Seasonal Curves for Turfgrass Using Dual Coefficient Method

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Abstract

Seasonal crop coefficient or Kc curves were developed for ten turfgrasses at Berthoud, Colorado utilizing the FAO-56 dual crop coefficient method. Nine grasses were cool-season and one was warm season. Actual turf evapotranspiration or ET was measured by small weighing lysimeters, with four replicates of each turfgrass (40 lysimeters total). All were seeded in 2010. Daily lysimeter measurements of ET during three seasons (2011-2013) were compared to daily ETo calculated using the ASCE standardized reference evapotranspiration equation.

The dual Kc method partitions ET into evaporation from wet soil/plant surfaces and transpiration from vegetation. This provides a substantially improved fit of simulated ET (using calculated ETo) to measured ET (from weighing lysimeters). The increased evaporation from wetted surfaces following a rain or irrigation event and the reduced transpiration resulting from soil moisture depletions are calculated on a day-to-day basis, not imbedded in averages as with the single Kc method. Consequently, developed Kc curves are not skewed by local rainfall frequency or irrigation management practices and are more readily transferable to other locations.

$ET = Kc\ ETo = (\ Ks\ Kcb + Ke\ )\ ETo$

Ks *stress factor based on available soil moisture,*

Kcb *basal Kc factor, visually dry surface soil, no stress, and*

Ke *evaporation factor based on percent of soil surface wetted.*

The resultant seasonal Kc curves are expected to readily transfer to other similar locations and prove more accurate day-to-day than single Kc curves, particularly when rooting depths, frequency of rainfall, and/or irrigation management practices vary. The length of the four time periods within the seasonal curves can be readily adjusted to match localized plant growth and development.

Keywords: evapotranspiration, irrigation scheduling, lysimeters, soil moisture balance, turfgrass weighing lysimeters.

Procedures

Background

Use of weighing lysimeters provides a defensible basis for quantifying and comparing various inputs into the soil moisture balance calculations. Along with measurement of actual plant water use or $ET_{c\ act}$ (evapotranspiration), lysimeters may also aid in determination of net and effective rainfall, and net and effective irrigation. This improved input information may assist in the programming of weather-based smart controllers. It can also be utilized by municipalities to develop landscape water use standards and budgets in support of efficient water use and conservation.

A previous paper by Crookston, et al. (2010) included an overview of several previous studies regarding turfgrass water use. An additional paper by Crookston, et al. (2011) included preliminary results from work with the Berthoud lysimeter data. A presentation titled: Turfgrass ET from Small Weighing Lysimeters in Colorado (paper number 1862438) was made by Crookston on April 9, 2014 at the ASABE Symposium on Evapotranspiration: Challenges in Measurement and Modeling from Leaf to the Landscape Scale and Beyond, Raleigh, NC. A more recent paper was presented by Crookston (2016) at the 2016 ASABE Annual International Meeting, Orlando, FL, July 17-20, 2016, using the same information as is included herein.

Considerable information regarding utilization of the dual coefficient method of calculating evapotranspiration has been provided by Allen et al. (20016. 2011, 2005, and 1998). Interested professionals are referred to these reference documents for more in-depth explanations of appropriate methods and procedures.

Methods

In 2009, Northern Water staff commenced construction and installation of a 30-ft x 30-ft study plot for turfgrass lysimeters within its Conservation Gardens located at its headquarters in Berthoud, Colorado. A sandy clay loam soil was fully packed into all 44 lysimeters and also replaced the top 12 inches of soil in the entire lysimeter plot. The turfgrasses were seeded May 28 to June 2, 2010. Frequent sprinkler irrigation for establishment of the turfgrasses continued through most of July 2010. However, the turfgrasses had not yet filled the small gap surrounding each lysimeter and the top rims of most were still clearly visible. By the end of the 2010 growing season, all turfgrasses were well established in the lysimeters. The 2011 season became the first full season for evaluation of ETc act.

The lysimeter plot was divided into 4-ft x 4-ft sub-plots, separated by 1-inch x 6-inch PVC plastic composite decking/edging material. This edging clearly delineated the subplots and helped prevent the spread of one grass variety into another subplot. It also provided support for foot traffic by study technicians without compaction of the soil or inadvertently stepping onto a lysimeter. Turfgrasses were planted into 44 of the 49 sub-plots, with the four corners and center sub-plots excluded from the study, but planted to a bluegrass blend to maintain fetch. The lysimeter plot was divided into four blocks, with each block containing 11 randomized sub-plots, each with a lysimeter seeded to a different turfgrass. However, one of the turfgrasses (Ephraim Crested Wheatgrass) did not thrive and was subsequently eliminated from the study plot. Consequently, the study included four replicates of each of the following 10 turfgrasses:

- Blue gramma – buffalograss mix
- Drought hardy Kentucky bluegrass
- Fine fescue mix
- Kentucky bluegrass blend
- ‘Low Grow’ mix
- ‘Natures Choice’ - Arkansas Valley mix
- Perennial ryegrass
- Reubens Canada bluegrass
- Tall fescue
- Texas hybrid bluegrass blend

Equipment

The weighing platform for each lysimeter included a Revere PC6-100kg-C3 load cell transducer. Each load cell was connected to one of three AM 16/32 multiplexers, each connected to a Campbell Scientific CR10X data logger. Figure 1 is a diagram of the small turfgrass lysimeters and their arrangement within the lysimeter plot.

Every three seconds a weight measurement in inches of H2O was taken from each lysimeter load cell. These measurements were averaged every 60 seconds. This 1-minute average weight was time-stamped and stored in the data logger at the end of each 15-minute period. Stored data was automatically downloaded every 15 minutes to a desktop PC via an RF401 spread-spectrum radio. Hourly differences in lysimeter weights can be compared to calculated ETos utilizing data from the adjacent Campbell Scientific ET-106 weather station. The weather station instruments are calibrated annually. Hourly ETos can be obtained from the REF-ET software v.3.1.16 (http://extension.uidaho.edu/kimberly/2013/04/ref-et-reference-evapotranspiration-calculator/)

The weighing platforms for each lysimeter were calibrated in-place (without lysimeters loaded) in April 2009 over their full load range, using steel weights. The platforms were again re-calibrated in-place during March 2011 and March 2013, but only over their operational range (from dry soil to wet soil), again using steel weights. In-place full range re-calibration was again performed in March 2014. No problems were identified during the re-calibrations, and all weighing platforms were measuring the lysimeter weights properly. The calibration factors applied to each lysimeter were for the 11.875-inch inside diameter of the lysimeters. The outside diameter of the PVC reducer attached to the top of the outer shell containing the lysimeter was

13.188 inches, leaving a 0.656-inch space to be filled by turfgrass growing from inside and outside of the lysimeter. Consequently, the effective diameter for the ETc act from the turfgrass within each lysimeter was 12.531 inches. Changes in lysimeter weight were converted to ETc act by multiplying the weight difference by a factor of 0.898.

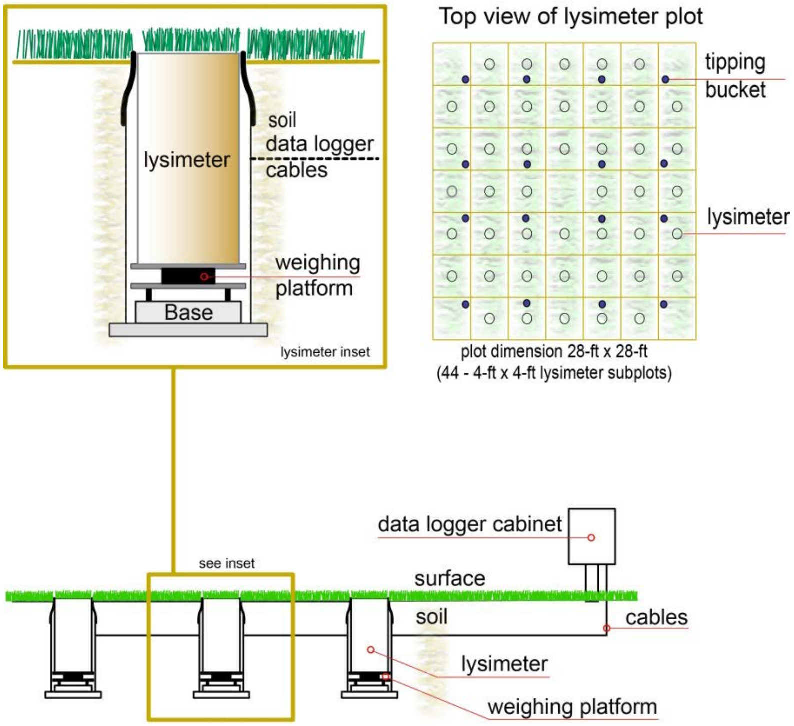

Figure 1. Diagram of small turfgrass lysimeters and arrangement of lysimeter study plot.

The entire lysimeter plot is on a single irrigation zone using Hunter MP Rotator 2000 sprinklers on 15-ft spacing. The gross application rate was 0.57 inch/hr. Daily gross irrigation applications were measured by a dedicated DLJ ¾-inch x ¾-inch brass multi-jet flow meter with pulse output connected to a Campbell Scientific data logger which measured all sprinkler irrigation applications to the lysimeter plot. In addition, fifteen Texas Electronics tipping bucket rain gauges were installed flush with the turf height throughout the lysimeter plot to measure net sprinkler irrigation application as well as rainfall. A second DLJ flow meter measured irrigation water applied by hand to bring each lysimeter up to field capacity following sprinkler irrigation.

Per field observation, the depth of the established turfgrass root zone was taken to be the depth of the lysimeter. Following removal of the lysimeters in November 2013, many lysimeters had significant root growth down to the filter fabric placed beneath the soil. During mid-season, all turfgrasses were mulched mowed to a height of 3 inches weekly. The observed steady infiltration rate was no more than 0.4 inch/hr.

Rainfall Measurements

Daily rainfall was measured every 15 minutes at an adjacent weather station having a weighing bucket precipitation gauge as well as a tipping bucket rain gauge. As noted above, combined daily rainfall and sprinkler irrigation catch was measured by fifteen tipping bucket rain gauges installed in-ground within the lysimeter grid with their collector rims at turf level.

Measurement agreement was typically very good between the weighing bucket precipitation gauge and the tipping bucket rain gauges. However, the weighing bucket precipitation gauge proved most consistent and reliable. The tipping bucket rain gauges under-measured catch during higher intensity rainfall events. The in-ground tipping buckets were also susceptible to partial plugging from windblown grass clipping debris. Catch readings would then be extended over longer time periods as the rain drained much more slowly through the collector funnel obstruction.

Deep Percolation

Deep percolation through the lysimeters was free draining and not measured directly. The sandy clay loam soil in each lysimeter was only 20-inches deep. Following field observations and inspection of the 15-minute lysimeter data, any deep percolation from irrigation was generally observed to be completed before sunrise. Turf water use during this nighttime drainage period was considered negligible. Beginning in late July 2010, all sprinkler irrigations were scheduled for after 9:00 P.M. and before midnight. Beginning in 2013, irrigations were cycle/soaked three times to insure infiltration without runoff. However, hand watering to bring each individual lysimeter up to field capacity did occur during daytime hours–usually the day following sprinkler irrigation. Any excessive percolate that ponded below a lysimeter following prolonged or heavy rainfall was removed as needed (rarely) through a manually-controlled vacuum extraction system.

Lysimeter Calculations

The following equation was utilized as the basis for the soil moisture balance in the root zone:

$$\text{LysWTend} = \text{LysWTstart} + \text{Rain} + \text{NetIrrig\_sprink} + \text{NetIrrig\_hand} - \text{ETc act} - \text{DeepPerc} \quad (1)$$

LysWT_{end} = Ending weight of lysimeter at midnight of current day, inches H_2O
LysWT_{start} = Beginning weight of lysimeter at midnight of previous day, inches H_2O
Rain = Measured weighing bucket precipitation, inches H_2O
NetIrrig_sprink= Net irrigation infiltrated from in-ground sprinkler system, inches H_2O (gross irrigation as measured by flow meter – wind drift and overspray losses)

NetIrrig_hand = Net irrigation applied by hand to bring each lysimeter up to field capacity, inches H_2O

$ET_{c\ act}$ = ET_{os} x (K_s x K_{cb} + K_e), inches H_2O

DeepPerc = Deep percolation losses to drainage when field capacity is exceeded, inches H_2O

ET_{os} = Reference evapotranspiration for short reference crop (clipped grass) calculated hourly by the ASCE standardized reference evapotranspiration equation, then summed daily, inches H_2O

EffAreaFactor = conversion factor of 0.898 utilized to convert lysimeter weight changes to $ET_{c\ act}$, ($LysWT_{end}$ – $LysWT_{begin}$) x EffAreaFactor = $ET_{c\ act}$, assuming no rain/irrigation or other losses

The net irrigation both by sprinklers and by hand was calculated for each lysimeter as the net positive change in lysimeter weight over each 15-min time period when irrigation was applied. The sprinkler applied irrigation correlated closely to the average irrigation derived from lysimeter gains, averaging nearly 92%.

Deep percolation was likewise estimated for each lysimeter as any unaccounted for weight loss in excess of [ETos x 1.25 x 1.1] following an irrigation or rain event. See Allen et al. (2011).

The following rearrangement of equation 1 was utilized to calculate daily Kc for 2011-2013:

$$K_c = [\ LysWT_{start} - LysWT_{end} + Rain + NetIrrig\_sprink + NetIrrig\_hand - DeepPerc\ ] / ET_{os} \quad (2)$$

Results

The nine cool season grasses were very similar in watering needs, with only minor differences. However the following ranking was applied:

Table 1. Ranking of cool season turfgrasses by water use.

High water use	Medium high water use	Medium water use	Medium low water use
‘Natures Choice’ Arkansas Valley mix	Fine fescue mix	Perennial ryegrass	Reubens Canada bluegrass
	Drought hardy Kentucky bluegrass	Kentucky bluegrass blend	Texas hybrid bluegrass blend
	‘Low Grow’ mix	Tall fescue	

The warm season blue gramma – buffalograss mix had the lowest water use. However it was only modestly lower than the Texas hybrid bluegrass blend.

Seasonal Kc curves were developed for both cool season and warm season turfgrasses. The timeline for the Kc curves was determined seasonally based on the following parameters:

Table 2. Seasonal timeline for Kc curve.

	Cool season turfgrass	**Warm season turfgrass**
Initial	K_{cb} = 0.20	K_{cb} = 0.20
Start of development	Starts when average daily air temperature reaches 1 deg C. Ends when cumulative growing degree days (base 0) exceeds 530.	Starts when average daily air temperature reaches 8 deg C. Ends when cumulative growing degree days (base 0) exceeds 276.
Mid-season	K_{cb} = 0.921	K_{cb} = 0.881
Late season	Starts when minimum daily air temperature reaches -2.5 deg C. Ends when minimum daily air temperature reaches -15 deg C.	Starts when minimum daily air temperature reaches 0 deg C. Ends when minimum daily air temperature reaches -5 deg C.
Dormancy	K_{cb} = 0.20	K_{cb} = 0.20

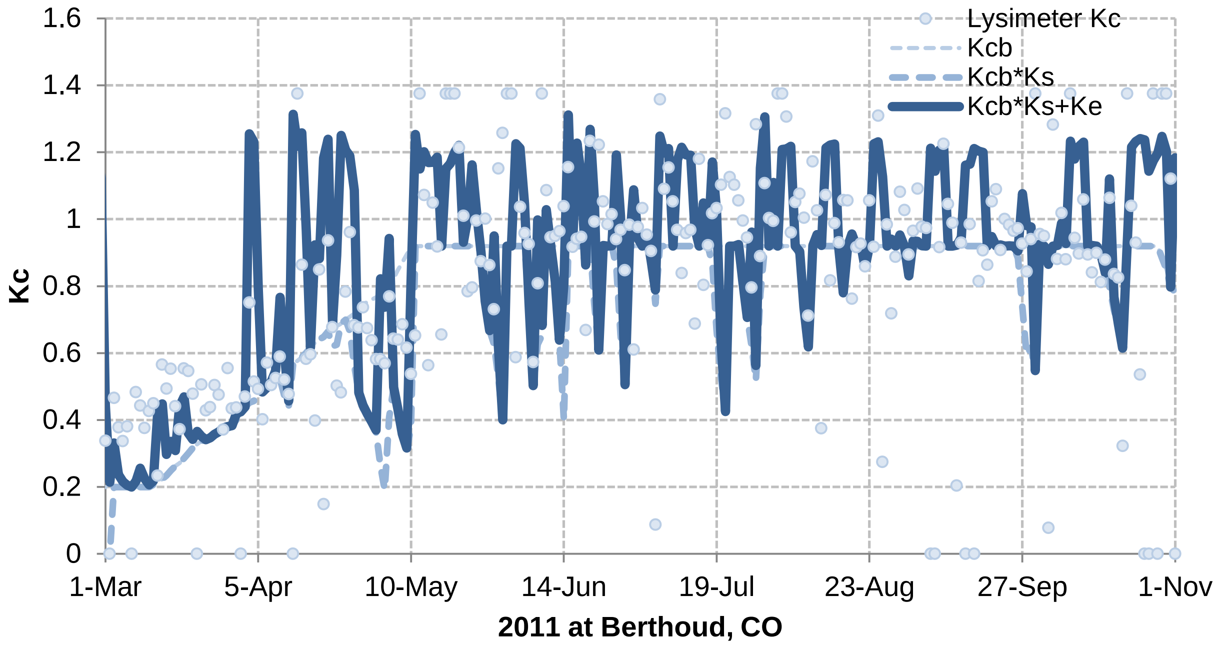

Figure 1. Seasonal Kc curve for cool season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2011 season.

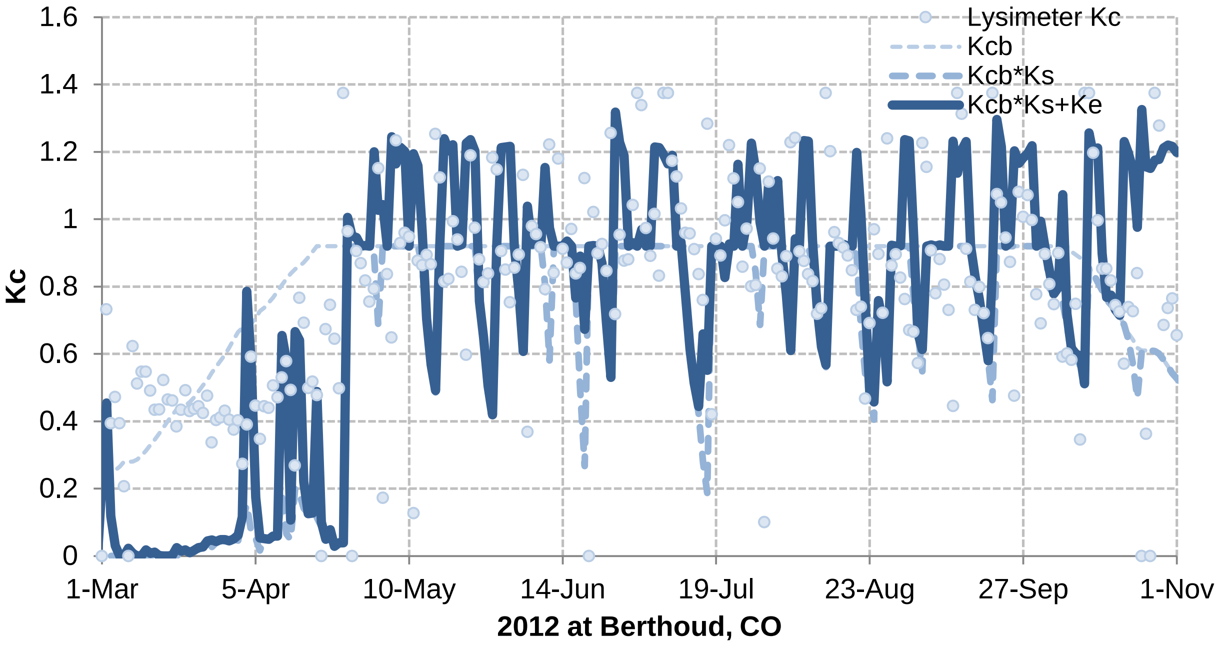

Figure 2. Seasonal Kc curve for cool season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2012 season.

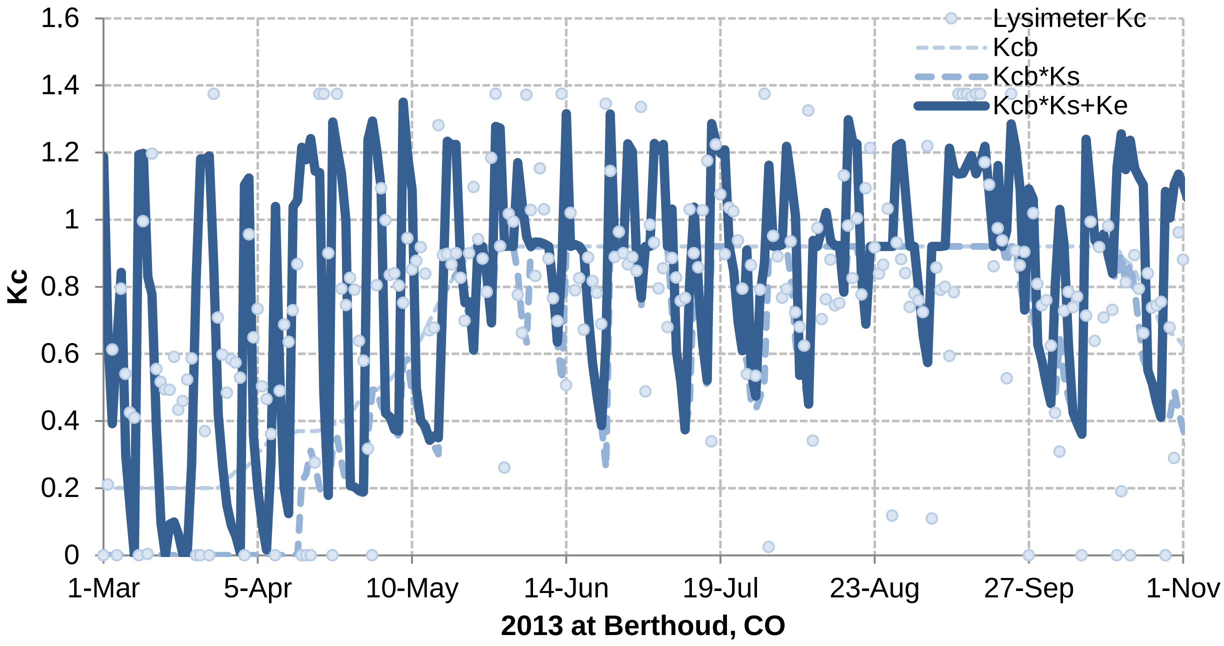

Figure 3. Seasonal Kc curve for cool season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2013 season.

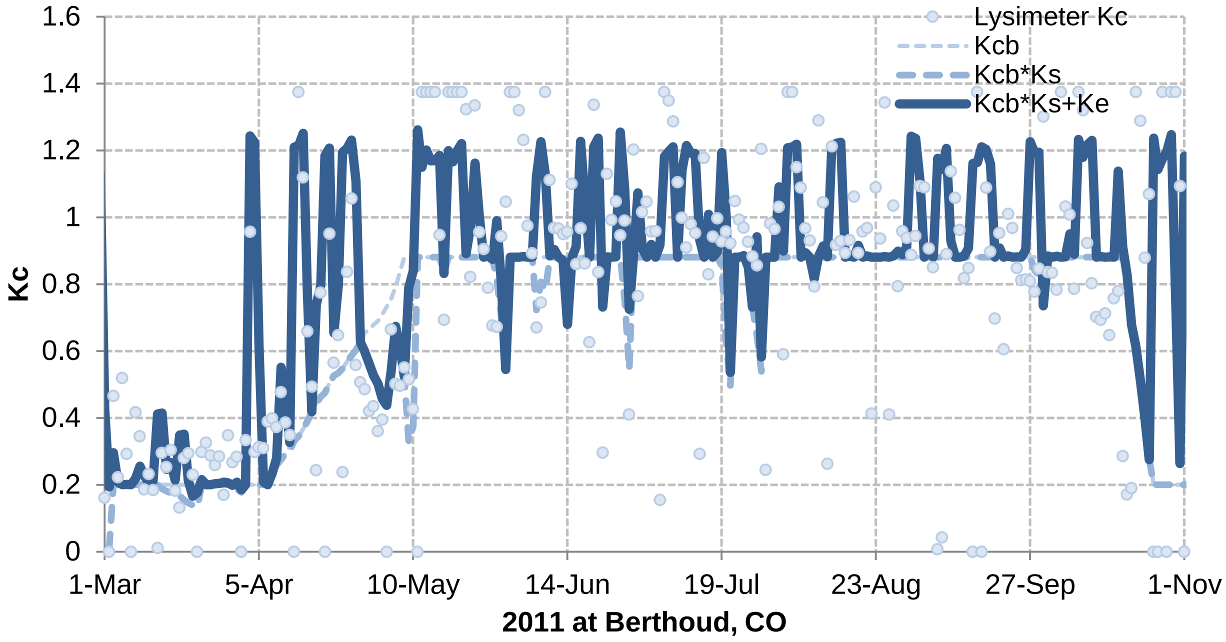

Figure 4. Seasonal Kc curve for warm season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2011 season.

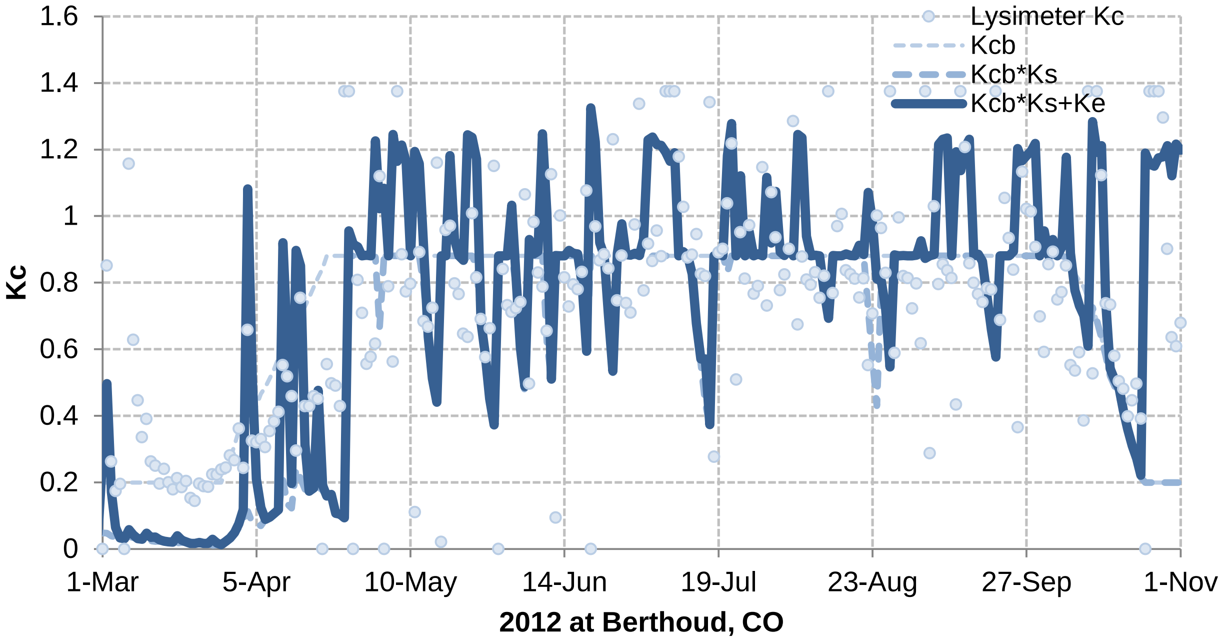

Figure 5. Seasonal Kc curve for warm season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2012 season.

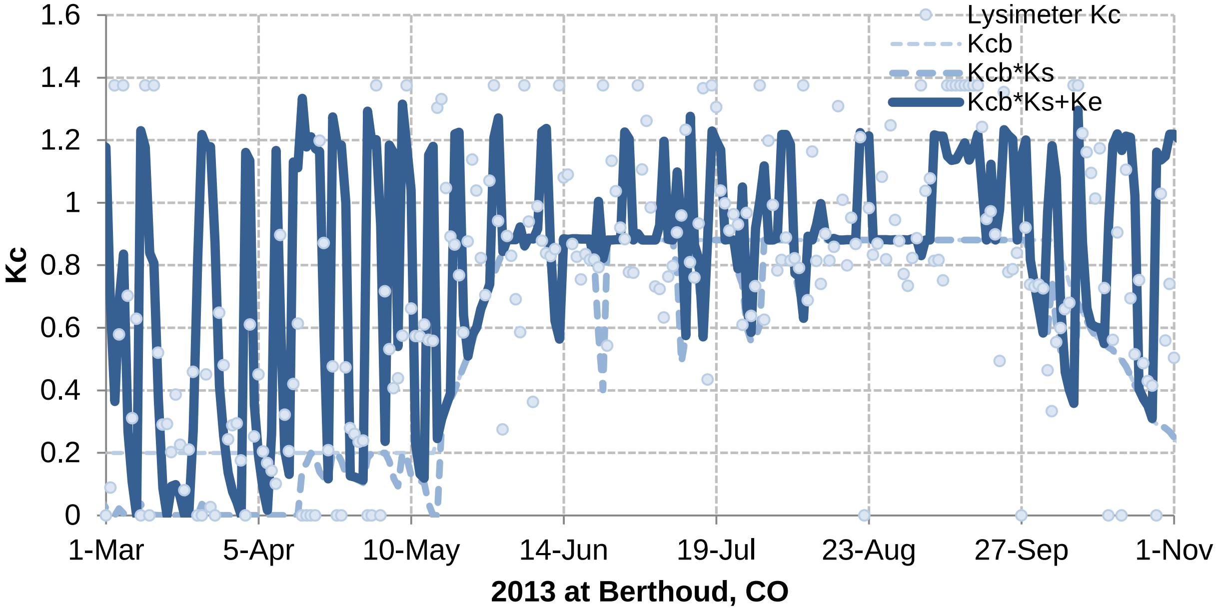

Figure 6. Seasonal Kc curve for warm season turfgrass at Berthoud, Colorado. Data from 40 small weighing lysimeters during the 2013 season.

Summary Conclusions

The application of the FAO-56 dual crop coefficient method for development of seasonal curves for both cool and warm season turf grasses proved workable and reasonably accurate. Incorporation of this method into the soil moisture balance computations of weather based smart controllers holds good potential for further improvement in the irrigation management of urban landscapes. The use of seasonally adjusted timelines for Kc curves should improve accuracy of plant water use calculations, particularly during the starting and ending of the irrigation season. Significant potential for increased water conservation may result.

Acknowledgements

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