ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

CROP COEFFICIENT OF MARANDU PALISADE GRASS: AN APPROACH INVOLVING LEAF AREA INDEX AND CANOPY HEIGHT*

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[*]Trabalho desenvolvido a partir dos dados da dissertação de mestrado da primeira autora.
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1 ABSTRACT

Determining the evapotranspiration rate enhances our understanding of plant water needs, potentially improving irrigation management. This study aimed to investigate the water consumption of the Marandu palisade grass (*Urochloa brizantha*), 'Marandu' cultivar, single cropped and intercropped with black oat and ryegrass, by determining the crop coefficient (Kc) and their correlation with canopy height (CH) and leaf area index (LAI). The experiment was carried out at ESALQ/USP from April 2016 to January 2017. Two weighing lysimeters were used to calculate the Crop evapotranspiration (ETc): one with single-crop Marandu palisade grass throughout the year and the other intercropped with black oat and ryegrass during autumn and winter (from April to September 2016). The estimated Kc, CH, and LAI were measured every 4-day. Regression equations were generated to determine the correlation between Kc and CH, and Kc and LAI in each season. Minimum and maximum Kc values for single cultivation in each season were: 0.61 and 0.97 for spring, 0.45 and 1.10 for summer, 0.47 and 0.74 for autumn, and 0.52 and 0.94 for winter. In the intercropped cultivation, Kc values ranged from 0.62 to 1.04.

Keywords: evapotranspiration, *Urochloa brizantha*, irrigated pasture management

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COEFICIENTE DE CULTURA DO CAPIM MARANDU: UMA ABORDAGEM ENVOLVENDO ÍNDICE DE ÁREA FOLIAR E ALTURA DE DOSSEL

Recebido em 15/06/2021 e aprovado para publicação em 20/10/2021
DOI: http://dx.doi.org/10.15809/irriga.2021v26n4p924-937

2 RESUMO

A determinação da taxa de evapotranspiração aumenta a compreensão das necessidades de água da planta, melhorando potencialmente o gerenciamento da irrigação. Este trabalho teve como objetivo investigar o consumo de água do capim-marandu (*Urochloa brizantha*), cultivar 'Marandu', em monocultivo e consorciado com aveia-preta e azevém, por meio da determinação do coeficiente de cultura (Kc) e sua a correlação com a altura do dossel (CH) e o índice de área foliar (IAF). O experimento foi realizado na ESALQ/USP no período de abril de 2016 a janeiro de 2017. Foram utilizados dois lisímetros de pesagem para cálculo da evapotranspiração da cultura (ETc): um com capim-marandu ao longo do ano inteiro e o outro consorciado com aveia-preta e azevém durante o outono e inverno (de abril a setembro de 2016). O Kc ~~foi~~ estimado, CH e IAF foram medidos a cada 4 dias. Equações de regressão foram geradas para determinar a correlação entre Kc e CH, e Kc e LAI em cada estação. Os valores mínimo e máximo de Kc para cultivo único em cada estação foram: 0,61 e 0,97 (primavera); 0,45 e 1,10 (verão); 0,47 e 0,74 (outono) e 0,52 e 0,94 (inverno). No cultivo consorciado, os valores de Kc variaram de 0,62 a 1,04.

Palavras-chave: evapotranspiração, *Urochloa brizantha,* manejo de irrigação em pastagem

3 INTRODUCTION

Brazil has the second largest bovine cattle herd in the world, consisting of more than 214 million animals (IBGE, 2018). Numerous annual crop species such as oats, Italian ryegrass, and millet are cultivated alongside the Pampa biome's natural pastures in the subtropical climes of Brazil. In these areas, rainfall is sufficiently regular throughout the year to cover pastures' water requirements (SANTOS *et al*., 2015).

However, in other regions of Brazil, including the Southeast, Midwest, Northeast, and North, tropical pastures may experience brief or prolonged droughts during the year. In addition, in the Southeast and Midwest, the cold of autumn and winter cause pronounced forage seasonality. The impact of climate on forage productivity may interfere with meat and milk production, affecting the national economy (ALENCAR *et al.*, 2009).

In response to the unfavorable climate, cattle breeders have adopted pasture irrigation techniques to minimize or eliminate production dynamics, the efficiency of which depends on adequate management information (ALENCAR *et al.*, 2009). The determination of crop evapotranspiration by assessing water flows in the soil-plant-atmosphere system is central to improving pasture irrigation efficiency (SOUZA *et al*., 2011; SCHRADER *et al*., 2013).

Estimates of crop coefficients (Kc) may vary across seasons and stages of plant growth, for example, for the tropical forage grass *Panicium maximum* 'Tanzania, one study in Uberlândia estimated Kc values ranging from 0.46 to 0.98 during the initial period of plant growth while another in Montes Claros/MG, estimated for this cultivar, Kc values ranging from 0.97 to 1.2 in the winter season (BUENO *et al*., 2009; BARBOSA *et al*., 2015). Other studies focused on the relationship between ETo and maximum forage production. Antoniel *et al*. (2016) studied *P. maximum* 'Mombaça' in the subtropical Cidade Gaúcha/PR, and obtained maximum dry matter yields with irrigation depths ranging from 96% to 154% of ETo, leading to maximum Kc values varying from 0.96 to 1.54.

In addition, cattle grazing or cutting dynamics make it difficult to interpret and use crop coefficient information. This is illustrated by the fact that the Food and Agriculture Organization of the United Nations (FAO) bulletin n° 56 (ALLEN *et al*., 1998, 2006) reports Kc values only based on plant height or age.

Canopy height (CH) of forage plants is the most frequently metric used in grazing management (ALENCAR *et al*., 2010; GIMENES *et al*., 2011), although recent approaches also have been using leaf area index (LAI) (ALENCAR *et al*., 2013; ARAUJO *et al*., 2013; DANTAS *et al*., 2016). This study aimed, firstly, to estimate Kc values for Marandu palisade grass (*Urochloa brizantha* 'Marandu'), cultivated as a single-crop and intercropped with black oats (*Avena strigosa*) and ryegrass (*Lolium multiflorum*), and secondly, to evaluate across the seasons, the relationship between Kc and CH, and KC and LAI.

4 MATERIALS AND METHODS

The experiment was conducted at the 'Luiz de Queiroz' College of Agriculture (ESALQ/USP), Piracicaba, SP (latitude 22° 42′ S; longitude 47º 38′ W; altitude 569 m). According to the Köppen-Geiger classification, the regional climate is Cwa, humid subtropical with a sizzling summer and dry winter (KOTTEK *et al*., 2006). According to the Brazilian System of Soil Classification, the local soil is a Nitosol Red Eutroferric Latosolic (SANTOS *et al.*, 2013).

The experimental area was composed of two 144 m² plots. Before sowing with Marandu palisade grass (*Urochloa brizantha* 'Marandu'), the plots were prepared for planting by following conventional measures outlined by Raij *et al*. (1996), which included soil preparation (plowing), pH correction, and soil fertilization.

Marandu palisade grass was sown in November 2016, nitrogen (N) fertilizer (125 kg ha^{-1}) was applied 21 days after sowing and invasive plants were manually controlled after germination.

Immediately after the third cutting cycle (28 days $cycle^{-1}$), at the beginning of autumn, one of the two plots was overseeded with two winter crops: black oat (*Avena strigosa* 'EMBRAPA 29') and ryegrass (*Lolium multiflorum* 'Fepagro São Gabriel'), while the other plot remained single cropped. The winter crops were sown on May 4th, resulting in an intercrop consisting of three forage crops. Marandu palisade grass was cut to a height of 0.15 m, after which the winter crop, consisting of 100 kg ha^{-1} of black oat seeds and 60 kg ha^{-1} of ryegrass, was manually spread.

Nitrogen fertilizer was applied after each forage cut, with dosage varying according to the season (50 kg ha^{-1} autumn/winter and 80 kg ha^{-1} spring/summer). Both plots, single- and intercropped, received the same N-dosage during autumn/winter period.

Cutting intervals varied according to the climate; for single-cropped Marandu palisade grass, we used 28-day cycles during spring/summer and 40-day cycles during autumn/winter. In the overseeded plot, the cycles varied, and we cut when the canopy reached a light interception level of 95%. The LAI and light interception level were measured in ~~8~~ eight to ~~10~~ ten points per treatment above the crop and ~~2~~ two to five ~~5~~ below the plants per point, using the LAI 2000 Plant Canopy Analyzer (LI-COR®) sensor. The resulting duration between cutting was 40 days for cycle one, 28 days for cycle two, 24 days for cycle three, and 32 days for cycles four and five.

There were nine cutting cycles during the experimental period for the plot with single cropped Marandu palisade grass with a height of cut of 0.15 m. The duration of the experiment cycles totaled 300 days. Kc values generate by the correlations between Kc versus LAI and Kc versus CH, the cycles of growth, and cut were allocated into the seasons, depending on the starting date of each cycle. There were two cycles in spring (October to December 2016), three cycles in summer (December 2016 to January 2017), two cycles in autumn (May to July 2016); and two cycles in winter (July to October 2016).

Irrigation was applied using a conventional solid-set sprinkler system with plot with spacing (sprinklers x lines) of 12 m x 12 m, using the NaanDanJain 427B sprinkler model. Four sprinklers were set in each the plot, equipped with a sectorial device to restrict irrigation to an angle of 90°.The sprinklers operated at a pressure of 250 kPa and discharge of 590 L h^{-1}. The application uniformity of which was tested before starting the experiment, resulting in a Christiansen Uniformity Coefficient (CUC) = 87%, calculated according to Christiansen (1942).

The plots were irrigated every four days in order to maintain the soil moisture content higher than 70%, with the soil drainage between the upper and lower limit point at 15 atm. The irrigation water depth was based on the crop consumption measured in weighing lysimeters, and for the water replacement, were considered 100% of ~~to~~ the pasture evapotranspiration, aiming to avoid water deficit.

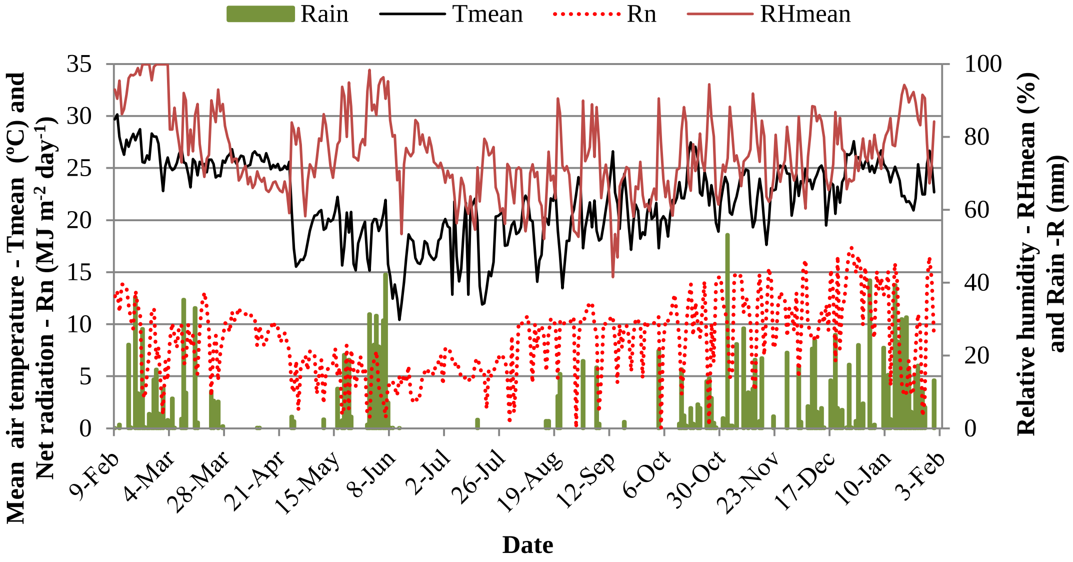
The crop-canopy water consumption, represented by crop evapotranspiration (ETc), was measured with a weighing lysimeter placed at the center of each experimental plot. The lysimeters occupied an area of 1.17 m² and a depth of 0.58 m and used an automatic drainage system; the datalogger program controlled both sets. The calibrations of both lysimeters and the automatic drainage weighing systems (dataloggers) were carried out before the forage crops were sowing, as described by Sanches *et al.* (2017).

As recommended by Campeche *et al.* (2011) and Schrader *et al*. (2013), we used the lysimeter weight variation to calculate the daily ETc, but we excluded values associated with high rainfall periods (P), which could cause data inaccuracy.

Furthermore, data were excluded when evaporation rose above 0.20 mm over 15 min intervals, as these values were likely associated with hot air inputs from northerly, northwesterly, and westerly winds that blew over areas of bare soil near the experimental area, increasing soil evaporation and potentially leading to data inaccuracy.

Reference evapotranspiration (ETo) was calculated using the Penman-Monteith model (ALLEN *et al*., 1998, 2006). It was obtained meteorological data (wind speed, solar radiation, air temperature, and relative air humidity) from the ESALQ weather station, located 100 m from the experimental area (Figure 1).

Figure 1. Meteorological data from the weather station (ESALQ/USP) during the experiment: mean air temperature (T_{mean}), Net Radiation (Rn), Air Relative Humidity (RH) and Rainfall (R), Piracicaba/SP, 2017.



ETc and ETo values were used to obtain the crop coefficient (Kc). The daily Kc values were determined every four days to calculate the mean data for each period, considering the forage growth for the best grazing interval along the cycle (PEREIRA *et al*., 2015).

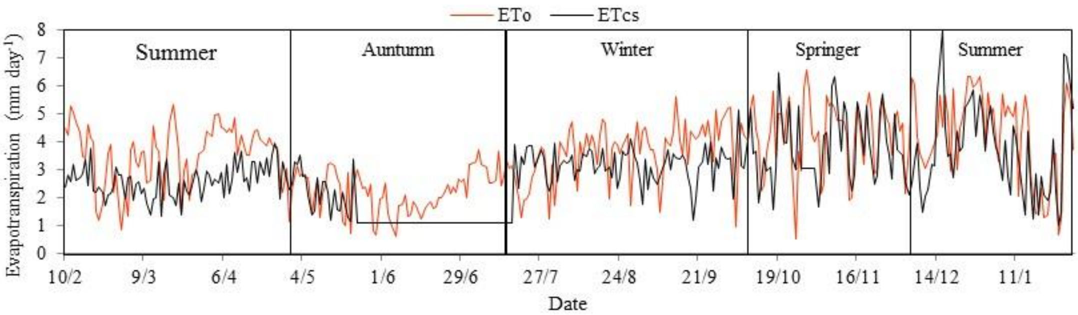
To better understand the behavior of Kc throughout the productive cycle, we used two approaches: leaf area index and canopy height both estimated and measured at 4-days intervals. For LAI measures, the LAI 2000 Plant Canopy Analyzer (LI-COR®) was used to measure together and with the same repetitions of the light interception measurement; for CH, we used a ruler created using a graduated tape measure. Both LAI and CH were measured on the same day and with an interval of 4 days.

To determine whether CH and LAI values could be used to estimate Kc, the correlation between daily Kc means and CH and LAI for each group of cycles in the same season (spring, summer, autumn, and winter) was estimated. We obtained one regression equation for each season for the single and intercropped 'Marandu'.

5 RESULTS AND DISCUSSION

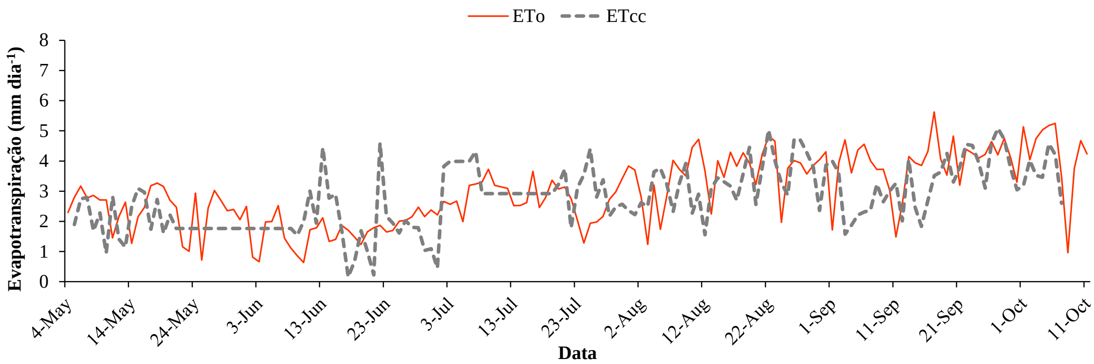
The Figure 2 shows ETc data estimated from weighing lysimeter measurements throughout the experimental period for the single cropped plot (ETcs).

Figure 2. Reference evapotranspiration (ETo) calculated with data from the ESALQ/USP weather station, and crop evapotranspiration of single cropped Marandu palisade grass (ETcs), estimated by weighing lysimeter during all seasons, from 2016 to 2017, Piracicaba/SP.



The Figure 3 shows ETc data for the intercropped plot (ETcc) from May to October 2016. A decreasing trend of ETo and ETc values is observed from May to July, with the lowest ETo value on June 6th (0.64 mm day^{-1}). There was 42.2 mm of precipitation and intense net solar radiation (Rn) (1.05 MJ/m/day) on June 6th (Figure 1).

Figure 3. Reference Evapotranspiration (ETo) calculated with data from ESALQ/USP weather station, and crop evapotranspiration of Marandu palisade grass intercropped with black oat and ryegrass (ETcc), estimated by weighing lysimeter during autumn and winter (May to October 2016), Piracicaba/SP.



In contrast, the highest ETo values were observed from October to January, with values in excess of 6 mm day^{-1} occurring during this period. Although the mean air temperature values were above 20°C (Figure 1) during the warm, in the rainy season (spring and summer), the ETc tends to decrease due to cloudiness on rainy days. The cumulative rainfall from October 2016 to January 2017 was approximately 820 mm.

Within the same month, ETcs behaved similarly to ETo, with a peak value of 7.99 mm day^{-1} (Figure 2). Another study by Barbosa *et al.* (2015) in Montes Claros/MG measured the ETc of Guinea grass cultivar 'Tanzania' over a year and reported values ranging from 1.98 to 7.21 mm day^{-1}. Bueno *et al*. (2009) observed a peak in mean ETc values of 6.65 mm day^{-1} for Guinea grass 'Tanzania', which is lower than that obtained by Barbosa *et al.* (2015) and in this present study due to the use of 10-day means by these authors.

Considering the variable ETc responses of the Marandu palisade grass crop depending on the time of the year or season, we chose to demonstrate Kc responses according to the season and together with the correlations between Kc and LAI (Figures 4), and Kc and CH (Figures 5) in mean values throughout the cutting cycles included in each season.

Figure 4. Empirical models of crop coefficient (Kc) versus leaf index area (LAI) for the single cropped palisade grass during the seasons: spring (○), summer (●), autumn (▲), and winter (×), Piracicaba/SP.

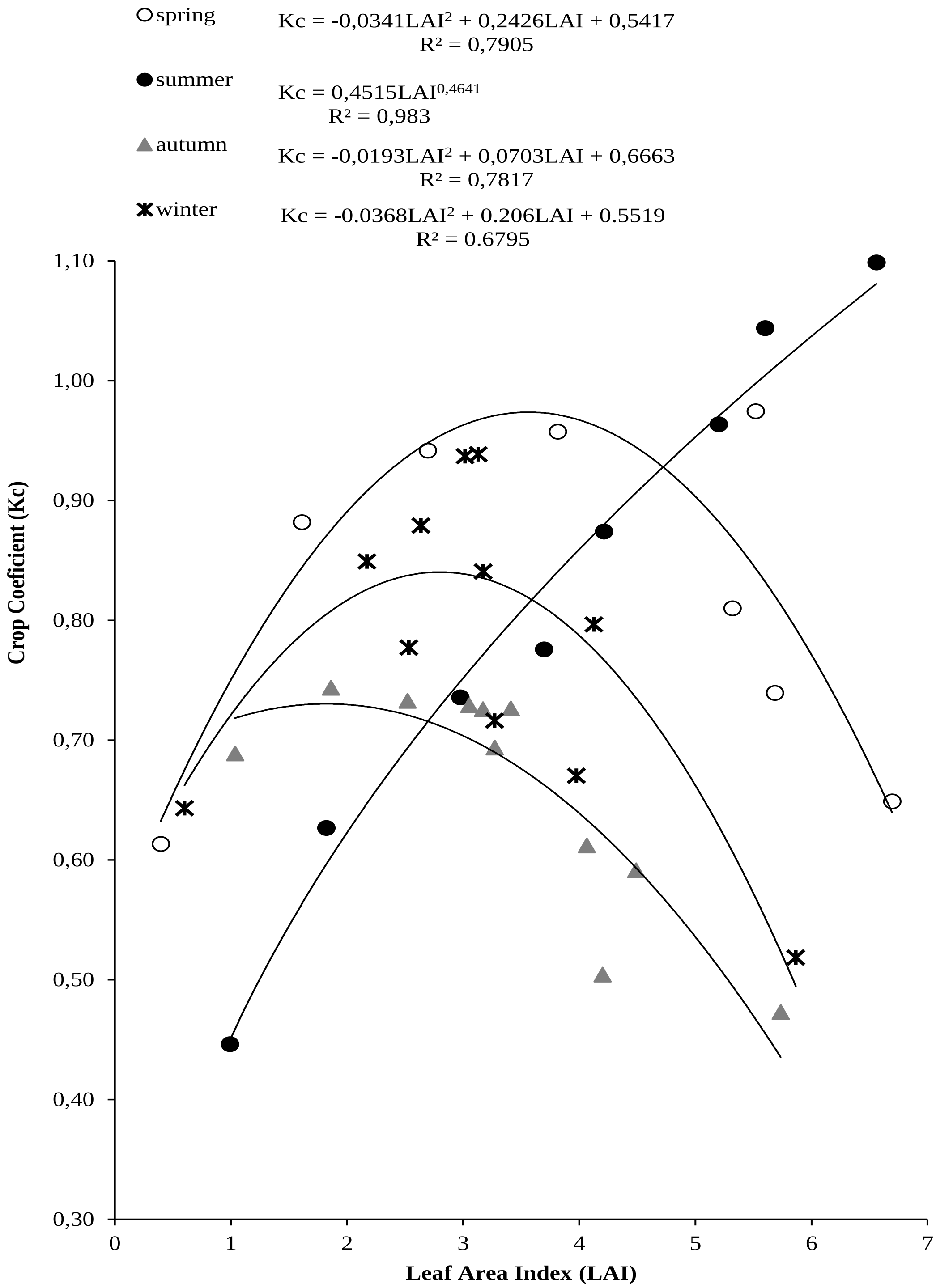
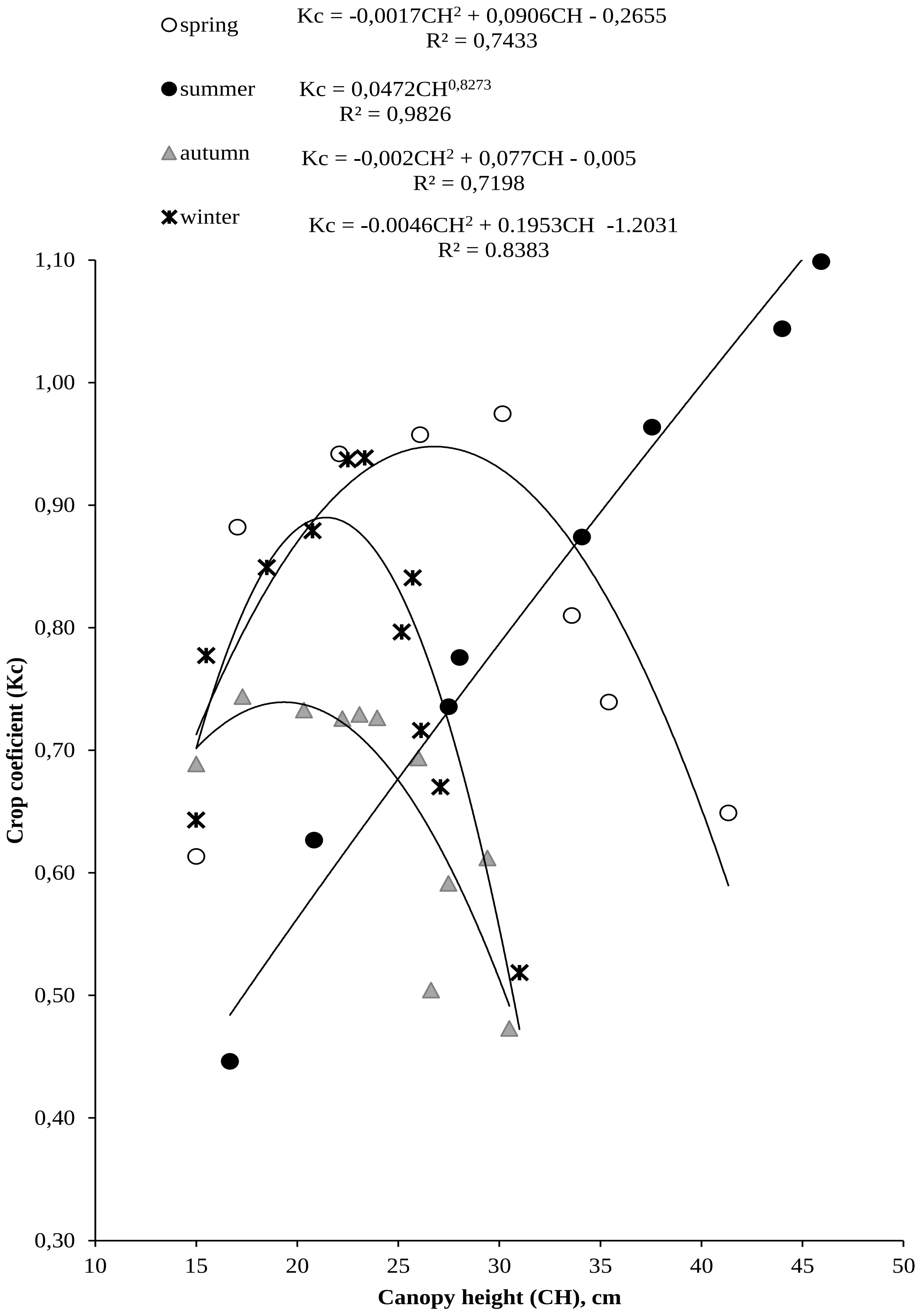


Figure 5. Empirical models of crop coefficient (Kc) versus versus canopy height (CH) for the single cropped palisade grass during the seasons: spring (○), summer (●), autumn (▲), and winter (×), Piracicaba/SP.



ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

The empirical models of LAI versus Kc for spring, autumn, and winter were polynomial and met the standard models of Kc presented in the literature, with growth rate rising to a maximum, followed by a decline (e.g., Figure 4). For Marandu palisade grass, the initial Kc in these periods presented values close to 0.60, which later increases.

In the spring (Figure 4), the peak (Kc = 0.96) occurred with LAI near 4. In the summer, the Kc values ranged from 0.45 to 1.10, and the plants reached a LAI peak of 6.56. The differences between the LAI x Kc models between summer and spring can be attributed to mature growth. After autumn and winter, the plants mature in fewer days under irrigation. It is important to pointed out that in the spring, plants require less water, observed by Pezzopane *et al*. (2018).

In the autumn (Figure 4), the Kc behaved differently due to the response of tropical forage plants to a reduction in air temperature and solar radiation, and the subsequent reduction in forage plant productivity (seasonality). The Kc values varied within a narrow range, from 0.47 to 0.70. In the winter (Figure 4), the highest Kc values occurred between LAI values ranging from 2 to 4, with a decrease of Kc in LAI values above the upper limit.

The approach of correlating Kc curves and canopy height (Kc × CH) revealed similar trends to the Kc × LAI analysis. CH was higher in the summer (Figure 5) and autumn (Figure 5) when stem elongation of Marandu palisade grass was stimulated. Lopes *et al*. (2014) studied the effect of different irrigation water depths in *Urochloa decumbens*, reporting increases in leaf and stem elongation rates as the applied water depth increased.

During autumn and winter, the CH reached a maximum of 0.31 m (Kc = 0.74), with a Kc value peak when CH was equal to 0.23 m (Kc = 0.94), as shown in the Figures 5.

In the spring (Figure 5), the highest Kc was 0.97, observed when CH was equal to 0.30 m, as previously reported. During the summer, the highest CH was 0.44 m, with a maximum Kc of 1.10. In the summer, stem mass (25.5%) contributes to canopy height to a greater extent than it does in the spring (11.4%) (SOUZA *et al*., 2018), suggesting that the stem elongation and equation model is progressive (Figure 5).

Changes in forage yield and morphophysiological characteristics during the seasonal period are influenced by climatic elements, such as water deficit, luminosity, solar radiation, and low temperatures, varying according to the physiology of each species (ALENCAR *et al*., 2010; GOBBI *et al.*, 2011).

Several papers have been demonstrating the mechanisms of response to seasonal water deficit in tropical forage plants. Even with low water intake, some plants can maintain their physiological functions despite a water deficit, although this becomes more challenging as the water deficit increases. To prevent water deficit increases, plants stimulate stomatal closure and deepening of the root system, increasing their capacity to retain water in tissues and water absorption, respectively, thus enabling plants to maintain physiological functions even with less water available. Plants may also undergo alterations in their foliar area and foliar abscission in response to low water availability (ALENCAR *et al*., 2010, 2013; JIANG; HUANG, 2001; MANAVALAN; NGUYEN, 2012; SALEHI-LISAR; BAKHSHAYESHAN-AGDAM, 2016).

During the autumn and winter, the Kc models for the intercropped crops showed different behavior models for single Marandu palisade grass (Figure 6 and Figure 7). In a well-managed, intercropped system, water use efficiency (in terms of forage yield and water consumption) may be higher than in a single cropped system

Recebido em 15/06/2021 e aprovado para publicação em 20/10/2021
DOI: http://dx.doi.org/10.15809/irriga.2021v26n4p924-937

(YANG *et al*., 2011; CHIMONYO *et al*., 2016). Furthermore, the use of climatically adapted species can guarantee stable productivity through the intercropping cycles (TONATO *et al*., 2014).

Figure 6. Empirical models of crop coefficient (Kc) versus: Leaf index area (LAI) for Marandu palisade grass intercropped with black oat and ryegrass, Piracicaba/SP.

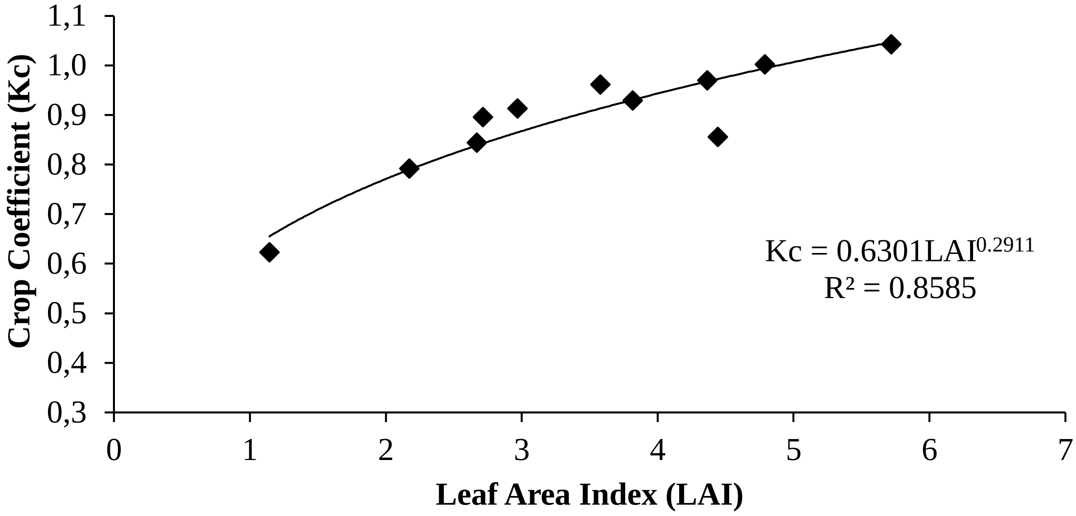
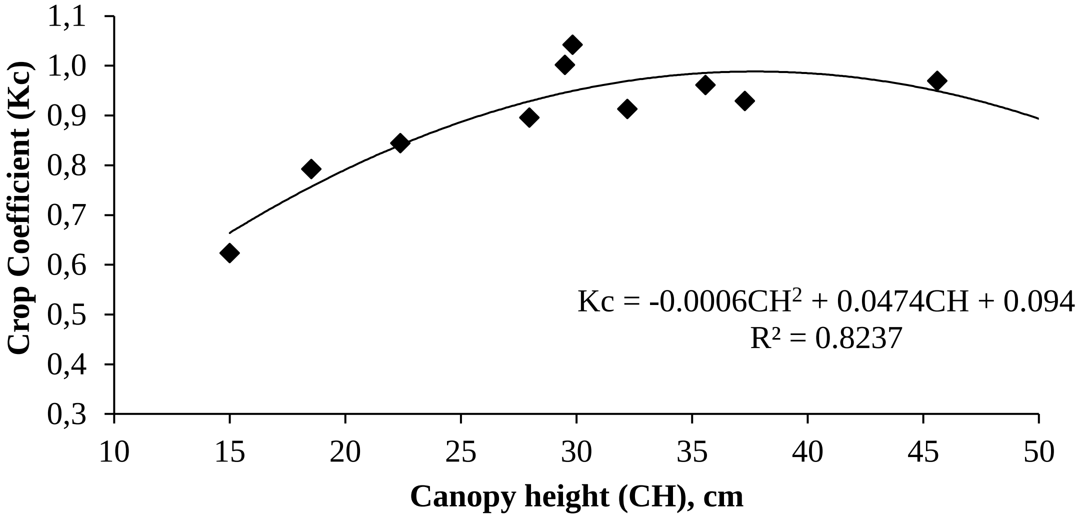


Figure 7. Empirical models of crop coefficient (Kc) versus Canopy height (CH) during autumn/winter from May 4th to October 7th, 2016, for Marandu palisade grass intercropped with black oat and ryegrass, Piracicaba/SP.



In FAO Irrigation and Drainage Paper N° 56 (ALLEN *et al*., 1998), the Kc values presented for perennial ryegrass crop are 0.95 for the initial phase, 1.05 for the middle period, and 1.00 for the final phase. The different cutting cycles used for annual ryegrass in this study (cuts after reaching a light interception of 95%) drove to the lower Kc values observed in the initial period of the crop growth.

6 CONCLUSIONS

Kc values for Marandu palisade grass showed correlation coefficients above 0.68 throughout the four seasons. Kc values were higher in the summer, ranging from 0.45 to 1.10, with LAI and CH equal to 6.56 and 0.44 m, respectively. The trend curve between Kc and CH in the winter had a better fit than the trend curve of Kc and LAI. Both correlations for Marandu palisade grass with black oat and ryegrass showed coefficients of determination above 0.80. The Kc ranged from 0.62 to 1.04, with a maximum LAI of 5.72 and CH of 0.46 m. Based on our models and field measurements of CH and LAI, we conclude that Kc values can be estimated for given periods by applying both approaches and the estimation may be very useful in areas with irrigated pastures.

7 ACKNOWLEDGMENTS

The authors thank the Sao Paulo Research Foundation (FAPESP) for the financial support with the regular research project nº 2012/23002-6.

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