Conserve Water by Irrigating Deeply and Less Frequently

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Abstract. *During periods of drought, watering restrictions for many municipalities limit the days per week when landscape irrigation can occur. Additionally, many smart irrigation controllers for residential landscapes schedule watering on a weekly or more often basis. These constraints can result in watering more frequently than would be required by the depletion of plant available water in the root zone. Under limited or partial soil moisture depletion, the number of days between irrigations is reduced. This increases the potential for losses to surface evaporation and provides less latitude for managing soil moisture levels below the 'no water stress' fraction.*

This paper summarizes results derived from a soil water balance which calculates evaporation from wetted plant-soil surfaces, including drying of the surface soil layer. Comparison is made of the needed net irrigation under likely irrigation frequencies resulting from limited water availability and watering restrictions.

Irrigating deeply and less frequently provides significant benefits.

- *Supports landscape health.*
- *Promotes deeper root zones.*
- *Provides significant potential for water conservation.*

Deeper rooting depths make landscapes more drought resistant. They better support managed deficit irrigation practices which can achieve significant water conservation by reducing landscape water use rates during the 'dry down' period before subsequent irrigation or watering is applied.

This information should assist water providers and irrigation managers in determining what watering schedules may better conserve limited water supplies while still meeting the needs for healthy urban landscapes.

Keywords. Conservation, Deficit Irrigation, Evapotranspiration, Plant Factors, Scheduling, Sprinkler, Turf/Landscape (Residential), Water Budget, Water Manager, Water Provider.

Background and Methodology

Benchmark values for constructing crop water use curves are presented for a diversity of plants and agricultural crops in Irrigation 6th edition, 2011, Table 5.2, pp. 117-122. Included are typical values for $K_{c\ ini}$, $K_{c\ mid}$, $K_{c\ end}$, $K_{cb\ ini}$, $K_{cb\ mid}$, and $K_{cb\ end}$ all for sub humid climatic conditions characterized by an average minimum daytime humidity of 45 percent and average wind speeds at 2-m height of 2 m/s (4.5 mph). All these factors are intended to represent evapotranspiration or ET under growing conditions having a high level of management and with little or no ET reducing environmental stresses, such as delayed irrigation under managed deficit irrigation. Hence $ET_c = K_c ET_o$ would represent potential levels of crop ET, not necessarily actual ET under reduced watering restrictions.

The dual K_c approach presented in Irrigation 6th edition, 2011, pp. 132-139 utilizes ($K_{cb} + K_e$) to separately account for wet surface evaporation resulting from precipitation or irrigation events, rather than relying on the average surface wetting frequency incorporated into the single K_c factor. Utilization of a plant stress factor K_s further improves estimates of actual ET. Hence $ET_{c\ act} = (K_s K_{cb} + K_e) ET_o$ represents ET under any condition, ideal or non-ideal.

Actual ET for cool season turfgrass was calculate using the $ET_{c\ act} = (K_s K_{cb} + K_e) ET_o$ approach utilizing reference ET or ET_o calculated from weather data obtained from the meteorological station managed by Northern Water at their headquarters in Berthoud, Colorado. Various irrigation management strategies were assumed and the monthly actual ET and needed net irrigation depth applied were compared.

Landscape Plant and Soil Parameters

Cool season turfgrass dominates in the irrigated urban landscapes along Colorado's Front Range. Consequently turf accounts for the majority of the demand for outdoor watering during summer months and is specifically targeted by some municipal drought watering restrictions. However, because of turf's stand density and heavy shading of the soil surface, differences in wet surface evaporation losses are expected to be less significant for turfgrass than many other landscape plantings. Consequently, cool season turfgrass was selected for this comparison both for its being representative of Coloradr landscapes and also for its perceived immunity to high evaporative losses.

The soil at the Berthoud site is deep silty clay. Turfgrass study plots at this site are typically watered once per week with minimal evidence of water stress. The following parameters were utilized in the soil moisture balance.

Table 1. Plant and Soil Parameters.

Cool season turfgrass (bluegrass)	$K_{c\ min} = 0.15$, $K_{CB\ ini} = 0.81$, $K_{cb\ mid} = 0.86$, $K_{cb\ end} = 0.86$	
Depletion fraction for no stress, p	0.4	
Managed stress level, K_{sm}	Average = 0.80	
Maximum rooting depth, Z_r	12 inch	(305 mm)
Average crop height, h	3 inch	(76 mm)
Silty clay soil	Surface layer amended with compost	

Field capacity, Θ_{FC}	0.360 ft^3/ft^3	(0.360 m^3/m^3)
Wilting point, Θ_{WP}	0.230 ft^3/ft^3	(0.230 m^3/m^3)
Adjustment factor for soil matric potential	0.95	
Total available water in root zone, TAW	1.48 inch	(38 mm)
Uniform ground surface	slope < 2%	
Sprinkler irrigation	popup sprays	
Full sun exposure	No micro climate adjustment	
No salinity or drainage concerns	Ks factor reflects only water limiting stress	
No drainage concerns	No capillary rise from ground water table	

Irrigation Management Strategies

Utilizing weather data for Berthoud, Colorado from May to September of 2014, the following strategies were selected for comparison.

Table 2. Selected Irrigation Management Strategies.

	MAD	K_{sm}	K_{cb} x K_{sm}	Peak season irrigation interval	Effective root zone depth
No irrigation frequency restrictions	0.51	0.95	0.81	4 days	12 inch (305 mm)
No irrigation frequency restrictions	**0.71**	**0.80**	**0.68**	**7 days**	**12 inch** (305 mm)
No irrigation frequency restrictions	0.80	0.70	0.60	9 days	12 inch (305 mm)
Irrigation limited to every 5th day	**0.70**	**0.80**	**0.68**	**5 days**	**10.4 inch** (264 mm)
Irrigation limited to every 4th day	**0.69**	**0.80**	**0.68**	**4 days**	**8.8 inch** (224 mm)
Irrigation limited to every 3rd day	**0.68**	**0.80**	**0.68**	**3 days**	**7 inch** (178 mm)

The following equations were used in calculation of the daily soil moisture balance in the root zone:

$$ET_{c\,act} = (K_s \times K_{cb} + K_e) \times ET_o$$

$$K_s = \frac{TAW - D_r}{(1-p) \times TAW}$$

$$K_e = [F_t + (1 - F_t)K_r](K_{c\,max} - K_s K_{cb})$$

$$F_t = \frac{REW - D_{REW,j-1}}{K_{e\,max} ET_o}$$

$$K_r = \frac{TEW - D_{e,j-1}}{TEW - REW}$$

$$D_{REW,j} = D_{REW,j-1} - \left\{(1 - f_b)\left[\left(P_j - RO_j\right) + \frac{I_j}{f_w}\right] + f_b\left[\left(P_{j+1} - RO_{j+1}\right) + \frac{I_{j+1}}{f_w}\right]\right\} + \frac{E_j}{f_{ew}}$$

$$D_{e,j} = D_{e,j-1} - \left\{(1 - f_b)\left[\left(P_j - RO_j\right) + \frac{I_j}{f_w}\right] + f_b\left[\left(P_{j+1} - RO_{j+1}\right) + \frac{I_{j+1}}{f_w}\right]\right\} + \frac{E_j}{f_{ew}} + T_{ei,j}$$

Where:

$ET_{c\,act}$	= actual crop ET under any condition, ideal or non-ideal, mm
K_s	= stress factor computed for available soil moisture in the root zone
K_{cb}	= basal crop coefficient for dry plant/soil surfaces
K_e	= soil evaporation coefficient
ET_o	= short crop reference ET, typically clipped cool season turfgrass, mm
TAW	= total plant available water in the root zone, mm
D_r	= depletion of soil moisture in the root zone below field capacity, mm
p	= soil water depletion fraction for no plant stress
F_t	= fraction of calculation time step/interval that resides in stage 1 drying
K_r	= evaporation reduction coefficient - fraction wetted by precipitation only
$K_{c\,max}$	= maximum value of K_c following rain or irrigation
REW	= readily evaporable water during stage 1 drying, mm
$D_{REW,j-1}$	= cumulative depletion from soil skin layer at end of previous day, mm
$D_{REW,j}$	= cumulative depletion from soil skin layer at end of day j, mm
$K_{e\,max}$	= maximum value of soil evaporation coefficient
TEW	= total evaporable water – maximum depth that can be evaporated from a completely wetted surface soil layer, mm
$D_{e,j-1}$	= cumulative depletion from surface soil layer at end of previous day, mm
$D_{e,j}$	= cumulative depletion from surface soil layer at end of day j, mm
f_b	= fraction of precipitation and irrigation contributing towards evaporation during the current calculation time step/interval
P_j	= precipitation on day j, mm
RO_j	= runoff of precipitation from soil surface on day j, mm

I_j = irrigation depth that infiltrates the soil on day j, mm
f_w = fraction of ground surface wetted by irrigation and/or precipitation
E_j = evaporation depth from exposed soil surfaces on day j, mm
f_{ew} = fraction of soil both exposed to solar radiation and wetted
$T_{ei,j}$ = transpiration depth from the exposed and wetted fraction of the soil layer on day j, mm
$DP_{ei,j}$ = deep percolation from the soil surface layer on day j if soil water content exceeds field capacity, mm

Surface runoff of precipitation RO_j was estimated using the USDA-NRCS curve number method presented in Irrigation 6th edition, 2011, pp. 162-264.

Results

The soil moisture balance calculations indicate that more frequent wetting of landscape plants by precipitation or rainfall does increase water losses to evaporation and reduce soil moisture available for plant transpiration. More significant was the reduction of the effective plant root zone as irrigation frequency was increased while still maintaining a modest level of deficit irrigation for water conservation. Decreased rooting depths directly diminish drought resistance of the landscape.

More frequent irrigation events provide less latitude for managing soil moisture levels below the 'no water stress' fraction. Only when depletions exceed this fraction will landscape ET drop below the higher 'well watered' rate. Significant water can be conserved through management practices that provide a drier root zone before the next irrigation event. However, care must be taken to avoid deficits which could result in undesirable and damaging plant stress. Consequently, irrigations are commonly scheduled to occur on the day before soil moisture levels are expected to drop below the limit set for the management allowed deficit. Under managed stress, a shallow rooted landscape on a hot dry summer day can ill afford to go one day too long before watering occurs. As irrigation is typically scheduled as a daily event (not hourly), an allowable irrigation interval of 3½ days would be shortened to 3 days, an interval of 4½ days would be shortened to 4 days, etc. This 'protection factor' diminishes the water conservation potential proportionally more for short irrigation intervals than for longer, less frequent intervals.

Conclusions

Under limited water availability and watering restrictions, irrigating deeply and less frequently provides significant benefits.

- Supports plant and landscape health.
- Promotes deeper more extensive root zones.
- Provides significant potential for water conservation.

Deeper rooting depths make landscapes more drought resistant. They further support managed deficit irrigation practices which can achieve significant water conservation by reducing landscape water use rates during the ‘dry down’ period before subsequent irrigation is applied. The potential for water conservation may thereby be reduced with too frequent applications of irrigation water.

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