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Developing a soil moisture Decision Support Tool to quantify the occurrence of flash droughts and saturated soil conditions for pasture grasses in the southeast of the United States

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ABSTRACT

Developing a soil moisture Decision Support Tool to quantify the occurrence of flash droughts and saturated soil conditions for pasture grasses in the southeast of the United States

Water-related disasters such as droughts and floods have been of a high critical importance especially in the areas with high evapotranspiration demands and poor water holding capacity of the soil. Although a flash drought could cause dire consequences on agricultural commodities, has not been studied appropriately. To improve the cropping model system, soil moisture as a key variable to be quantified, was monitored by use of data from weather station and ground sensors. To develop the smart irrigation forage application as the main goal of the research, four common species including Bermudagrasses (*Cynodon dactylon* and *C. dactylon 'C. nlemfuensis*), Bahiagrass (*Paspalum notatum*), and Tall Fescue (*Lolium arundinaceum*) were determined. Crop coefficient (K_c) values were derived through calculating crop evapotranspiration (ET_c) using sensors' records and reference evapotranspiration (ET_o), from weather stations. Soil sensors' data were obtained from five locations grassed diversely with afore mentioned species. Crop coefficient curves are the basis to forecast the water demands of the forage. The final product as a decision support system, helps the decision maker to observe the magnitude of the soil moisture as well as vegetative stresses. It means the stakeholders could have access to real time data to determine necessary agricultural practices to avoid drought stress. On the other hand, a database has been created that will be available for any other scientific or governmental purposes. Besides, the socio-economic implications of using new remote sensing tools such as Forage Smart Irrigation App are undeniable.

Key words: remote sensing, evapotranspiration, crop coefficient, smart irrigation.

1 Introduction

Drought can develop and intensify in a short period of time and result in major agricultural losses if it is not predicted and detected in a timely manner such phenomena were noted in the early 2000s when the US drought monitor USDM was inaugurated and they were termed flash drought by USDM authors (Chen et al., 2019).

The southeastern United States (hereafter referred to as “the Southeast”) is a region with abundant precipitation and water resources resulting from local convection and tropical cyclones during the warm season, and cold fronts during the cool season (Kunkel et al., 2013). But several drought events have been recorded in the last few decades. These droughts typically do not last as long as droughts experienced in the southwestern United States, but they have proved to be highly detrimental to the regional environment and economy (Yuhas et al., 2006, Manuel et al., 2008 and Price et al., 2017).

Under drought conditions, plants cannot uptake water and nutrients through their roots which adversely affects photosynthesis, respiration, and growth. Severe drought can also induce vegetation mortality rate due to cavitation and/or carbon starvation (reduced photosynthesis and enhanced autotrophic respiration). Thus, more frequent and intense drought periods can alter the phytosociology of entire plant communities over time (Albuquerque et al., 2013). Flash drought is a term which means a short period and rapid drought. Rapid drought intensification occurs via two key drivers: a critical lack of precipitation and increased evaporative demand (Otkin, 2018). In areas where soil moisture and evapotranspiration have a near-linear relationship, ET decreases as a response to decreased soil moisture (Koster et al., 2009). The rapid onset of flash droughts significantly reduces time available for impact mitigation, potentially resulting in greater adverse agricultural and societal effects than a slowly evolving drought event (Otkin et al., 2015).

1.1 Flash drought definition

As flash drought occurs suddenly, often there is no early warning or prediction for the upcoming flash drought. So, farmers are unable to take precautions to decrease crop damage due to this short-term drought. The U.S. Drought Monitor (USDM) is an effective tool for quantifying regional or long-term drought, but flash drought can be very localized and occur too rapidly to be registered by the USDM. Observations of soil moisture content and evaporative demand are two important factors to identify flash drought at a particular time. Although observations of surficial soil moisture are important for drought monitoring, particularly in sparsely-vegetated regions, ideally analysis of flash drought in the eastern United States should be grounded in root zone soil moisture (Hunt et al., 2009).

Given the increasing use of the term flash drought by the media and scientific communities it is prudent to develop a consistent definition that can be used to identify these events and to understand their salient characteristics it is generally accepted that flash droughts occur more often during the summer owing to increased evaporative demand. However, two distinct approaches have been used to identify them. The first approach focuses on their rate of intensification whereas the second approach implicitly focuses on their duration. These conflicting notions for what constitute a flash drought introduce ambiguity that affects our ability to detect their onsets, monitor their development, and understand the mechanisms that control their evolution (Otkin et al., 2018).

Flash droughts are the confluence of heat waves and dryness. Both heat waves and precipitation deficit flash droughts require the temperature of the air to be higher than one standard deviation in addition to dryness. The main difference aside from the fact that conventional droughts have much longer length scales, is the role of temperature anomalies. Conventional droughts are not necessarily associated with warm temperature anomalies, whereas heat waves are typically a result of precipitation deficit flash droughts (Mo and Lettenmaier, 2016).

Mo and Lettenmaier (2015, 2016) mandate that heat wave flash droughts occur when soil moisture is already in deficit. Claiming the shorter timescales relative to conventional droughts, they offer some hope of forecasting both the onset and termination of events. Nevertheless, as their definition does not consider the changes in soil moisture condition with the time, nor is that threshold dry enough to be considered drought, Otkin et al. (2018) argue that its use should be discontinued.

Soil moisture has been recognized as a key variable for assessing the magnitude of a drought but accurately measuring it over a large spatial extent and systematically reporting it has proven to be challenging. Improving the quality and extent of soil moisture monitoring as well as that of the derived higher-level products should improve NOAA’s capacity to provide information that affects a wide range of stakeholders.

In a detailed analysis of four flash droughts, the results showed that rapid increases in moisture stress as depicted by rapid decreases in the evaporative stress index over several weeks were usually associated with higher air temperatures, fewer clouds, larger vapor pressure deficits, and the stronger winds (Otkin et al. 2013).

Hunt et al. (2014) did a study related to the type of increases in evaporative demand that will lead to dramatic decreases in evapotranspiration and increasing vegetation moisture stress as a result of approaching the wilting point in water limited conditions. They showed that evapotranspiration from adjacent rainfed and irrigated corn fields diverged significantly after plant available soil moisture in the rain-fed crop dropped below 30%.

Flash drought is not a new occurrence in the Southeast. The southeastern Coastal Plain which is the region’s dominant crop production area contains mostly sandy soils which have low water holding capacity. Actively growing crops associated with high ET rates and high summer temperatures rapidly deplete plant available soil moisture. If the moisture is not replenished by regular precipitation events, then the crops may undergo water stress and associated reductions in yield. Simply measuring days without precipitation does not in itself quantify flash drought. That is a function of soil type, previously available soil moisture, and ET rates (Mo and Lettenmaier, 2015).

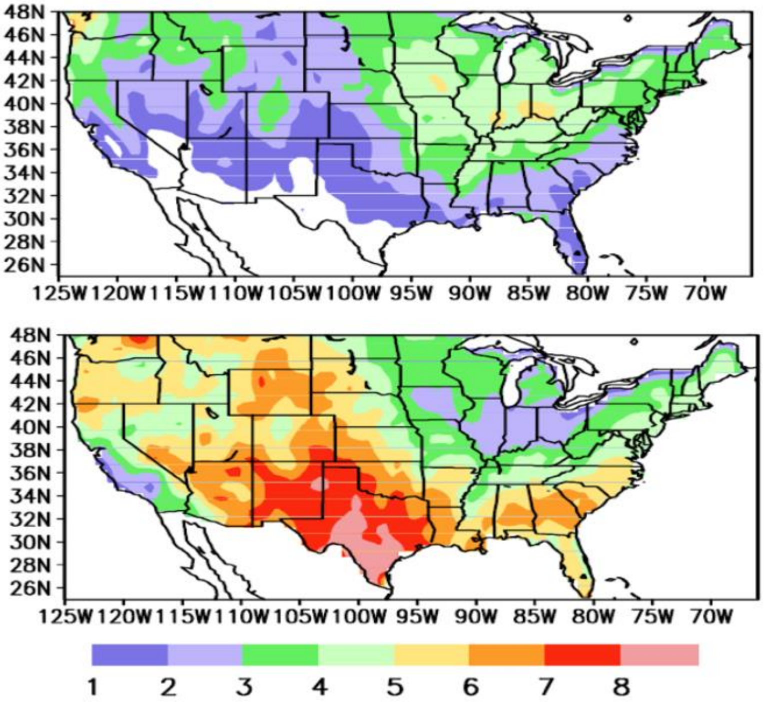


Figure 1-1. Frequency of occurrence of heat wave flash droughts (top map) and precipitation deficit flash droughts (bottom map). The units are percentiles. Shadings are given by the color bar. (Mo and Lettenmaier, 2015).

1.2 Soil moisture

Sonia et al. (2010) published a study in which they discuss the role of soil moisture for the land energy and water balance through its impact on transpiration and provide some basic definitions for solid moisture. They also provide an overview on soil moisture-evapotranspiration coupling and its representation in the models. They also discussed the main resulting impacts on temperature and precipitation.

In practice often only a fraction of soil moisture is relevant or measurable. Thus, soil moisture needs to be considered with regard to a given soil volume. One conceptual issue with the definition of soil moisture is the characterization of the soil volume in the equation. Indeed, soil moisture content is not homogeneously distributed vertically or horizontally and thus differs for different soil volumes.

1.3 Soil moisture measurements

In recent years there has been rapid progress in the field of techniques of ground-based and also remotely sensed soil moisture measurements. Soil moisture can mean different things depending on the application. Measurements at the near surface (0-5cm) are critical for calibrating remote sensing tools such as satellite observations. Measurements between 2-60 centimeters represent the root zone critical to agriculture. Deeper measurements can represent streamflow, groundwater recharge, and long-term drought intensity or susceptibility to flash flooding.

1.4 Evapotranspiration (ET)

Evapotranspiration entails the combination of two different processes; the vaporization of liquid water from surfaces known as evaporation and that from plant tissues called transpiration and their vapor removal to the atmosphere. The evaporation process occurs at different water surfaces such as lakes, rivers, soils, and vegetation and requires enough solar energy for the vaporization of the liquid water. The vapor water removal from the water surface to the atmosphere is driven by the vapor pressure difference between the water vapor in the water surface and that in ambient air.

1.4.1 Reference evapotranspiration (ET_o)

Reference crop evapotranspiration (ET) or reference ET is denoted as ET_o. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency (FAO 56 paper).

1.4.2 Crop water use (ET_c)

There are numerous studies on ET in grasslands with the aim of modeling the irrigation needs based on penman-monteith equation. In this study, estimations for daily crop water use (ET_c) are derived based on FAO 56 method.

Turfgrass ET_c depends on several factors, and two components of evaporative demand in the Penman-Monteith equation (Allen et al., 1988), including energy and transfer, vary with climate, season, daily weather, and microclimates, as well as species, management practices, and soil water availability (Romero and Dukes, 2016).

1.5 Crop coefficient (K_c)

The crop coefficient, K_c, is basically the ratio of the crop ET_c to the reference ET_o, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, albedo, canopy resistance, and evaporation from soil, especially exposed soil.

The FAO has recommended a standardized computation method based on penman-monteith equation. It could enhance the effectiveness of research programs for irrigation scheduling systems. Nevertheless, in some cases suggested in the literature, crop coefficients (K_c) reported are not supported with direct references. For example, Allen et al. (1998) recommend Kc of 0.80 to 0.85 for warm season grasses and 0.90 to 0.95 for cool season grasses to estimate the reference evapotranspiration (ET_o).

Investigating reasons why the results from different research are not the same for a distinct type of grass, could be helpful for selecting the most appropriate approach to estimate ET_c and crop coefficients. In some studies, such as the work done by Gibeault et al. (1988), total water applied was increased ~35% higher than Et_a accommodate irrigation nonuniformity. This produced a change in K_c reported, compare with their previous work, that is in more accordance with some research done afterwards.

Previous studies show variability in ET_c in turfgrasses, not only between different species, but within same species. This variability was also observed in K_c values due to the weather conditions, genotypes, and morphological characteristics.

1.6 Estimating Daily Penman-Monteith ET (ET_o)

The Cotton SmartIrrigation App, one of the several SmartIrrigation Apps (SI Apps) developed by the University of Georgia and the University of Florida (https://smartirrigationapps.org/), was used to estimate daily Penman-Monteith ET (ET_o) for all sites in the study. The SI Apps use an application programming interface (API) to pull meteorological data from the Georgia Weather Station Network's server for individual weather stations. The SI Apps than use these data to calculate ET_o. In this study, the weather station closest to the location of each field was used for this purpose.

1.6.1 Operating Principles of the SI Apps

The SI Apps take two different approaches to scheduling irrigation. The specialty crop apps (blueberry, citrus, vegetable, etc.), provide the user with the frequency and duration of irrigation events needed to replace cumulative weekly ET_c. In contrast, the agronomic crop apps use a soil water balance model. The model uses daily ET_c, soil parameters, precipitation, and irrigation applications to estimate a daily root zone soil water deficit in terms of percent and inches of plant available soil water and provides these two pieces of information to the user. Plant available soil water is defined as the water held by the soil matrix between field capacity and the wilting point. A 50% RZSWD or depletion of 50% of plant available soil water is a commonly accepted irrigation threshold for agronomic crops.

In the models, plant available soil water is a function of the soil's plant available water holding capacity and current rooting depth. As the plant rooting system grows, the depth of the profile from which the plant can extract water also increases. The soil's plant available soil water holding capacity is a required variable of the agronomic SI Apps.

1.6.2 Crop coefficient (K_c) use in the SI Apps.

The SI Apps estimate daily crop water use with equation.1, the widely accepted FAO 56 method (Allen et al., 1998) or irrigation scheduling.

$$ET_c = ET_o \times K_c \tag{1}$$

Where ET_c= daily crop water use (mm day^{-1}),

ET_o reference ET calculated using the Penman-Monteith equation, and
K_c= a crop coefficient (mm day^{-1}).

Daily ET_o is typically calculated from meteorological data. The K_c the corresponds to the daily ET_o is estimated from a season-long K_c curves that are typically developed empirically from experimental data. The FAO maintains a catalogue of general K_c curves for a large variety of crops (fao.org). K_c curves for agronomic crops begin at or near zero at planting, increase to near one or slightly above one at peak crop water use periods, and then decline to zero at crop maturity. K_c curves for perennial crops are developed for the entire calendar year, and depending on the crop, may go to zero during periods of dormancy or may fluctuate between low and high values depending on the season.

In agronomic crop apps, the soil water balance model uses daily ET_c, soil parameters, precipitation, and irrigation applications to estimate a daily root zone soil water deficit, which is expressed in percent and inches of plant available soil water.

1.7 Warm season and Cool season grasses

Interspecies and intraspecies variations in ET_c rates can be explained by differences in stomatal characteristics, canopy configuration, growth rate, and characteristics of the roots (Kenna, 2008).

The results reported in the literature could also be classified into warm-season and cool-season grasses according to the type of climatic adaptation. Huang (2006) describes warm-season grasses as the grasses which are adapted to tropical and subtropical areas, and cool-season grasses as the ones which are adapted to temperate and sub-arctic climates. Warm-season grasses become active in mid-spring, with optimum growth at temperatures between 27°C and 35°C, which can develop in the hot, dry weather of mid-summer, and they become dormant in the winter. Bahiagrass (*Paspalum notatum*), and bermudagrass (*Cynodon dactylon*) are two of well-known species of warm-season grasses. Some other grasses in this category are St. Augustinegrass [*Stenotaphrum secundatum* (Walt) Kuntze], zoysiagrass (*Zoysia* spp.), and seashore paspalum (*Paspalum vaginatum*).

Cool-season grasses are described as generally more susceptible to moisture stress in comparison with warm-season grasses. The differences in photosynthetic efficiency in warm-season grasses help them to reduce water use. It means they can maintain high level of carbohydrate production and continue to grow even when the stomata are just partially open. Cool-season grasses do not have the before mentioned ability. They need to keep open their stomata and when the water is limited, transpiration rates are generally higher than those of warm-season grasses (Gibeault et al., 1989). Tall fescue (Festuca spp.) is a cool-season grass. They are active during the spring and fall, when average daytime temperatures are cool (between 18°C and 24°C) and precipitation is enough. Then in dry, hot conditions of summer or freezing cold of winter they become dormant.

In the literature, there are several references for ET determination for turfgrasses. These studies can be classified according to the methodology and water availability conditions. In some studies, the aim is to determine ET_c, while in the others the final objective is to calculate annual K_c, on a monthly, weekly, or shorter period. In most of the studies, lysimeters have been used (in form of lysimeters or mini-lysimeters). Kim and Beard (1988), by using black plastic mini-lysimeter inserted in open-end metal cylinders placed in the center of turfed plots, estimated ET rates for several turfgrasses in well-water conditions. Green et al. (1991), studied zoysia grass by the same method, but in different timing, as they perform their experiments partly in glasshouse (from November to April), and partly in the field (from May to October).

1.8 Base temperatures for GDDs

Growing degree days are used to describe the amount of heat energy received by a plant over a given time. Growing degree days are used extensively in agriculture to predict plant growth stages. Growing degree days are calculated by averaging the daily high and low air temperature and subtracting a base temperature. Base temperature is defined as the temperature at which a plant species becomes physiologically inactive causing shoot growth to cease. Calculating growing degree days with an inaccurate base temperature can equate to a difference of up to two or three calendar weeks.

Although the Smart Irrigation Apps were designed to provide users with actionable information that can be used to make irrigation scheduling decisions, the Apps can also be used to track soil water condition in rainfed fields and thus capture the occurrence and duration of flash droughts. The Apps can also be used to track the duration of saturated soil conditions resulting from excess precipitation that also could lead to major crop losses.

1.9 Goals and Objectives

The research objective of this thesis is part of a larger project whose overall goal is to quantify the incidence of flash drought and its effect on cotton, maize, and commonly used forage crops grown under rainfed conditions in the Coastal Plain areas of Florida, Georgia, and Alabama. Hypotheses of the larger project are that:

- Flash drought occurs regularly in the Southeast.
- The timing of flash drought during the growing season is a critical factor in determining its effect on the yield of rainfed crops.

Specific objectives of this thesis are to:

- Measure daily crop water use of three forage crops (Bahiagrass, Bermudagrass, and Tall Fescue) grown in the Coastal Plain areas of Florida, Georgia, and Alabama.
- Develop annual crop coefficient (K_c) curves for these three forage crops that can be used in the future to develop a SmartIrrigation Forages App.

2 Materials and Methods

The sections below describe the materials and methods used to develop a model for estimating daily crop water use in perennial forages commonly used in the southeastern USA. Instrumented field sites were used to measure daily crop water use at five locations in Georgia, USA. These data were then used to develop a predictive model based on the widely accepted FAO 56 method (Allen et al., 1998) for irrigation scheduling.

2.1 Area of the Study

The five sites used in the study are illustrated in Figure 2-1. These locations are grassed with the most common pasture grass species used in the southeastern USA including two Bermudagrasses, Tifton 85 Bermudagrass (*Cynadon dactylon)* and Alicia Bermudagrass (*C.dactylon*× *C.nlemfuensis*), Bahiagrass (*Paspalum notatum*), and Tall fescue (*Lolium arundinaceum*). These species are widely used as a rainfed or irrigated perennial forages.

The fields are located in Upson County, Georgia, grassed with Tall Fescue, Brooks County, Georgia, and Colquitt County, Georgia, both grassed with Bahiagrass, and Tift County, Georgia, are grassed with Bermudagrass from two above-mentioned different species. The Tall fescue and Bahiagrass fields are large, commercial fields while the two Bermudagrass fields are research fields located on the University of Georgia's Tifton campus.

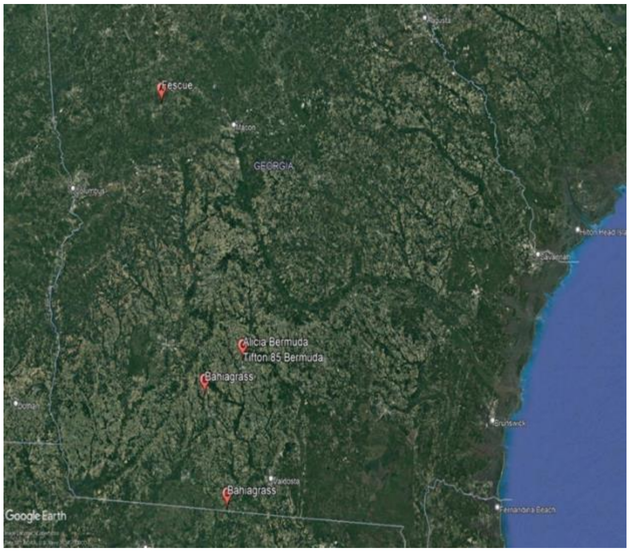


Figure 2-1. Sites of the study area located in Upson County, Georgia, grassed with Tall Fescue, Brooks County, Georgia, and Colquitt County, Georgia, both grassed with Bahiagrass, and Tift County, Georgia, grassed with two species, Tifton 85 Bermudagrass (*Cynadon dactylon)* and Alicia Bermudagrass (*C.dactylon*× *C.nlemfuensis*).

2.2 Data Collection

Soil moisture sensor probes were installed in each of the five fields in April and May 2021. The probes were used to track moisture changes in the soil from which daily crop water use was estimated.

2.2.1 Soil Moisture Sensors

The instrument used in this study was a Sentek 24 in (61 cm) soil moisture probe which measures volumetric water content (VWC) and temperature at six different depths: 4, 8, 12, 16, 20, and 24 in (10, 20, 30.5, 40.5, 51, 61 cm, respectively). This probe is fully encapsulated and can be completely buried, reducing the risk of machinery damage. It allows for accurate measurements of the soil profile as it is installed with relatively little disturbance to the surrounding soil profile. The probe is durable, low maintenance, with pre-calibrated sensors able to measure relatively difference in VWC readings in most soil types with high precision. However, accurate measurement of VWC requires calibration of the sensors using well defined measures of VWC at field capacity and at the wilting point.

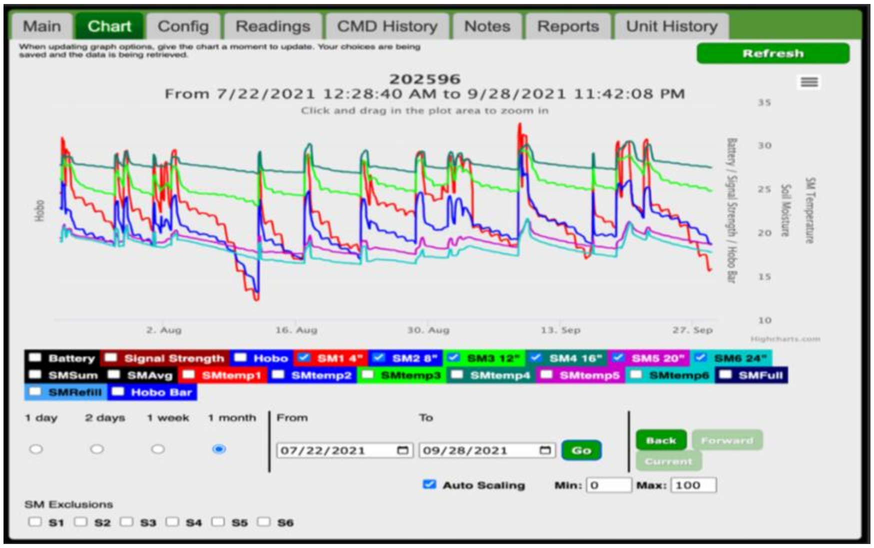
2.2.1.1 Soil Moisture Sensor Installation, Data Logger, and Rain Gauges

Sentek probes were installed by drilling a tapered hole matching the geometry of the probe. This was done with a battery-powered drill as shown in Figure 2-2. At the surface, the diameter of the hole was approximately 4 cm. The diameter was narrower at the bottom of the hole. The probe was pushed into the hole until flush with the surface. The instrumentation cable, sheathed in flexible metal conduit to protect from rodents, was then connected to the probe and to an AgSense data logger (Figure 2-3). The data logger was mounted on 5 cm pipe approximately 3 m away from the probe. Afterwards, approximately 20 L of water were poured onto the soil around the probe to bring the soil to near saturation for initial measurements of probe performance. A tipping bucket rain gauge was mounted on the pole adjacent to the data logger to provide accurate precipitation records.

Figure 2-2. Installation by drilling a hole matching the geometry of the probe.

Figure 2-3. AgSense data logger mounted on 5 cm pipe approximately 3 m away from the probe.

Data from the Sentek probe and the rain gauge were recorded by the AgSense data logger in 30-minute intervals and transmitted to a cloud server (www.wagnet.net) with a cellular modem. The data were visualized online as timeseries or instantaneous measurements. Figure 2-4 shows a time-series of VWC by depth for the six sensors of the probe installed at the Colquitt County Bahiagrass site. Data from the Sentek probes were available from May 2021. Figure 2-5 shows the precipitation record from the same site. Rain gauge data were available from mid-May 2021. The entire data record was downloadable in the form of comma-separated variable (CSV) files.



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202596
From 7/22/2021 12:28:40 AM to 9/28/2021 11:42:08 PM

☐ Battery ☐ Signal Strength ☐ Hobo ☑ SM1 4" ☑ SM2 8" ☑ SM3 12" ☑ SM4 16" ☑ SM5 20" ☑ SM6 24"
☐ SMSum ☐ SMAvg ☐ SMtemp1 ☐ SMtemp2 ☐ SMtemp3 ☐ SMtemp4 ☐ SMtemp5 ☐ SMtemp6 ☐ SMFull
☐ SMRefill ☐ Hobo Bar

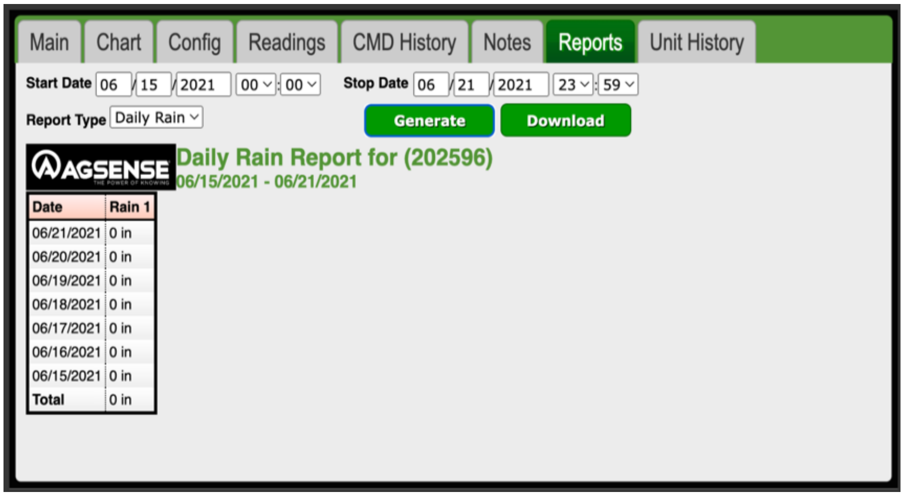
1 day ○ 2 days ○ 1 week ○ 1 month ●

From 07/22/2021 To 09/28/2021

☑ Auto Scaling Min: 0 Max: 100

SM Exclusions
☐ S1 ☐ S2 ☐ S3 ☐ S4 ☐ S5 ☐ S6

Figure 2-4. A time-series of VWC by depth for the six sensors of the probe installed at the Colquitt County Bahiagrass site.



Start Date 06/15/2021 00:00 Stop Date 06/21/2021 23:59

Report Type Daily Rain

Daily Rain Report for (202596)
06/15/2021 - 06/21/2021

Date	Rain 1
06/21/2021	0 in
06/20/2021	0 in
06/19/2021	0 in
06/18/2021	0 in
06/17/2021	0 in
06/16/2021	0 in
06/15/2021	0 in
Total	0 in

Figure 2-5. The precipitation records from the Colquitt County Bahiagrass site.

2.2.2 Weather Stations

The University of Georgia Weather Station Network (http://weather.uga.edu/) maintains a network of 88 weather stations throughout the state of Georgia (Figure 2-6). The meteorological data collected at each station include air temperature, relative humidity, atmospheric pressure, wind speed and direction, solar radiation, and precipitation using two independent rain gauges. additional meteorological variables like dew point and wet bulb temperature are also calculated as well as agriculturally important quantities like degree days, chill hours, and evapotranspiration. this stations also measure soil temperature at 5, 10 and 20 cm and soil moisture in the top 30.5 cm of the ground. Soil moisture at the weather station sites is measured with a Campbell scientific CS616 water content reflectometer.

Meteorological data from the weather station closest to each of the five field sites was used to calculate parameters used in the soil water balance model described below.

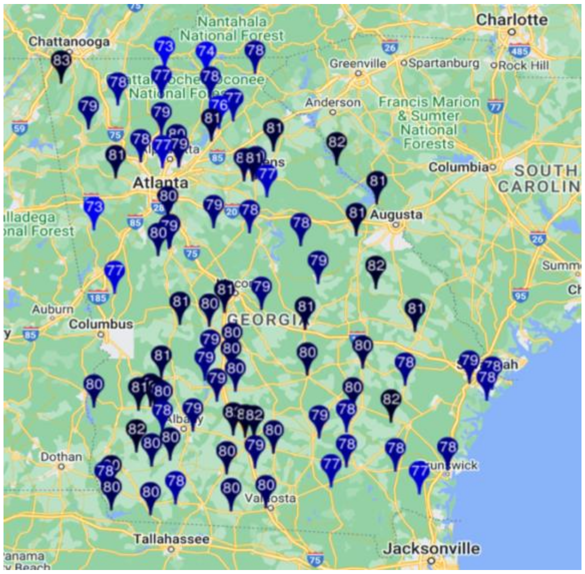


Figure 2-6. A network of 88 weather stations throughout the state of Georgia.

2.3 Estimating Daily Crop Water Use from Soil Moisture Data

As mentioned above, data recorded from the Sentek probes, by the AgSense data logger, were available on a cloud server. These data were visualized in form of time-series graphs of VWC and temperature for any time period within the data record. The daily change in VWC (ΔVWC) was estimated by subtracting today's VWC from yesterday's VWC during the drying cycle of the graphs. Sentek probes come from the factory calibrated for a generic, medium-range soil. Because of this, they do not accurately measure field capacity or wilting point unless calibrated with site-specific values. However, the embedded VWC sensors are very precise and thus difference between individual VWC measurements is accurate. Consequently, it was not necessary to calculate each probe for local soil texture. Instead, the factory calibration was used.

The ΔVWC calculation was performed for sections of the time-series graphs with optimal conditions for these calculations. When VWC is increasing rapidly because of irrigation or precipitation, it is difficult to estimate ΔVWC resulting from crop water use. Optimal conditions for estimating ΔVWC occur when VWC is decreasing and is between field capacity and when ΔVWC begins to decrease (Figure 2-7). The rational for this is that this is the period during which daily crop water use is at its maximum because of the availability of water in the soil profile to be used by the plant roots. When the slope of the graph begins to decrease, this indicates that daily crop water use is declining because the remaining soil water is strongly attached to soil particles, and consequently becomes less available to the plants' roots. Identifying the beginning and the end of these optimal periods is typically done by using lines tangential to the VWC curves to identify the critical inflection points as shown in Figure 2-7 which identifies the field capacity inflection point. ΔVWC was calculated only for these optimal periods. Following selection of the optimal periods, the VWC data were downloaded as CSV files from the WagNet online portal.

Figure 2-8 demonstrates an example of the plot visualization and the selected parts of the graph to estimate the plant evapotranspiration rates.

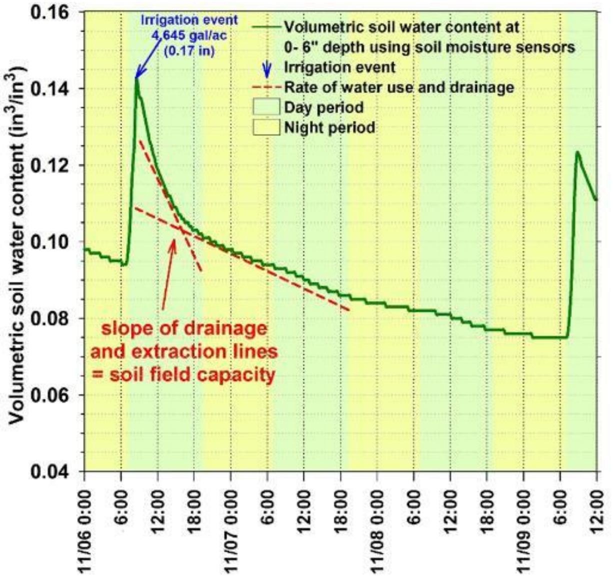


Figure 2-7. Identification of soil field capacity by using lines tangential to the VWC curves.

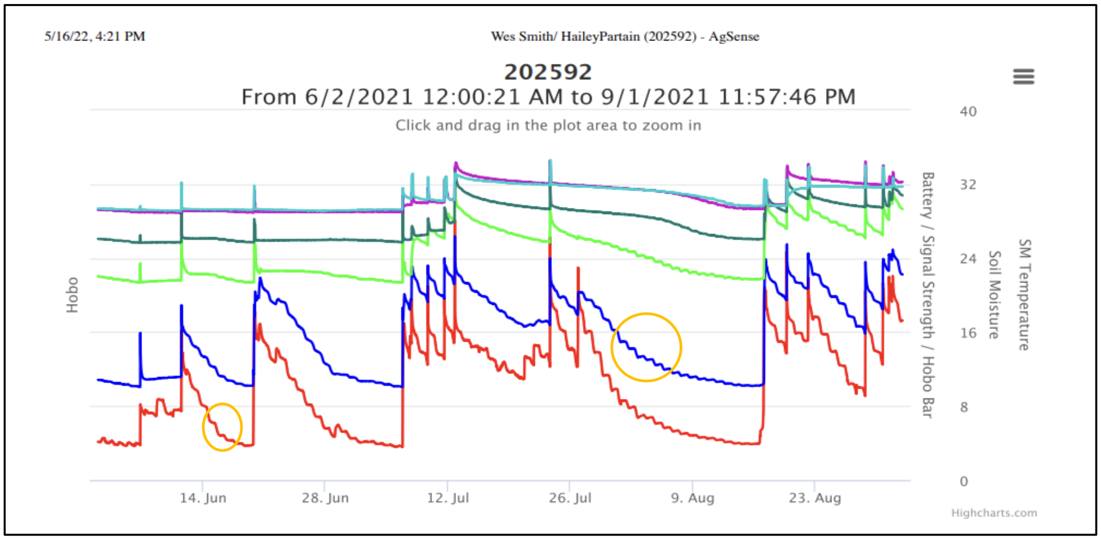


Figure 2-8. An example of the plot visualization and the selected parts of the graph to estimate the plant evapotranspiration rates.

ΔVWC was calculated for all six depths, as well as from the average VWC of all six depths which represented the entire profile. It was important ΔVWC calculations were done for each depth, as in some cases, they resulted in negative values for one depth, and positive for the other depths. For the modelling effort, which is described later, ΔVWC derived from the average VWC values was used, but the ΔVWC values from individual depths were important in selecting which average ΔVWC values were used for further analyses.

VWC data were recorded every 30 minutes. However, only VWC data points recorded between 05:00 and 05:30 were used in the ΔVWC calculations. It is typical for these types of calculations to use data points from early in the morning which allows for overnight redistribution of soil moisture and avoids the effects of uneven solar radiation during the day (Liakos et al., 2017).

ΔVWC values resulting from these calculations represent the percent difference in VWC per unit depth. ΔVWC values were multiplied by the corresponding depth and divided by 100. Final values were considered daily crop water use (ET_c) which are used to develop crop coefficient (K_c) values.

As shown in Equation 1, ET_c is the product of K_c and reference ET (ET_o). ET_o is calculated from meteorological data using the Penman-Monteith equation (Allen et al., 1998). In this study, the Cotton SmartIrrigation App (Cotton App) was used to provide daily ET_o values for each of the five field sites. The Cotton App is one of several SmartIrrigation Apps (SI Apps) – irrigation scheduling smartphone applications developed jointly by the University of Georgia and the University of Florida that use the widely accepted FAO 56 method (Allen et al., 1998). In the Cotton App, as well as the other SI Apps, daily ET_o is calculated using meteorological data from weather stations. Within the Cotton App, a virtual cotton field was established at each of the five project field sites. The Cotton App used meteorological data from the closest UGA Weather Station Network weather station to calculate daily ET_o. The ET_o values were downloaded from the Cotton App as CSV files. Distances to the weather station closest to each site are shown in Table 2-1.

Table 2-1. Distance between each of the five sites from the nearest weather station.

Location	Grass type	Nearest weather station	Distance (km)
Upson County, GA	Tall fescue	Williamson	27
Tift County, GA	Bermudagrass	Tifton	0.3
Tift County, GA	Bermudagrass	Tifton	0.3
Brooks County, GA	Bahia grass	Dixie	12
Colquitt County, GA	Bahia grass	Moultrie	19

For each site, K_c values were calculated for all six depths, and the average of the six depths from the subset of ΔVWC values and were graphed as shown in Figure 2-9. The daily fluctuation of the K_c values is a function of the daily fluctuations in meteorological conditions that affect ET_o. Because K_c values should reflect the daily crop water use under optimal weather conditions, measured solar radiation, a key variable of ET_o, and measured precipitation was used to further refine the K_c values and remove outliers.

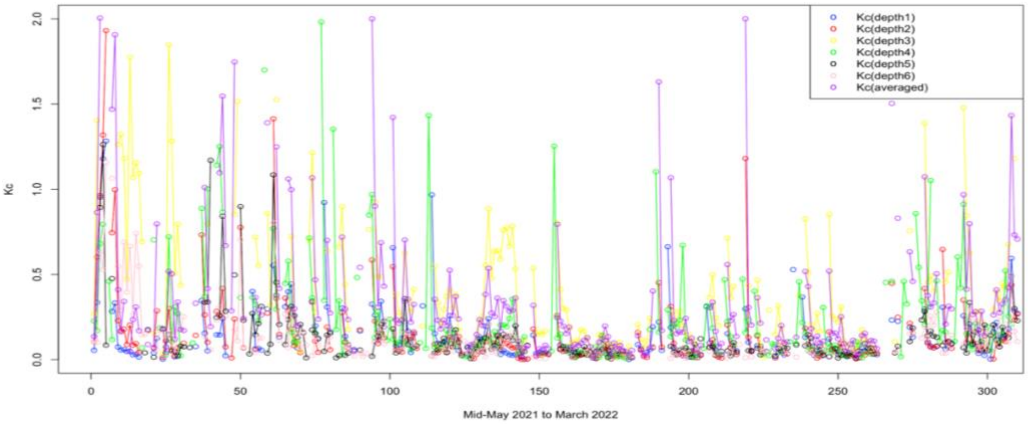


Figure 2-9. K_c values calculated for all six depths, and the average of the six depths from the subset of ΔVWC values for Colquitt County (Bahiagrass).

2.3.1 Precipitation and Solar Radiation

K_c values for all days on which precipitation was recorded at the weather station associated with a field site were eliminated from further consideration. Similarly, solar radiation was used as an indicator of ET_o. Lower than the approximate maximum anticipated solar radiation for a specific month may indicate overcast skies which result in lower ET_o values. Using several years of data from the weather stations, daily solar radiation thresholds ranging from 7 – 20 MJ/m^2 were established for each month of the year. A systematic approach was applied to eliminate days that were below the selected threshold for that month. Figure 2-10 shows daily solar radiation from May 2021 – May 2022 from Tifton weather station (www.weather.uga.edu). At this site, 20 MJ/m^2 was used as the threshold for the months May to September while 7-10 MJ/m^2 was used for November and December.

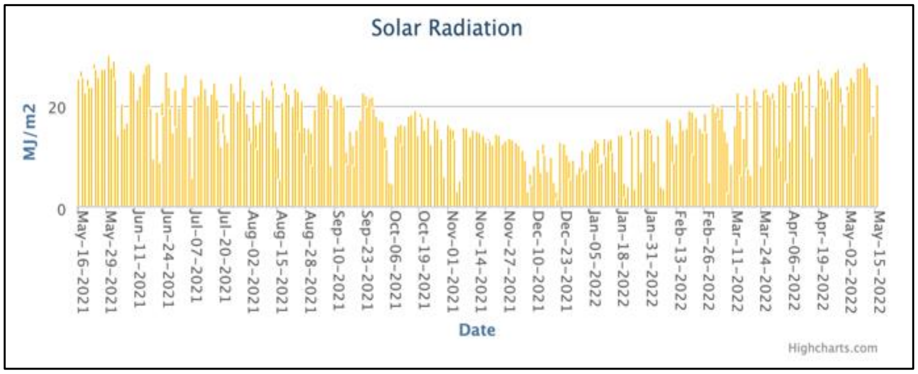


Figure 2-10. daily solar radiation from May 2021- May 2022 from Tifton weather station (www.weather.uga.edu).

2.3.2 Growing Degree Days

For many irrigation scheduling tools developed for agronomic crops like cotton and maize, scheduling is a function of days after planting. But because most annual crops and many perennial crops like grasses, develop at a rate dictated by daily accumulated heat units, also referred to as growing degree days (GDDs), the SI Apps and most crop growth models use GDDs to estimate phenological changes in the crops and in parallel implement changes in K_c that are associated with increasing or decreasing water demand. GDDs are calculated using Equation 2.

$$GDD = \frac{Tmax+Tmin}{2} - T_{base} \tag{2}$$

where

T_{max} is the daily maximum temperature,

T_{min} = daily minimum temperature, and

T_{base} = the temperature above which a crop actively grows.

When $(T_{max}-T_{min})/2$ is $\leq T_{base}$ GDD = 0 and there is no phenological development on that day.

In this study, T_{base} varied based by grass species.

2.3.2.1 T_{base} for Grass Species

A study conducted to determine T_{base} for five cool-season and five warm-season turfgrasses, resulted in T_{base} ranging from 12.51 to 13.21°C for the bermudagrasses cultivars, and -2.23 to 4.96°C for cool-season species such as fescue (Flournoy et al. 2016). Because the phenology and growth properties of turf grasses cultivars are similar to those of the pasture cultivars of the same species, the above T_{base} values for warm-season and cool-season grasses were applied during GDD determination in this study.

3 Results and discussion

The deliverable of the larger project the encompasses the study reported here is to develop an ET-based decision support tool (DST) for scheduling irrigation in forages. K_c curves are a fundamental requirement of these types of tools and K_c curves for three forages was the deliverable of this study. As described in previous sections, using ET_c and ET_o data, we empirically developed K_c curves. Because little work has been published on developing K_c curves for forages, we compared the K_c curves developed in this study to those developed for turfgrasses of the same species as the forage grasses. Published studies used to compare the results from this work are shown in Table 3-1 by grass species. Previous research on turfgrasses has shown that K_c values fluctuate over short time periods. As a result, daily values are averaged and reported as monthly K_c values (Carrow, 1995). Nevertheless, averaging K_c values reduces monthly precision. Factors that affect K_c values in turfgrasses include seasonal canopy characteristics, rate of growth, and soil moisture stress (Gibeault et al., 1989).

Table 3-1. Crop coefficient (K_c) values from the literature for the three grasses (Bahiagrass, Bermudagrass, and Tall Fescue) evaluated in this study. Some values are for turfgrass cultivars rather than forage cultivars.

Turfgrass Species	K_c		Methodology	Reference
Bahiagrass	2008		PVC weigh lysimeters; ET_c gravimetrically determined twice a month; ET_o determined by ASCE-EWRI standardized method	Wherley et al. (2015), Central Florida
	9 April	0.78		
	21 April	0.68		
	5 May	0.76		
	6 May	0.78		
	17 June	0.81		
	1 July	0.89		
	18 July	0.74		
	5 August	0.67		
	3 September	0.76		
	24September	0.65		
	18 October	0.64		
	8 November	0.33		
	19December	0.33		
	2009			
	9 February	0.45		
	20 March	0.36		
	9 April	0.74		
	27 April	0.64		
	30 September	0.85		
	20 October	0.85		
	3 November	0.86		
	23 November	0.91		
	21 December	0.60		
	2010			

Turfgrass Species	**K_c**	**Methodology**	**Reference**
	27April 0.77 11 May 0.89 25 May 0.95 8 June 0.87 6 July 0.94 20 July 1.02 3 August 0.88		
Bermudagrass	2008 9 April 0.74 21 April 0.67 5 May 0.74 26 May 0.81 17 June 0.81 1 July 0.92 18 July 0.77 5 August 0.80 3 September 0.77 24September 0.64 18 October 0.56 8 November 0.32 19 December 0.21	PVC weigh lysimeters; ET_c gravimetrically determined twice a month; ET_o determined by ASCE-EWRI standardized method	Wherley et al. (2015), Central Florida
	2009 9 February 0.17 20 March 0.32 9 April 0.63 27 April 0.59 30September 0.69 20 October 0.66 3 November 0.70 23November 0.58 21December 0.45		
	2010 7 April 0.66 11 May 0.79 25 May 0.82 8 June 0.75 22 June 0.73 6 July 0.88 20 July 0.99 3 August 0.92		
Bahiagrass	January 0.35 February 0.35 March 0.55 April 0.80 May 0.90 June 0.75 July 0.70 August 0.70 September 0.75 October 0.65 November 0.60 December 0.45	ET_c= eddy correlation ET_o=ASCE=EWRI equation K_c= ET_c/ ET_o	Jia et al. (2009), Central Florida
Tall fescue	2017 May 0.78 June. 0.80 July. 0.71 August 0.72 September. 0.89 October 0.74	Direct measurements of ET_c by weighing lysimeters	Pinnix and Miller, 2019
	2018		

Turfgrass Species	**K_c**	**Methodology**	**Reference**
	May 0.64 June. 0.86 July. 0.74 August 0.64 September. 0.68 October 1.00		

3.1 Daily ET_c Estimates

3.1.1 Tall fescue

Monthly average daily ET_o is ranged from 0.16 during May 2021 to 0.14 in April 2022. The evaporative demand increased to its maximum (0.17) in June. Due to the lack of data during January to April 2021, for soil moisture monitoring, curves have been plotted using data from 2022. Average tall fescue water use ranged from 0.05 to 0.33 during the study period. Tall fescue ET_c has the highest level in July and the lowest in December. In the previous studies, for tall fescue, ET_c in the range of 0.18-0.38 has been reported (Kopec et al., 1988). Beard (1994) reported water use of cool-season grasses to range from 0.12 to 0.31 in/day, under nonlimiting soil conditions.
Table 3-2 shows the data for daily ET_c values, ET_o and daily K_c values. Days were selected according to the refining approach described in the Methods chapter.

Table 3-2. Daily ET_c values, ET_o and daily K_c values for Tall Fescue derived from the VWC data and used for calculating the monthly average K_c. Days were selected according to the refining approach described in the Methods chapter. ET_c 1 – ET_c 6 indicate ET_c values calculated for that day from VWC measured at each of the six depths allowed by the Sentek soil moisture probe.

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
21-May2021	0.121	0.16088	0.02616	0.01072	0.0094	0.02064	0.2184	0.206	1.06	**0.67**
22-May	0.0808	0.17416	0.02556	0.00832	0.0224	0.02832	0.18768	0.2016	0.93	
23-May	0.07732	0.1804	0.03708	0.01488	0.0224	0.036	0.19408	0.1935	1.00	
24-May	0.060584	0.11568	0.04308	0.0224	0.0328	0.05616	0.154304	0.2013	0.77	
25-May	0.038756	0.06944	0.05136	0.0296	0.0398	0.05088	0.114436	0.206	0.56	
26-May	0.027084	0.05152	0.0558	0.0304	0.0328	0.03816	0.091964	0.1917	0.48	
27-May	0.012332	0.038	0.03684	0.02208	0.0244	0.01776	0.056972	0.2196	0.26	
29-May	0.104464	-0.00432	-0.00168	0.00176	0.014	0.01008	0.106664	0.1428	0.75	
30-May	0.060096	0.00944	0.00216	0.0024	0.0034	-0.00384	0.066176	0.1631	0.41	
1-Jun	0.015444	0.01992	0.02148	0.01376	0.014	0.00864	0.040244	0.1835	0.22	**0.68**
12-Jun	0.0808	0.10288	0.01668	0.00176	-0.001	0.00504	0.13888	0.1489	0.93	

Date	*ET_c 1* *(in/day)*	*ET_c 2* *(in/day)*	*ET_c 3* *(in/day)*	*ET_c 4* *(in/day)*	*ET_c 5* *(in/day)*	*ET_c 6* *(in/day)*	*ET_c Sum* *(in/day)*	*ET_o* *(in/day)*	*K_c sum* *(in/day)*	*Averaged Monthly K_c*
13-Jun	0.07024	0.08648	0.00156	0	0.0022	0.0036	0.11504	0.1429	0.81	
14-Jun	0.072772	0.08464	0.00864	-0.00416	-0.0046	0.00648	0.117092	0.1908	0.61	
15-Jun	0.052848	0.08224	0.03264	0.01552	-0.0022	-0.00648	0.107208	0.1906	0.56	
16-Jun	0.022012	0.03848	0.03072	0.02352	0.0184	0.00888	0.062532	0.2218	0.28	
20-Jun	0.04028	-0.05128	0.0234	0.00416	0.0034	0.00768	0.02544	0.0584	0.44	
21-Jun	0.0784	0.1112	-0.00108	-0.00256	0.0024	0.00888	0.13496	0.1257	1.07	
23-Jun	0.0876	0.12808	0.00276	-0.0024	-0.0034	0.0024	0.15168	0.1146	1.32	
24-Jun	0.04896	0.09752	0.00216	-0.0048	0.0034	0.00624	0.09896	0.2022	0.49	
25-Jun	0.0632	0.10744	0.00708	0	0.0012	0.00768	0.1208	0.1428	0.85	
26-Jun	0.05108	0.0996	0.00804	0.0032	0.0036	0.00384	0.10572	0.1853	0.57	
27-Jun	0.050636	0.10808	0.01836	-0.0056	-0.0048	-0.00264	0.107996	0.1731	0.62	
13-Jul	0.04388	0.07344	0.1026	0.11056	0.1178	0.0768	0.1788	0.1636	1.09	**0.81**
14-Jul	0.02424	0.07096	0.07452	0.0664	0.051	0.03912	0.11788	0.1517	0.78	
16-Jul	0.04268	0.06288	0.0384	0.03728	0.0286	0.012	0.10396	0.1798	0.58	
17-Jul	0.02472	0.06488	0.03636	0.0256	0.0222	0.02016	0.08348	0.1529	0.55	
24-Jul	0.09588	0.06712	0.0774	0.03664	0.0184	0.02136	0.17164	0.1997	0.86	
25-Jul	0.07656	0.09104	0.05328	0.0192	0.0208	0.01848	0.15188	0.1883	0.81	
28-Jul	0.09084	0.06536	0.02124	0.00864	0.0134	0.01056	0.1372	0.1624	0.84	
29-Jul	0.09928	0.10568	0.03156	0.01824	0.0134	0.01848	0.17296	0.1975	0.88	
30-Jul	0.05908	0.0912	0.03312	0.0112	0.0074	0.01584	0.12264	0.2044	0.60	
5-Aug	0.019324	0.03744	0.0438	0.03568	0.0228	0.02496	0.070284	0.1569	0.45	**0.68**
6-Aug	0.01496	0.03128	0.039	0.05312	0.0324	0.03	0.06836	0.1675	0.41	
11-Aug	0.00732	0.01584	0.01872	0.02784	0.055	0.06192	0.04976	0.1374	0.36	
12-Aug	0.008928	0.01744	0.01872	0.01472	0.0456	0.06912	0.048208	0.1404	0.34	
23-Aug	0.07384	0.10248	0.06672	0.03296	0.0186	0.00528	0.16016	0.1217	1.32	
24-Aug	0.07412	0.08712	0.05196	0.04336	0.0196	-0.00264	0.14932	0.1725	0.87	
25-Aug	0.06312	0.06024	0.05016	0.02288	0.0098	0.00264	0.11808	0.1875	0.63	
26-Aug	0.07732	0.11272	0.0618	0.02016	0.0222	0.012	0.16576	0.1825	0.91	
2-Sep	0.08904	0.09256	0.07788	0.0464	-0.0024	-0.01872	0.16928	0.1522	1.11	**0.72**
4-Sep	0.08028	0.10824	0.06804	0.016	0	-0.00648	0.16	0.163	0.98	
5-Sep	0.06576	0.12184	0.0756	0.0168	0.0136	0.00912	0.16032	0.1582	1.01	
6-Sep	0.02944	0.08144	0.06036	0.02992	0.0122	0.00792	0.10152	0.1593	0.64	
9-Sep	0.073	-0.00192	0.02268	0.02192	0.0062	0.01176	0.08828	0.1529	0.58	
10-Sep	0.07588	0.0384	0.03252	0.02272	0.0206	0.00936	0.11728	0.1472	0.80	
11-Sep	0.0698	0.06232	0.04704	0.04096	0.016	0.02232	0.1338	0.14	0.90	
12-Sep	0.03748	0.05512	0.04212	0.04592	0.0352	0.01728	0.10048	0.1417	0.71	
23-Sep	0.05612	0.0628	0.04068	0.03344	0.0088	-0.00408	0.11052	0.0903	1.20	
24-Sep	0.055	0.05808	0.04104	0.0216	0.0162	0.00552	0.10728	0.1356	0.79	
25-Sep	0.06032	0.05288	0.03036	0.0232	0.0112	0.01608	0.1076	0.1249	0.86	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
26-Sep	0.0522	0.0528	0.0258	0.02064	0.0088	0.00552	0.09504	0.1226	0.78	
27-Sep	0.04364	0.06272	0.03984	0.01872	0.0186	0.012	0.09868	0.119	0.83	
28-Sep	0.04036	0.0524	0.02424	0.01072	0.01	0.00816	0.08068	0.1286	0.63	
29-Sep	0.03944	0.062	0.02604	0.01072	0.01	0.0108	0.0856	0.1254	0.68	
30-Sep	0.02308	0.02448	0.01512	0.01424	0.0136	0.01344	0.04888	0.1253	0.39	
1-Oct	-0.02796	0.06384	0.0342	0.01232	0.0186	0.01464	0.0246	0.1021	0.24	**0.79**
2-Oct	0.02576	0.03288	0.02568	0.0072	0.0198	0.01344	0.05876	0.1215	0.48	
9-Oct	0.0472	0.06824	0.06804	0.05936	0.099	0.32904	0.19348	0.1068	1.81	
10-Oct	0.02708	0.04952	0.03852	0.03776	0.0486	0.08352	0.09776	0.1069	0.91	
11-Oct	0.03304	0.04048	0.03264	0.0248	0.0242	0.0444	0.0826	0.1183	0.70	
12-Oct	0.00724	0.03216	0.02244	0.02192	0.0228	0.03024	0.04588	0.099	0.46	
13-Oct	0.0622	0.04272	0.02988	0.02192	0.0254	0.03048	0.10916	0.0799	1.37	
14-Oct	0.05312	0.03296	0.02412	0.01184	0.0278	0.03432	0.09188	0.098	0.94	
15-Oct	0.07024	0.05256	0.0228	0.02	0.0102	0.02184	0.1148	0.1059	1.08	
16-Oct	0.05076	0.05296	0.0276	0.01184	0.015	0.01656	0.09516	0.111	0.86	
17-Oct	0.03252	0.05496	0.0366	0.0136	0.014	0.03144	0.08364	0.0874	0.96	
18-Oct	0.03892	0.05432	0.02484	0.01904	0.0214	0.01776	0.08636	0.0991	0.87	
19-Oct	0.04252	0.06008	0.01752	0.01792	0.0138	0.03408	0.09132	0.0918	0.99	
20-Oct	0.03216	0.05704	0.0372	0.01632	0.0238	0.01896	0.08508	0.0912	0.93	
21-Oct	-0.00444	0.02712	0.021	0.01168	0.0176	0.01776	0.02552	0.0932	0.27	
23-Oct	0.02216	0.02904	0.02652	0.02064	0.0112	0.02016	0.05628	0.0988	0.57	
24-Oct	0.01396	0.0068	0.02184	0.01616	0.01	0.01896	0.03384	0.0956	0.35	
25-Oct	0.01776	0.03432	0.03096	0.01696	0.025	0.0216	0.05808	0.0759	0.77	
26-Oct	0.0198	0.03088	0.03264	0.02928	0.0124	0.02712	0.06044	0.0827	0.73	
27-Oct	0.0146	0.02448	0.03348	0.02048	0.0284	0.01752	0.05172	0.1011	0.51	
3-Nov	0.0416	0.036	0.00108	0.0088	0.005	0.0132	0.06536	0.0795	0.82	**0.50**
4-Nov	0.02044	0.0196	0	0.00528	0.0048	0.00936	0.03408	0.065	0.52	
6-Nov	0.03376	0.0308	0.00984	0.00528	0.005	0.012	0.05676	0.0554	1.02	
7-Nov	0.03472	0.0324	0.00984	0.01664	0.011	0.01464	0.063	0.0707	0.89	
8-Nov	0.03652	0.03352	0.01152	0.01136	0.0122	0.01056	0.06416	0.0685	0.94	
9-Nov	0.03164	0.03464	0.01548	0.0184	0.0124	0.01608	0.06388	0.0729	0.80	
10-Nov	0.02568	0.02808	0.015	0.0112	0.0146	0.0132	0.05264	0.0725	0.73	
13-Nov	0.03256	0.00432	0.00456	0.01296	0.0134	0.02136	0.04572	0.0769	0.59	
14-Nov	0.03372	0.0088	0.00576	0.0088	0.0072	0.00528	0.04456	0.0643	0.69	
15-Nov	0.03264	0.00856	0.01128	0.01728	0.0062	0.01968	0.04952	0.0676	0.73	
16-Nov	0.02564	0.01144	0.0108	0.01472	0.0146	0.00936	0.04312	0.0689	0.63	
17-Nov	0.02052	0.0108	0.0108	0.01456	0.023	0.00792	0.03908	0.069	0.57	
18-Nov	0.01808	0.01464	0.01416	0.024	0.0218	0.01968	0.04376	0.0741	0.55	
19-Nov	0.01488	0.01168	0.01572	0.01728	0.0134	0.01704	0.0358	0.0784	0.46	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
20-Nov	0.01012	0.01184	0.01356	0.01792	0.0204	0.01056	0.03088	0.0879	0.35	
21-Nov	0.00328	0.01056	0.01224	0.0256	0.0218	0.00912	0.02492	0.0732	0.34	
23-Nov	0.00516	0.00256	0.00384	0.00848	0.0096	0.0132	0.01396	0.057	0.24	
24-Nov	0.00612	0.00232	0.00396	0.00848	0.012	0.0132	0.01532	0.0607	0.25	
25-Nov	0.0062	0.00664	0.00828	0.01536	0.0228	0.01296	0.02284	0.0559	0.41	
27-Nov	0.00656	0.00584	0.01164	0.01344	0.0192	0.01824	0.0236	0.0628	0.38	
28-Nov	0.00352	0.00672	0.00324	0.01184	0.025	0.01704	0.01876	0.0598	0.31	
29-Nov	0.00556	0.00784	0.01392	0.01088	0.0142	0.02592	0.024	0.0416	0.58	
30-Nov	0.00616	0.00792	0.00828	0.00768	0.0202	0.02328	0.02272	0.0675	0.34	
1-Dec	0.00584	0.00944	0.00984	0.01344	0.019	0.0144	0.0234	0.0603	0.39	**0.40**
2-Dec	0.00488	0.00792	0.00768	0.00832	0.0188	0.0168	0.02004	0.0487	0.41	
3-Dec	0.00384	0.00568	0.00768	0.0016	0.0154	0.0168	0.01552	0.0488	0.32	
4-Dec	0.00296	0.00536	0.0072	0.01184	0.0106	0.01416	0.01548	0.0633	0.24	
5-Dec	0.00296	0.00584	0.00384	0.0008	0.0142	0.018	0.0132	0.0493	0.27	
15-Dec	0.0104	0.03376	0.0246	0.02704	-0.023	-0.00912	0.03612	0.0484	0.75	
16-Dec	0.0296	0.0132	0.03204	0.01328	-0.0316	-0.018	0.04088	0.0485	0.84	
7-Jan2022	0.00668	0.02648	0.03624	0.03424	0.0346	0.04464	0.05492	0.0469	1.10	**0.71**
8-Jan	-0.00836	0.02016	0.01728	0.02128	0.0076	0.03192	0.01964	0.0363	0.54	
12-Jan	0.01708	0.02248	0.02868	0.04192	0.0244	0.07416	0.0656	0.055	1.10	
29-Jan	0.01012	0.01224	0.009	0.00816	0.0052	0.01248	0.0244	0.0818	0.30	
30-Jan	0.01876	0.03008	0.02676	0.02192	0.0138	0.00408	0.05164	0.0641	0.81	
31-Jan	0.01368	0.0216	0.02028	0.01184	-0.0012	0.01776	0.03692	0.0558	0.66	
23-Feb	0.03492	0.04144	0.04476	-0.00368	-0.005	-0.01224	0.0666	0.0768	0.87	**0.72**
24-Feb	0.02652	0.02944	0.03096	0.01184	-0.0064	0.00264	0.05368	0.1145	0.47	
25-Feb	0.01372	0.02048	0.0264	0.00912	0.009	0.00408	0.03752	0.1199	0.31	
26-Feb	0.04564	0.05248	0.0516	0.03008	0.0162	0.0096	0.10144	0.121	0.84	
27-Feb	0.00816	0.02072	0.01968	-0.0008	0	0.00144	0.02512	0.0606	0.41	
28-Feb	0.03348	0.03288	0.03348	0.0208	0.014	0.01488	0.07156	0.0909	0.79	
5-Mar	0.05096	0.07696	0.06696	0.03648	0.041	0.03912	0.1356	0.1309	1.04	**0.70**
6-Mar	0.0442	0.06032	0.05736	0.03456	0.031	0.02688	0.1128	0.1147	0.98	
13-Mar	0.02904	0.01528	0.01116	-0.00528	-0.005	0.012	0.04008	0.1248	0.32	
14-Mar	0.03932	0.06344	0.0042	0.01408	0.0026	0.01464	0.07892	0.1277	0.62	
21-Mar	0.04456	0.05456	0.04536	0.0568	0.0306	0.04152	0.1142	0.1295	0.88	
22-Mar	0.0372	0.05584	0.0438	0.04816	0.0308	0.0444	0.10532	0.1137	0.93	
25-Mar	0.04212	0.052	0.06	0.0568	0.028	0.0276	0.11252	0.1019	1.10	
26-Mar	0.0478	0.05544	0.0624	0.0544	0.0306	0.03576	0.122	0.1147	1.06	
2-Apr	0.03576	0.03472	0.04416	0.04176	0.0268	0.03168	0.08892	0.1526	0.58	**0.76**
12-Apr	0.0662	0.07216	0.05928	0.05984	0.051	0.05424	0.15624	0.1626	0.96	
13-Apr	0.02636	0.04488	0.03624	0.02928	0.0294	0.04128	0.08096	0.1856	0.44	

Date	ET_c 1 (in/day)	ET_c 2 (in/day)	ET_c 3 (in/day)	ET_c 4 (in/day)	ET_c 5 (in/day)	ET_c 6 (in/day)	ET_c Sum (in/day)	ET_o (in/day)	K_c sum (in/day)	Averaged Monthly K_c
14-Apr	0.05784	0.05648	0.06132	0.06192	0.043	0.05112	0.13912	0.174	0.80	
19-Apr	0.07052	0.05744	0.03864	0.03872	0.03	0.03264	0.13324	0.1565	0.85	
20-Apr	0.06116	0.06008	0.0414	0.03392	0.03	0.03672	0.1256	0.1662	0.76	
21-Apr	0.0408	0.0524	0.03216	0.02672	0.0226	0.03	0.09392	0.1417	0.66	
22-Apr	0.0574	0.07392	0.0516	0.0416	0.0398	0.03912	0.13644	0.1433	0.90	
23-Apr	0.05416	0.07792	0.07368	0.05024	0.0396	0.05808	0.14784	0.1357	1.09	
24-Apr	0.04676	0.07008	0.0522	0.03936	0.0432	0.04296	0.12484	0.1362	0.92	

3.1.2 Bahiagrass

Two Bahiagrasses, showed different ranges for ET_c and consequently in K_c values. Irrigated Bahiagrass, demonstrated ET_c ranged from 0.03 to 0.17, with its maximum during months of May and June. For the non-irrigated field, the minimum ET_c of 0.02 occurred in November, December, and January. The highest values for ET_c in that field were derived in May and June, as well. Although the averaged curve was used for comparing with the curve from Jia et al. (2009), it might be more appropriate to apply the curves from irrigated and non-irrigated Bahiagrass, based on irrigation plans. Tables 3-3 and 3-4 show the data for daily ET_c values, ET_o and daily K_c values for non-irrigated and irrigated Bahiagrass, respectively. Days were selected according to the refining approach described in the Methods chapter.

Table 3-3. Daily ET_c values, ET_o and daily K_c values for Irrigated Bahiagrass derived from the VWC data and used for calculating the monthly average K_c. Days were selected according to the refining approach described in the Methods chapter. ET_c 1 – ET_c 6 indicate ET_c values calculated for that day from VWC measured at each of the six depths allowed by the Sentek soil moisture probe.

Date	ET_c 1 (in/day)	ET_c 2 (in/day)	ET_c 3 (in/day)	ET_c 4 (in/day)	ET_c 5 (in/day)	ET_c 6 (in/day)	ET_c Sum (in/day)	ET_o (in/day)	K_c sum (in/day)	Averaged Monthly K_c
16-May	0.00474	0.00849	0.0198	0.0032	-0.005	0.00144	0.01218	0.014	0.86	**0.48**
25-May	0.00301	0.00925	0.051	-0.0072	-0.0088	0.02208	0.016592	0.040	0.41	
27-May	0.00188	0.00567	0.03744	-0.01104	-0.0228	0.02184	0.010832	0.032	0.34	
31-May	0.00138	0.00406	0.0498	-0.01136	-0.0038	0.03192	0.013328	0.043	0.31	
10-Jun	0.00297	0.00686	-0.08844	0.0168	0	0.00144	0.01904	0.024	0.79	**0.51**
14-Jun	0.00380	0.00777	0.04788	0.0008	-0.004	-0.01176	0.013408	0.026	0.52	
15-Jun	-0.00068	0.00161	0.03504	0.01968	0.0014	0.00432	0.013724	0.027	0.5	
23-Jun	0.00612	0.01134	-0.33588	0.00784	-0.0212	-0.0336	0.026392	0.080	0.33	
27-Jun	0.00526	0.00891	0.07464	0.03008	0.0114	0.00456	0.034272	0.034	1.01	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
28-Jun	0.00362	0.00717	0.05616	0.02608	0.0238	0	0.029364	0.070	0.42	
5-Jul	0.00058	0.00190	-0.46944	0.02192	0.0072	0.00648	0.016928	0.025	0.67	**0 .56**
16-Jul	0.00684	0.00640	0.07692	0.03904	0.0156	0.00456	0.03908	0.107	0.37	
17-Jul	0.00660	-0.00392	0.0558	0.03264	0.0214	0.01272	0.02944	0.101	0.3	
26-Jul	0.01452	0.01632	-0.30852	0.03264	0.0228	0.01248	0.04612	0.110	0.42	
29-Jul	0.04368	0.03120	0.17964	0.04896	0.0258	0.00768	0.116	0.109	1.01	
30-Jul	0.04632	0.01880	0.0756	0.06032	0.0326	0.03	0.10416	0.104	0.99	
1-Aug	0.01160	0.00904	0.01332	0.01776	0.0286	0.02064	0.03308	0.111	0.34	**0.59**
8-Aug	0.04492	0.04400	0.15864	0.09328	0.0228	0.00312	0.1394	0.131	1.01	
9-Aug	0.02384	0.01304	0.03348	0.04368	0.0184	0.0156	0.05636	0.120	0.47	
13-Aug	0.03036	0.01880	0.063	0.03424	0.0142	0.00792	0.06896	0.099	0.7	
19-Aug	0.04272	0.03888	0.12648	0.04864	-0.0042	-0.00312	0.10136	0.141	0.71	
20-Aug	0.02164	0.01608	0.06996	0.00416	0.0042	0.0108	0.04712	0.158	0.36	
26-Aug	0.02580	0.02688	-0.0126	0.07392	0.0086	0.00624	0.08304	0.153	0.54	
2-Sep	0.03972	0.03448	0.14064	0.1472	0.0158	0.0156	0.1368	0.152	0.9	
4-Sep	0.01808	0.01496	0.07632	0.02048	0.0214	0.02376	0.04852	0.157	0.31	**0.45**
5-Sep	0.04988	0.02984	0.0708	0.04096	0.023	0.02664	0.09992	0.146	0.68	
7-Sep	0.01952	0.01296	-1.0212	0.01504	0.0228	0.00936	0.04364	0.101	0.43	
14-Sep	0.02056	0.00912	0.03756	0.01392	0.0214	0.00936	0.042	0.060	0.7	
15-Sep	0.01360	0.00952	0.02784	0.00768	0.0072	0.01248	0.02876	0.081	0.35	
17-Sep	0.01188	0.01264	0.03228	0.00432	0.0056	0.00768	0.02536	0.078	0.32	
24-Sep	0.02792	0.01664	0.09996	0.03376	0.0072	0.00312	0.06456	0.182	0.35	
29-Sep	0.04036	0.02072	0.0642	0.02688	0.03	0.02976	0.08204	0.156	0.52	
2-Oct	0.02680	0.01872	0.06864	0.03104	0.0314	0.02664	0.06644	0.179	0.37	**0.36**
13-Oct	0.01952	0.01032	0.05508	0.01072	0.0128	0.00168	0.03804	0.099	0.38	
14-Oct	0.02120	0.01216	0.078	0.01072	0.0184	0.01848	0.04724	0.088	0.54	
17-Oct	0.01335	0.02400	0.11448	0.0296	0.0254	0.00624	0.064588	0.179	0.36	
19-Oct	0.01108	0.02496	0.15888	0.04224	0.0308	0.0216	0.072156	0.209	0.35	
20-Oct	0.00800	0.01912	0.156	0.04096	0.0268	0.02952	0.062764	0.201	0.31	
21-Oct	0.00680	0.01913	0.15408	0.04496	0.032	0.02784	0.06596	0.232	0.28	
22-Oct	0.00510	0.01355	0.15528	0.04784	0.0224	0.03072	0.057472	0.198	0.29	
23-Oct	0.00572	0.01353	0.1008	0.0672	0.0376	0.02304	0.068364	0.189	0.36	
29-Oct	0.03132	0.03920	0.11736	-0.04336	-0.0264	0.00312	0.06968	0.219	0.32	
7-Nov	0.04768	0.05016	0.15516	0.24192	-0.0114	-0.10752	0.15332	0.193	0.72	**0.30**
9-Nov	0.01232	0.00944	0.05928	0.0184	0.0086	-0.01248	0.03272	0.144	0.23	
10-Nov	0.00996	0.00800	0.04992	0.0248	0.0128	0.00936	0.0326	0.165	0.2	
12-Nov	0.01024	0.01144	0.02796	0.01184	0.0086	0.01104	0.0292	0.153	0.19	
26-Nov	0.00540	0.00712	0.01284	0.0128	0.01	0.01104	0.01772	0.090	0.2	

Date	ET_c *1 (in/day)*	ET_c *2 (in/day)*	ET_c *3 (in/day)*	ET_c *4 (in/day)*	ET_c *5 (in/day)*	ET_c *6 (in/day)*	ET_c *Sum (in/day)*	ET_o *(in/day)*	K_c *sum (in/day)*	*Averaged Monthly* K_c
14-Dec	0.00816	0.00320	-0.40548	0.00752	0.003	0.00312	0.01712	0.043	0.41	**0.34**
27-Dec	0.00508	0.00536	0.02376	0.13712	0.0142	0.00168	0.04956	0.204	0.26	
4-Jan	0.01816	0.01368	0.06708	0.05792	0.013	0.00936	0.05576	0.184	0.31	**0.38**
5-Jan	0.00788	0.01144	0.04872	0.0304	0.0072	0	0.03288	0.098	0.34	
11-Jan	0.02536	0.03368	0.11856	0.07792	0.0086	0.00168	0.09264	0.166	0.55	
18-Jan	0.01960	0.02504	0.08352	0.03056	0.0102	0	0.05912	0.193	0.31	
23-Jan	0.01600	0.02688	0.09048	0.07776	0.013	-0.0048	0.07032	0.193	0.36	
9-Feb	0.01648	0.02288	0.10308	0.05696	0.0102	0.01272	0.06456	0.125	0.51	**0.47**
10-Feb	0.01848	0.01808	0.06444	0.0272	0.0114	0.00624	0.05376	0.125	0.42	
19-Feb	0.01964	0.02608	0.13632	0.04896	0.0028	0	0.08308	0.160	0.5	
17-Mar	0.02924	0.03232	-0.66612	0.05968	0.0102	0.00792	0.10764	0.130	0.83	**0.59**
21-Mar	0.02572	0.02888	0.10224	0.06208	0.0144	0.02064	0.08552	0.135	0.63	
22-Mar	0.01332	0.01584	-0.79884	0.03312	0.0188	0.01608	0.04652	0.101	0.46	
26-Mar	0.02440	0.03416	0.11364	0.04432	0.0232	0.01584	0.08788	0.082	1.07	
27-Mar	0.01168	0.01080	0.051	0.03872	0.0158	0.0144	0.04216	0.112	0.38	
28-Mar	0.00896	0.00816	0.05484	0.0232	0.0188	0.02856	0.03452	0.112	0.31	
29-Mar	0.00872	0.00856	0.05004	0.0384	0.0172	0.0252	0.04136	0.124	0.33	
30-Mar	0.00840	0.00880	-0.76296	0.11472	0.0144	0.03024	0.05496	0.109	0.5	
9-Apr	0.01048	0.01128	0.09492	0.0472	0.0044	0.02064	0.04632	0.112	0.41	**0.48**
10-Apr	0.02244	0.01696	0.06732	0.09808	0.036	0.03312	0.08572	0.108	0.79	
20-Apr	0.01292	0.00632	0.02364	0.0032	0.007	0.00624	0.02436	0.060	0.4	
21-Apr	0.00804	0.00576	0.02628	0.01184	0.0058	0.01896	0.02104	0.076	0.27	
22-Apr	0.01084	0.00952	0.03672	0.00864	0.0156	0	0.0268	0.082	0.32	
23-Apr	0.01244	0.00968	0.03852	0.00976	0.013	0.01872	0.03176	0.090	0.35	
24-Apr	0.01380	0.01160	0.05196	0.01184	0.0098	0.00792	0.03236	0.077	0.42	
26-Apr	0.02164	0.01752	0.08892	0.0192	0.0226	0.01248	0.05516	0.075	0.73	
27-Apr	0.02372	0.02336	3.95244	0.01824	0.02	0.00936	0.0618	0.087	0.7	

Table 3-4. Daily ET_c values, ET_o and daily K_c values for Non-irrigated Bahiagrass derived from the VWC data and used for calculating the monthly average K_c. Days were selected according to the refining approach described in the Methods chapter. ET_c 1 – ET_c 6 indicate ET_c values calculated for that day from VWC measured at each of the six depths allowed by the Sentek soil moisture probe.

Date	ET_c *1 (in/day)*	ET_c *2 (in/day)*	ET_c *3 (in/day)*	ET_c *4 (in/day)*	ET_c *5 (in/day)*	ET_c *6 (in/day)*	ET_c *Sum (in/day)*	ET_o *(in/day)*	K_c *sum (in/day)*	*Averaged Monthly* K_c
16-May	0.15704	0.01312	0.02112	0.0152	0.0314	0.02736	0.18528	0.213	0.86	**0.86**

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
24-May	0.08852	0.11984	0.01404	0.00864	0.0784	0.1092	0.18916	0.2117	0.89	
25-May	0.10032	0.09712	0.01692	0.00768	0.0394	0.04992	0.17264	0.2157	0.80	
26-May	0.13812	0.09672	0.02136	0.01136	0.0292	0.04416	0.20964	0.2233	0.94	
28-May	0.11396	0.08664	0.01044	-0.00064	0.0638	0.12144	0.1936	0.2338	0.83	
29-May	0.12256	0.10432	0.0024	0.00416	0.0228	0.0696	0.19272	0.2497	0.77	
30-May	0.12948	0.13184	0.01344	0.00496	0.0272	0.05352	0.21548	0.2434	0.89	
6-Jun	0.05128	0.09976	0.1884	-0.2112	0.0802	0.19488	0.15968	0.2015	0.79	**0.88**
7-Jun	0.07132	0.09848	0.05508	0.00224	-0.054	0.05544	0.13792	0.158	0.87	
8-Jun	0.07316	0.09216	0.04728	0.04688	0.02	0.02712	0.15524	0.1428	1.00	
9-Jun	0.03936	0.07408	0.0468	0.04864	0.0198	0.01632	0.11084	0.183	0.60	
10-Jun	0.04492	0.07128	0.04296	0.03952	0.0204	0.0084	0.11024	0.1671	0.66	
11-Jun	0.08884	0.09472	0.05772	0.03568	0.0212	0.01176	0.17056	0.221	0.77	
13-Jun	0.05792	0.08424	0.04404	0.03808	0.021	0.012	0.13044	0.1716	0.76	
15-Jun	0.11824	0.10992	0.0348	0.02912	0.0246	0.02712	0.20152	0.2201	0.92	
22-Jun	0.03712	0.05648	0.05052	0.04816	0.1144	0.09264	0.13256	0.1555	0.85	
1-Jul	0.04844	0.0496	0.01572	-0.00768	0.0098	0.0252	0.08272	0.1418	0.58	**0.80**
2-Jul	0.0706	0.06816	0.03288	0.01456	0.0212	0.02496	0.12768	0.1783	0.72	
12-Jul	0.05444	0.05376	0.04968	0.04176	0.0904	0.09888	0.14288	0.2024	0.71	
14-Jul	0.07792	0.1156	0.20904	0.12	0.0206	-0.006	0.23852	0.2221	1.07	
23-Jul	0.03496	0.03248	0.0366	0.02144	0.037	0.05544	0.0854	0.168	0.51	
24-Jul	0.04876	0.0368	0.03168	0.01968	0.0508	0.07536	0.10536	0.121	0.87	
28-Jul	0.0398	0.04144	0.048	0.02848	0.05	0.07344	0.10588	0.1315	0.81	
2-Aug	0.03184	0.05032	0.054	0.0216	0.0462	0.05112	0.09816	0.1728	0.57	
5-Aug	0.04028	0.04752	0.0126	0.02048	0.0472	0.06792	0.09412	0.169	0.56	
8-Aug	0.08404	0.12144	0.03168	0.01728	0.0462	0.06696	0.18004	0.1538	1.07	**0.87**
11-Aug	0.05968	0.04496	0.03828	0.01888	0.0152	0.03048	0.10776	0.1754	0.67	
12-Aug	0.08032	0.0632	0.0282	0.01792	0.0182	0.03504	0.13528	0.1921	0.96	
22-Aug	0.04468	0.06888	0.08448	0.02688	0.028	-0.00864	0.11816	0.1579	0.75	
31-Aug	0.01312	0.12016	0.07356	0.11264	-0.0172	-0.1368	0.09964	0.1283	0.88	
8-Sep	0.03064	0.09	0.14268	0.0432	0.0752	0.10608	0.16672	0.1646	1.01	**0.84**
9-Sep	0.01724	0.03472	0.03264	0.02064	0.0512	0.07728	0.07376	0.063	1.00	
11-Sep	0.04456	0.03696	0.0264	0.01824	0.0416	0.05976	0.09468	0.1562	0.61	
12-Sep	0.06352	0.0772	0.0222	0.01504	0.0404	0.0516	0.12996	0.1403	0.92	
21-Sep	0.02128	0.02792	0.11028	0.0168	0.062	0.08856	0.10336	0.1215	0.85	
22-Sep	0.02644	0.02176	0.03564	0.0216	0.0424	0.06816	0.07444	0.1344	0.55	
23-Sep	0.04464	0.03536	0.02064	0.02144	0.05	0.06576	0.09552	0.1344	0.71	
24-Sep	0.07696	0.05352	0.02232	0.02064	0.0398	0.0552	0.13348	0.1634	0.81	
25-Sep	0.05876	0.06256	0.0276	0.01984	0.0356	0.04872	0.11944	0.1568	0.76	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
26-Sep	0.06476	0.08688	0.036	0.01568	0.0374	0.0552	0.1408	0.1502	0.93	
27-Sep	0.055	0.1256	0.05196	0.02608	0.044	0.05688	0.15992	0.1465	1.09	
28-Sep	0.0234	0.11248	0.0474	0.01568	0.0348	0.05448	0.1154	0.1479	0.78	
29-Sep	0.01864	0.1216	0.05472	0.01952	0.0464	0.05496	0.121	0.1327	0.91	
30-Sep	0.01388	0.122	0.05028	0.02352	0.0478	0.06312	0.1176	0.1351	0.87	
1-Oct	0.00188	0.05216	0.02496	0.01008	0.0294	0.05208	0.05336	0.123	0.43	**0.65**
2-Oct	0.00408	0.05944	0.03792	0.02176	0.0444	0.0528	0.06956	0.1419	0.49	
9-Oct	0.03848	0.04216	0.00048	-0.0008	0.012	0.01824	0.06496	0.123	0.52	
10-Oct	0.05396	0.0576	0.00744	0.00544	0.0156	0.01992	0.09304	0.1135	0.81	
11-Oct	0.05428	0.06184	0.01476	0.00624	0.011	0.02904	0.09872	0.1233	0.80	
12-Oct	0.0458	0.07144	0.01584	0.00848	0.0256	0.0252	0.09824	0.1022	0.96	
13-Oct	0.03816	0.08216	0.02652	0.01456	0.0248	0.02976	0.10164	0.1301	0.78	
14-Oct	0.01528	0.06688	0.0168	0.00848	0.0262	0.03288	0.06716	0.124	0.54	
15-Oct	0.01736	0.08056	0.02568	0.01616	0.029	0.04008	0.08272	0.1235	0.66	
16-Oct	0.01216	0.06544	0.0294	0.01392	0.0324	0.0396	0.07124	0.1249	0.57	
17-Oct	0.01216	0.07288	0.03696	0.02224	0.0366	0.04464	0.08124	0.1185	0.68	
18-Oct	0.01016	0.06	0.03288	0.0304	0.0398	0.0408	0.07348	0.1349	0.54	
19-Oct	0.00792	0.04664	0.0336	0.032	0.0466	0.05352	0.06868	0.1035	0.66	
20-Oct	0.00588	0.03496	0.02748	0.03328	0.0488	0.04776	0.05856	0.115	0.50	
21-Oct	0.0074	0.02272	0.01992	0.03312	0.0456	0.0492	0.051	0.1148	0.44	
4-Nov	0.04744	0.01312	0.0222	0.01168	0.0104	0.01008	0.06808	0.1073	0.63	**0.56**
5-Nov	0.0322	0.02864	0.02388	0.02	0.0146	0.01416	0.06476	0.0889	0.72	
8-Nov	0.0304	0.04408	0.02124	0.01312	0.0128	0.00816	0.06672	0.1145	0.58	
9-Nov	0.0132	0.04496	0.01536	0.01824	0.0136	0.01176	0.05004	0.0912	0.54	
10-Nov	0.01052	0.0364	0.012	0.00608	0.0078	0.01152	0.03772	0.0867	0.44	
11-Nov	0.01572	0.03336	0.0108	0.00464	0.0094	0.01152	0.04096	0.0759	0.56	
14-Nov	0.02128	0.03976	0.01128	0.00384	0.0076	0.0072	0.0486	0.0913	0.56	
15-Nov	0.02236	0.04368	0.01464	0.01216	0.0152	0.01152	0.05708	0.0827	0.69	
16-Nov	0.0166	0.03952	0.01236	0.01056	0.006	0.01464	0.04676	0.0871	0.53	
17-Nov	0.01284	0.03744	0.01632	0.01216	0.0134	0.00888	0.0442	0.0732	0.60	
18-Nov	0.01044	0.028	0.00888	0.00832	0.0134	0.01296	0.03432	0.0845	0.40	
19-Nov	0.01048	0.02952	0.0078	0.00832	0.0118	0.01632	0.035	0.0779	0.45	
23-Nov	0.00608	0.01784	0.00948	0.0112	0.0156	0.01272	0.0262	0.0592	0.45	
23-Dec	0.01168	0.03024	0.02436	0.01696	0.023	0.01104	0.0456	0.0678	0.67	**0.67**
24-Dec	0.01232	0.032	0.02484	0.02016	0.0238	0.01584	0.04904	0.0648	0.75	
25-Dec	0.00864	0.02704	0.0192	0.01536	0.0172	0.01176	0.0378	0.0635	0.59	
26-Dec	0.01196	0.0256	0.02772	0.016	0.0256	0.0156	0.04572	0.0654	0.69	
27-Dec	0.01132	0.02824	0.01596	0.02	0.0188	0.01272	0.04164	0.0682	0.61	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
8-Jan	0.0638	-0.00088	-0.06024	-0.03424	-0.027	-0.018	0.02632	0.0295	0.46	**0.56**
11-Jan	0.00856	0.01416	0.0144	0.004	0.009	0.018	0.02624	0.0443	0.69	
12-Jan	0.00908	0.01672	0.0156	0.00896	0.019	0.012	0.03068	0.0294	0.42	
17-Jan	0.01324	0.02528	0.02976	0.01472	0.0256	0.03672	0.05072	0.0715	0.70	
2-Feb	0.01428	0.03072	0.01692	0.00912	0.019	0.01512	0.04388	0.093	0.47	**0.55**
3-Feb	0.01432	0.03208	0.02364	0.01872	0.022	0.03	0.05232	0.0993	0.53	
4-Feb	0.01272	0.02928	0.0198	0.01792	0.023	0.02016	0.0464	0.0844	0.55	
9-Feb	0.02312	0.01424	0.01992	0.00576	0.0174	0.01656	0.04456	0.0754	0.59	
13-Feb	0.00776	0.02216	0.02268	0.0064	0.0202	0.0204	0.03544	0.0596	0.59	
14-Feb	-0.00228	0.00184	0.00756	0.00496	0.0142	0.0264	0.00964	0.02	0.48	
17-Feb	0.01504	0.03392	0.02436	0.02032	0.025	0.01416	0.05256	0.0767	0.68	
18-Feb	0.01508	0.04048	0.02172	0.02288	0.017	0.02712	0.0562	0.0814	0.69	
21-Feb	0.01552	0.02864	0.01716	0.00736	0.004	0.00912	0.03972	0.0939	0.42	
22-Feb	0.00896	0.02432	0.01824	0.01472	0.023	0.01488	0.03796	0.0997	0.38	
23-Feb	0.00832	0.02592	0.0138	0.01872	0.017	0.0192	0.03716	0.0532	0.69	
4-Mar	0.0138	0.01944	0.01236	0.0064	0.0118	0.00888	0.03308	0.0544	0.60	**0.60**
13-Mar	0.15404	-0.00904	-0.05196	-0.05232	-0.1212	-0.17544	0.06564	0.1333	0.49	
14-Mar	-0.03264	0.01176	0.05316	0.05312	0.1202	0.18048	0.05836	0.1397	0.48	
15-Mar	0.02144	0.03688	0.03228	0.01728	0.0222	0.01608	0.06208	0.1477	0.52	
22-Mar	0.02368	0.05992	0.06624	0.01712	0.0492	0.0672	0.10104	0.1243	0.81	
23-Mar	0.01416	0.03816	0.04092	0.02288	0.0476	0.05856	0.07188	0.159	0.45	
29-Mar	0.0242	0.03592	0.02736	0.01792	0.018	0.02904	0.0642	0.1543	0.51	
30-Mar	0.02988	0.0436	0.03024	0.01616	0.0326	0.03192	0.07764	0.1614	0.48	
31-Mar	0.03224	0.04624	0.03312	0.02352	0.0258	0.02784	0.08208	0.1388	0.60	
2-Apr	0.04412	0.15496	0.04752	0.00656	0.018	0.00504	0.14352	0.1662	0.86	**0.69**
5-Apr	0.02632	0.05104	0.02808	0.01776	0.0278	0.04296	0.07836	0.1462	0.57	
11-Apr	0.04116	0.0188	-0.02712	-0.01472	-0.007	0.0132	0.03864	0.0578	0.67	
13-Apr	0.03736	0.07064	0.04008	0.03328	0.0518	0.05496	0.11388	0.1925	0.59	
14-Apr	0.0368	0.07256	0.03672	0.02096	0.0336	0.04584	0.10492	0.1886	0.57	
24-Apr	0.05776	0.05736	0.01668	0.00624	0.0302	0.04392	0.10692	0.1636	0.68	
27-Apr	0.06864	0.09088	0.03216	-0.012	0.0276	0.03768	0.1336	0.1875	0.72	
30-Apr	0.08188	0.16576	0.06372	-0.0568	-0.0478	-0.0072	0.16104	0.1829	0.88	

3.1.3 Bermudagrass

ET_c values for Alicia Bermudagrass (*C.dactylon×C.nlemfuensis*), range from 0.03 to 0.13, with the highest value in July and the least value in December. For Tifton 85 Bermudagrass

(*Cynadon dactylon*), the maximum ET_c occurred in June (0.14), and the minimum derived value was 0.03 in December and January. The average values for ET_c and K_c were used for comparing results with other published studies. Tables 3-5 and 3-6 show the data for daily ET_c values, ET_o and daily K_c values for Tifton 85 Bermudagrass and Alicia Bermudagrass, respectively. Days were selected according to the refining approach described in the Methods chapter.

Table 3-5. Daily ET_c values, ET_o and daily K_c values for Tifton 85 Bermudagrass (*Cynadon dactylon*) derived from the VWC data and used for calculating the monthly average K_c. Days were selected according to the refining approach described in the Methods chapter. ET_c 1 – ET_c 6 indicate ET_c values calculated for that day from VWC measured at each of the six depths allowed by the Sentek soil moisture probe.

Date	*ET_c 1 (in/day)*	*ET_c 2 (in/day)*	*ET_c 3 (in/day)*	*ET_c 4 (in/day)*	*ET_c 5 (in/day)*	*ET_c 6 (in/day)*	*ET_c Sum (in/day)*	*ET_o (in/day)*	*K_c sum (in/day)*	*Averaged Monthly K_c*
14-May	0.0704	0.18288	0.0864	0.02384	0.004	0	0.1974	0.1565	0.71	**0.60**
15-May	0.02696	0.08696	0.0618	0.01504	0.016	0.02544	0.10224	0.2083	0.54	
9-Jun	0.07764	0.21672	0.14892	0.04592	-0.012	-0.01368	0.24244	0.1681	1.06	**0.73**
10-Jun	0.02368	0.13936	0.11292	0.01488	-0.0264	-0.00144	0.1292	0.1656	0.78	
21-Jun	0.01728	0.076	0.05076	0.00256	0.0014	0.00144	0.07336	0.1573	0.50	
24-Jun	0.02492	0.10632	0.06912	0.0008	-0.0028	-0.0144	0.09836	0.1747	0.56	
25-Jun	0.02272	0.08024	0.08112	0.02784	0.0326	0.01992	0.10668	0.1617	0.66	
3-Jul	0.05784	0.088	0.0846	0.01744	-0.0042	-0.02184	0.12992	0.1251	1.03	**0.79**
4-Jul	0.03532	0.09096	0.06744	0.03552	0.036	0.04968	0.12764	0.1954	0.75	
9-Jul	0.03156	0.06752	0.05352	0.0248	0.0336	0.03216	0.10144	0.1845	0.65	
10-Jul	0.02716	0.08664	0.0672	0.04048	0.0514	0.0528	0.12208	0.1573	0.78	
11-Jul	0.02176	0.0832	0.07716	0.052	0.0514	0.05088	0.12084	0.1999	0.69	
17-Jul	0.03736	0.07856	0.06696	0.03136	0.035	0.0264	0.1182	0.1827	0.66	
25-Jul	0.0352	0.05808	0.10236	0.04144	0.02	0.00744	0.11396	0.1983	0.76	
26-Jul	0.04296	0.06608	0.069	0.03936	0.0566	0.02664	0.1246	0.1942	0.64	
28-Jul	0.03424	0.05776	0.09276	0.02352	0.0128	0.00744	0.10372	0.1761	0.69	
29-Jul	0.04508	0.0744	0.07944	0.044	0.0638	0.02232	0.13624	0.1761	0.77	
30-Jul	0.03292	0.08304	0.05748	0.07872	0.0718	0.04992	0.13596	0.2149	0.63	
4-Aug	0.02332	0.06664	0.05292	0.01472	0.0126	0.00576	0.08144	0.1127	0.72	**0.81**
8-Aug	0.03048	0.07376	0.05664	0.04304	0.0334	0.02952	0.1086	0.1429	0.76	
13-Aug	0.04508	0.122	0.07128	0.0208	0.0192	0.03048	0.14396	0.2049	0.74	
18-Aug	0.05488	0.08848	0.07452	0.04352	0.0548	0.03552	0.15172	0.1899	0.79	
19-Aug	0.03012	0.0888	0.06372	0.044	0.0404	0.06024	0.12488	0.2078	0.81	
23-Aug	0.09728	0.15016	0.08616	0.00368	0.0042	-0.01008	0.20116	0.1818	1.00	

Date	*ET_c 1* (in/day)	*ET_c 2* (in/day)	*ET_c 3* (in/day)	*ET_c 4* (in/day)	*ET_c 5* (in/day)	*ET_c 6* (in/day)	*ET_c Sum* (in/day)	*ET_o* (in/day)	*K_c sum* (in/day)	*Averaged Monthly K_c*
24-Aug	0.03848	0.10464	0.06792	0.03088	0.0234	0.03048	0.13092	0.1935	0.68	
26-Aug	0.0378	0.07784	0.05376	0.02176	0.0152	0.01896	0.10628	0.1358	0.78	
29-Aug	0.05112	0.07592	0.03828	0.0064	-0.0026	-0.00576	0.10196	0.1079	0.94	
2-Sep	0.06496	0.098	0.04416	0.0072	-0.0028	-0.00144	0.12968	0.1744	0.74	**0.79**
3-Sep	0.0348	0.0952	0.0594	0.01904	0.0192	0.0204	0.1142	0.1375	0.83	
4-Sep	0.02664	0.06496	0.05412	0.01264	0.018	0.01896	0.08708	0.184	0.50	
10-Sep	0.04624	0.12016	0.06252	0.008	0.0068	-0.00288	0.13004	0.1457	0.89	
11-Sep	0.02872	0.07952	0.06108	0.01616	0.0082	0.01152	0.09644	0.1743	0.65	
23-Sep	0.03116	0.07752	0.03384	-0.00368	-0.0098	0.00144	0.07856	0.1375	0.67	
24-Sep	0.02472	0.0672	0.05484	0.0192	0.0194	0	0.08528	0.1551	0.76	
29-Sep	0.0974	0.02888	0.02088	0.0152	0.0246	0.02304	0.13136	0.1494	0.87	
1-Oct	0.00693	0.02712	0.045	0.1784	0.0246	0.02304	0.088852	0.1162	0.76	**0.72**
9-Oct	0.04224	0.09352	0.04044	-0.00624	-0.0164	-0.02016	0.09428	0.1157	0.87	
10-Oct	0.02272	0.07896	0.03264	0.0008	-0.0028	-0.00144	0.07248	0.1202	0.61	
11-Oct	0.01532	0.05152	0.03864	0.00624	0.0178	0.00576	0.06004	0.1136	0.53	
12-Oct	0.0106	0.03984	0.03156	-0.00176	0.022	0.03192	0.05032	0.0915	0.56	
29-Oct	0.04664	0.07648	0.03984	-0.00368	-0.0208	-0.01992	0.08976	0.0963	0.93	
30-Oct	0.02616	0.07296	0.03036	-0.0008	-0.0054	-0.01872	0.06836	0.0994	0.69	
31-Oct	0.01196	0.04856	0.03108	0.008	0.0042	0.0072	0.05064	0.0585	0.87	
1-Nov	0.01424	0.04072	0.03468	0.01344	0.0026	0.00576	0.051	0.0651	0.78	**0.62**
2-Nov	0.01324	0.0372	0.02676	0.01152	0.0166	0.01272	0.04908	0.0785	0.63	
3-Nov	0.01028	0.0308	0.02112	0.01952	0.0192	0.01008	0.04312	0.082	0.53	
7-Nov	0.01144	0.03696	0.02148	0.01056	0.0138	0.0072	0.04368	0.067	0.65	
8-Nov	0.01332	0.0344	0.01944	0.01072	0.0124	0.0084	0.04356	0.0975	0.45	
9-Nov	0.01404	0.03344	0.02268	0.01328	0.0164	0.00432	0.04564	0.0847	0.54	
10-Nov	0.0154	0.03792	0.0264	0.01856	0.0096	0.01872	0.05284	0.0741	0.71	
11-Nov	0.012	0.03416	0.02892	0.03168	0.0286	0.03	0.05736	0.0767	0.74	
17-Nov	0.01012	0.02584	0.01584	0.01312	0.0176	0.01992	0.03844	0.0702	0.56	
1-Dec	0.00430	0.01264	0.01056	0.01472	0.0202	0.02088	0.025348	0.0501	0.51	**0.61**
2-Dec	0.00443	0.00928	0.01092	0.01712	0.02	0.03216	0.026356	0.0634	0.42	
3-Dec	0.00483	0.014	0.00948	0.0112	0.0214	0.01272	0.024192	0.0534	0.45	
10-Dec	0.00173	-0.00392	0.00852	0.00768	0.0264	0.01224	0.011856	0.0256	0.46	
23-Dec	0.01588	0.0632	0.0324	0.00704	0.0054	-0.00408	0.06044	0.0709	0.85	
24-Dec	0.01628	0.04936	0.04116	0.01424	0.0096	0.00696	0.06132	0.0698	0.87	
26-Dec	0.0112	0.03552	0.0306	0.02128	0.0284	0.02976	0.05512	0.0706	0.78	
27-Dec	0.0084	0.02848	0.02208	0.01136	0.0188	0.01968	0.03988	0.0618	0.64	
28-Dec	0.00584	0.0236	0.02148	0.0176	0.019	0.01968	0.03628	0.0551	0.65	
1-Jan	0.0106	0.03128	0.01764	0.00352	0.0026	0.00288	0.034	0.0454	0.74	**0.58**

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly K_c***
3-Jan	0.03944	0.02664	0.0408	-0.07408	-0.0808	-0.07416	0.01932	0.0377	0.51	
4-Jan	0.03112	0.0416	0.01152	-0.01296	-0.0472	-0.06144	0.03284	0.0439	0.74	
5-Jan	0.00964	0.02032	0.01596	0.00464	0.0072	-0.012	0.02572	0.0462	0.55	
7-Jan	0.00428	0.0168	0.00468	0.00272	0.01	0.10608	0.0346	0.0693	0.50	
14-Jan	0.01028	0.03152	0.01704	0.024	0.0414	0.04656	0.05376	0.0691	0.77	
27-Jan	0.00552	0.02472	0.01812	0.01776	0.0418	0.0408	0.04352	0.0794	0.55	
28-Jan	0.00256	0.01912	0.01296	0.02048	0.0374	0.03336	0.0346	0.0838	0.42	
31-Jan	0.0064	0.0208	0.02448	0.02864	0.0412	0.04656	0.04812	0.0988	0.49	
1-Feb	0.0128	0.03352	0.02928	0.03488	0.0356	0.05088	0.06364	0.0919	0.69	**0.59**
2-Feb	0.01276	0.03328	0.03264	0.03744	0.0436	0.05208	0.06704	0.1099	0.61	
3-Feb	0.01028	0.03184	0.0318	0.03552	0.0394	0.05616	0.06292	0.1133	0.56	
12-Feb	0.0114	0.03608	0.02748	0.02944	0.0412	0.05088	0.06268	0.0875	0.71	
15-Feb	0.01368	0.0332	0.02616	0.01728	0.0312	0.02832	0.05428	0.0928	0.58	
16-Feb	0.01548	0.03648	0.03708	0.0456	0.0294	0.05928	0.07324	0.113	0.64	
17-Feb	0.0138	0.04048	0.03516	0.03808	0.0548	0.05328	0.07512	0.1326	0.56	
20-Feb	0.02504	0.0656	0.03492	0.01184	0	0.00312	0.07296	0.1192	0.61	
21-Feb	0.01748	0.05248	0.03828	0.03264	0.0252	0.0324	0.07508	0.1221	0.61	
14-Mar	0.02332	0.06272	0.03816	0.02672	0.0276	0.0132	0.0818	0.1131	0.72	**0.70**
17-Mar	0.01524	0.04272	0.02736	0.008	0.0136	0.01416	0.0528	0.1139	0.46	
20-Mar	0.0274	0.04096	0.02412	-0.00192	0.0014	0.02808	0.0604	0.0643	0.93	
21-Mar	0.02952	0.06632	0.03576	0.03488	0.0254	0.04464	0.09584	0.1686	0.56	
22-Mar	0.0234	0.06504	0.04332	0.03824	0.0452	0.05016	0.09732	0.1794	0.64	
25-Mar	0.00896	0.03016	0.02232	0.01456	0.0278	0.0264	0.04508	0.0812	0.56	
3-Apr	0.01908	0.05944	0.03912	0.01152	0.0206	0.0072	0.07004	0.0824	0.85	**0.76**
4-Apr	0.01836	0.05216	0.04128	0.0304	0.0096	0.0276	0.07232	0.1663	0.54	
7-Apr	0.04316	0.07552	0.09852	-0.0176	-0.017	0.00312	0.10544	0.12	0.87	
8-Apr	0.02732	0.042	0.02796	-0.0112	0.0098	-0.0132	0.0546	0.1349	0.81	
10-Apr	0.02428	0.06848	0.0474	0.04208	0.054	0.0504	0.10404	0.1511	0.68	
11-Apr	0.02172	0.0644	0.0468	0.04112	0.0606	0.05448	0.101	0.1668	0.60	
12-Apr	0.01584	0.04904	0.03888	0.048	0.0518	0.06888	0.08716	0.1774	0.69	

Table 3-6. Daily ET_c values, ET_o and daily K_c values for Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*) derived from the VWC data and used for calculating the monthly average K_c. Days were selected according to the refining approach described in the Methods chapter. ET_c 1 – ET_c 6 indicate ET_c values calculated for that day from VWC measured at each of the six depths allowed by the Sentek soil moisture probe.

Date	*ET_c 1* *(in/day)*	*ET_c 2* *(in/day)*	*ET_c 3* *(in/day)*	*ET_c 4* *(in/day)*	*ET_c 5* *(in/day)*	*ET_c 6* *(in/day)*	*ET_c Sum* *(in/day)*	*ET_o* *(in/day)*	*K_c sum* *(in/day)*	*Averaged Monthly Kc*
15-May	1.416	0.84	0.564	0.246	0.069	0.039	3.174	0.2083	0.60	**0.57**
16-May	1.027	0.524	0.3462	0.111	0.112	0.028	2.1482	0.2118	0.41	
17-May	1.009	0.485	0.3552	0.065	0.125	0.079	3.1182	0.1993	0.63	
23-May	0.5092	0.6198	0.3014	0.157	0.147	0.055	1.7894	0.1954	0.66	
24-May	0.3347	0.65	0.2715	0.13	0.17	0.133	2.6892	0.2196	0.58	
10-Jun	1.129	0.913	0.876	0.429	0.075	0.033	3.455	0.1656	0.83	**0.65**
17-Jun	2.072	0.6435	0.651	0.224	0.068	0.038	3.6965	0.2354	0.63	
21-Jun	0.635	0.4515	0.576	0.254	0.053	0.005	1.9745	0.1573	0.51	
25-Jun	0.9899	1.157	0.571	0.175	0.034	0.035	2.9619	0.1617	0.73	
3-Jul	0.739	1.09	0.546	0.025	0.014	-0.006	2.408	0.1251	0.77	**0.75**
8-Jul	0.622	0.934	0.509	0.112	0.112	0.079	2.368	0.0646	1.00	
17-Jul	0.556	0.92	0.672	0.22	0.147	0.139	2.654	0.1827	0.58	
25-Jul	0.94	1.293	0.658	0.608	0.395	0.03	3.924	0.1983	0.79	
26-Jul	0.78	1.553	0.731	0.467	0.234	0.098	3.863	0.1942	0.79	
28-Jul	0.606	0.948	0.54	0.298	0.171	0.025	2.588	0.1761	0.59	
29-Jul	0.55	1.18	0.722	0.364	0.298	0.201	3.315	0.1761	0.75	
4-Aug	0.683	0.78	0.499	0.115	0.042	-0.012	2.107	0.1127	0.74	**0.67**
8-Aug	0.637	0.523	0.416	0.17	0.133	0.115	1.994	0.1429	0.56	
18-Aug	1.061	1.377	0.578	0.382	0.261	0.202	3.861	0.1899	0.81	
19-Aug	0.828	0.838	0.392	0.244	0.274	0.189	2.765	0.2078	0.53	
26-Aug	0.891	0.601	0.453	0.102	0.091	0.042	2.18	0.1358	0.64	
29-Aug	0.71	0.718	0.572	0.056	0.014	-0.03	2.04	0.1079	0.76	
2-Sep	1.219	0.899	0.668	0.052	-0.021	-0.043	2.774	0.1744	0.64	**0.66**
3-Sep	0.925	0.669	0.564	0.118	0.07	0.073	2.419	0.1375	0.70	
5-Sep	0.704	0.552	0.517	0.133	0.126	0.531	2.563	0.1822	0.56	
9-Sep	2.68	0.868	-0.409	-0.204	-0.138	-0.113	2.684	0.0839	1.02	
10-Sep	1.176	0.921	0.731	0.051	0.013	0	2.892	0.1457	0.79	
11-Sep	0.843	0.7	0.611	0.077	0.049	0.024	2.304	0.1743	0.53	
17-Sep	1.111	0.71	0.583	0.071	0.076	-0.012	2.539	0.0742	1.03	
21-Sep	0.526	0.861	0.478	-0.021	-0.021	-0.048	1.775	0.1317	0.54	
23-Sep	0.863	0.64	0.454	0.016	-0.091	-0.073	1.809	0.1375	0.53	
24-Sep	0.841	0.66	0.613	0.149	0.014	0.097	2.374	0.1551	0.61	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly Kc***
25-Sep	0.606	0.506	0.472	0.103	0.091	0.145	1.923	0.1535	0.51	
26-Sep	0.622	0.473	0.445	0.159	0.111	0.138	1.948	0.1422	0.55	
27-Sep	0.568	0.485	0.435	0.158	0.133	0.125	1.904	0.1417	0.54	
1-Oct	0.506	0.406	0.347	0.141	0.09	0.107	1.597	0.1162	0.55	**0.70**
10-Oct	0.894	1.045	0.737	0.097	0.028	0.018	2.819	0.1202	0.94	
11-Oct	0.681	0.704	0.557	0.108	0.028	0.006	2.084	0.1136	0.73	
12-Oct	0.551	0.501	0.483	0.112	0.091	0.095	1.833	0.0915	0.80	
13-Oct	0.578	0.462	0.424	0.081	0.083	0.06	1.688	0.1205	0.56	
14-Oct	0.49	0.423	0.398	0.116	0.055	0.059	1.541	0.1223	0.50	
15-Oct	0.501	0.439	0.377	0.107	0.083	0.066	1.573	0.1161	0.54	
19-Oct	0.42	0.284	0.252	0.101	0.097	0.06	1.214	0.0876	0.55	
30-Oct	0.78	0.95	0.681	0.041	-0.028	-0.012	2.412	0.0994	0.96	
2-Nov	0.556	0.49	0.447	0.046	0.048	0.083	1.67	0.0785	0.85	**0.78**
3-Nov	0.482	0.414	0.401	0.045	0.035	0.042	1.419	0.082	0.69	
7-Nov	0.727	0.399	0.345	0.051	0.035	0.012	1.569	0.067	0.93	
8-Nov	0.617	0.403	0.357	0.04	0.034	0.036	1.487	0.0975	0.61	
9-Nov	0.603	0.449	0.358	0.081	0.083	0.029	1.603	0.0847	0.75	
10-Nov	0.608	0.481	0.39	0.117	0.062	0.065	1.723	0.0741	0.93	
11-Nov	0.419	0.435	0.372	0.166	0.151	0.123	1.666	0.0767	0.86	
17-Nov	0.339	0.307	0.252	0.075	0.075	0.047	1.095	0.0702	0.62	
1-Dec	0.159	0.169	0.109	0.079	0.088	0.088	0.692	0.0501	0.55	**0.55**
2-Dec	0.115	0.141	0.138	0.074	0.068	0.052	0.588	0.0634	0.37	
3-Dec	0.12	0.153	0.126	0.059	0.034	0.035	0.527	0.0534	0.39	
14-Dec	0.494	0.183	0.073	0.015	-0.047	0.017	0.735	0.0433	0.67	
15-Dec	0.416	0.301	0.195	0.029	0.067	-0.046	0.962	0.0647	0.59	
16-Dec	0.33	0.271	0.213	0.093	0.02	0.057	0.984	0.0708	0.56	
17-Dec	0.196	0.268	0.207	0.024	0.04	0.035	0.77	0.0498	0.62	
26-Dec	0.431	0.491	0.447	0.151	0.123	0.088	1.731	0.0706	0.98	
28-Dec	0.284	0.312	0.295	0.1	0.074	0.035	1.1	0.0551	0.79	
29-Dec	0.104	0.344	0.304	0.109	0.055	0.064	0.98	0.0885	0.44	
27-Jan	0.27	0.321	0.31	0.143	0.121	0.197	1.362	0.0794	0.69	**0.60**
28-Jan	0.175	0.219	0.236	0.105	0.171	0.177	1.083	0.0838	0.53	
31-Jan	0.261	0.302	0.296	0.156	0.106	0.182	1.303	0.0988	0.54	
1-Feb	0.475	0.436	0.372	0.167	0.155	0.181	1.786	0.0919	0.77	**0.58**
2-Feb	0.466	0.444	0.38	0.211	0.232	0.175	1.908	0.1099	0.69	
3-Feb	0.317	0.408	0.364	0.165	0.168	0.181	1.603	0.1133	0.56	
14-Feb	0.327	0.271	0.222	0.041	0.036	0.067	0.964	0.0909	0.42	
15-Feb	0.562	0.464	0.364	0.145	0.063	0.09	1.688	0.0928	0.72	

Date	***ET_c 1*** *(in/day)*	***ET_c 2*** *(in/day)*	***ET_c 3*** *(in/day)*	***ET_c 4*** *(in/day)*	***ET_c 5*** *(in/day)*	***ET_c 6*** *(in/day)*	***ET_c Sum*** *(in/day)*	***ET_o*** *(in/day)*	***K_c sum*** *(in/day)*	***Averaged Monthly Kc***
16-Feb	0.526	0.496	0.432	0.18	0.161	0.151	1.946	0.113	0.68	
17-Feb	0.477	0.496	0.427	0.21	0.223	0.15	1.983	0.1326	0.59	
20-Feb	0.83	0.693	0.56	0.129	0.021	0.072	2.305	0.1192	0.77	
21-Feb	0.564	0.597	0.521	0.133	0.125	0.059	1.999	0.1221	0.65	
23-Feb	0.258	0.317	0.314	0.107	0.097	0.114	1.207	0.1531	0.31	
24-Feb	0.365	0.319	0.311	0.101	0.048	0.083	1.227	0.1185	0.41	
25-Feb	0.223	0.299	0.271	0.091	0.145	0.107	1.136	0.1145	0.39	
1-Mar	0.37	0.07	0.038	0.031	0.027	0	0.536	0.0431	0.49	**0.61**
4-Mar	0.529	0.384	0.285	0.08	0.076	0.077	1.431	0.1287	0.45	
17-Mar	0.9	0.55	0.456	0.076	0.061	0.053	2.096	0.1139	0.73	
22-Mar	0.913	0.918	0.713	0.252	0.223	0.247	3.266	0.1794	0.72	
25-Mar	0.494	0.357	0.315	0.087	0.097	0.095	1.445	0.0812	0.71	
29-Mar	0.734	0.515	0.407	0.161	0.164	0.13	2.111	0.1495	0.56	
4-Apr	0.963	0.679	0.622	0.096	0.096	0.071	2.527	0.1663	0.60	**0.66**
9-Apr	0.887	1.184	0.534	0.194	0.176	0.825	3.8	0.1923	0.79	
12-Apr	0.924	0.657	0.601	0.2	0.166	0.197	2.745	0.1774	0.61	
13-Apr	0.67	0.492	0.446	0.108	0.159	0.162	2.037	0.1777	0.46	
15-Apr	0.922	0.533	0.459	0.137	0.138	0.155	2.344	0.1116	0.84	
17-Apr	0.478	0.41	0.4	0.111	0.137	0.065	1.601	0.092	0.69	

3.2 K_c Curves

3.2.1 Tall fescue

Data for creating the tall fescue K_c curve were collected from a single commercial field. The curve is shown in Figure 3-1. The data used to create Figure 3-1 are shown in Table 3-7. Figure 3-2 compares the tall fescue K_c curve developed in this study to K_c curves developed by Pinnix and Miller (2019) for May-October for two years. The three curves compare very favorably. Differences can be attributed to air temperature ranges, solar radiation, and in general, changes in weather trends. Pinnix and Miller (2019), suggested that an average of August and October coefficients maybe better than the September coefficients for scheduling irrigation in September. In this study, the September coefficient is almost the average of the August and October coefficients.

In some other studies, other ranges of K_c for Tall fescue have been published. Ervin and Koski (1998), reported K_c from 0.50 to 0.80. results might be different according to the water availability conditions.

For instance, Smeal et al. (2001) reported crop coefficients for tall fescue ranging from 0.05 to 0.72, in water-stressed condition.

Table 3-7. Average monthly ET_o, ET_c and K_c for tall fescue

Month	**Average ET_o (in/day)**	**K_c**	**ET_c (in/day)**
January	0.04	0.71	0.03
February	0.08	0.72	0.06
March	0.10	0.70	0.07
April	0.14	0.76	0.10
may	0.16	0.67	0.11
June	0.17	0.68	0.11
July	0.16	0.81	0.13
August	0.15	0.68	0.10
September	0.12	0.72	0.08
October	0.12	0.79	0.09
November	0.06	0.50	0.03
December	0.04	0.40	0.02

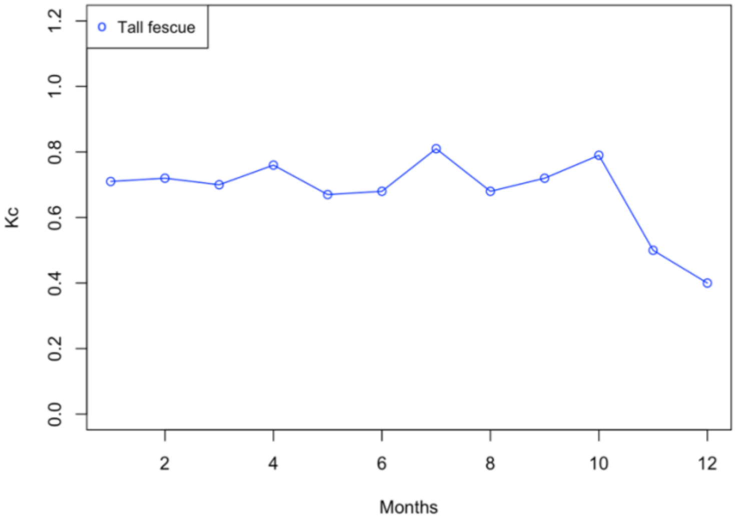


Figure 3-1. Tall fescue K_c curve, using average monthly K_c shown in table 2-7.

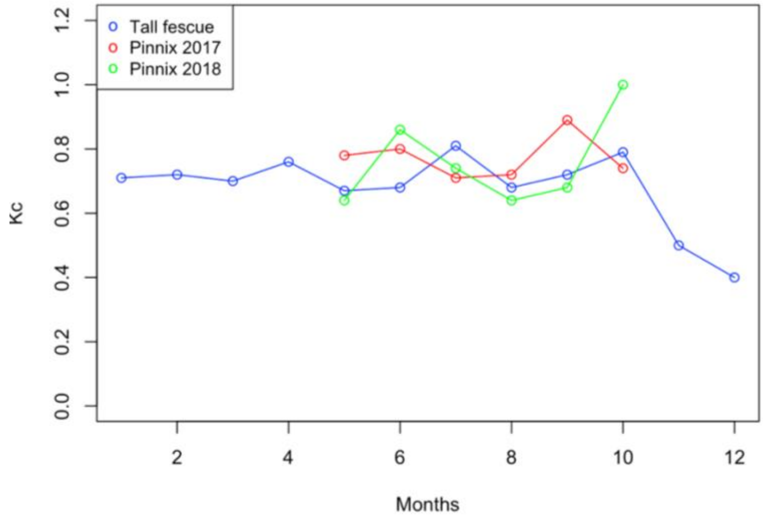


Figure 3-2. A comparison among resulted K_c curve for tall fescue with the curves published by Pinnix and Miller (2019) for two years, 2017 and 2018 for months of May to October.

3.2.2 Bahiagrass

In this study, data were collected from two commercial Bahiagrass fields – one irrigated and one rainfed (Figure 3-3). The highest daily water use occurred between June to August, with a peak in August. Crop coefficients range from 0.55 to 0.88 for field 1 (irrigated), 0.38 to 0.59 for field 2 (non-irrigated), and 0.42 to 0.79 in average. The data used to create Figure 3-3 are shown in Table 3-8. A study by Wherley et al. (2015) showed that K_c ranges varied from 0.47 to 0.92 for Bahiagrass. It should be mentioned that K_c values determined under stress conditions may be site specific values and cannot be transferable to other locations.

As with the two individual Bermudagrass K_c curves, the two Bahiagrass K_c curves were averaged to produce an average Bahiagrass K_c curve (Figure 3-4). This approach is valid even though one field was irrigated and the other rainfed because crop water use values for the development of K_c values were used only for periods of adequate soil moisture. The average K_c curve was compared to a study conducted by Jia et al. (2009) (Figure 3-5) in the southeastern U.S. in which they estimated K_c values for well-watered Bahiagrass based on Eddy covariance measurements and suggested the K_c values shown in Table 2-1. These results demonstrate that K_c for Bahiagrass fluctuates throughout the year, and during peak growth periods is considerably greater than the commonly recommended warm season turfgrass K_c of 0.6 to 0.65 (McCarty, 2011).

For both fields grassed with Bahigrass, averaged monthly ET_o, K_c, and ET_o are shown in table 3-8. The averaged evapotranspiration and crop coefficients are also included, which are also used to draw the averaged curve illustrated in figure 3-4.

Table 3-8. Monthly ET_o, ET_c, and Kc values for irrigated and non-irrigated Bahiagrass, and the average ET_c and Kc values of two Bahiagrass sites.

Month	**Average ETo (in/day)**	**Irrigated Bahiagrass**		**Non-irrigated Bahiagrass**		**Average**	
		K_C	**ET_C (in/day)**	**K_C**	**ET_C (in/day)**	**K_C**	**ET_C (in/day)**
January	0.06	0.56	0.03	0.38	0.02	0.42	0.03
February	0.09	0.55	0.05	0.47	0.04	0.51	0.05
March	0.13	0.60	0.08	0.59	0.08	0.59	0.08
April	0.16	0.69	0.12	0.48	0.07	0.58	0.09
May	0.2	0.86	0.17	0.48	0.10	0.69	0.14
June	0.18	0.88	0.16	0.51	0.10	0.75	0.14
July	0.16	0.80	0.13	0.56	0.09	0.68	0.11
August	0.16	0.87	0.14	0.59	0.09	0.79	0.13
September	0.14	0.84	0.12	0.45	0.06	0.68	0.09
October	0.11	0.65	0.07	0.36	0.05	0.58	0.06
November	0.08	0.56	0.05	0.30	0.02	0.45	0.04
December	0.05	0.67	0.03	0.34	0.02	0.51	0.03

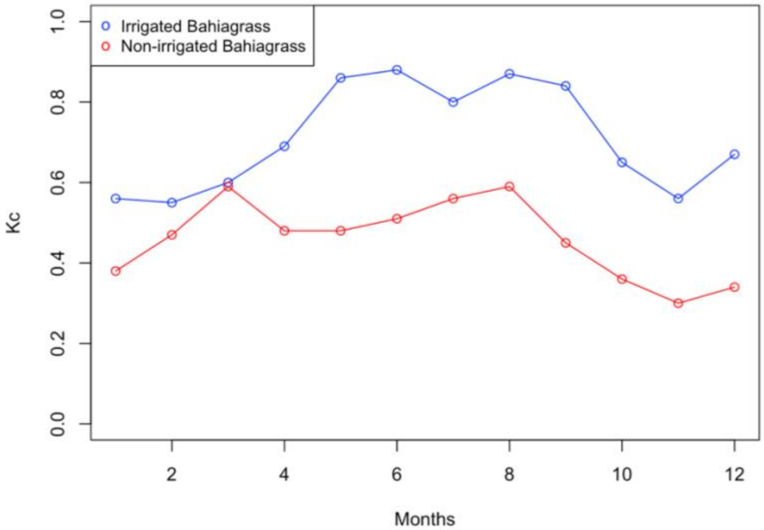


Figure 3-3. K_c curves for irrigated and non-irrigated Bahiagrass using the average monthly K_c values in Table 3-8.

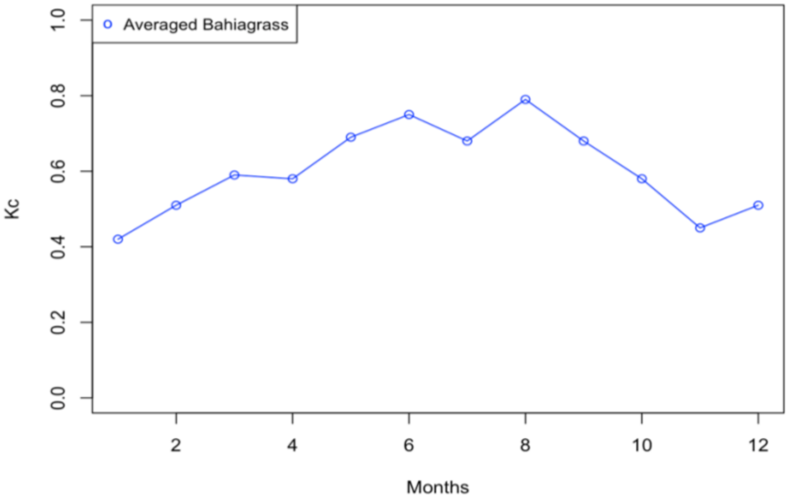


Figure 3-4. Bahiagrass K_c curve using the average K_c values of the two Bahiagrass

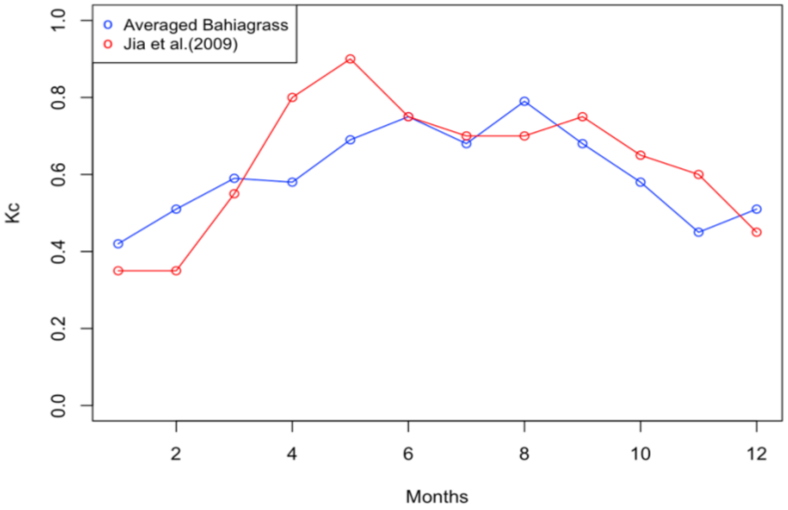


Figure 3-5. A comparison between average K_c curve for Bahiagrass with the curve published by Jia et al. (2009).

3.2.3 Bermudagrass

Two Bermudagrass cultivars were evaluated in this study: Tifton 85 Bermudagrass (*Cynadon dactylon*) and Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*). K_c curves were developed for each cultivar (Figure 3-6). K_c values ranged from 0.58 to 0.81 for Tifton 85 Bermudagrass and 0.55 to 0.78 for Alicia Bermudagrass. The data used to create Figure 3-6 are shown in Table 3-9. Wherley et al. (2015), also reported a K_c range of 0.33 to 0.90 for Bermudagrass. Brown et al. (2001) reported a maximum Kc of 0.83 in September.

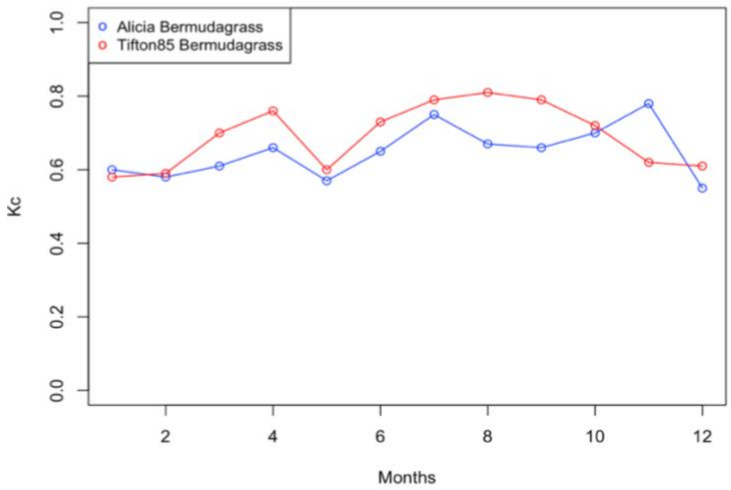


Figure 3-6. K_c curves for Tifton 85 Bermudagrass (*Cynadon dactylon*) and Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*) using the average monthly K_c values in Table 2-9.

Table 3-9. Monthly ET_o, ET_c, and Kc values for Tifton 85 Bermudagrass (*Cynadon dactylon*) and Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*), and the average ET_c and Kc values of Tifton 85 Bermudagrass (*Cynadon dactylon*) and Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*).

Month	**Average ET_O (in/day)**	**Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*)**		**Tifton 85 Bermudagrass (*Cynadon dactylon*)**		**Averaged**	
		K_C	**ET_C (in/day)**	**K_C**	**ET_C (in/day)**	**K_C**	**ET_C (in/day)**
January	0.06	0.60	0.04	0.58	0.03	0.59	0.03
February	0.09	0.58	0.05	0.59	0.05	0.58	0.05
March	0.13	0.61	0.08	0.70	0.09	0.65	0.08
April	0.17	0.66	0.11	0.76	0.13	0.71	0.12
May	0.21	0.57	0.12	0.60	0.12	0.58	0.12
June	0.19	0.65	0.12	0.73	0.14	0.69	0.13
July	0.17	0.75	0.13	0.79	0.13	0.77	0.13
August	0.16	0.67	0.10	0.81	0.13	0.74	0.11
September	0.14	0.66	0.09	0.79	0.11	0.72	0.10
October	0.11	0.70	0.07	0.72	0.07	0.71	0.07
November	0.08	0.78	0.06	0.62	0.05	0.70	0.05
December	0.06	0.55	0.03	0.61	0.03	0.58	0.03

The data used for developing the K_c curves for these two cultivars were collected from two large plots located adjacent to each other. Consequently, weather conditions were identical for both. Data for temperature, evapotranspiration, rainfall, wind speed, and solar radiation for the study period (May 2021 to April 2022) are provided in Figure 3-7(a-e). These data may help in interpreting the reasons for the fluctuation in the curves and the relatively large differences between them from January - April. For example, the periods in which the minimum temperature reaches negative values may indicate periods of dormancy and the two bermudagrasses may respond differently to these environmental conditions. Specifically, the characteristics of the cultivars, such as root development, stomatal characteristics, canopy configuration, and growth rate, may affect the response of the grass under cooler temperatures that fluctuate between freezing and T_{base} (ranging from 12.5 to 13.2°C for bermudagrass cultivars).

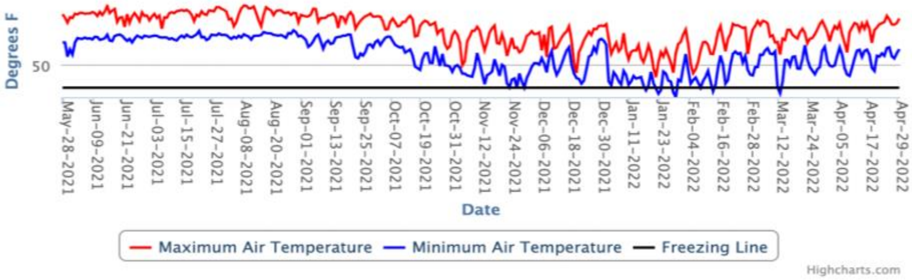


Figure 3-7(a). Maximum, minimum air temperature fluctuations during the study period (May 2021-April 2022), (www.georgiaweather.net).

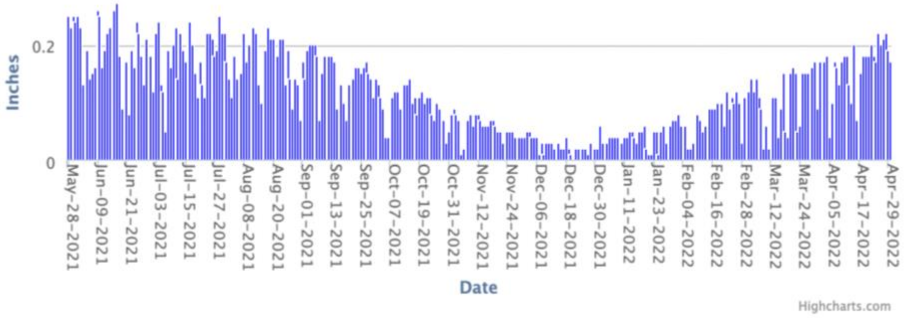


Figure 3-7(b). Evapotranspiration fluctuations during the study period (May 2021-April 2022), (www.georgiaweather.net).

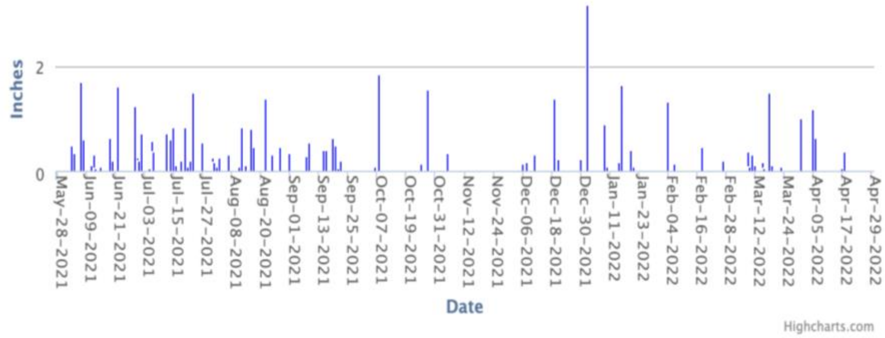


Figure 3-7(c). Rainfall records during the study period (May 2021-April 2022), (www.georgiaweather.net).

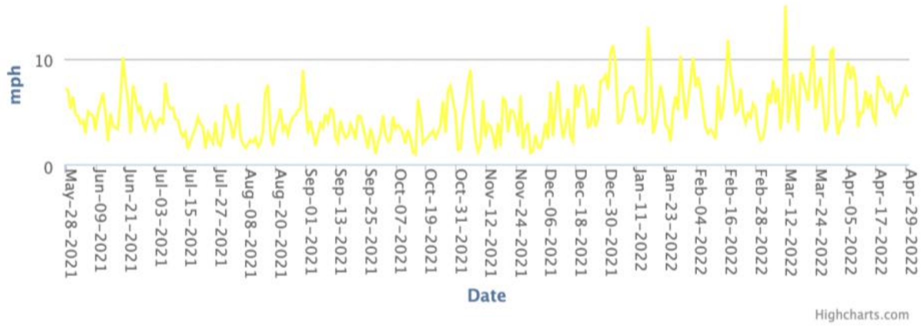


Figure 3-7(d). Windspeed records during the study period (May 2021-April 2022), (www.georgiaweather.net).

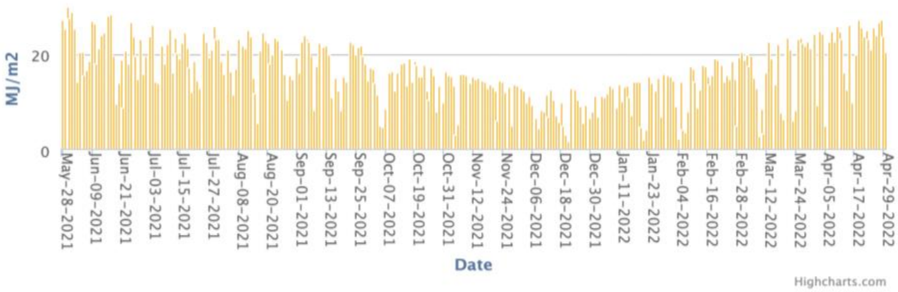


Figure 3-7(e). Solar radiation fluctuations during the study period (May 2021-April 2022), (www.georgiaweather.net).

Because the DST will include a single K_c curve for Bermudagrass, monthly values for the individual curves were averaged to create an average Bermudagrass K_c curve as shown in Figure 3-8. Figure 3-9 shows K_c curves from the literature and the average Bermudagrass K_c curve from this study for comparison purposes. Although the curves from the literature are for portions of a calendar year only, in general, the trends are similar for all curves indicating that the average curve developed for this study which represents environmental conditions in southern Georgia and northern Florida can be used for the DST.

Kopec et al. (1991), suggest bermudagrass K_c values decrease from ~0.83 in mid-summer to 0.73 during the fall, when growth declines as the grass progress into dormancy, which is in accordance with some other studies (Brown et al., 2001). Qian et al. (1996), did not compute K_c in their work, but report that the slope of the regression line relating ET_c of Midiron to Penman-Monteith ET_o was equal to 0.80. Devitt et al. (1992), found K_c ranged from 0.82 to 0.89.

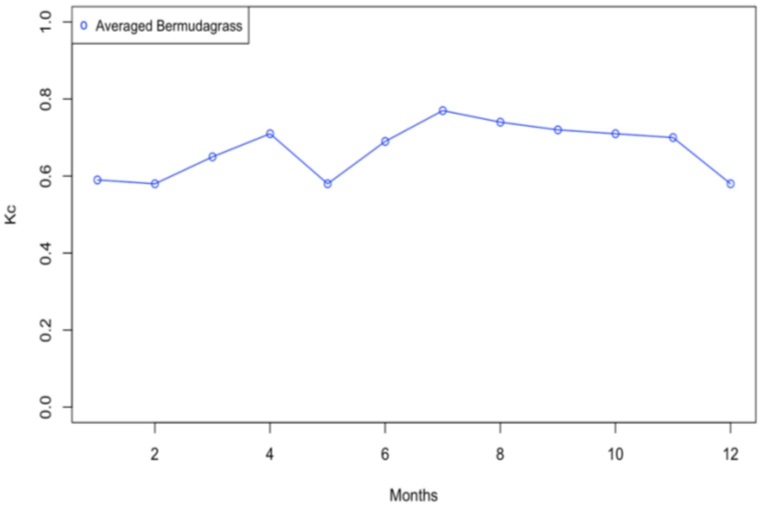


Figure 3-8. Average Bermudagrass K_c curve resulted from two curves plotted in Figure 3-6.

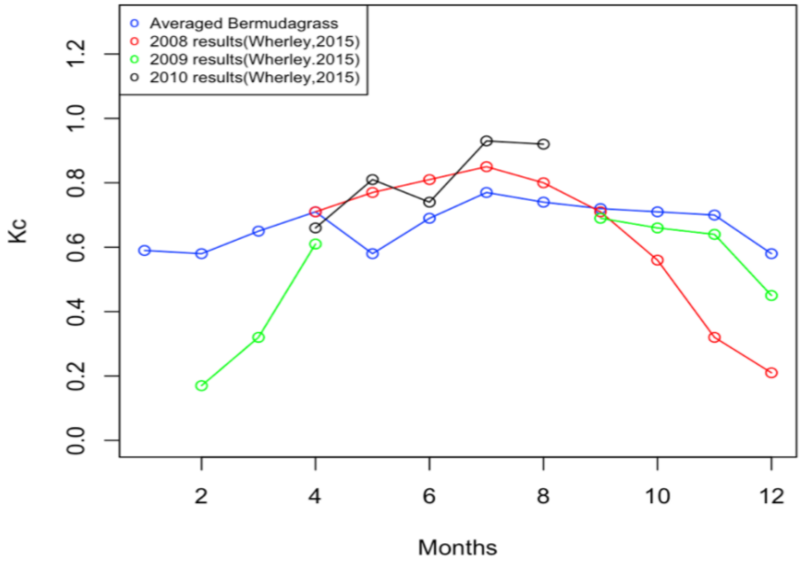


Figure 3-9. A comparison among average K_c curve of Tifton 85 Bermudagrass (*Cynadon dactylon*) and Alicia Bermudagrass (*C.dactylon× C.nlemfuensis*) with Wherley et al. (2015) crop coefficient curves for Bermudagrass in a three year study in 2008,20009, and 2010.

4 Conclusion

Overall, the K_c curves developed during this study compared well to similar curves reported in the literature. The K_c curves reported here were developed from 12 consecutive months of data collection spanning two calendar years (May 2021-April 2022). Consequently, the K_c curves are a function of the environmental conditions experienced during those 12 months. Environmental conditions can significantly affect forage development and water use. As an example, Figure 4-1 illustrates GDD accumulation at the tall fescue site for 2020 and 2021. The difference in GDD accumulation between the two years is 6.9%. Additional years of data collection are needed to validate and likely adjust the Kc curves reported here. Although collecting additional data collection is beyond the scope of this thesis, the project is ongoing and additional years of data will be collected.

As described earlier, there is relatively little literature available on daily water use or K_c values for forages. Most of the available literature is for warm-season turfgrasses. Dr. Lisa Baxter, a forage specialist at the University of Georgia, USA, indicated that forage researchers commonly utilize turfgrass data for comparison because although the cultivars are different, the species is the same and comparisons are appropriate. It should be taken into consideration that some K_c values in the literature were developed under limited irrigation, and it is likely the plots were not well-watered during the entire study as part of their objectives. The K_c values may be appropriate for water conservation in their location of study, but it may not be appropriate to extend them to other regions.

The methodology and the specific conditions of determining the crop coefficient curves in various studies, can impact the results. Consequently, when comparing the results of different studies, the methods are important criteria. In each of the steps of collecting data by soil sensors, estimating ET rates, making decisions for data classification and refinement, there are possibilities to change the results.

In some cases, for development of the crop coefficient curves, some data points were not used because they were outliers. It may be helpful to study the cause of those outliers and have a database for future crop coefficient computing.

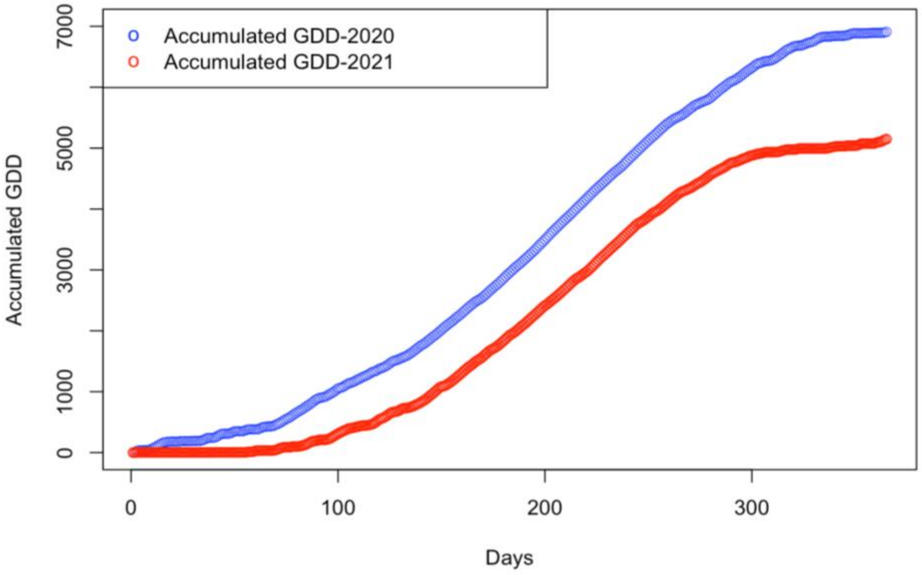


Figure 4-1. GDD accumulation at the tall fescue site for 2020 and 2021.

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