Turf Irrigation Series No. 1

Use of Meteorological Data to Estimate Irrigation Requirements of Recreational Turf: Evapotranspiration and Crop Coefficients for the Cool-Humid Region

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Recreational Turf vs. Lawn Turf

Recreational turf is under intense stress from athletic activities caused by damage from wear, scuffing, shearing, turf displacement and soil compaction. Numerous factors affect the durability of turf to traffic stresses including the type and time of traffic, turfgrass species and cultivar, soil type, soil water content during use, recovery time, and maintenance practices. Major shortages of water applied as irrigation to turf can have significant and diminishing affects on maintaining safe and durable athletic turf and playable golf greens and tees. Lawn turf may enter into a temporary state of dormancy as a result of water deficits with little impact on long-term survival of turf. Alternatively, trafficked recreational turf under the same water deficits can cause permanent damage to the survival of the turfgrass plant as well as increase potential injuries to athletes including children.

Meeting without exceeding the proper amounts of water applied as irrigation is critical to maintaining safe and durable recreational playing surfaces. Over-irrigation promotes leaching of water and the movement of contaminants into ground water and must be avoided to preserve environmental health and to conserve water. As such, over-watering as irrigation promotes significant waste of water with no benefit to plant health and society.

Recreational turf is not only different from lawn turf because of its higher irrigation requirements for optimal function under traffic, but in addition, trafficked turf has higher requirements for aerial shoot density. Low soil exposure and high turfgrass cover are tantamount to reducing soil compaction tendencies and promoting proper ball bounce, footing and traction, and tolerance to wear stress. High leaf area and low soil exposure are unique properties to turf that make estimating water use more reliable when using meteorological (climatic) data.

Turf Water Use and Evapotranspiration

Quantifying water use in turfgrass is essential for proper irrigation. To that end, using the proper amount of water lost from turf systems as evaporation from the soil plus transpirational water lost from associated leaf surfaces can be effectively measured as evapotranspiration (ET).

> **Evapotranspiration (ET)** = The sum total of water loss as evaporation from the soil surface plus transpirational water loss associated with the leaf surface. In recreational turf systems the majority of ET is water loss as transpiration because of the high leaf area (and soil shading) and density of recreational turf.

The water lost from the soil-root zone through the vegetative system into the bulk atmospheric air as turf ET is the amount of water that should be applied as irrigation and is referred as "ET replacement". Turf ET replacement allows for recharge of root zones while at the same time diminishes leaching and movement of water below the effective rooting depth during irrigation practices. Actual turf ET is denoted as "ET_T" and is accurately measured using weighing-lysimeters. Turf ET_T using lysimeters is rarely measured except for experimental purposes. Lysimeter-based turf ET_T is labor intensive and is not practical for estimating irrigation requirements.

Turf ET_T = Actual evapotranspiration from a turf system measured directly using weighing lysimeters. This is the ideal (standard) amount of water to apply as irrigation to fully recharge turf rootzones and to prevent leaching by over-watering. Lysimeter-based turf ET_T is determined experimentally but can be predicted using reference ETo.

Turf water use measured using lysimeter-based turf ET_T is affected by numerous factors including soil water content, climatic (evaporative demand) factors, and cultural management factors. To sustain active vegetative growth for optimal traffic tolerance soil water is generally maintained at levels sufficient for active growth. Therefore, soil moisture for recreational turf under traffic is generally not growth limiting. Under these conditions where soil water is favorable for growth, meteorological and cultural management factors are important factors affecting turf ET_T. Alternatively, under progressively greater soil moisture deficits caused by soil drying resulting in turf dormancy from drought, turf ET_T approaches zero and meteorological and turf management factors exhibit less influence on turf ET_T.

Turf ET_T is the transfer of heat as water vapor (i.e., heat transfer as ET_T) from the soil surface and leaf-canopy surfaces into the bulk (atmospheric) air above the turf system. This process is influenced by a number of cultural management practices. One of the most important factors affecting heat transfer as turf ET_T is the mowing height of cut (HOC). Furthermore, the frequency of mowing is another important factor in the transfer of heat as turf $ET_{T.}$ Both increasing mowing frequency and lower HOC diminish leaf area and therefore both practices inhibit (lower) turf ET_T and heat transfer. Less leaf area in summer under shorter HOC can cause greater warming of turf canopies. In such cases it's not unusual for shorter HOC golf course turf such as greens and fairways to exhibit significantly higher canopy temperatures in summer caused by lower turf ET_T (i.e., less heat transfer) compared to taller lawn grass or golf course rough areas. Similarly, faster leaf growth rates in summer from nitrogen (N) induced leaf growth increases leaf area and promotes greater interception of solar radiation as heat, which increases heat transfer as higher turf ET_T (i.e., cooler leaf temperature). Overall, practices in summer such as higher HOC (and decrease mowing frequency) combined with higher N rates will promote greater leaf area and turf ET_T, thereby increasing heat transfer into the bulk atmosphere.

Compared to short cut turfgrasses, faster and taller growing turfgrasses not only interact with and intercept greater solar radiation as heat (which increase turf ET_T), but the taller canopies interact more effectively with wind (turbulence). Greater turbulence (wind) associated with taller canopies causes' greater turbulent flow and results in mixing of the more humid canopy air with the drier bulk atmospheric air. Greater turbulent flow transfers more water vapor as turf ET_T. As such, meteorological (climatic) factors such as solar radiation, relative humidity (RH), air temperature and wind speed (turbulence) are major meteorological factors affecting ET. Evapotranspiration increases with greater solar radiation (clear sky vs. cloud cover), drier air (lower RH), higher air temperatures, and greater turbulence as wind speed increases. For example, climatic factors measured in summer (June through September) at the Troll Turf Research & Education Center in South Deerfield MA follow closely with these meteorological factors with 74%, 53%, and 21% of turf ET accounted for by solar radiation, relative humidity, and air temperature, respectively.

Meteorological Data and Reference Evapotranspiration (ET_o)

As an alternative to direct measurement of actual turf ET_T using lysimeters, daily meteorological measurements (solar radiation, air temperature, wind speed, and relative humidity) collected by nearby weather stations can be used to predict ET. These predictions are also referred to as "Reference ET" and are denoted as "ET_o". As predictions, reference ET_o is not necessarily directly comparable to actual turf ET_T derived using weighing-lysimeters. First, mathematical models are used to calculate and convert meteorological data to ET_o as inches of water lost per day. Second, numerous reference ET_o models exist that have different mathematical solutions and predictions for reference ET_o. However, the reference ET_o model accepted as the single equation for crop irrigation as recommended by the scientific community in their report (paper 56) to the Food and Agriculture Organization of the United Nations, is the Penman-Monteith (PM) reference ET_o equation (Allen et al., 1998); designated as FAO-56 PM ET_o. Third, meteorological data does not adjust for cultural factors such as mowing frequency, HOC, N fertilization as well as other factors such as species and cultivars or conditions such as thatch and soil compaction, which can alter actual turf ET_T as the amount of water to be applied as irrigation.

> **Reference ETo** = Prediction of turf ET_T derived using daily meteorological measurements collected from nearby weather stations. Reference ETo is calculated using a reliable reference equation such as FAO 56 Penman-Monteith (PM). Reference ETo must be adjusted (corrected) to match turf ET_T using crop coefficients.

To transfer meteorologically derived reference ET_o values from nearby weather stations to match actual turf water use as turf ET_T, transfer factors or multipliers must be derived. These multipliers or coefficients are computed and tested experimentally and are called "crop coefficients" and are denoted as "K_c" values.

Crop Coefficients (K_c) for Transferring Reference ET_o to Turf ET_T

Crop coefficients are simple mathematical ratios calculated as:

$$K_c = \frac{ET_T}{ET_o} \qquad \text{[Eq. 1]}$$

where ET_T is actual water lost from the turf as ET measured using weighing-lysimeters and ET_o is the reference ET computed using some meteorological equation such as FAO-56 PM ET_o procedures from a nearby weather station. Meteorological reference equations such as FAO-56 PM ET_o assume the turf is tall grass (3 to 6 inch HOC) that is not short of water and therefore the turf is actively growing turfgrass providing 100% grass cover and soil shading.

Crop coefficient (Kc) = A unitless, mathematical multiplier used to adjust reference ETo (inch/day) to match actual turf ET_T (inch/day). Crop coefficients are determined experimentally through research and are used to derived turf ET_T by calculation as: turf ET_T = Kc x ETo. The appropriate crop coefficient must be selected to match (account for) the variations in turf ET_T caused by factors such as mowing, fertilization as well as other cultural practices.

Crop coefficients (i.e., K_c values calculated as Eq. 1) are determined experimentally using replicated studies. Once reliable K_c values are in-hand, these K_c values are then used to adjust meteorological reference ET_o to predict actual turf ET_T as:

$$ET_T = K_c \times ET_o \qquad \text{[Eq. 2]}$$

According to Eq. 1, it's plausible that different K_c values will be required for different management scenarios because of the effects that HOC, and mowing and fertilization schedules have on actual turf ET_T. Similarly according to Eq. 1 and Eq. 2, K_c values = 1 indicate that no adjustment is made to reference ET_o from the weather station because $ET_T = ET_o$. Alternatively, K_c values > 1 and K_c values < 1 indicate the reference ET_o predictions from the weather station under-estimate and over-estimate actual turf ET_T, respectively.

Three years of testing at the Troll Turf Research & Education Center investigated the effects of HOC and N on actual turf ET_T measured using weighing-lysimeters. Three cool-season turfgrass species were evaluated including creeping bentgrass (CB) as golf turf and pure stands of Kentucky bluegrass (KB) and perennial ryegrass (PR) as sports-lawn turf. Species were fertilized in summer at two N rates (0 and 1 lb 1000 ft^{-2}). All species were mowed at two HOC with KB and PR mowed at 1.25 and 2.50 inch while CB was mowed at 0.125 and 0.375 inch HOC. Daily turf ET_T and reference ET_o measurements were made and K_c values were computed daily during the summer-irrigation period in July and August.

Actual ET_T and reference ET_o both co-vary with evaporative demand (meteorological factors). Reference ET_o and turf ET_T are highly variable from day-to-day and year-to-year but their ratios (i.e., K_c values) are relatively constant (Fig. 1). Month-to-month and year-to-year variation in K_c values are uniform and consistent in the cool-humid region of Massachusetts. As such, monthly and yearly ET are not important factors that need to be adjusted using K_c values when computing turf ET_T in summer according to Eq. 2.

Crop Coefficients (K_c) for Recreational Turf Use

The challenge becomes selecting the most appropriate K_c value that best fits your turf management practices under irrigation (Fig. 2). Mowing HOC is the single most important cultural factor affecting K_c values for turf under irrigation (Table 1). Average (i.e., mid-point) K_c values in summer ranged from 0.92 (0.125 inch HOC) to 1.20 (2.50 inch HOC) which represents a 25% increase in irrigation requirements due to the effects of a taller HOC (Table 1). Taller grass canopies as discussed previously promote higher turf ET_T and therefore higher K_c values (Eq. 1). Greater heat transfer with higher turf ET_T under taller grass canopies promotes greater transpirational cooling, which lower turf canopy temperatures in summer by several degrees (Fig. 3).

Short grass canopies mowed at less than 1.0 inch HOC would have to be irrigated according to FAO-56 PM ET_o using an average K_c values less than 1. Taller HOC turf would require K_c values greater than 1.0. Generally, K_c values increase incrementally with higher HOC above 1.0 inch with an increase of approximately 0.01 in K_c for every 0.1 inch increase in HOC. These guidelines assume, however, that turf is maintained under conditions where water applied as irrigation is not growth limiting.

Fertilizing with N in summer at 1.0 lb $1000ft^{-2}$ promoted only a 6% increase in K_c values when compared to unfertilized turf which is a relatively small increase compared to HOC. The fertilizer N-source used in this study (in summer) contained approximately 82% of the total N as slow-release, which has the capacity to lower leaf area and actual turf ET_T compared to N-sources using more readily available forms of N. Practices such spoon-feeding with N in summer at reduce N rates (0.10 to 0.20 lbs N $1000ft^{-2}$) will help in reducing leaf area to lower K_c values.

Conditions or practices that have a greater capacity to increase leaf and shoot vigor can promote higher turf ET_T and higher K_c values. The effects of these potential practices or conditions that influence turf ET_T are reported in Table 1 as ranges from low to high for K_c values. These reported K_c ranges serve as guidelines for selecting the most appropriate K_c value depending on the HOC and your management conditions. For example, golf greens are mowed daily and golf fairways are mowed three times per week and therefore these short grass canopies will need less water as irrigation indicated by their K_c values < 1.0. However, because management practices are not uniform within any one HOC, practices or conditions that may reduce turf ET_T will require adjusting K_c values down. Moreover, recreational turf under more intensive foot traffic causing greater thinning of the turf will require lower K_c values and less water as irrigation because of their reduced turf ET_T rates.

Computing Turf ET_T for Irrigation

Computing daily ET amounts using weather stations' climatic data are relatively simple calculations. First, reliable reference ET_o values are needed. Table 1 reports K_c values computed using reference ET_o derived from FAO-56 PM ET_o, which is a standardized procedure. Numerous companies offer weather stations and software that provide reference ET_o values. A specific Penman or Penman-Monteith equation computes a slightly different reference value under identical meteorological conditions. Crop coefficients were calculated according to Eq. 1 using FAO-56 PM ET_o. As such, FAO-56 PM ET_o computed K_c values may vary slightly from other equations when using K_c values reported in Table 1. These K_c values presented in Table 1 may need some adjustment when using other weather stations that compute reference ET_o using a different mathematical procedure.

According to Eq. 2, turf $ET_T = K_c \times ET_o$. To determine the amount of water to apply as irrigation (turf ET_T), the following steps are recommended:

STEP 1. Select the best K_c value using Table 1. For example, if a golf green under irrigation is mowed at 0.125 inch HOC, a K_c value of 0.92 may be selected according to Table 1. Furthermore, if PGRs are routinely applied in summer at this HOC, then a lower K_c value of 0.89 (from Table 1) may be a more appropriate K_c value because of the lower turf ET_T that would be expected when using PGRs. Lower K_c values will provide additional water savings for an irrigated site when lower water use (turf ET_T) rates are expected because of the effects of turf maintenance practices (see Table 1 footnotes).

STEP 2. Retrieve daily reference ET_o values (i.e., FAO-56 PM ET_o) computed from a reliable (nearby) weather station. For this example, let's assume the weather station computed reference ET_o value was 0.14 inch over the previous 24 hour period.

STEP 3. Calculate the amount of water to be applied as irrigation using the K_c value from Table 1 followed by substituting the K_c value (0.89) and weather station computed reference ET_o value (0.14 inch per day) into Eq. 2, where

Turf $ET_T = 0.89 \times 0.14$ inch = 0.13 inch.

For this example, 0.13 inch would be applied as irrigation.

Where a sports turf is mowed at a 2.00 inch HOC under similar evaporative (climatic) conditions (i.e., reference $ET_o = 0.14$ inch per day), a K_c value of 1.11 may be selected according to Table 1. The amount of water applied as irrigation would be 0.16 inch per day after adjusting the reference ET_o using the best K_c value (calculated as 1.11×0.14 inch per day = 0.16 inch per day).

> **ET replacement** = The amount of water applied as irrigation according to a weather station computed reference ETo corrected using the most appropriate crop coefficient.

Reference ET_o values from weather stations will vary day-to-day with evaporative demand, and in turn, irrigation amounts as ET replacement will vary day-to-day. In the previous examples described above, 0.13 inch per day was calculated as ET replacement for the golf green while 0.16 inch per day (23% more as irrigation) was calculated as ET replacement for the taller sports turf. These irrigation amounts are based on the reference ET_o values calculated by the nearby weather station from the previous 24 hour period. Assuming the same evaporative demand (i.e., reference $ET_o = 0.14$ inch per day) and no rainfall, the cumulative (total) amount of water applied as irrigation (ET replacement) by the end of one week (7 days) would equal 0.91 and 1.12 inch as irrigation for the golf green and taller sport turf, respectively. In cool-humid environments rainfall may occur in summer during the irrigation season. In such cases the reference ET_o after correcting using the appropriate K_c value will need to be adjusted by subtracting rainfall from the calculated turf ET_T.

In order to implement more effective irrigation scheduling and water management practices weather stations and associated software that calculate reference ET_o should be updated to include standardized procedures (FAO-56 PM ET_o, Allen et al., 1998) and their equivalent procedures such as ASCE-EWRI standardized equation (Allen et al., 2005; Wherley et al., 2015). In addition, reference ET_o used with calculated K_c values as reported in Table 1 require meteorological sensors to be routinely calibrated to ensure reliable measures for solar radiation, air temperature, wind speed, and relative humidity. This ensures the computation of reliable estimates for reference ET_o from the weather station in computing reliable turf ET_T estimates for irrigation according to Eq. 2.

Other Considerations

Irrigating turf under cool-humid conditions to replace that lost as turf ET_T does not necessarily require daily irrigation using ET replacement. Tracking of daily reference ET_o corrected for rainfall can be computed over several days. The sum total of all daily reference ET_os for that period can be computed followed by adjustment (Eq. 2) using the most appropriate K_c value (Table 1). It is important to recognize that the period in days between irrigation events is distinctly different from computing daily ET replacement using Eq. 2. Where Eq. 2 is the computed “amount” applied as ET replacement, the days between irrigation are a “timing variable” which involves many aspects of the turf system’s drought resistance capacity (drought avoidance + drought tolerance mechanisms).

The timing of irrigation events is highly variable because drought resistance is under the influence of numerous soil, cultural, and environmental factors. For a detailed discussion of the guidelines for determining the efficient timing of irrigation see *Turf Irrigation Series No. 2* entitled “*Drought Resistance and Efficient Irrigation for the Cool-Humid Region*”. In addition, timing of irrigation in terms of frequency of irrigation (days between irrigation) depends on the level of turf quality desired. Less frequent irrigation may be appropriate where lower turf quality standards are acceptable. Similarly, lower K_c values than those presented in Table 1 may be appropriate in some situations. However, major departures (i.e., arbitrary decreases) in K_c values may not support sufficient turf growth needed for optimal traffic tolerance. This research is currently lacking and results showing the impact of deficit irrigation levels on traffic tolerance are not available for cool-season turfgrass growing in Massachusetts. Recent research on deficit irrigation is available for warm-season turfgrass under traffic (Hejl et al., 2016). However, this research has little relevance to cool-season turfgrass under traffic and irrigation because of the higher tolerance for traffic and drought exhibited by warm-season turfgrasses.

The use of reference ET_o and K_c values allows turf managers to effectively schedule irrigation to meet the consumptive water use demands of turfgrass. However, ET replacement using meteorological data from on-site weather stations is practiced by only 17% of all golf courses in the United States (Throssell et al., 2009). Implementing appropriate K_c values for use with on-site weather stations and meteorological data can effectively address water conservation and water quality concerns expressed by many advocates from the general public, as well as federal, state, and municipal regulators.

References

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Table 1. Crop coefficients (K_c values, adapted from Poro et al., 2017) for adjusting daily FAO-56 PM ET_o computed by weather stations for irrigated turf. These K_c values are appropriate for cool-season turfgrass used for recreational turf in Massachusetts and other similar cool-humid climatic environments. Crop coefficients were computed for recreational turf maintained under favorable soil moisture for optimal growth at different heights of cut (HOC) and management levels.

	Crop coefficients (K_c values)		
HOC, inch†	Low range‡	High range¶	Mid-Point#
0.125	0.89	0.95	0.92
0.375	0.92	0.98	0.95
0.50	0.93	0.99	0.96
0.75	0.96	1.02	0.99
1.00	0.99	1.05	1.02
1.25	1.02	1.08	1.05
1.50	1.05	1.11	1.08
1.75	1.08	1.14	1.11
2.00	1.11	1.17	1.14
2.25	1.14	1.20	1.17
2.50	1.17	1.23	1.20

†HOC tested included creeping bentgrass mowed at 0.125 and 0.375 inch HOC, and 1.25 and 2.50 inch HOC for Kentucky bluegrass and perennial ryegrass. Other reported K_c values were derived from statistical fitting. For K_c values outside these tested HOC ranges, K_c values may be adjusted up by 0.01 per 0.10 inch increase in HOC.

‡Low range K_c values are most appropriate for conditions of lower leaf area and reduced shoot vigor caused by lower N, spoon-feeding, PGR use, frequent mowing, high traffic, and greater thatch or soil compaction tendencies.

¶High range K_c values are most appropriate for conditions of higher leaf area and favorable shoot vigor caused by higher N use, low traffic, infrequent mowing, fungicide use, and lower thatch or soil compaction tendencies.

#Mid-point K_c values are most appropriate for average conditions of leaf area and shoot vigor.

Figure 1. Crop coefficients (K_c values) calculated as the ratio of actual ET_T-to-reference ET_o are uniform from month-to-month and year-to-year in the cool-humid region of Massachusetts.

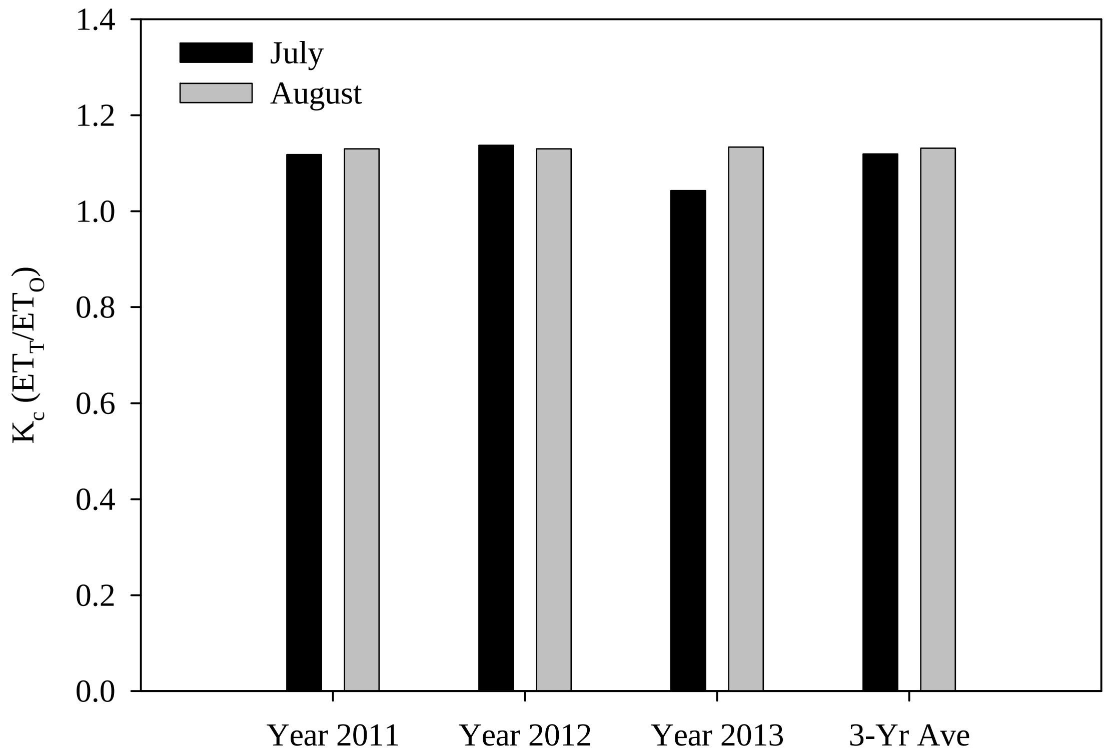

Figure 2. Reference ET_o calculated using mathematical equations such as FAO-56 PM ET_o are derived from meteorological data and need to be adjusted using K_c values to match the actual ET_T of the turf under irrigation. Inappropriate K_c values may cause over-watering (i.e., K_c values too high) or dehydration stress (i.e., K_c values too low) for irrigated recreational turf grown under the same evaporative (climatic) conditions (i.e., same reference ET_o). Crop coefficients (K_c values) need to adjust for different turf ET_T caused by the effects of management.

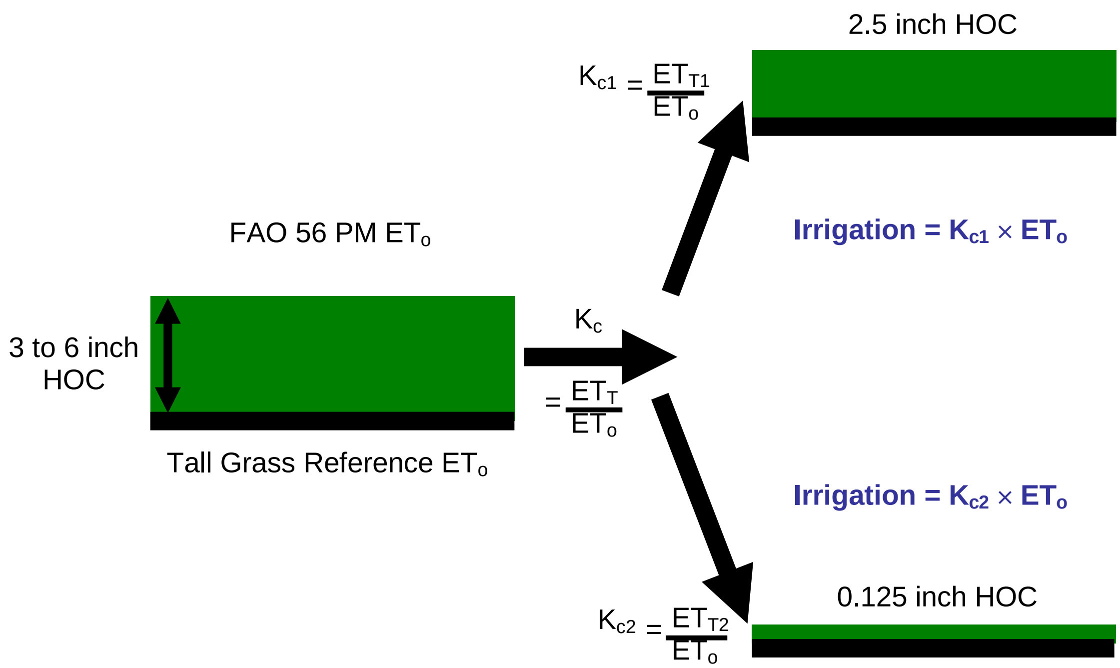

Figure 3. Increasing height of cut (HOC) promotes higher turf ET_T rates and increases crop coefficients (K_c values). Greater transpirational cooling (heat transfer) results from higher turf ET_T with taller HOC, which decreases leaf-canopy temperatures. Leaf-canopy temperatures were measured under clear sky in August at the Troll Turf Research & Education Center, South Deerfield, MA.