Irrigation Science
https://doi.org/10.1007/s00271-021-00737-z

ORIGINAL PAPER

Water requirement and crop coefficient of three chickpea cultivars for the edaphoclimatic conditions of the Brazilian savannah biome

Kátia Freitas Silva[1] · **Diogo Henrique Morato de Moraes**[2] · **Marcio Mesquita**[2] · **Henrique Fonseca Elias de Oliveira**[1] · **Warley Marcos Nascimento**[3] · **Rafael Battisti**[2] · **Rilner Alves Flores**[2]

Received: 10 December 2020 / Accepted: 20 April 2021

Abstract

Chickpea (*Cicer arietinum* L.) is a very important legume crop mainly due to its nutritional properties, being cultivated in several countries. However, parameters on water consumption and crop coefficient (Kc) are limited by cultivar for irrigation management. Thus, this study aimed to determine the water requirements and Kc for three chickpea cultivars. The crop reference evapotranspiration (ETo) was estimated using the Penman–Monteith method with meteorological data recorded inside the greenhouse. Crop evapotranspiration (ETc) was obtained by weighing minilysimeters and soil moisture sensors. The Kc was determined by the ETc/ETo ratio. The chickpea cultivars evaluated were Cícero, BRS Aleppo, and BRS Cristalino. The average ETc throughout the cycle was 4.5, 4.1, and 4.5 mm days^{-1} for cultivars Cícero, BRS Aleppo, and BRS Cristalino, respectively. The average ETc for the respective cultivars was 2.3, 2.5, and 2.4 mm days^{-1} in the initial phase, reaching 5.6, 4.5, and 5.4 mm days^{-1} in the crop phase of growth. The Kc values ranged from 0.38 to 1.00 for Cícero, 0.39 to 0.80 for BRS Aleppo, and 0.38 to 0.95 for BRS Cristalino. The cultivar Cícero showed higher Kc and higher water demand. The cultivar BRS Aleppo was the one with the lowest Kc and water demand, but longer duration of maximum value due to indeterminate growth habit. The variation in Kc correlated positively with the leaf number and crop phases patterns. This demonstrates the importance of determining Kc to increase efficiency in irrigation management by cultivar instead of adopting generalized Kc values.

Abbreviations

ETo	Reference evapotranspiration
ETc	Crop evapotranspiration
Kc	Crop coefficient
FAO	Food and Agriculture Organization
EMBRAPA	Brazilian Agricultural Research Corporation
FC	Field capacity
PWP	Permanent wilting point
DAP	Days after planting

Introduction

Chickpea (*Cicer arietinum* L.) is among the oldest and most widely consumed legumes, especially in tropical and subtropical regions. Chickpea is produced and consumed mainly in the Mediterranean, Middle East, Central Asia, and America (Mohammed et al. 2017). Chickpea consumption has been greatly stimulated, because it is a rich source of vitamins, amino acids, calcium, phosphorus, iron, magnesium, and potassium, and because it has protective effects against cardiovascular diseases, cancer, and diabetes (de Camargo et al. 2019). Grains are an alternative to nutritious food as they have 20–22% protein and are rich in fibers, minerals (phosphorus, calcium, magnesium, iron, and zinc), and β-carotene (Gaur et al. 2010).

Chickpea is characterized by having long roots, which allow access to soil water at greater depths, making it an attractive crop for rainfed agriculture (Kashiwagi et al. 2015). However, soil moisture correlates with nutrient availability for plants, thus affecting grain quality, especially with regard to protein levels (Wijewardana et al. 2019). Adequate soil moisture increases protein, starch, and fat content in

✉ Marcio Mesquita
marcio.mesquita@ufg.br

[1] Cerrado Irrigation Graduate Program, Goiano Federal Institute, GO-154, KM 3, Ceres 76300-000, Brazil

[2] Graduate Program in Agronomy, Federal University of Goiás, Avenida Esperança, Goiânia 74690-900, Brazil

[3] Embrapa Hortaliças, Brazilian Agricultural Research Corporation (Embrapa), Brasília, DF, Brazil

the grain (Kale et al. 2018; Kaplan et al. 2019). Therefore, managing the quantity and frequency of irrigation is essential to meet crop demand with greater water use efficiency, especially in arid and semi-arid regions (Talebnejad and Sepaskhah 2015). This is the case of winter cultivation in the Brazilian Savannah. In this region, accurate determination of water demand in cultivation systems is essential for hydrological management (Libardi et al. 2019), since drought periods generate conflict over water use between agriculture and other activities (Justino et al. 2019).

In the Brazilian Savannah, chickpea yield reached an average of 0.45 t ha^{-1} in rainfed conditions. Notwithstanding, the crop reached a yield of 3.00 t ha^{-1} in non-limiting water conditions (Artiaga et al. 2015). In this sense, irrigation management can include methods for estimating crop water requirement. The FAO-56 is considered a standard method to estimate reference evapotranspiration (ETo) (Allen et al. 1998). The potential crop evapotranspiration (ETc) is obtained by multiplying ETo with the crop coefficient (Kc) (ETo × Kc = ETc). Reference evapotranspiration (ETo) is estimated using local climate variables, while the crop coefficient (Kc) needs to be determined experimentally (Anapalli et al. 2019).

The Kc is obtained by the relation between ETc (measured) and ETo (measured or estimated), where ETc is affected by crop phenology, growth, and physiological traits (Gao et al. 2020). The values of Kc can define the use of water by the crop, where its value is essential to quantify water requirement for dimensioning irrigation systems and water management (Saeidi et al. 2021; Sousa et al. 2021). The Kc values change across plant growing stage depending on the canopy architecture and dynamics of the leaf area index (LAI), which affect solar radiation intercepted and stomatal control (Gong et al. 2020). It is important to highlight that Kc is quantify in condition of disease-free plants and well fertilized, growing under optimal soil water content (Allen et al. 1998).

The chickpea cultivars grown in Brazilian Savanna Biome have different growth habits, which affect the canopy architecture (de Medeiros et al. 2001). The cultivars differ in the crop height and leaf area index, associated with phenology (Moraes et al. 2019), and leaf types and size, which can influence the coupling between plant and atmosphere (Giordano and Nascimento 2005; Nascimento et al. 2014, 2017). Based on this, a general Kc across the specie can lead to an inefficiency estimating of irrigation demand, reducing water use efficiency and increasing yield losses (Martins et al. 2013; Anapalli et al. 2019).

In this context, we hypothesize that chickpea cultivars grown in Brazilian Savanna Biome have different Kc patterns *e* values throughout the phenology cycle due to their different growth habits and canopy architecture. Thus, the present study aims to (i) determine the water requirement of the three chickpea cultivars throughout the cycle; (ii) quantify the daily potential crop evapotranspiration (ETc) in greenhouse cultivation using weighing lysimeters and soil water content sensors; and (iii) determine the crop coefficient (Kc) through the ETc/ETo ratio.

Materials and methods

Study location

The experiment was conducted in a greenhouse in Goiânia city, Goiás State, Brazil, (16° 32′ S, 49° 21′ W, 730 m above sea level). The region has a tropical savanna climate with dry winter and rainy summer (A_w), according to the Köppen classification, with mean air temperatures ranging between 16 and 29 °C and total annual rainfall amount of 1500 mm, concentrated between October and March (Alvares et al. 2013).

Chickpea cultivars and experiment design

Three chickpea cultivars were used, namely BRS Aleppo, BRS Cristalino, and Cícero, developed by the Brazilian Agricultural Research Corporation (EMBRAPA). The cultivars have different characteristics, with good performance and adaptability under edaphoclimatic conditions in the Brazilian Savannah. The cultivars were characterized by cycle duration, growth habit, maximum plant height, leaf type, and observed yield (Table 1).

The experiment included three cultivars which were arrange followed the experimental design of randomized block, following recommendation for greenhouse experiment (Ghoulem et al. (2019). A total of 108 pots were used and distributed in 9 lines (12 pots by line), where measurements were done in the central lines to create the border lines (Supplementary Material—Figure S1). The pots were arranged in a spacing between plants and rows of 0.25 m, which represents the spacing used in mechanized crops, with

Table 1 Characteristics of the cultivar's chickpea Cícero, BRS Aleppo, and BRS Cristalino

Characteristic	Genotypes		
	Cícero	BRS Aleppo	BRS Cristalino
Cycle (days)	110	120	120
Growth habit	Erect	Semierect	Semierect
Height (cm)	45	66	84
Leaf type	Simple	Compound	Compound
Yield (t ha^{-1})	1.6–2.7	2.9–3.0	3.0

Adapted from Giordano and Nascimento (2005); Nascimento et al. (2014); and Nascimento et al. (2017)

a plant density of 16 plants m^{-2}. The cultivars had a total of 12 pots available for evaluation in central lines, where 4 replications were used to measured soil water moisture (three pots with soil moisture sensor e one with minilysimeter).

Substrate characteristics

The seeds were manually selected to remove those mechanically damaged. The seeds were sown directly in 8-L pots filled with 4.7 kg of a mix sand–clayey texture, including 90% of oxisol and 10% of sand, creating a substrate with proper fertilization conditions (Table 2). The substrate texture and total chemical content are shown in Table 2. The substrate had field capacity (FC) and the permanent wilting point (PWP) of 0.41 and 0.21 m^3 m^{-3}, respectively, resulting in a total available water of 200 mm m^{-3} (Table 2).

Irrigation management

Soil water was supplied using a drip irrigation system, which applied 4 L h^{-1} dripper per plant, located at 0.02 m beside of plant. Irrigation was performed based on the readings of capacitive soil moisture sensors (Soil Watch 10, Pino Tech, Poland), calibrated by Antunes Júnior (2018). These sensors were installed at 0.08 m in the substrate, with recordings of soil moisture every 5 min, and connected in an automated irrigation controller (Bristom DSC-210; Bristom Inc., Brazil). The irrigation was set to start when the soil water potential reached – 60 kPa (0.30 m^3 m^{-3}), applying water based on pulses, where each pulse turn-on the system for by 6 min (0.4 L pulse^{-1}). The system was turn-off when soil water reached the potential of – 15 kPa (0.41 m^3 m^{-3}). The irrigation was done manually in the begging of cycle (0–20 days), due to the low demand and higher evaporation from substrate surface. The automatic irrigation system had problem at 18 and 42 days after sowing, which required a higher amount of irrigation (20 mm) to fill the soil for optimal soil water content.

Table 2 Total chemical content, texture, field capacity (θ_{fc}), and permanent wilting point (θ_{pwp}) for the substrate used for chickpea cultivation

	Unit	Value
Chemical property		
Phosphorus (P)	mg kg^{-1}	29.30
Potassium (K)	mg kg^{-1}	315.40
Calcium (Ca)	mg kg^{-1}	499.50
Magnesium (Mg)	mg kg^{-1}	200.00
Sulphur (S)	mg kg^{-1}	481.50
Copper (Cu)	mg kg^{-1}	32.00
Iron (Fe)	mg kg^{-1}	2697.30
Organic matter	mg kg^{-1}	1697.80
Nitrogen (N)	mg kg^{-1}	180.00
pH (H_2O)	–	5.90
Physical property		
Sand	%	53.00
Silt	%	12.00
Clay	%	35.00
θ_{fc}	m^3 m^{-3}	0.41
θ_{pwp}	m^3 m^{-3}	0.21

Weather data and ETo

The meteorological data were collected inside the greenhouse, including: mean air temperature, mean relative humidity, wind speed at 2 m above the ground, and total solar radiation, with recordings every 5 min (Bristom EMS-210 PRO; Bristom Inc., Brazil). The data were converted for daily measurements and used to estimate the reference evapotranspiration (ETo) by the Penman–Monteith equation.

Potential crop evapotranspiration (ETc)

The potential crop evapotranspiration (ETc) was obtained from one weighing minilysimeters (Bristom BLC-2010; Bristom Inc., Brazil) and three capacitive soil moisture sensors by cultivar (See Supplementary Material—Figure S1 for details of location for each sensor). The minilysimeters were installed with positional adjustments in the greenhouse to ensure free fluctuation above the load cells supporting the pots, avoiding any external interference. The measurement was done every 5 min in the minilysimeters. The minilysimeters have an accurate to 0.05–0.1 g, and were previously calibrated according to the methods of Vilela et al. (2015). Three capacitive soil moisture sensors were installed for monitoring the soil water content, ensuring that at least four plants of each cultivar had the monitored evaporative demand (Fares and Polyakov 2006). ETc was obtained by the difference from the maximum and minimum soil water contents in the day obtained from minilysimeters and capacitive soil moisture sensors.

Determination of the crop coefficient

The crop coefficient (Kc) was obtained through the ratio between ETc, estimated by weighing minilysimeters and capacitive soil moisture sensors, and ETo, estimated by the Penman–Monteith equation, both on a daily scale, according to the single crop coefficient method (Eq. 1) (Allen et al. 1998):

$$\mathrm{K_c} = \frac{\mathrm{ETc}}{\mathrm{ETo}}, \tag{1}$$

where Kc is the crop coefficient (dimensionless), ETc is the potential crop evapotranspiration (mm day^{-1}), and ETo is the reference evapotranspiration (mm day^{-1}).

Data analysis

Crop coefficient (Kc) was determined as a function of cultivars and phenological phases of chickpea. The crop cycle was divided into four phases for analysis, defined according to the methodology of Doorenbos and Pruitt (1977), as follows: (I) initial phase: from the seedling emergence to the second multifoliate leaf has unfolded from the stem; (II) growth phase: from the third multifoliate leaf has unfolded from the stem to the nth multifoliate leaf has unfolded from the stem; (III) intermediate phase: from the early bloom, one open flower on the plant to full seed, all seeds fill the pod cavity which is rounded; and (IV) final phase: from the leaves start yellowing, and 50% of the pods have turned yellow to from the 90% of pods on the plant are golden-brow. In each phase was adjusted the splines equations to represent Kc values as a function of the growing degree days and days after sowing. Growing degree days (°C days^{-1}) were obtained by the method of Ometto (1981), using basal temperature of 4.5 °C for chickpea crop (Soltani et al. 2006). The Kc values and response curves throughout the cycle were compared with the reference values obtained by Allen et al. (1998) and Doorenbos and Pruitt (1977). The Kc values was adjusted in function of number of leaves, and number of leaves in function of growing degree days through regression analysis.

Results

Greenhouse weather

The maximum, mean, and minimum daily air temperature were, respectively, 33.4, 26.0, and 20.3 °C, during the experimental period. The air temperature range was almost of cycle inside of optimal range for chickpea, except at 33, 93, and 109 days after sowing (DAS) when the maximum air temperature exceeded the upper basal temperature for the crop (Fig. 1), with a maximum record of 46.7 °C. This occurred due to a failure in the greenhouse temperature control.

The mean solar radiation was 18.7 MJ m^{-2} in the greenhouse, ranging from 11.5 to 23.1 MJ m^{-2} during the experiment (Fig. 2). The mean relative air humidity was 82.1%, ranging from 72.1 to 98.0% (Fig. 2). For these climatic conditions, the accumulated ETo was 674.6 mm during the experimental period, with a daily variation between 3.60 and 7.00 mm days^{-1}, and mean of 5.80 mm days^{-1}. The ETo in phase I and II were quite similar for three tested cultivars, with a mean, respectively, of 5.78 and 5.75 mm days^{-1} (Supplementary Material—Table S1). The maximum value for ETo was near 7.00 mm days^{-1}, occurring in the beginning and ending of cycles (Fig. 2).

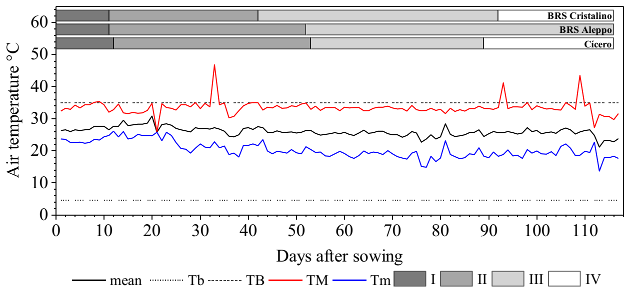


Fig. 1 Maximum (TM), mean, and minimum (Tm) air temperature in the greenhouse during the experimental period, and the lower (Tb) and upper (TB) basal temperature of the crop. The upper bars represent the crop phases I (initial), II (growth), III (intermediate), and IV (final) of the three chickpea cultivars

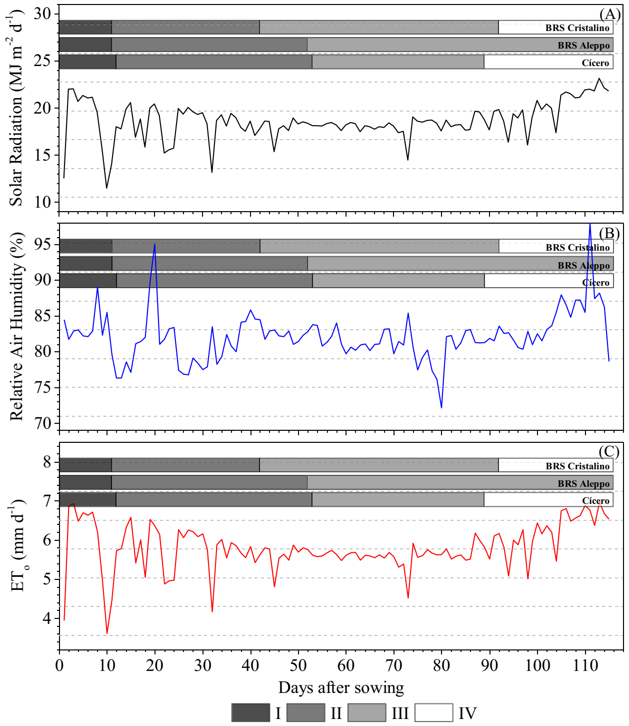


Fig. 2 Solar radiation (**a**), relative air humidity (**b**), and reference evapotranspiration (ETo) (**c**) during the experimental period. The upper bars represent the crop phases, I (initial), II (growth), III (intermediate), and IV (final) of the three chickpea cultivars

ETo followed a the reduction tendency from phases I to III, with an increase during phase 4, following the solar radiation value (Fig. 2b). In phase III, the mean ETo across cultivars ranged from 5.60 to 5.86 mm days^{-1}, highlighting that cultivar BRS Aleppo had a longer phase III than other cultivar with a not characterized phase IV. Cultivars Cícero and BRS Cristalino had a mean ETo in phase IV of 6.27 mm days^{-1} (Supplementary Material—Table S1).

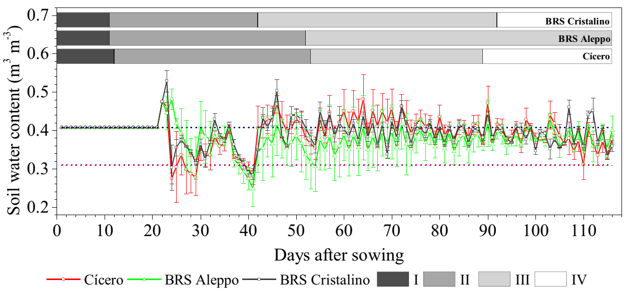


Fig. 3 Daily volumetric soil moisture during the experimental period as a function of days after sowing. The upper bars represent the crop phases, I (initial), II (growth), III (intermediate), and IV (final) of the three chickpea cultivars. The bars represent the standard deviation from four replication (1 minilysimeter and 3 sensors by cultivar)

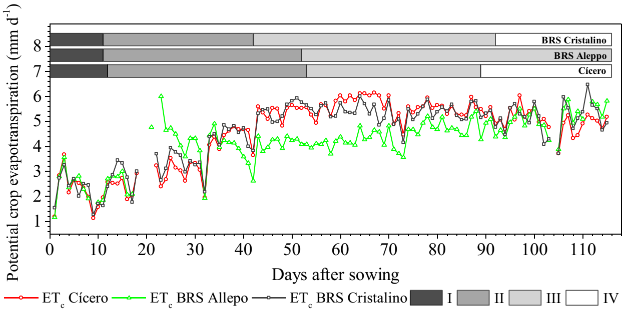


Fig. 4 Potential crop evapotranspiration (ETc) during the experimental period for cultivars Cícero, BRS Aleppo, and BRS Cristalino as a function of days after sowing. The upper bars represent the crop phases, I (initial), II (growth), III (intermediate), and IV (final) of the three chickpea cultivars

Soil water content

Irrigation management aimed to keep the soil water content within the ideal range for the crop, between field capacity and the potential of – 60 kPa, ensuring water availability.

The irrigation management maintained the water content in the optimal range during 95% of the crop cycle (Fig. 3). The total irrigation applied was 493 mm, with daily amount applied ranging from 1.1 to 22.2 mm day^{-1} across crop cycle.

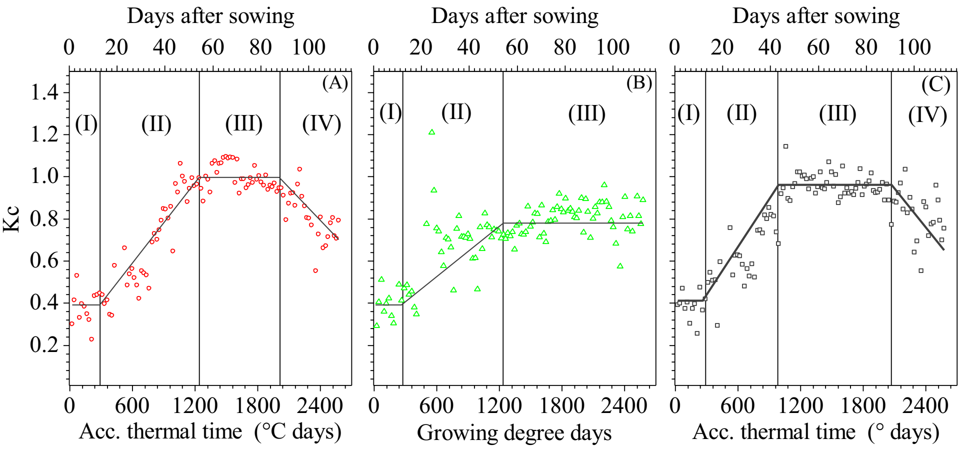
Potential crop evapotranspiration (ETc)

The ETc was quite similar for different cultivars in phase I (Fig. 4), with mean around of 2.2 mm days^{-1} (Supplementary Material—Table S1). Cultivars Cícero and BRS Cristalino had a very similar pattern for ETc across the cycle (Fig. 4), with a, respectively, mean of 3.9 and 3.7 mm days^{-1}; and 5.6 and 5.4 mm days^{-1}, for phase II and III (Supplementary Material—Table S1). The cultivar BRS Aleppo had a rate of ETc increase lower than that of other cultivars during phase II (Fig. 4). This cultivar had an initial and final ETc during phase III, respectively, of 2.3 and 4.7 mm days^{-1} (Fig. 4). In phase IV, cultivars Cícero and BRS Cristalino had, respectively, a mean ETc of 5.0 and 5.1 mm days^{-1} (Supplementary Material—Table S1).

Determination of the crop coefficient (Kc)

Cultivars Cícero (Fig. 5a) and BRS Cristalino (Fig. 5c) showed a classic pattern of Kc evolution for the crop, with the initial values for phase I being 0.38 and 0.39, reaching the maximum point, respectively, of 1.00 and 0.95 during phase III (Fig. 5). At phase IV, these two cultivars showed reduced growth and leaf senescence, decreasing Kc values to final values of 0.75 and 0.65, respectively, for cultivars Cícero and BRS Cristalino. The cultivar BRS Aleppo showed a different Kc pattern by keeping growth, characterized by phase III and a nonoccurrence of phase IV. The initial Kc value was similar than other cultivares, with 0.39 in phase II, with a gradual increase during phase II until reach a maximum value of 0.8 in phase III (Fig. 5).

Fig. 5 Chickpea crop coefficient (Kc) for cultivars Cícero (**a**), BRS Aleppo (**b**), and BRS Cristalino (**c**) as a function of the growing degree days (°C days) and in days after sowing (DAS). The period are divided in phases I (initial), II (growth), III (intermediate), and IV (final)



The Kc values were adjusted for each cultivar as a function of the days after sowing (DAS) and the growing degree days (°C days), considering the spline functions (Table 4). The transition from phases I to II occurred at 12 DAS for cultivar Cícero, with 289 °C days; from II to III at 52 DAPS, with 1240 °C days; and from III to IV at 89 DAS, with 2008 °C days, with cycle ending at 116 DAS and 2578 °C days. BRS Cristalino had four phases, where transition from phase I to II occurred at 11 DAS, with 264 °C days; from II to III at 42 DAS, with 994 °C days; and from III to IV at 92 DAS, with 1774 °C days, finishing the cycle at 116 DAS, with a total accumulated of 2578 °C days (Table 4). BRS Aleppo had two points of intersection (Fig. 5b), which represent the transition from phase I to II occurred at 11 DAS, with 264 °C days, and from II to III at 52 DAS, with 1218 °C days. This cultivar had plants with an active growth until the end of the experiment.

KC had a smaller differed between cultivars for phases I, II, and IV, with a deviations lower than 0.05. The Kc values obtained for chickpea cultivars were compared with those recommended by FAO (Allen et al. 1998; Doorenbos and Pruitt 1977) (Fig. 6). The difference was a longer period of phase I by FAO (Allen et al. 1998; Doorenbos and Pruitt 1977) when compared with cultivars Cícero, BRS Aleppo, and BRS Cristalino; however, the value is similar, around 0.40 (Fig. 6). In phase II, the three cultivars differed from the condition presented by FAO, which showed a rate of increase higher than that of the present experiment. The maximum Kc value occurred in phase III, where values of FAO and the cultivars Cícero and BRS Cristalino were close to 1.0, while FAO and cultivar Cícero had similar duration period for maximum value. The values reported by FAO show a more marked reduction rate in the maturation phase (IV) in comparison with the values of cultivars Cícero and BRS Cristalino (Fig. 6). On the other hand, BRS Aleppo, with its indeterminate growth pattern, presented results quite different from those of FAO, Cícero, and BRS Cristalino.

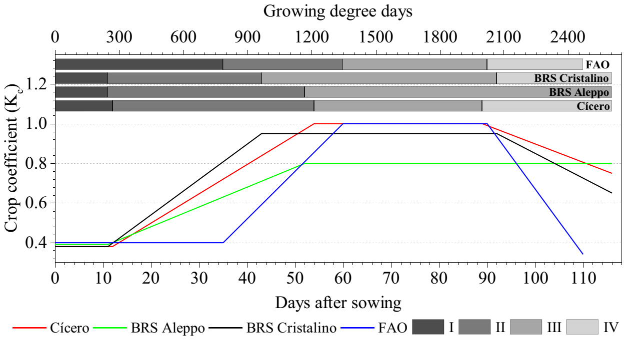


Fig. 6 Chickpea crop coefficient (Kc) for cultivars Cícero, BRS Aleppo, and BRS Cristalino compared to the values recommended by FAO (Allen et al. 1998; Doorenbos and Pruitt 1977). The phases are defined as initial (I), growth (II), intermediate (III), and final (IV). Note: the growing degree days sum is represented only for the cultivars of this study

Plant growth and Kc

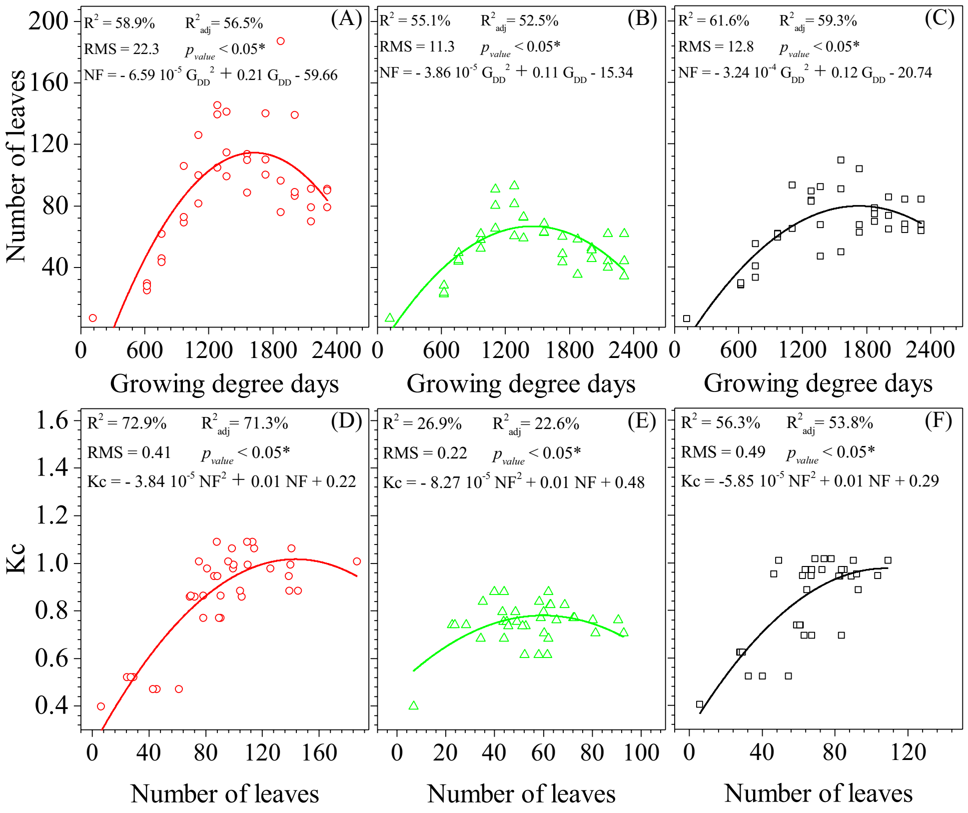
Plant growth was characterized by the number of leaves. Cultivar Cícero presented a higher number of leaves at 83 DAS, with a subsequent decrease in the number of leaves (Fig. 7a). Cultivar BRS Cristalino behaved similarly, with the highest number of leaves recorded at 68 DAS and successive decreases after that (Fig. 7c). Cultivar BRS Aleppo did not show a decreasing trend in the number of leaves (Fig. 7b). The number of leaves patterns correlate with the Kc values obtained for each cultivar. The highest Kc values were recorded during phase III (intermediate) (Fig. 5), when the number of leaves was high, with high evaporative demand (Fig. 7).

Table 4 Crop coefficient (Kc) by development phase adjusted using spline approach equations as a function of accumulated growing degree days (GDD, °C days)

Genotype	Crop phase[a]	Days	GDD (°C days)	Kc	R^2
Cícero	I	1–12	289	0.38	–
	II	13–53	1240	0.0007 × GDD + 0.1072	0.84
	III	54–89	2008	1	–
	IV	90–116	2578	− 0.0004 × GDD + 1.8037	0.45
BRS Aleppo	I	1–11	264	0.39	–
	II	12–52	1218	0.0002 × GDD + 0.5053	0.13
	III	53–116	1987	0.8	–
	IV	–	–	–	–
BRS Cristalino	I	1–11	264	0.38	–
	II	12–42	994	0.0005 × GDD + 0.3062	0.57
	III	43–92	1774	0.95	–
	IV	92–116	2578	− 0.0002 × GDD + 1.3423	0.10

[a] The period is divided in phases I (initial), II (growth), III (intermediate), and IV (final)

Fig. 7 Leaves number in function of growing degree days (**a**–**c**), and crop coefficient (Kc) in function of number of leaves (**d**–**f**) for chickpea cultivars Cícero (**a**, **d**), BRS Aleppo (**b**, **c**), and BRS Cristalino (**c**, **f**)



On the other hand, the lowest Kc values during the initial phase correlate with low number of leaves and low plant growth, showing that the leaf area index is directly proportional to Kc (Fig. 7). The Kc decreased markedly at 80 days after planting for cultivars Cícero and BRS Cristalino (Fig. 6). For cultivar BRS Aleppo, the Kc and the number of leaves varied little from 50 days after planting (Fig. 6).

Discussion

The microclimate and crop management affect the water requirement of plants (Contreras et al. 2017). In the experiment, the maximum temperature was near the upper limited of air temperature for chickpea (35 °C), but in some days reaching values above 40 °C (Fig. 1). The cultivars Cícero, BRS Aleppo, and BRS Cristalino reduced the ETc in these extremes weather days, where an increase in air temperature initially leads to plant responses by increasing stomatal conductance (Bartlett et al. 2016), but leading to close stomata when above upper limited temperature to avoid excessive loss of water by transpiration (Urban et al. 2017). Marin et al. (2016) verified that coffee, citrus, and sugarcane crops reduced Kc values with increase of ETo, resulted by stomatal closing due to high air temperature, vapor pressure deficit, and solar radiation. This pattern was observed for chickpea in days with higher air temperature, where further studies can be considered in the determination of Kc values based on ETo driving.

The weather in the greenhouse showed similar conditions than field cultivation. The Brazilian Savannah region has a mean annual air temperature between 23.0 and 26.5 °C, with solar radiation between 11.26 MJ m^{-2} and 29.86 MJ m^{-2} $days^{-1}$, and a mean crop reference evapotranspiration of 4.8 mm $days^{-1}$ (Meirelles et al. 2011; Alvares et al. 2013; Rodrigues et al. 2014; Ghoulem et al. 2019), which are favorable for chickpea grown (Artiaga et al. 2015). The weather conditions were similar to those other growing regions for chickpea, such as Australia, making the study applied for these regions. In that country, Pendergast et al. (2019) cultivated chickpeas under rainfed and irrigated conditions, observing a thermal amplitude of 37.8 °C, and an average ETc of 6.0 mm $days^{-1}$.

Chickpeas is a crop that adapt very well to tropical regions, showing good development and yield (Hoskem et al. 2017). Under these conditions, irrigation is essential for high yield and grain quality. In the Brazilian Savannah, rainfed areas are up to 85% less productive than irrigated areas (Artiaga et al. 2015), making the management of limited water resources and greater water use efficiency indispensable tools for sustainable agriculture (Xu et al. 2018). In this context, the Kc values diverge both from the Kc values recommended by FAO and from those obtained experimentally, reaching differences of up to 40% during crop development (Libardi et al. 2019). In legumes, the Kc values recommended by FAO underestimate crop evapotranspiration by up to 36%, while potential yield can be reduced by up to 12% due to lack of water (Odhiambo and Irmak 2012; Wei et al. 2015).

The Kc values observed for the chickpeas in this study for the cultivars Cícero and BRS Cristalino were higher in phase II and IV than the values recommended by FAO (Doorenbos and Pruitt 1977; Allen et al. 1998). This difference occurs due to the genetic material, mainly regarding the growth rate and the duration of each crop phases (Lozano et al. 2017). These cultivars had around of 10 days from sowing to start of growth (Phase I), while FAO standard Kc indicated a total of 35 days. It can be associated with grown in temperate environmental, where lower temperature could increase the duration of this phase. However, the cultivars Cícero and BRS Cristalino had similar values than FAO for phase I (Fig. 6), probably by the higher contribution of evaporation than transpiration in the beginning of cycle (Wang et al. 2020). Furthermore, the cultivars differed in leaf shape, plant size, and growth habit (Table 1; Supplementary Material—Fig. S2). In this sense, leaf development correlated with absolute Kc values (Wei et al. 2015; Libardi et al. 2019), given the variation in the number of leaves over the cycle and the Kc value (Fig. 7).

The chickpea cultivars have different growth habits. Indeterminate growth habit, for example, leads the plant to continue its vegetative growth after the beginning of flowering (Gaur et al. 2010). Cultivar BRS Aleppo showed this pattern, which remained Kc value at the maximum (phase III) until the end of the experiment. In this growth habit, leaf emission is maintained, and there is no reduction in physiological processes, leaf water potential, and stomatal conductance, ensuring an ideal internal CO_2 concentration for maintaining transpiration to avoid leaf senescence (Bartlett et al. 2016; Wang et al. 2020). It is possible to observe this pattern in development of canopy for BRS Aleppo on the slopes of the regression curves (Fig. 7). The Aleppo leaf number pattern lead to a lower Kc value during phase III than FAO e other cultivars. Cultivar Aleppo kept leaf number near of the maximum observed value in the end of cycle (Fig. 7). However, the leaf size for Aleppo was lower than cultivars Cícero and BRS Cristalino, while Kc was higher at the end of cycle, indicating a leaf activities reduction and senescence for others cultivars (Anapalli et al. 2020; Gong et al. 2020).

The ETc varied between experimental days (Fig. 4). This variability occurs due to the use of the microlysimeter methodology and crop response to extremes weather (Marin et al. 2016; López-Urrea et al. 2020). Despite uncertainties, the use of weighing lysimeters provides the most accurate and direct measurements of evapotranspiration, which are subject to variations due to uncontrollable factors (Evett et al. 2015). Anapalli et al. (2016) reported that lysimeters express differences between evapotranspiration measurements of 5–40%. However, lysimetry is the most used technique in studies characterizing the water needs of plants. In association with the use of trend equations and the removal of outliers, this technique generates reliable Kc values (Xu et al. 2018; Libardi et al. 2019; López-Urrea et al. 2020).

Conclusion

The water demands of chickpeas varied according to crop growth, phenology, and weather across the growing season. This interferes with the reference evapotranspiration and the cycle dynamics of the cultivars under study, including the number of leaves throughout the cycle. The potential crop evapotranspiration varied among the three chickpea cultivars under greenhouse conditions, which resembled the conditions of the natural environment of the Brazilian Savannah biome. The cultivars showed different patterns of Kc curves as a function of vegetative growth. When managing irrigation and quantifying the water demand of the crop, using Kc values defined for each cultivar or for cultivars with similar growth habit has preference over the generalized. Thus, estimating ETc for each cultivar is a more efficient method, which assists in irrigation management and in estimating water relations in chickpea crop.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00271-021-00737-z.

Acknowledgements The authors would like to thank the Federal Institute of Goiás-Campus Ceres (IF Goiano) and to the School of Agronomy of the Federal University of Goiás (UFG) for the infrastructure, support, and inputs made available. To the Brazilian Agricultural Research Corporation (EMBRAPA) for the concession of seeds, to Bristom Inc. for the equipment and technical support, and to everyone who contributed to this research.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration—guidelines for computing crop water requirements. In: FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome

Alvares CA, Stape JL, Sentelhas PC et al (2013) Köppen's climate classification map for Brazil. Meteorol Z. https://doi.org/10.1127/0941-2948/2013/0507

Anapalli SS, Ahuja LR, Gowda PH et al (2016) Simulation of crop evapotranspiration and crop coefficients with data in weighing lysimeters. Agric Water Manag 177:274–283. https://doi.org/10.1016/j.agwat.2016.08.009

Anapalli SS, Fisher DK, Reddy KN et al (2019) Modeling evapotranspiration for irrigation water management in a humid climate. Agric Water Manag 225:105731. https://doi.org/10.1016/j.agwat.2019.105731

Anapalli SS, Fisher DK, Pinnamaneni SR, Reddy KN (2020) Quantifying evapotranspiration and crop coefficients for cotton (*Gossypium hirsutum* L.) using an eddy covariance approach. Agric Water Manag 233:106091. https://doi.org/10.1016/j.agwat.2020.106091

Antunes Júnior EDJ, Alves Júnior J, Casaroli D (2018) Calibração do sensor capacitivo EC-5 em um latossolo em função da densidade do solo. Reveng 26:80–88. https://doi.org/10.13083/reveng.v26i1.864

Artiaga OP, Spehar CR, Boiteux LS, Nascimento WM (2015) Avaliação de genótipos de grão de bico em cultivo de sequeiro nas condições de Cerrado - DOI:10.5039/agraria.v10i1a5129. Revista Brasileira de Ciências Agrárias (Agrária) 10:102–109

Bartlett MK, Klein T, Jansen S et al (2016) The correlations and sequence of plant stomatal, hydraulic, and wilting responses to drought. PNAS 113:13098–13103. https://doi.org/10.1073/pnas.1604088113

Contreras JI, Alonso F, Cánovas G, Baeza R (2017) Irrigation management of greenhouse zucchini with different soil matric potential level. Agronomic and environmental effects. Agric Water Manag 183:26–34. https://doi.org/10.1016/j.agwat.2016.09.025

de Giordano LB, Nascimento WM (2005) Grão-de-bico Cícero, Sabor e qualidade

de Camargo AC, Favero BT, Morzelle MC et al (2019) Is chickpea a potential substitute for soybean? Phenolic bioactives and potential health benefits. Int J Mol Sci 20:2644. https://doi.org/10.3390/ijms20112644

de Medeiros GA, Arruda FB, Sakai E, Fujiwara M (2001) The influence of crop canopy on evapotranspiration and crop coefficient of beans (*Phaseolus vulgaris* L.). Agric Water Manag 49:211–224. https://doi.org/10.1016/S0378-3774(00)00150-5

de Sousa DP, Fernandes TFS, Tavares LB et al (2021) Estimation of evapotranspiration and single and dual crop coefficients of acai palm in the Eastern Amazon (Brazil) using the Bowen ratio system. Irrig Sci 39:5–22. https://doi.org/10.1007/s00271-020-00710-2

Doorenbos J, Pruitt WO (1977) Guidelines for predicting crop water requirements. Rev. Food and Agriculture Organization of the United Nations, Rome

Evett S, Howell T, Schneider AD et al (2015) The bushland weighing lysimeters: a quarter century of crop et investigations to advance sustainable irrigation. Trans ASABE 58:163–179. https://doi.org/10.13031/trans.58.11159

Fares A, Polyakov V (2006) Advances in crop water management using capacitive water sensors. Advances in agronomy. Academic Press, New York, pp 43–77

Gao Z, Wang Y, Tian G et al (2020) Plant height and its relationship with yield in wheat under different irrigation regime. Irrig Sci 38:365–371. https://doi.org/10.1007/s00271-020-00678-z

Gaur PM, Tripathi S, Gowda CLL, et al. (2010) Chickpea seed production manual Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. p 28

Ghoulem M, El Moueddeb K, Nehdi E et al (2019) Greenhouse design and cooling technologies for sustainable food cultivation in hot climates: review of current practice and future status. Biosys Eng 183:121–150. https://doi.org/10.1016/j.biosystemseng.2019.04.016

Gong X, Qiu R, Sun J et al (2020) Evapotranspiration and crop coefficient of tomato grown in a solar greenhouse under full and deficit irrigation. Agric Water Manag 235:106154. https://doi.org/10.1016/j.agwat.2020.106154

Hoskem BCS, da Costa CA, Nascimento WM et al (2017) Produtividade e qualidade de sementes de grão-de-bico no Norte de Minas Gerais. Revista Brasileira de Ciências Agrárias (Agrária) 12:261–268. https://doi.org/10.5039/agraria.v12i3a5445

Justino LF, Alves Júnior J, Battisti R et al (2019) Assessment of economic returns by using a central pivot system to irrigate common beans during the rainfed season in Central Brazil. Agric Water Manag 224:105749. https://doi.org/10.1016/j.agwat.2019.105749

Kale H, Kaplan M, Ulger I et al (2018) Feed value of maize (*Zea mays* var. indentata (Sturtev.) L.H. Bailey) grain under different irrigation levels and nitrogen doses. Turk J Field Crops. https://doi.org/10.17557/tjfc.421974

Kaplan M, Karaman K, Kardes YM, Kale H (2019) Phytic acid content and starch properties of maize (*Zea mays* L.): effects of irrigation process and nitrogen fertilizer. Food Chem 283:375–380. https://doi.org/10.1016/j.foodchem.2019.01.029

Kashiwagi J, Krishnamurthy L, Purushothaman R et al (2015) Scope for improvement of yield under drought through the root traits in chickpea (*Cicer arietinum* L.). Field Crop Res 170:47–54. https://doi.org/10.1016/j.fcr.2014.10.003

Libardi LGP, de Faria RT, Dalri AB et al (2019) Evapotranspiration and crop coefficient (Kc) of pre-sprouted sugarcane plantlets for greenhouse irrigation management. Agric Water Manag 212:306–316. https://doi.org/10.1016/j.agwat.2018.09.003

López-Urrea R, Sánchez JM, de la Cruz F et al (2020) Evapotranspiration and crop coefficients from lysimeter measurements for sprinkler-irrigated canola. Agric Water Manag 239:106260. https://doi.org/10.1016/j.agwat.2020.106260

Lozano CS, Rezende R, de Freitas PSL et al (2017) Estimatation of evapotranspiration and crop coefficient of melon cultivated in protected environment. Revista Brasileira de Engenharia Agrícola e Ambiental 21:758–762. https://doi.org/10.1590/1807-1929/agriambi.v21n11p758-762

Marin FR, Angelocci LR, Nassif DSP et al (2016) Crop coefficient changes with reference evapotranspiration for highly canopy-atmosphere coupled crops. Agric Water Manag 163:139–145. https://doi.org/10.1016/j.agwat.2015.09.010

Martins JD, Rodrigues GC, Paredes P et al (2013) Dual crop coefficients for maize in southern Brazil: model testing for sprinkler and drip irrigation and mulched soil. Biosyst Eng 115:291–310. https://doi.org/10.1016/j.biosystemseng.2013.03.016

Meirelles ML, Franco AC, Farias SEM, Bracho R (2011) Evapotranspiration and plant–atmospheric coupling in a *Brachiaria brizantha* pasture in the Brazilian savannah region. Grass Forage Sci 66:206–213. https://doi.org/10.1111/j.1365-2494.2010.00777.x

Mohammed A, Tana T, Singh P et al (2017) Identifying best crop management practices for chickpea (*Cicer arietinum* L.) in Northeastern Ethiopia under climate change condition. Agric Water Manag 194:68–77. https://doi.org/10.1016/j.agwat.2017.08.022

Moraes DHM, Casaroli D, Evangelista AWP et al (2019) Determination of basal temperature and its relationship with Jatropha crop in irrigated and non-irrigated system. J Agric Sci 11:p465. https://doi.org/10.5539/jas.v11n2p465

Nascimento WM, Artiaga OP, Boiteux LS, et al. (2014) BRS Aleppo: grão de bico. Maior tolerância a fungos de solo. In: Hortaliças Leguminosas. Embrapa Hortaliças, Brasília, pp. 01–04

Nascimento WM, Suinaga FA, Boiteux LS, et al (2017) BRS Cristalino: grão de bico. Nova cultivar de grão-de-bico de dupla aptidão

Odhiambo LO, Irmak S (2012) Evaluation of the impact of surface residue cover on single and dual crop coefficient for estimating soybean actual evapotranspiration. Agric Water Manag 104:221–234. https://doi.org/10.1016/j.agwat.2011.12.021

Ometto JC (1981) Bioclimatología vegetal, 1st edn. Agronomica Ceres, São Paulo

Pendergast L, Bhattarai SP, Midmore DJ (2019) Evaluation of aerated subsurface drip irrigation on yield, dry weight partitioning and water use efficiency of a broad-acre chickpea (*Cicer arietinum* L.) in a vertosol. Agric Water Manag 217:38–46. https://doi.org/10.1016/j.agwat.2019.02.022

Rodrigues TR, Vourlitis GL, de Lobo FA et al (2014) Seasonal variation in energy balance and canopy conductance for a tropical savanna ecosystem of south central Mato Grosso, Brazil. J Geophys Res Biogeosci 119:1–13. https://doi.org/10.1002/2013JG002472

Saeidi R, Ramezani Etedali H, Sotoodehnia A et al (2021) Salinity and fertility stresses modify Ks and readily available water coefficients in maize (case study: Qazvin region). Irrig Sci. https://doi.org/10.1007/s00271-020-00711-1

Soltani A, Robertson MJ, Torabi B et al (2006) Modelling seedling emergence in chickpea as influenced by temperature and sowing depth. Agric For Meteorol 138:156–167. https://doi.org/10.1016/j.agrformet.2006.04.004

Talebnejad R, Sepaskhah AR (2015) Effect of deficit irrigation and different saline groundwater depths on yield and water productivity of quinoa. Agric Water Manag 159:225–238. https://doi.org/10.1016/j.agwat.2015.06.005

Urban J, Ingwers MW, McGuire MA, Teskey RO (2017) Increase in leaf temperature opens stomata and decouples net photosynthesis from stomatal conductance in *Pinus taeda* and *Populus deltoides* x *nigra*. J Exp Bot 68:1757–1767. https://doi.org/10.1093/jxb/erx052

Vilela MDS, Cabral Filho FR, Teixeira MB et al (2015) ACURÁCIA DE UM MINI-LISÍMETRO DE PESAGEM ELETRÔNICA DE BAIXO CUSTO. R_I 1:158–167. https://doi.org/10.15809/irriga.2015v1n2p158

Wang Y, Cai H, Yu L et al (2020) Evapotranspiration partitioning and crop coefficient of maize in dry semi-humid climate regime. Agric Water Manag 236:106164. https://doi.org/10.1016/j.agwat.2020.106164

Wei Z, Paredes P, Liu Y et al (2015) Modelling transpiration, soil evaporation and yield prediction of soybean in North China Plain. Agric Water Manag 147:43–53. https://doi.org/10.1016/j.agwat.2014.05.004

Wijewardana C, Reddy KR, Bellaloui N (2019) Soybean seed physiology, quality, and chemical composition under soil moisture stress. Food Chem 278:92–100. https://doi.org/10.1016/j.foodchem.2018.11.035

Xu G, Xue X, Wang P et al (2018) A lysimeter study for the effects of different canopy sizes on evapotranspiration and crop coefficient of summer maize. Agric Water Manag 208:1–6. https://doi.org/10.1016/j.agwat.2018.04.040