass ($K_c = 0.8$) with a 12-inch rooting depth in a loam soil, the available water is 1.5 inches (from table 6). Fifty percent of 1.5 is 0.75 inches. If the E_{To} is 0.2 inches per day, the turfgrass ET equals 0.20×0.8 , or 0.16 inches per day ($E_{To} \times K_c$). It will take about 5 days ($0.75 \div 0.16 = 4.7$) to deplete 50 percent of the available water. It is normally desirable to water turf as infrequently as possible, so in this case the site would be irrigated by applying 0.80 inches (0.16×5) of water after 5 days.

Water application

The duration of sprinkler operation to resupply the water used by ET must be determined on-site and depends on how fast and how efficiently the water

Table 6. Water available to turfgrass under three soil textures and with three root system depths.

Soil texture	Available water (in/ft)	Water available (in/ft) to turfgrass at root depth		
		6 in.	12 in.	36 in.
sand	1.0	0.5	1.0	3.0
loam	1.5	0.75	1.5	4.5
clay loam	2.0	1.0	2.0	6.0

Note: 1 in/ft = 8.3 cm/m



is applied. The efficiency of irrigation is a function of system performance and management. Irrigation systems that are well designed, in good condition, and apply water uniformly will be much easier for managers to schedule.

The fieldwork to determine system performance can be either a brief, simple procedure or a complete, full inspection of all the irrigation system stations and hardware. Often referred to as an irrigation audit, the process is used to accurately determine the system precipitation rate (PR) and distribution uniformity (DU).

The precipitation rate is the rate at which water is delivered to the turfgrass area; it is measured in inches per hour. The distribution uniformity is a calculated statistic that indicates the amount of variation in the precipitation rate of the system. The precipitation rate and the distribution uniformity are the two most important irrigation system performance characteristics in calculating station run times and determining how evenly water is applied to the area.

Irrigation uniformity is important in turfgrass areas, since turfgrass consists of many small plants, each requiring access to soil and water. An irrigation system with poor uniformity yields areas that are too wet or too dry and nonuniform turfgrass performance. If there are dry areas, irrigation managers usually increase runtime to adequately irrigate them. In this case, water loss to deep percolation or runoff can be significant and may increase with poorer distribution uniformity. The distribution uniformity is only one measure of system performance; information on other statistical measures, such as the Christiansen's coefficient of uniformity and the scheduling coefficient, as well as procedures for determining precipitation rates can be found in *Evaluating Turfgrass Sprinkler Irrigation Systems* (ANR Publication 21503).

The actual run time is determined by dividing the crop coefficient (0.80 inches of water used, in the above example) by the precipitation rate of the sprinkler system. The run time is increased if the irrigation efficiency is considered. The distribution uniformity is a good estimate of the irrigation efficiency as long as the scheduling (management) is good and runoff is limited.

Using the efficiency in the above example, the run time (in hours) would be calculated by dividing 0.80 inches by the precipitation rate times

the distribution uniformity; multiply by 60 to convert to minutes. More detailed information on irrigation scheduling can be found in *Turfgrass Irrigation Scheduling* (ANR Publication 21499).

Every effort should be made to prevent runoff. Application of water in short cycles, until the entire amount of water has been applied, is an effective way to reduce water waste due to runoff.

To prevent puddling or runoff on clay or compacted soils, and to prevent excessive drainage in sandy soils, plan on irrigating turfgrasses no less frequently than every third day. The total amount of water to be applied stays the same, but it should be adjusted for more frequent applications. In the example shown above, instead of applying 0.8 inches of water every 5 days, apply 0.5 inches every third day. If too much water is applied at once, water is lost to runoff or percolation below the root zone.

Deficit irrigation strategies

In drought conditions, it may be advisable to reduce turfgrass irrigation to the deficit level or even to the survival level (see fig. 1). If that is the case, in the example given above, instead of using a crop coefficient of 0.8, use the other reduced values given in table 2. This strategy applies less water than the turfgrass has used, which results in mild water stress. The available water will gradually become depleted below 50 percent. As mentioned previously, turfgrass species with drought resistance (especially warm-season grasses) reduce their water use rate as available soil water is used up. To maintain adequate turf quality, careful irrigation management is necessary and cultural practices may need to be adjusted.

Mowing

In addition to irrigation practices, mowing affects turfgrass growth, including root system development and water use. Higher cutting heights promote deeper root systems and higher water use rates. The higher water use rate with taller turf results from the more open canopy and reduced shoot density. Conversely, closely mowed turf has higher shoot density and a tight canopy, characteristics which reduce evapotranspiration.

The frequency of mowing also affects evapotranspiration. The long grass leaves of infrequently mowed turfgrass use more water. Infrequently mowed turf is also aesthetically

and functionally inferior to turfgrass maintained consistently at an appropriate height.

The desired balance is achieved by mowing practices that enhance root system depth and density (and thus drought resistance) while efficiently using water.

Combining all factors involved, the turfgrass should be maintained at the tallest allowable height, within the recommended mowing height range, for the species being grown. Turf mowed at the tallest allowable height for the individual species and at a frequency that allows no more than one-third of the leaf blade to be removed best achieves that balance. Table 7 recommends mowing height ranges for selected turfgrasses.

Mowing turfgrasses when it is hot or when the soil is dry can injure the plants. When grasses are stressed by heat and drought, such as during a drought-declared summer, it is best to mow infrequently at a taller height.

Fertilization

Sufficient amounts of most nutrients required for turfgrass growth are normally available in native soils. However, all turfgrasses require nitrogen

fertilizer, and in some soils they need phosphorus, potassium /or iron and other essential elements.

Turfgrass fertilization practices directly influence water use: fertilization, especially nitrogen fertilization, increases turfgrass growth, and the greater the growth rate, the greater the water use. Root and shoot growth increase as nitrogen nutrition is raised from a deficiency level. The resulting deeper roots and more vigorous topgrowth benefit the turfgrass. Excessive nitrogen fertilization is not beneficial and can result in excessive topgrowth, poor root growth, and water pollution. To avoid excessive water use, nitrogen fertilizer programs must be monitored to produce the least amount of topgrowth and the greatest rooting possible within the use parameters of the turf. During drought, it is advisable that the lowest amount of nitrogen be applied within the recommended range. Most cool-season grasses grown as general purpose turf require about 2 pounds of actual nitrogen per 1,000 square feet (about 1 kilogram per 100 square meters), applied during March through April and again during late September through mid-October. During this period, due to temperature and water availability, grasses can use nitrogen efficiently to develop deep and extensive root systems. Fertilizing based on these recommendations allows the grass to survive deficit irrigation, heat, and drought stresses much better. Avoid nitrogen fertilization of cool-season grasses from May through September. During this period, if nitrogen must be applied because of play or other special use it should be applied lightly and infrequently. During drought, nitrogen application to warm-season grasses should not exceed 0.25 pounds of nitrogen per 1,000 square feet per month (125 grams per 1,00 square meters), between April and September.

Adequate potassium may increase the drought tolerance of turfgrass. In general, an application of 1 to 2 pounds of potassium (as K_2O) per 1,000 square feet (0.5 to 1 kilogram per 100 square meter) in spring (March through April) may provide increased drought tolerance during the summer months.

Soil Compaction and Thatch

Soil compaction reduces the root and shoot growth of turfgrasses and also lowers the water infiltration rates. Turfgrass quality decreases in compacted soils; water use decreases with the slower growing, poorer quality turfgrass cover. Soil aerification is recommended to improve aeration, which increases

Table 7. Mowing height ranges for commonly grown turfgrasses.

Turfgrass species	Cutting height range (in.)
Cool-season turfgrasses	
creeping bentgrass	0.2–0.5
colonial bentgrass	0.5–1.0
red fescue	1.0–2.0
Kentucky bluegrass	1.5–2.5
perennial ryegrass	1.5–2.5
tall fescue	1.5–3.0
Warm-season turfgrasses	
bermudagrass	0.5–1.0
zoysiagrass	0.5–1.0
seashore paspalum	0.5–1.0
St. Augustinegrass	0.5–1.5
kikuyugrass	0.5–1.0

Note: 1 in = 2.54 cm.



shoot and root growth, water infiltration rate, and water use efficiency.

Thatch is an intermingled layer of dead and living organic matter that develops between the soil surface and the green turfgrass tissue. It consists of roots, stems, stolons, and rhizomes. A deep thatch layer, if hydrophobic (water repellent), reduces or eliminates water infiltration into the turfgrass soil profile. Water use efficiency increases when thatch is maintained at acceptable depths (around one-half inch, or 13 mm) and is not allowed to dry out.

Aerification and dethatching should be undertaken in fall (October) or spring (March or April) for optimum results. Avoid aerifying and dethatching in midsummer when high temperatures may negatively affect the grass.

OTHER CONSIDERATIONS

- Conduct an irrigation system uniformity test (audit) in spring to identify and correct the irrigation system's inefficiency and non-uniformity (see *Evaluating Turfgrass Sprinkler Irrigation Systems*, UCCE Publication 21503).
- Irrigate late at night or early in the morning. At these times water loss by evaporation is minimal and distribution uniformity is usually good because of good water pressure and limited wind.
- Avoid runoff by ensuring that water application rates are not greater than soil infiltration rates (the rate water enters the soil). To avoid runoff, cycle water applications by applying the required amount of water over a series of consecutive shorter irrigations. Cycling should not be confused with watering every day, which is not recommended.
- Apply less water in shaded areas than in areas of open sun. Soil moisture measuring devices can be used to determine water needs of turfgrasses growing in various microclimates. In general, during the hot summer months, grasses planted in shade require about half as much water as same grass grown nearby in full sun.
- Repair and maintain irrigation systems. Observe system operation and make necessary repairs to increase uniformity and climate runoff.

- Act now if your facility is considering installing a new, more effective and more efficient irrigation system.
- Regrade mounds and redesign topographic features that create irrigation challenges. Turfgrass grown on slopes and mounds is prone to water loss due to runoff. Landscape design features that deflect irrigation water intended for turfgrass to elsewhere, such as sidewalks, driveways, and other hard surfaces should be modified.
- Investigate irrigating with recycled water. Drought will happen again!

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Tools for Turfgrass Irrigation Water Management

By Garry Grabow, Ph.D., PE, Dept. of Biological and Agricultural Engineering, NC State University

Increasing competition for water in North Carolina will require improvement in the water management of turf and landscape irrigation. Water-use restrictions have recently been enacted in several North Carolina municipalities. Installation of residential and commercial irrigation systems is on the increase in the state. All of these trends point to a need to use "smart" irrigation technologies and techniques to prevent water waste.

With most buried irrigation systems, irrigation events and durations are controlled with an irrigation-control clock. While these controllers are set to apply a certain amount of water at a certain time, numerous calculations must be done to achieve the correct controller settings, and changes must be made as the turf's water demand changes. Applying the correct amount of water requires not only that the water demand of the turf be known, but also the application rate of the irrigation system. Most homeowners and operators of these systems know neither. To complicate matters, irrigation scheduling (when and how much to water to apply) in humid regions such as North Carolina is difficult due to unpredictable rain events.

Because buried irrigation systems have high investments costs, it is important that these systems are used to maximize their benefit, applying the proper amount of water at the proper time, thereby keeping turf healthy while using no more water than necessary. The dual objectives of conserving water and preserving turf quality suggest that the use of controllers that incorporate "smart" technology holds promise for turf irrigation.

There are a number of commercially available tools to help with turf and landscape irrigation water management. They can be broadly separated into two categories — those that use feedback from a sensor that monitors the

amount of moisture in the root zone and those that use weather data to estimate the amount of water used by the turf to adjust irrigation.

The irrigation industry calls these tools "Smart Water-Application Technology" or SWAT. These systems are more prevalent in the western United States, and some water utilities in California are offering vouchers or rebates for customers who purchase approved SWAT technology.

WEATHER-BASED CONTROLLERS

Irrigation controllers based upon weather data, also referred to as "ET" controllers, use weather data to adjust the amount of water applied as the turf's demand for water changes. As the name implies, ET controllers estimate evapotranspiration (ET) of the turf. ET is the total amount of water used by the plant (transpiration) and by evaporation from the soil and plant canopy.

Most ET controllers collect "real time" weather data and update the estimated ET daily or even hourly. The data is obtained either from local weather stations via phone line or satellite, or from on-site measurements taken by simple weather instruments supplied with the controller. Other variations of ET controllers base their system upon long-term historical weather data and may adjust the long-term average ET to current conditions using an on-site temperature sensor. Some systems factor in on-site rainfall, while others consider general rainfall patterns in the area.

Ease of setup and operation of ET controllers range from fairly easy to complex. Depending upon the controller, users may be required to input a variety of information, including: the type of turf or landscape to be irrigated; specifications of the irrigation system, such as sprinkler type or application rate, and application efficiency; and site conditions, such as shading and ground slope.

Using the supplied system and site information and weather data, ET controllers run a "water balance" that keeps track of how much water is in the soil. The basic operation of these controllers is to adjust the run times at each irrigation event, thereby adjusting the amount of water applied to the turf. An ET controller operates most efficiently when set in an "automatic mode," in which case the controller itself will select the appropriate days to water. Users can also enter schedules that prohibit watering on specific days, such as those associated with local watering restrictions.

When selecting one of these systems, it is important to know the flexibility of the controller, and from where it collects weather data. In areas of highly localized rainfall such as North Carolina, systems that collect local rainfall data have an advantage. There are many manufacturers of these systems, which vary in cost depending upon the number of irrigation zones that can be served, programming features and any associated weather sensors. For systems that use communication systems such as satellites to retrieve weather data, there is also a modest monthly or annual fee.

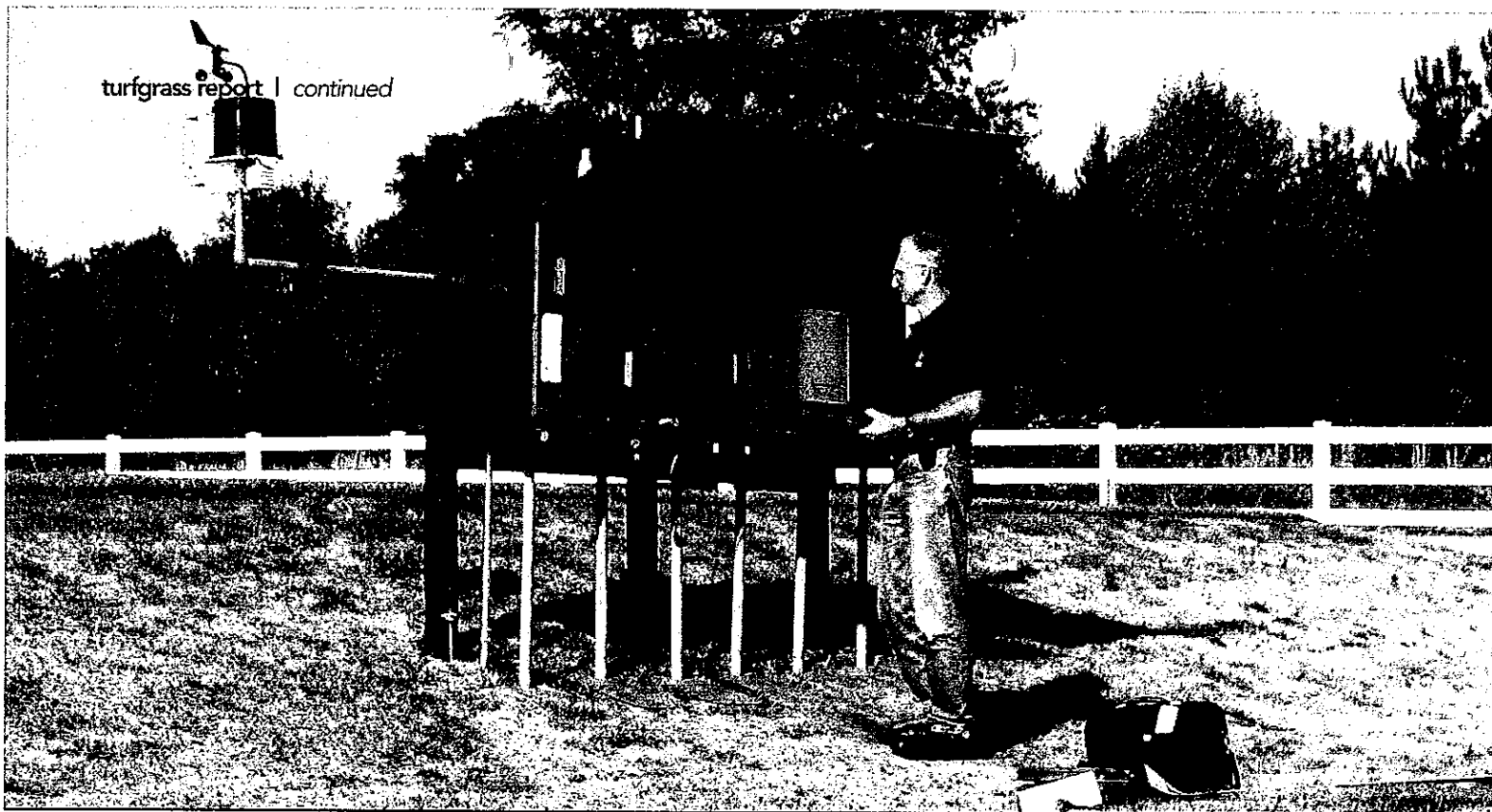
SOIL-MOISTURE-BASED SYSTEMS

Systems based on soil moisture use feedback from sensors placed in the soil to adjust watering. In theory, these systems integrate the elements of a water balance into one measurement — the amount of water in the soil.

The simplest type of soil-moisture-based



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Dr. Garry Grabow at the shed that houses the "smart" technology systems being evaluated. On the site are forty 13' X 13' fescue plots irrigated with pop-up spray heads.



Two of the systems being evaluated have moisture sensors like the one in this photo (here, Dr. Grabow is "adjusting" the "on-demand" system).

system is an "add-on" system that is added on to a standard irrigation-control clock. Such systems came on the market about ten years ago. They comprise a soil-moisture sensor and a module with user interface. In operation, the clock is programmed to irrigate as normal, and the sensor is used to override a scheduled irrigation if the soil is too wet. This "too wet" setpoint level may be adjusted by the user.

Some systems use a somewhat arbitrary scale of wetness (e.g., 1–10), while others let the user specify a soil-moisture level by entering a volumetric soil-water content (percent water by volume of soil), above which any pre-scheduled irrigations will be disabled. To set the setpoint of these systems, the soil is saturated (e.g., by a garden hose or sprinkler) and then allowed to drain for a period of time (usually one day for medium- to heavy-textured soil and perhaps 12 hours for a sandy soil). This establishes the "field capacity" of the soil, or the amount of water held by the soil against gravity. The setpoint is normally set to 75% of the water content at field capacity. Adjustments to the setpoint can be made at any time as required. Some manufacturers of soil-moisture-based systems also sell units with controllers, rather than just the "add-on" sensor with module.

In more sophisticated soil-moisture-based systems, "on-demand" irrigation can be achieved. Two levels of soil moisture can be set — a lower setpoint to initiate irrigation and a higher setpoint to terminate irrigation. Soaking cycles (when irrigation is temporarily halted) can be used to allow the water to reach the sensor so that over-irrigation does not occur. Watering windows can be programmed to allow for constraints such as watering-day restrictions.

"On-demand" systems are complete systems, unlike the add-on systems, and may have a number of added features. These include system monitoring of flow rates and electrical-current usage to warn of any potential irrigation system problems, as well as the ability to add multiple moisture sensors that can be assigned to control any zone(s) the user specifies. Software interfaces and remote communication options are available with these more sophisticated systems.

COSTS

Most ET controllers range from \$300 to \$500, depending upon the number of irrigation zones they control, the level of sophistication and on-site weather sensors (if any). The most expensive ET-based systems provide flow monitoring and a software interface and cost up to \$4,000.

The cheapest of the "smart technologies" are the add-on soil-moisture-based systems, starting under \$200. Soil-moisture-based systems that have their own controller are slightly more expensive and depend upon the number of zones they can control.

The most expensive soil-moisture-based technologies are the "on-demand" systems. The cost depends upon whether or not they are retrofitted to existing systems or installed in a new system. When installed with a new system, all sensors and valves are part of a "two-wire system," eliminating the need for separate wiring of each zone. When installed in existing irrigation systems, "zone adapters" are required to allow the system to emulate a two-wire system that allows communication between the sensors and the solenoid valves. These controllers cost about \$2,500, not including the zone adapters.

The more-expensive systems are not targeted to homeowners but to commercial turf and landscape irrigation. Reduced pricing is generally available to contractors for all systems.

RECENT RESEARCH

Three "smart" systems are being evaluated at NC State University by the Dept. of Biological and Agricultural Engineering (Drs. Garry Grabow and Rod Huffman) and the Dept. of Crop Science (Drs. Dan Bowman and Grady Miller). A study site with forty 13' X 13' plots sod in tall fescue and irrigated with pop-up spray heads was installed in fall of 2006. One season's worth of data has been collected for an ET controller and two soil-moisture-based systems (an add-on system and an "on-demand"

(Right) A soil-moisture probe being installed in one of the study plots, about 5" below the soil surface.



Table 1. Total Applied Water in Inches from April 22 to September 8, 2007 (20 weeks).

Technology	Irrigation Frequency, days per week		
	1	2	7
Timer ¹	16.88"	16.92"	15.62"
Add-On ²	8.56"	12.81"	13.87"
On-Demand ³		17.64"	
ET ⁴	16.27"	24.54"	25.66"

¹ Standard irrigation control clock set to replace long-term average irrigation requirement with added rain sensor.

² "One setpoint" add-on system with soil-moisture sensor and module added to standard timer.

³ "Two setpoint" on-demand stand-alone system with soil-moisture sensor.

⁴ ET controller with rain sensor added.

system). These systems are being compared to a standard irrigation-control clock set to replace the long-term average irrigation requirement.

Irrigation frequency is also being evaluated in this study. All systems except for the "on-demand" system are set to water daily, twice a week and once a week. Turf quality is being assessed by a visual rating system, and turf-canopy temperatures are being recorded to monitor moisture stress.

Total applied water in inches for the 20-week duration of the study in 2007 is presented in Table 1. These

amounts factor in an irrigation system efficiency of 80%, which roughly means that, on average, the net irrigation amount (water received by the turf) was only 80% of the applied amount.

This past summer was hotter and drier than normal, so the net amount of water applied by the timer treatment (long-term average irrigation requirement) was below that required for full irrigation of fescue. The estimated turf water requirement over the course of the 20-week study was 20.9", assuming a crop coefficient

of 0.8. The crop coefficient is multiplied by the "reference ET" to estimate the water requirement of a specific "crop," in this case tall fescue. A crop coefficient value of 0.8 is commonly used for a cool-season turf such as fescue.

The reference ET was estimated using the Penman-Monteith equation and weather data collected on-site. Although 11.4" of rain fell during the 20-week study period, less than half that amount was usable, since much of the rain came in unevenly distributed intense thunderstorms, and only a portion was stored in the root zone.

The last half of June and the first half of July were particularly hot and dry, so the plots irrigated by the standard irrigation-control clock and by the soil-moisture system added to a standard control clock did not receive the amount of water the plots demanded. Turf quality was best for plots irrigated with the "on-demand" system and the ET controller system. **The "on-demand" system provided the best combination**



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of efficient irrigation and turf quality, and this was the most expensive system tested.

While the plots irrigated by the ET controller at twice-a-week and daily intervals had high turf quality, more water was applied than the "on-demand" system that provided equal turf quality. In general, plots watered only once a week had poorer turf quality than those watered twice a week or daily.

The study is planned to continue for two more years so that longer-term trends in performance can be assessed.

CONCLUSIONS

"Smart" irrigation technologies hold promise for efficient irrigation, thereby conserving water while maintaining healthy turf. However, these systems are not a "magic bullet," and setup and adjustments by a landscape professional may be required, especially for the weather-based (ET) controllers. Setup, monitoring and adjustment are especially important if the dual goals of water conservation and acceptable turf quality are to be met.

Dr. Bir Thapa will use a soil-moisture probe to record moisture in all forty plots. The probe is lowered into a 1" diameter access tube and measures moisture at several depths.



Reducing water application through the use of these technologies may expose poorly designed irrigation systems (poor uniformity), and these "smart" systems will not solve problems due to poor irrigation-system design.

One easy, effective and inexpensive way of reducing water used by turf and landscape irrigation is to install a rain sensor. In regions of high rainfall, this can result in substantial water savings by simply preventing irrigation during or immediately after a rain. ☼


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Measuring On-Farm Irrigation Efficiency with Chloride Tracing under Deficit Irrigation

by **Zohrab Samani**, (Prof., Civ. Engrg. Dept., Box 3CE, New Mexico State Univ., Las Cruces, NM 88003 (corresponding author). E-mail: zsamani@nmsu.edu), **Ted Sammis**, (Prof., Dept. of Agronomy and Horticulture, New Mexico State Univ., Las Cruces, NM 88003. E-mail: tsammis@nmsu.edu), **Rhonda Skaggs**, (Prof., Dept. of Agric. Economics, Box 3169, New Mexico State Univ., Las Cruces, NM 88003. E-mail: rskaggs@nmsu.edu), **N. Alkhatiri**, (Grad. Student, Civ. Engrg. Dept., New Mexico State Univ., Las Cruces, NM 88003), and **Jose Deras**, (Grad. Student, Civ. Engrg. Dept., New Mexico State Univ., Las Cruces, NM 88003)

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Water is a limited resource in agricultural production in arid climates. Under such conditions, high irrigation efficiency can be obtained either through implementation of efficient irrigation systems such as drip or sprinkler systems or through the age-old practice of deficit irrigation with gravity systems. The method used to increase irrigation efficiency is often dictated by economic and/or social factors. In either case, the effectiveness of water management at the farm level needs to be evaluated by measuring irrigation efficiency. The objective of this study was to evaluate the irrigation efficiencies for three crops in Southern New Mexico using the chloride technique. The chloride technique is a simple method in which the natural chloride in the irrigation water is used as a tracer to estimate the leaching fraction and the irrigation efficiency at the farm level. Soil samples were collected from various fields in 15 cm increments to a depth of 180 cm at the end of the irrigation season. The samples were analyzed for moisture and chloride content. In addition to the chloride technique, on-farm irrigation efficiencies were measured using applied water, yield, and water production functions. Water production functions and yields were used to estimate total evapotranspiration while flow measurements were used to calculate the amount of applied water. The results showed that high irrigation efficiency can be accomplished using deficit irrigation. Irrigation efficiency values ranged from 83 to 98%. Irrigation efficiencies using the chloride technique were compared with efficiencies estimated from direct flow measurements. The differences between the two methods ranged from 2 to 11.4%. The results showed that even though the chloride technique is subject to sampling errors and simplified theoretical assumptions, it can be used to estimate on-farm irrigation efficiency with considerable accuracy.

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Average extension	33 days
Median extension	37 days
% >= Aug 31	90%
% >= Sept 30	75%
% >= Oct 31	74%

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Year	Cutoff date	Historic Alfalfa Volume Recharge (ac-ft)	Proposed Turf Volume Needed (ac-ft)	Deficient Vol (ac-ft)	Dried up Acres (ac-ft)	Season end	For plotting:		Season extension	Average extension Median extension % >= Aug 31 % >= Sept 30 % >= Oct 31	33 days 37 days 90% 75% 74%
							Year	Credit			
1948	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1948	53.9	0		
1949	22-Aug	55.1	53.9	0.0	0.0	31-Oct	1949	53.9	70		
1950	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1950	53.9	0		
1951	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1951	53.9	0		
1952	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1952	53.9	0		
1953	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1953	53.9	0		
1954	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1954	53.9	0		
1955	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1955	53.9	0		
1956	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1956	53.9	0		
1957	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1957	53.9	0		
1958	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1958	53.9	0		
1959	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1959	53.9	0		
1960	09-Aug	49.1	53.9	4.9	0.0	16-Sep	1960	49.1	38		
1961	25-Jul	45.2	53.9	8.8	0.0	31-Aug	1961	45.2	37		
1962	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1962	53.9	0		
1963	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1963	53.9	0		
1964	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1964	53.9	0		
1965	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1965	53.9	0		
1966	26-Aug	51.8	53.9	2.2	0.0	27-Sep	1966	51.8	32		
1967	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1967	53.9	0		
1968	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1968	53.9	0		
1969	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1969	53.9	0		
1970	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1970	53.9	0		
1971	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1971	53.9	0		
1972	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1972	53.9	0		
1973	22-Aug	55.7	53.9	0.0	0.0	31-Oct	1973	53.9	70		
1974	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1974	53.9	0		
1975	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1975	53.9	0		
1976	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1976	53.9	0		
1977	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1977	53.9	0		
1978	08-Aug	57.9	53.9	0.0	0.0	31-Oct	1978	53.9	84		
1980	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1980	53.9	0		
1981	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1981	53.9	0		
1982	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1982	53.9	0		
1983	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1983	53.9	0		
1984	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1984	53.9	0		
1985	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1985	53.9	0		
1986	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1986	53.9	0		
1987	02-Aug	53.3	53.9	0.6	0.0	19-Oct	1987	53.3	52		
1988	28-Aug	35.6	53.9	18.3	0.0	7-Aug	1988	35.6	5		
1989	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1989	53.9	0		
1990	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1990	53.9	0		
1991	12-Aug	40.5	53.9	13.4	0.0	19-Aug	1991	40.5	7		
1992	14-Jul	27.0	53.9	26.9	0.0	19-Jul	1992	27.0	5		
1993	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1993	53.9	0		
1994	1-Jul	23.7	53.9	30.3	0.0	13-Jul	1994	23.7	12		
1995	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1995	53.9	0		
1996	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1996	53.9	0		
1997	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1997	53.9	0		
1998	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1998	53.9	0		
1999	31-Oct	58.4	53.9	0.0	0.0	31-Oct	1999	53.9	0		
2000	2-Aug	47.0	53.9	6.9	0.0	8-Sep	2000	47.0	37		
2001	30-Jul	36.6	53.9	17.3	0.0	10-Aug	2001	36.6	11		
2002	15-Aug	50.2	53.9	3.8	0.0	21-Sep	2002	50.2	37		
2003	14-Aug	49.9	53.9	4.0	0.0	20-Sep	2003	49.9	37		
2004	13-Aug	46.4	53.9	7.5	0.0	5-Sep	2004	46.4	33		
2005	22-Aug	51.9	53.9	2.1	0.0	28-Sep	2005	51.9	27		
2006	31-Oct	58.4	53.9	0.0	0.0	31-Oct	2006	53.9	0		
2007	10-Jul	26.8	53.9	27.1	0.0	19-Jul	2007	26.8	9		
2008	21-Aug	48.2	53.9	5.7	0.0	13-Sep	2008	48.2	23		
Dry Up		54.2	53.9	2.9	0.0	14-Oct					
		0	acre								

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Department of Water Resources

Valley Club HOA - Dry Lot
Hiawatha Canal
Priority 3/24/1883 Cut Dates

*													
Year	cut	%	Remarks	cut	%	Remarks	cut	%	reinstated	%	Attachment	Year	Other Notes
1949	8/22	75	Good								130	1949	9/9 extension by-pass cancelled
1960	8/9	75	Good	8/12	50	Good					117	1960	
1961	7/25	50	Good								102	1961	7/25 all water in extension by-pass
1966	8/17	75	Good	8/26	50	Good					134	1966	
1973	8/22	50					9/5				130	1973	
1979	8/8	50					8/10				116	1979	
1987	8/28	50									136	1987	
1988	8/2										110	1988	
1991	8/12										120	1991	
1992	7/14										91	1992	8/12 Furtile coil below Bellevue
1994	7/1	50									78	1994	8/12 Furtile coil below Bellevue
2000	8/2	50									110	2000	
2001	7/30	50									107	2001	8/28 River Dammed Bellevue- 9/16 removed
2002	8/15	50									123	2002	
2003	8/14	50									122	2003	
2004	8/13	50									121	2004	
2005	8/22	50									130	2005	
2007	7/10	75									87	2007	
2008	8/21	50		8/26	75		9/10	100	9/23	25		2008	

* Water Master Kevin Lakey: interpret "cut date" in WD #37 & 37M books as receiving water on the 'cut date' listed in book...

2/1/2010

AP:Worksheet