Climate-Based Irrigation Scheduling for Warm Season and Cool Season Turfgrasses

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ABSTRACT

Recent droughts and increasing demands for limited water supplies in the arid southwestern U.S. have caused many municipalities in the region to impose water restrictions that have reduced the volume available for urban irrigation. The potential adverse effects of these reduced water supplies on landscape quality, however, can be mitigated through careful irrigation management and selection of drought-tolerant species for planting. During 2002 and 2003, turfgrass crop coefficients (relationships between measured turf evapotranspiration [ET] and climate-based, Penman-Monteith reference ET [ETo]) formulated during a three-year study (1998 – 2000) at Farmington, New Mexico were used to schedule irrigations on established cool season and warm season turfgrasses. The ET estimates derived from the coefficients were designed to equal the minimum water required to maintain acceptable turfgrass quality. The crop coefficients (Kc) functioned well for turfgrass irrigation scheduling between early April and late October during 2002 and 2003 in Farmington. A correction ratio must be employed, however, if the Kc is used for scheduling irrigations at sites having significantly different growing season lengths than Farmington's.

INTRODUCTION

Booming population growth in the southwestern United States has placed an ever-increasing demand on available water supplies in the region. Due to below average precipitation in much of the area in recent years, many water storage reservoirs and groundwater aquifers used to help provide for this demand, are at their lowest levels since being filled. Consequently, municipalities such as Denver, Albuquerque, Santa Fe and Las Vegas, and many smaller communities, have imposed restrictions on the amount of water that can be used for irrigating landscapes. Potential adverse effects of reduced water availability on landscape quality, however, can be mitigated through wise irrigation scheduling and selection of drought-tolerant species for planting.

Irrigation scheduling techniques can be categorized as climate based or soil based but aspects from both categories should be used for high efficiency water management. In climate based turfgrass irrigation scheduling, an accurate estimate of the turf's water-use or evapotranspiration (ET) at various times during the growth cycle is required. These ET requirements, while primarily a function of climatic factors (air temperature, solar radiation, humidity, and wind), are also related to grass species or cultivar, growth stage or size of the plant, and cultural practices. By correlating measured ET to a reference ET (ETo) calculated from weather data, crop coefficients (ET/ETo or K_c) have been developed that can be used to derive a baseline estimate of actual crop ET on a daily basis if local weather parameters are available. Most states of the southwest maintain a network of automated weather stations that provides the data necessary to calculate ETo at various locations within each state. These weather data (along with ETo calculations) are downloaded periodically to a central computer and are usually made available to the public through the Internet. In many cases, K_c and irrigation scheduling recommendations for various agricultural crops and turfgrasses are also provided at the web sites. Unfortunately, a K_c provided for a particular turfgrass at a given site or region may not be suitable for a similar grass at a different site or region. This may be due not only to differences in the length of growing seasons between the two sites but also to differences in the method used to calculate ETo at the sites. To compensate for growing season variability between sites, the use of heat units as a time scale (in lieu of day of year, days after planting, etc.) has been suggested (Sammis et al., 1985; Slack et al., 1996). Heat units, expressed as cumulative growing degree-days, provide an indication of the phenological and physiological development of the crop and this development relates to ET. To compensate for K_c variability due to different ETo methods used between sites, it has been recommended by a panel of experts (ASCE, ASAE, and IA) that the FAO 56 Penman Monteith equation (Allen et al. 1998) be used as a standard. This would alleviate some of the confusion in comparing K_c and ET estimates between sites.

As previously mentioned, variability in K_c for a given grass can even occur between sites located within very similar climatic zones because of varietal (Shearman, 1986; Bowman and Macaulay, 1991), cultural (Feldhake et al., 1983; Richie et al., 2002), and microclimatical (Feldhake et al., 1983) differences between the sites. Nonetheless, regional K_c values can serve as valuable baseline indicators (or starting points) that can be fine-tuned for specific situations at a particular site.

Differences in ET requirements between cultivars of the same species appear to be minimal (Shearman, 1986; Bowman and Macaulay, 1991) or insignificant (Green et al. 1991; Ebdon et al., 1998; Atkins et al., 1991) compared to the differences in ET requirements between warm season (bermudagrass, buffalograss, blue grama, etc.) and cool season (Kentucky bluegrass, tall fescue, perennial ryegrass, etc.) turfgrasses (Kneebone and Pepper, 1982; Kim and Beard, 1988; Gibeault et al., 1989; Qian and Fry, 1997). In a California study (Meyer and Gibeault, 1987) for example, 36% less water was needed for acceptable quality of warm season grasses than cool season grasses. Seasonal K_c, referenced to a modified Penman ETo (Doorenbos and Pruitt, 1977), averaged 0.6 for the warm season grasses and 0.8 for the cool season grasses. In southern Nevada, Dean et al. (1996) showed that turf quality declined when irrigation/ETo ratios dropped below 0.65 and 0.8 in bermudagrass and tall fescue, respectively, when referenced to a modified combination Penman (Campbell Scientific) ETo. In a Kansas study, Qian et al. (1996) reported tall fescue ET to be 35% higher than bermudagrass ET during a two-year period.

Much of the research resulting in the formulation of K_c for turfgrass has been accomplished in desert environments (Kneebone and Pepper, 1982; Kopec et al., 1992; Devitt et al., 1992; Mancino, 1993; Brown et al., 2001) or in southern California (Meyer and Gibeault, 1987). Borrelli et al. (1981) published a summary of Blaney-Criddle K_c for those areas plus Wyoming and northern Colorado, while Hill (1998) suggested seasonal mean K_c for cool season turfgrass on golf courses in northern Utah. Aronson et al. (1987) formulated K_c for cool season turfgrass at a humid site in southern New England. Limited information related to the ET requirements (or K_c) for acceptable quality of warm and cool season grasses in the turf transitional zone of the U.S. is available.

The objectives of this research were to: 1) identify the ET requirements for acceptable quality of several warm season and cool season turfgrasses in the transitional zone; 2) formulate crop coefficients (using the suggested standard Penman Monteith ETo) that may be used to efficiently schedule irrigations on turfgrasses; and 3) validate the crop coefficients by using them to schedule irrigations on established turfgrass plots.

METHODS AND MATERIALS

Site Description

This study was conducted in northwest New Mexico at New Mexico State University's Agricultural Science Center at Farmington. The site is located at 36^{o} 41' N latitude by 108^{o} 18' W longitude at an elevation of 1720 m (5640 ft) above mean sea level. The average annual precipitation at the semi-arid site is 21 cm (8.2 in). The soil type is a Kinnear very fine sandy loam (Anderson, 1970) having a total water holding capacity of 6.9 cm (2.7 in) in the upper 45 cm (18 in) of the profile. Based on soil moisture measurements at permanent wilting however, only about 60% or 4.1 cm (1.6 in) of this water is presumed to be available. Although Kentucky bluegrass and tall fescue are the most common lawn grasses in residential areas, native, warm season grasses such as blue grama and buffalograss are being increasingly planted for turf. Cold tolerant bermudagrass and zoysia are two other warm season grasses that can be grown successfully in the region.

Plot Design

Two separate sprinkler-line source plots (Hanks et al., 1976) were used to provide irrigation treatments to six cultivars of warm-season grasses and seven cultivars of cool season grasses in 1998, 1999, and 2000 (Table 1). Each plot consisted of a single sprinkler line that applied a continuous, decreasing gradient of water to each grass on each side of the line with increasing distance [0 to 14 m (0 to 45 ft)] away from the line. Catch-cans, to collect applied water for measurement after each irrigation, were located at 2.3 m (7.5 ft) intervals away from the line. Neutron probe access tubes were installed to a depth of 1.5 m (5 ft) in four grasses in each plot at equal distances from the line as the catch cans. Soil moisture measurements were taken at these localities in depth increments of 15 cm (6 in) in the top 45 cm (18 in), and 30 cm (12 in) increments in profile depths below 45 cm about every 10 days during the active growing season using a neutron probe (Troxler model 4302). Turf ET per period was calculated using the water balance equation:

$$ET = I + P \pm \Delta SW - D$$

Where…

I = depth of irrigation (in)

P = depth of rainfall (in)

ΔSW = change in soil water, 0-135 cm

D = estimated drainage below 135 cm

Heat units, expressed as growing degree-days (GDD), were used as an indicator of grass phenological development during the growing seasons. Daily GDD were calculated using the following equations:

Cool Season Grass:

$$GDD = (Tmax + Tmin)/2 - 4.4^{o}\,C \text{ (base)}$$

*(Tmax cutoff = 40.5 °C, Tmin cutoff = 4.4° C)

Warm Season Grass:

$$GDD = (Tmax + Tmin)/2 - 15.5^{o}\,C \text{ (base)}$$

*(Tmax cutoff = None, Tmin cutoff = 15.5° C)

Where…

Tmax = daily maximum temperature (^oC)

Tmin = daily minimum temperature (^oC)

*Observed temperatures above Tmax cutoff were set to Tmax and temperatures below Tmin cutoff were set to Tmin prior to calculating the mean.

Climatological data (air temperature, relative humidity, solar radiation, wind speed, and precipitation) were recorded with an automated weather station (Campbell Scientific, Inc. Model CR10) located about 60 m (200 ft) east of the plots in an area planted to cool season grass. Penman Monteith reference ET (ETo) was calculated using an Excel spreadsheet (Snyder and Eching, 2002) available on line at: http://biomet.ucdavis.edu/evapotranspiration/PMdayXLS/PMday.htm.

Irrigations were applied two to three times per week at a depth required to maintain soil moisture at a level near field capacity in the top 45 cm (18 in) of the soil profile at subplots located 4.6 m (15 ft) from the line-source. Total irrigation applied during 1998 (from low to high irrigation treatment) ranged from 40 cm (15.8 in) to 91 cm (35.8 in) in the warm season plots and from 64 cm (25.1 in) to 110 cm (43.5 in) in the cool season plots. In 1999, treatments ranged from 22 to 52 cm (8.8 to 20.3 in) and from 36 to 75 cm (14.3 to 29.6 in) across the warm season and cool season plots, respectively. In 2000, irrigation ranges were 33 to 73 cm (13.1 to 28.6 in) in the warm season plots and 43.4 to 99 cm (17.1 to 39.0 in) in the cool season plots. During the active growing period of the warm season grasses (early May to early October), rainfall amounts were 9.4, 18.5, and 6.9 cm (3.7, 7.3, and 2.7 in) in 1998, 1999, and 2000, respectively. While the cool season grasses were actively growing (early April to late October), they received 17.5, 22.1, and 12.4 cm (6.9, 8.7, and 4.9 in) of precipitation in 1998, 1999, and 2000, respectively.

All grass plots were mowed weekly throughout the active growing seasons using a riding mower equipped with a rotary mowing deck and two mulching blades. All grasses, except the blue grama, were cut to a uniform height of 6.5 to 7.5 cm (2.5 to 3 in) at all irrigation levels. In mid-June of 1999, it appeared that low mowing was having an adverse effect on blue grama quality and mowing height was adjusted to 9 to 10 cm (3.5 to 4.0 in) for that grass only.

Balanced fertilizers were applied to the plots in small quantities per application five to seven times during each growing season. Total seasonal N, P (as P_2O_5), and K (as K_2O) averaged 22.7, 8.3, and 6.9 kg/1000 m^2 (4.7, 1.7, and 1.4 lbs/1000 ft^2) respectively, in the warm season grasses, and 24.4, 16.6, and 22.5 kg/1000 m^2 (5.0, 3.4, and 4.6 lbs/1000 ft^2) respectively, in the cool season grasses. Appropriate pest control techniques for weeds, insects and diseases were used throughout the three-year study period to maintain turfgrass quality.

Independent judges and/or research personnel evaluated the grass plots on several occasions during each growing season. Turf acceptance at each irrigation level was based on general turf appearance and quality considering factors such as color (greenness), density, uniformity, incidence of disease, and blade texture. The water requirement was defined as the ET measured at the location farthest away from the line-source where turf quality was judged to be acceptable. In most cases, this subplot occurred at a location equidistant from the line as the soil moisture and catch can measurements. In cases where the acceptable level was located in-between catch-cans, ET was interpolated.

Table 1. Cultivars and planting rates of warm and cool season turfgrass varieties included in the Farmington irrigation study.

Cultivars	Seed Planting Rate kg/1000 m^2 (lbs/1000 ft^2)
Warm Season Turf	
Bison Buffalograss	24.9 (5.1)
Tatanka Buffalograss	25.9 (5.3)
Texoka Buffalograss	26.4 (5.4)
Guymon Bermudagrass	13.7 (2.8)
N.M. Sahara Bermudagrass	7.3 (1.5)
Lovington Blue Gramagrass	11.2 (2.3)
Cool Season Turf	
Adelphi Bluegrass	18.1 (3.7)
Ascot Bluegrass	16.1 (3.3)
Coventry Bluegrass	18.6 (3.8)
Goldrush Bluegrass	17.6 (3.6)
Park Bluegrass	17.1 (3.5)
Seville Perennial Ryegrass	51.3 (10.5)
Shenandoah Tall Fescue	47.9 (9.8)

Planting dates:
Warm-season grasses: July 7-11, 1997
Cool-season grasses: September 9, 1997

RESULTS AND DISCUSSION

Total Seasonal ET

Total seasonal measured ET resulting in acceptable turfgrass appearance and quality over all three years averaged 64 cm (25 in) in the warm season grasses and 94 cm (37 in) in the cool season grasses. There were slight differences in the measured ET required to produce acceptable quality between grasses within each grass type (warm season and cool season). In the warm season grasses, the Bison and Texoka buffalograsses used about 7% less water than the Guymon bermudagrass (61 cm vs. 66 cm, respectively), while the blue grama ET was intermediate (64 cm). The Sahara bermudagrass suffered winterkill damage and would not be recommended for the Farmington area. In the cool season grasses, the Adelphi bluegrass used a few cm less water than the other grasses (89 cm vs. 91 cm) for acceptable quality while the perennial ryegrass required about 97 cm (38 in). Due to apparent heat stress however, the ryegrass was given low quality ratings at the highest irrigation levels in mid summer.

A study conducted in southern California by Meyer and Gibeault (1987) showed that warm season and cool season grasses required 134 cm and 209 cm, respectively, for acceptable quality. This more than twofold difference in seasonal water requirements between northern New Mexico and southern California demonstrates the importance of growing season length in turf ET estimation.

Consumptive-use (Daily ET Patterns)

Seasonal consumptive-use patterns at the minimum acceptable irrigation level varied only slightly between turf species but were quite different between the cool season and warm season grasses. The cool season grasses greened up in mid to late March and exhibited a faster rate of growth in the spring than the warm season varieties, which did not green up until late April or early May. Daily water use rates in the cool season grasses increased rapidly after green-up and peaked in June and early July at an average rate of 0.58 cm (0.23 in)/day (Fig. 1A). This peak rate is nearly identical to the mean measured ET rates of Kentucky bluegrass and tall fescue (0.57 and 0.58 cm, respectively) grown in lysimeters from June 8 to August 16, 1981 in northern Colorado by Feldhake et al. (1983).

Daily ET rates of the warm season grasses increased more slowly than the cool season grasses in spring and early summer and the average peak daily ET rate of 0.46 cm (0.18 in)/day was not reached until mid July (Fig. 1B). This peak value is very similar to those means reported by Feldhake et al. for bermudagrass (0.45 cm) and buffalograss (0.45 cm) in the Colorado study during the same seasonal time frame.

Greater peak daily ET rates for both warm season and cool season grasses than those measured at Farmington and Colorado have been reported in hotter climates. Kneebone and Pepper (1982), for example, measured rates as high as 0.64 cm (0.25 in)/day for warm season grasses and more than 0.85 cm (0.34 in)/day for cool season grasses in southern Arizona, while in Texas (Kim and Beard, 1988), ET rates averaged 0.56 cm (0.22 in)/day for bermuda, buffalo and blue grama grasses, and 0.71 cm (0.28 in)/day for tall fescue.

Crop Coefficients (ET/PET)

While the consumptive-use curves (Fig. 1) can be of value for scheduling irrigations in Farmington (or similar climatic area) during a typical season, as shown by the studies cited, due to climatic variability between seasons and sites, they may be of limited value during unusual weather patterns or at sites having significantly different climate than Farmington. To compensate for this variability, a seasonal K_c curve was formulated for each type of grass using the Penman Monteith (PM) ETo (Figs. 2 A and B). To further compensate for the effects of temperature on the initiation and duration of the active growing (green) period, and on plant growth and development during the season, K_c was plotted against cumulative growing degree-days (CGDD) rather than day of year.

The average K_c for cool season grass rose sharply from 0.3 to 0.9 between 300 and 1200 CGDD (Fig. 2A). This generally corresponded to the time period from late March to early June. From early June (1200 CGDD) to mid September (3000 CGDD), K_c averaged about 0.85. This mean is nearly identical to the average cool season K_c reported during a similar timeframe in Irvine, California by Meyer and Gibeault (1987) using the California Irrigation Management Information System (CIMIS) modified FAO 24 Penman ETo (Doorenbos and Pruitt, 1977). A comparison between a modified FAO 24 ETo (http://weather.nmsu.edu) and the PM ETo, using climate data from Farmington between 1998 and 2000, however, showed that PM ET_o = 0.785 x Penman FAO 24 ETo. If the modified Penman equations used by CIMIS and the NMCC (New Mexico Climate Center) are similar, Meyer and Gibeault's K_c would become 1.08 when referenced against the PM equation.

The K_c for warm season grasses (Fig. 2B) increased from about 0.15 to 0.75 within the CGDD range of 50 to 500 (about mid April to the end of June). Between 500 and 1200 CGDD (June 1 to early October) K_c averaged about 0.7. This is very similar to the mean K_c of 0.68 reported by Meyer and Gibeault (1987) between June and September for warm season grasses in California. Again however, their K_c, if referenced to the PM ETo, would be closer to 0.87. Brown et al. (2001) found that PM referenced K_c for bermudagrass in Arizona in the summer ranged from 0.78 in June and July to 0.83 in September. While the 0.78 K_c for July in Arizona agrees with the July K_c at Farmington, bermudagrass growth (and ET rate) slows considerably (relative to ETo) as temperatures begin to decline in late August and September and the K_c drops to about 0.65 at Farmington (Fig. 2B).

Validating the K_c

To validate the crop coefficients formulated in our study, they were used to schedule irrigations on established cool season and warm season turfgrasses using two solid-set sprinkler irrigation systems in 2002 and 2003. Additionally, in 2003, two new line source studies (warm and cool season grasses) were initiated and the formulated K_c were used to provide 100% of estimated ET to plots 4.6 m (2 catch cans) away from each line source. Irrigations were scheduled to replace estimated ET when 40% and 60% of available water in the top 45 cm (18 in) of the soil profile was depleted in the cool season and warm season grasses, respectively, minus precipitation. This equated to a maximum allowable depletion of 1.6 cm (0.64 in) in the cool season turf and 2.4 cm (0.96 in) in the warm season turf. Using this technique, irrigation system runtimes stayed relatively constant throughout the season while irrigation frequency varied. Irrigation efficiency was assumed to be 100%. A 45 cm (18 in) soil-sampling probe was used to periodically check soil moisture.

Between April 9 and October 25, 2002, the cool season grasses were irrigated with 83 cm (32.8 in) of water in 48 applications, while the warm season grasses were irrigated with 62 cm (24.5 in) in 42 irrigations. An additional 6.8 inches of precipitation that fell on the plots between April 1 and November 10 resulted in total water application depths during this period of 102 cm (40 in) and 79 cm (31 in) in the cool and warm season grasses, respectively. These totals were nearly equal to the seasonal ET estimates of 104 cm (41 in) and 76 cm (30 in) for the respective grasses using the formulated K_c.

Irrigation water was not available from October 25, 2001 to April 8, 2002 and the grass plots received only 1.58 inches of precipitation during this period. Consequently, the cool season grasses did not green up and begin using water until a deep irrigation (2.05 inches) was applied on April 9 to replenish soil moisture that had been depleted from the top two feet of the profile after October 25, 2001 when these grasses were still actively growing. Had sufficient soil water been available, the cool season grasses would have broke dormancy and began using water in March based on estimated ET. A deep initial irrigation was not required in the warm season grasses since they went dormant prior to October 25, 2001 and did not extract significant soil moisture during the winter.

In 2003, 4.5 cm (1.8 in) of precipitation in February and March recharged the soil moisture somewhat so that the cool season grasses began greening up during the third week in March. Cumulative irrigation then followed cumulative estimated ET closely through August in both the cool season and warm season grasses. Visual symptoms of water stress were not observed in any plots that received irrigation depths equal to estimated ET.

SUMMARY

The crop coefficients developed from the 1998 to 2001 study functioned well for turfgrass irrigation scheduling between early April and late October in Farmington, New Mexico. While this is sufficient for warm season grasses at this site, some adjustments may be required at the beginning and end of the crop coefficient if used to schedule irrigations on cool season turf during the winter. During this study, irrigation water was available between the first week in April and the third week in October. In the Farmington area, cool season grasses can begin to green up in late February to early March, and may not enter dormancy until late November if sufficient soil moisture is available. Measurements of ET taken during March and November in years when sufficient soil moisture was available for growth of cool season grass, however, indicate that total monthly ET is probably less than 5 cm (2 in) within each month.

Adjustments must be made to the K_c curves of both grasses before they can be used to schedule irrigations at sites having different growing season lengths than Farmington's. This can be done by applying a correction ratio to the curve based on differences in cumulative growing degree-days (CGDD) between sites. Possibly, CGGD expressed in relative terms (i.e. CGDD/total GDD for site) can also adjust for this difference. This would expand or compress the K_c curve to accommodate longer or shorter growing seasons, respectively.

Most of the previously published K_cs for turfgrass have been referenced to a Penman or modified Penman ETo. If the maximum or mean Kc of these studies are adjusted by the 0.785 ratio between the PM method and FAO-24 Penman method as suggested by this report, the maximum or mean K_c at Farmington are generally lower than those formulated elsewhere. This is probably due to the methods used to define measured ET. In most other studies, turf ET was measured from lysimeters that were heavily irrigated and the grasses were never stressed for water. In the line-source experiment at Farmington, the K_cs were derived from ET measurements taken at the lowest irrigation treatments that exhibited acceptable quality. This may have resulted in some water stress but it was not visually exhibited.

The crop-coefficients presented in this report are designed to serve as a guide only. While they are valuable in establishing a baseline for irrigation scheduling, they are not designed to replace actual field observations. Irrigation management strategies must always consider factors such as proper irrigation system design and maintenance, water application efficiencies, microclimatic influences, soil characteristics, cultural factors and other variables. There is no substitute for the wise use of a soil-sampling probe to monitor soil moisture at various locations in a landscape on a regular basis.

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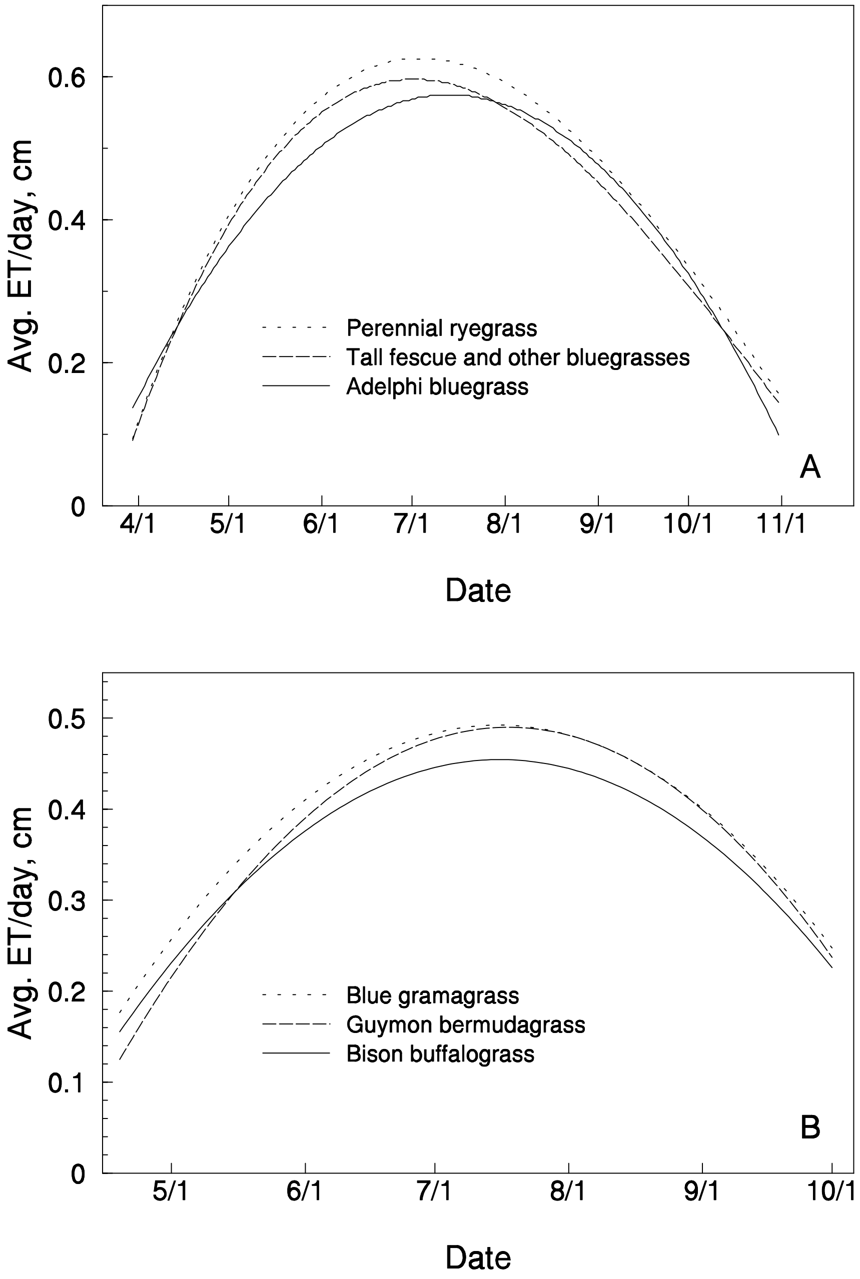

Fig. 1 (A & B). Average daily measured evapotranspiration (ET) of cool season (A) and warm season (B) turfgrasses at Farmington, NM over three years (1998, 1999, and 2000).

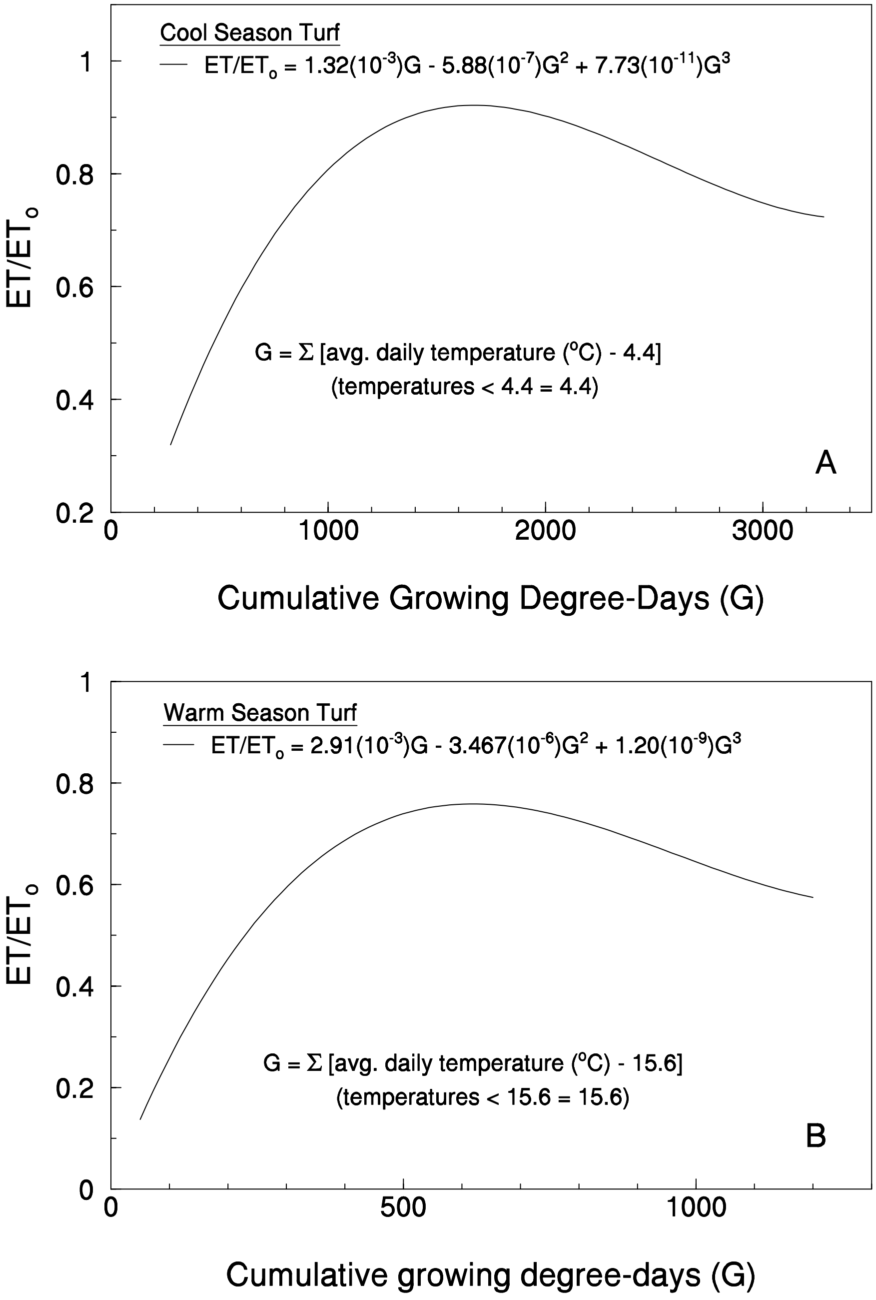

Fig. 2 (A & B). Crop coefficients for cool season (A) and warm season (B) turfgrasses at Farmington, NM. (ET = measured evapotranspiration, ET_o = Penman-Monteith reference ET).