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Evapotranspiration and crop coefficients of corn in monoculture and intercropped with jack bean[1]

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irrigation
organic cultivation

ABSTRACT

This study was carried out to determine the evapotranspiration (ETc) and crop coefficients (Kc) for four stages of "Caatingueiro" corn under the climate condition of Seropédica, RJ, Brazil, using weighing lysimeters. The field trial occurred in 2015, from March 18 to June 25, in two areas cultivated with "Caatingueiro' corn intercropped with jack bean and in monoculture. The reference evapotranspiration (ETo) was estimated by the FAO-56 Penman-Monteith model and the Kc values were determined by the ratio between ETc and ETo. The Kc values obtained for the intercropping and monoculture systems, were respectively: 0.78 (I); 1.01 (II); 1.10 (III) and 1.01 (IV), and 0.62 (I); 0.92 (II); 1.27 (III) and 0.81 (IV), and they were different from the values presented by FAO.

Palavras-chave:
demanda hídrica
lisímetro de pesagem
irrigação
cultivo orgânico

Evapotranspiração e coeficientes da cultura do milho Caatingueiro em monocultivo e consorciado com feijão-de-porco

RESUMO

Objetivou-se, neste trabalho, determinar a evapotranspiração (ETc) e os coeficientes de cultivo (Kc) para as quatro fases de desenvolvimento do milho Caatingueiro nas condições edafoclimáticas de Seropédica, RJ, utilizando lisímetros de pesagem. O experimento foi realizado de 18/03 a 25/06/2015, em áreas cultivadas com o milho Caatingueiro consorciado com feijão-de-porco e em monocultivo. A evapotranspiração de referência (ETo) foi estimada pela metodologia Penman-Monteith FAO-56 e os valores de Kc determinados pela razão entre ETc e ETo. Os valores de Kc para o consórcio e o monocultivo foram, respectivamente: 0,78 (I); 1,01 (II);1,10 (III) e 1,01 (IV) e 0,62 (I); 0,92 (II); 1,27 (III) e 0,81 (IV) que se diferenciaram dos valores apresentados pela FAO.

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Introduction

Corn is one of the main cereals produced in the world and Brazil is the third largest producer. The national production has increased in the last years and reached 84.7 million tons in the 2014/2015 season (CONAB, 2015). However, there is a large contrast of yield among the producing regions due to the different climatic conditions and cultivation practices (Souza et al., 2011).

The use of corn, cv. 'BRS Caatingueiro' (*Zea Mays*, 'BRS Caatingueiro') in organic systems increased because of its adaptability to environmental stress conditions, being indicated for regions with scarcity of rainfall. The organic production of corn intercropped with leguminous crops has become important because of the strategies of sustainability associated with this practice (Moura et al., 2008). The intercropped cultivation can improve grain yield through the more efficient use of nutrients, water and radiation (Lithourgidis et al., 2011), besides reducing the incidence of pests and diseases, soil degradation, environmental deterioration (Brooker et al., 2015) and the risks of production losses (Heredia et al., 2003).

However, the intercropped cultivation has disadvantages, such as the increase in water consumption. Working with 'mucuna-cinza' (*Mucuna cinereum*), Souza et al. (2012) observed greater water consumption in the intercropping in relation to corn monoculture, corroborating with Coll et al. (2012), but not affecting water use efficiency.

Regardless of the cultivation system, the determination of regional crop coefficients (Kc) is essential to improve irrigation planning and management (Kar et al., 2007), since their variation depends on the local energy availability, type of soil, variety and age of the plant (Silva et al., 2006).

Thus, the present study aimed to determine the water consumption and crop coefficients (Kc) of corn ('BRS Caatingueiro') in monoculture and intercropped with jack bean (*Canavalia eusiformis*).

Material and Methods

The experiment was carried out at the experimental area of the SIPA - Integrated System of Agroecological Production, called Fazendinha Agroecológica do km 47, located in the municipality of Seropédica-RJ (22° 48' S; 43° 41 W; 33 m), in a soil classified as Red Yellow Argisol.

The experiment was conducted in two experimental plots with available area of 144 m^2 containing, in their center, one weighing lysimeter to obtain crop evapotranspiration in two cultivation systems. The lysimeters were made of metal sheets with dimensions of 1.0 x 1.0 m at the base and 0.7 m of depth, mounted on transverse bars to concentrate all the mass of the set on one load cell located in the center of the system (Carvalho et al., 2007). The calibration of the lysimeters followed the methodology presented by Nascimento et al. (2011), obtaining the equations M = 1407.5*(L) - 1,077.7 and M = 1372.5*(L) - 1,008.5, respectively, for the lysimeters cultivated with the intercropping and in monoculture, in which M is the mass of the set (kg) and L the reading of the load cell (mV).

The cultivation systems consisted of the corn crop, cv. 'BRS Caatingueiro', in monoculture and intercropped with jack bean. Corn was sown on March 18, 2015, at spacing of 1.0 m between rows, adopting a basal fertilization of 0.2 kg m^{-1} of aged bovine manure, containing 11.0, 3.93, 8.25, 11.80 and 5.45 g kg^{-1} of N, P, K, Ca and Mg, respectively. Corn germination occurred on the 4^{th} day after sowing (DAS), while thinning and replanting were performed on the 15^{th} day after emergence (DAE), respecting the desired limit of 5 plants m^{-1} (Correa et al., 2014), which corresponded to a density of 50,000 plants per hectare.

In the plot intended for intercropping, jack bean was cultivated simultaneously to corn. Five seeds were planted in each linear meter in two planting rows in the interrow of the corn crop, spaced by 0.5 m between jack bean rows and 0.25 m away from the corn row. The jack bean emerged 2 days after sowing and its cycle was interrupted at 47 DAS, during the development stage, when plants reached virtually 100% of soil cover between corn rows. Plants were cut and distributed on the soil, as mulch.

For top-dressing fertilization, castor bean cake was used and its chemical analysis indicated 49.8, 4.7, 1.7, 8.5 and 14.5 g kg^{-1} of N, P, K, Ca and Mg, respectively, being characterized as a rich source of nitrogen (Bodake & Rana, 2009). It was applied 0.150 kg m^{-1}, which corresponded to 75 kg of N ha^{-1}. Fertilization was performed at 45 DAS, during the corn development stage and in a uniform way. Invasive plants were controlled by weeding, biweekly and weekly inside the lysimeters.

The experiment was irrigated using a conventional sprinkler system and each plot corresponded to one irrigation sector arranged in a closed grid and composed of four sectorial sprinklers with 90° spin (FABRIMAR - Pingo, nozzle of 3.2 mm). The spacing between sprinklers was equal to 12 x 12 m, at a service pressure of approximately 200 kPa, mean application intensity of 3.18 mm h^{-1} (measured in the field) and mean uniformity (CUC) of 90%. The irrigation depth was determined by the mass variation of the lysimeter and with irrigation interval fixed at 3 days. Irrigations were always performed in the early morning or late afternoon, in order to minimize the effect of the wind. Irrigation stopped at 88 DAS, to promote the loss of moisture in the corn grain.

The meteorological data were collected from an automatic station situated beside the studied area, equipped with sensors of incident global solar radiation (pyranometer, Kipp & Zonen, model SP-LITE-L), wind speed and direction (anemometer, 03001-L RM YOUNG), air temperature and relative humidity (Vaisala, model HMP45C-L) and a rain gauge (Globalwater, GL 400-1-1). The data collected by the station during the corn crop cycle are presented in Table 1.

The reference evapotranspiration was estimated using the FAO-56 Penman-Monteith model, indicated as standard by Allen et al. (1998), Eq.1.

$$ETo = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T_2 + 273} \cdot u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

where:

ETo - reference evapotranspiration, mm d^{-1};

Table 1. Biweekly means of maximum (Max), minimum (Min) and mean (M) temperature, relative humidity (RH), wind speed (WS) and cumulative solar radiation (SR) and rainfall (P), measured by the SIPA's meteorological station during the entire corn cycle

Period	Temperature (°C)			RH	WS	SR	P
	Max	Min	M	(%)	(m s^{-1})	(MJ m^{-2})	(mm)
Mar 18-31	30.75	21.37	26.06	84.59	1.28	202.18	42.00
Apr 01-15	30.48	19.59	25.03	77.86	1.30	238.49	12.82
Apr 16-30	29.52	20.64	25.08	84.29	1.35	182.55	16.54
May 01-15	27.23	18.00	22.62	82.53	1.24	167.78	24.93
May 16-31	28.83	18.52	23.68	78.43	1.26	184.98	2.56
Jun 01-15	29.87	17.97	23.92	71.38	1.52	169.51	4.43
Jun 16-25	25.79	17.18	21.485	83.64	1.45	78.13	36.35

Δ - slope of the vapor pressure curve in relation to temperature, for the temperature T_2, kPa °C^{-1};
e_s - saturation vapor pressure, kPa;
e_a - actual vapor pressure, kPa;
γ - psychrometric constant, kPa °C^{-1};
R_n - net radiation on the surface of the plant, MJ m^{-2} d^{-1};
G - heat flow through the soil, MJ m^{-2} d^{-1};
u_2 - wind speed at 2 m, m s^{-1}; and,
T_2 - air temperature (°C) at 2 m, °C.

R_n was obtained by the difference between the net shortwave radiation and net longwave radiation (Allen et al., 1998).

All readings of the lysimeters were daily analyzed to identify the occurrences of rainfall, irrigation or drainage and disregard them in the calculation of ETc. The lysimeter mass was obtained using the calibration equation specific for each cultivation system and considered as the stored water depth. Ultimately, the water depth evapotranspired in the period was calculated using Eq. 2.

$$ETc = P + I - DD \pm \Delta mass \quad (2)$$

where:
ETc - crop evapotranspiration, mm;
P - rainfall, mm;
I - applied irrigation depth, mm;
DD - deep drainage, mm; and,
Δmass - mass variation between the readings of the i-th day of interest and the i-th previous day (i-1).

The single crop coefficient (Kc) was obtained by the ratio between crop evapotranspiration (ETc), measured in the lysimeters, and the reference evapotranspiration (ETo), estimated by Eq. 1.

The Kc of the four phenological stages of the corn in monoculture and intercropped were determined and distributed according to the recommendation of FAO: I - Initial stage: from planting to 10% of soil cover (sowing - emergence); II - development stage: end of initial stage until 80% of soil cover (bolting - flowering); III - intermediate stage: from 80% of soil cover to the beginning of fruit maturation (production - grain filling) and IV - final stage: beginning of maturation until fruit harvest (maturation - harvest). Because of the difficulty to specify the stages of intercropped corn, the same phenological interval applied to the area with only corn was used.

The crop coefficients obtained in the lysimeters were compared using the values proposed by Allen et al. (1998) for grain corn and the corrected values for the conditions of minimum relative humidity and wind speed different from 45% and 2.0 m s^{-1}, respectively.

Considering the influence of leaf area (LA) on crop ETc rates, which is one way of justifying the variations in water consumption (Rosa et al., 2013), destructive analyses were performed with sampling of 10 plants at 47 and 80 DAS. Each sampled plant was subjected to measurements of length (L) and longest width (W) of its leaves. Then, the LI-3000 photoelectric meter (LICOR) was used to determine the actual leaf area (LA). From the correlation between LA (cm^2) and the product of L (cm) and W (cm), a linear model was generated using the statistical software Sisvar 5.6 (Eq. 3).

$$LA = 0.95(L \times W) \quad (3)$$

The generated model allowed to estimate LA in four periods (47, 65, 80 and 98 DAS) taking, as a reference, plants cultivated in the lysimeters.

Results and Discussion

The corn cultivation cycle lasted for 99 days, and the intercropped system showed a total water consumption of 314.9 mm (3.18 mm d^{-1}), while corn in monoculture showed 292.1 mm (2.92 mm d^{-1}). Working with weighing lysimeters in Mossoró-RN, Santos et al. (2015) found a total water consumption of 300.5 mm for the corn hybrid AG 1051, during 77 days of cycle. Evaluating water consumption in the monoculture of corn, cv. 'Eldorado', with weighing lysimeters in Seropédica-RJ, Souza et al. (2012) found total water consumption of 394 mm, for a cycle of 115 days. In cultivation intercropped with 'mucuna-cinza', planted in the final 40 days of the cycle, the total consumption was 437 mm for a cycle duration of 121 days (Souza et al., 2012).

The intercropped system showed higher water consumption compared with the monoculture (Figure 1), due to the higher number of plants per area in the initial stages. At 47 DAS, the jack bean was cut, which resulted in reduction of daily water consumption in the intercropping due to the decrease in the leaf area that covered the lysimeter.

After cutting the jack bean, the cumulative water consumption in the monoculture became equal to that of the intercropping, which became higher again from 80 DAS on. Such variation in the intercropping can be explained by the competition between jack bean and corn, resulting in the delay of corn growth.

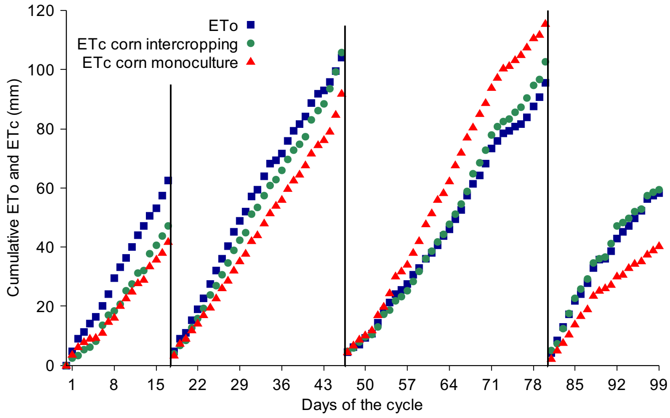

Figure 1. Cumulative values of ETo and ETc of corn intercropped with jack bean and in monoculture for the four phenological stages

The behavior of leaf area in both plots along the cycle is presented in Table 2. At the first two measurements, the monoculture showed small variation of area, with means ranging from 3078.57 to 3235.70 cm², which indicates that the plant had already reached its maximum development. In the plot with intercropping, there is an increase between the first and second measurements, suggesting that the jack bean competed with the corn crop.

At the third and fourth measurements, there was a decrease of leaf area in the monoculture (2,828.53 and 2,108.38 cm²), justifying the reduction in water consumption at the end of the cycle. At the third measurement, there was an increase in the leaf area of intercropped corn (2,736.44 cm²). Although the plant was in the maturation stage, there was still vegetative growth, which explains the increase in water consumption at the end of the cycle in relation to the monoculture.

The daily, weekly and mean Kc values of the phenological stages are presented in Figures 2A and 2B, respectively, for the intercropping and monoculture. The highest water consumption occurred in the 3rd crop stage, in which the leaf area reached 85 to 95% of its maximum value. Both cultivation systems showed a decrease in water consumption in the 10th week of the cycle. In the 12th week, the increase

Table 2. Leaf area of corn 'Caatingueiro' in monoculture and intercropped with jack bean cultivated in the lysimeters at the SIPA's experimental area in Seropédica, RJ

Days after sowing	Mean leaf area (cm²)		
	Corn monoculture	Intercropped corn	Jack bean
47	3078.57 a	2096.08 a	2887.47
60	3235.70 a	2678.35 a	-
80	2828.53 a	2736.44 a	-
98	2108.38 a	2689.89 a	-

Means followed by the same letters in the row do not differ by Tukey test at 0.05 probability level

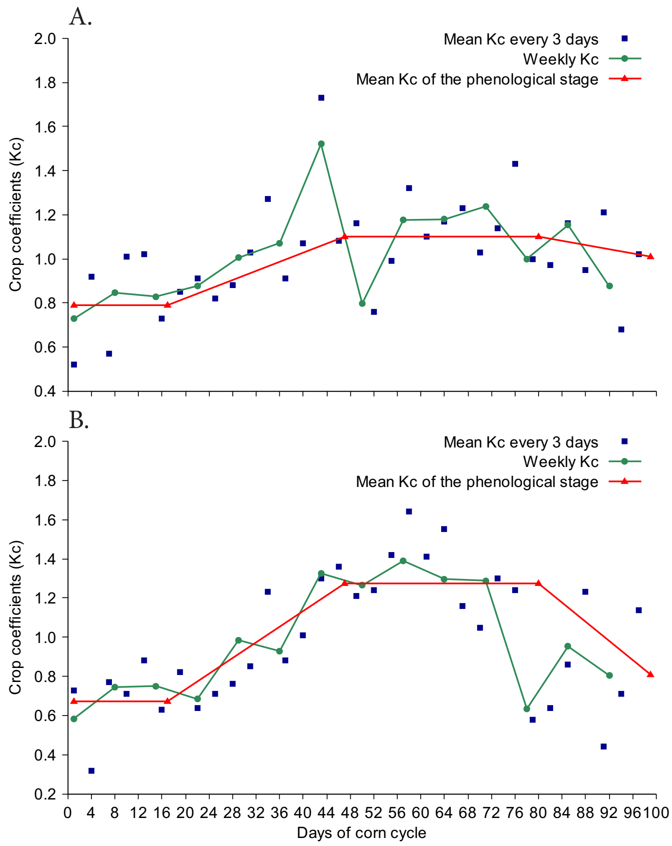

Figure 2. Daily, weekly and mean crop coefficients of 'Caatingueiro' corn intercropped with jack bean (A) and in monoculture (B), in the period of March 18 to June 26, 2015

in evapotranspiration can be attributed to the incidence of rainfall in the region, leading to increment in the rate of water evaporation from the soil.

The mean values of Kc obtained from readings in the lysimeters are presented in Table 3 along with the values of FAO Kc tabulated and adjusted (Allen et al., 1998) for the different phenological stages. For the monoculture, the observed values are close to those suggested by FAO.

The Kc of 1.27 found in stage III is close to that obtained by Caseiro et al. (1997), who cultivated corn in the autumn-winter period and found mean Kc values of 1.50 and 1.28 for stage III. The Kc of the intercropping is lower than the others in stage III, because in the beginning of this stage the jack bean was cut, reducing the leaf area that covered the lysimeter and, as a consequence, water consumption. However, the Kc values of the intercropped cultivation were close to the adjusted FAO Kc values.

Coll et al. (2012) observed increase in water demand of corn intercropped with soybean. Souza et al. (2012) also found increase in consumption of corn intercropped with 'mucuna-cinza' used in the final 40 days of the experiment.

Table 3. Mean crop coefficients and standard deviation (SD) obtained for the phenological stages of 'Caatingueiro' corn intercropped with jack bean and in monoculture, and the values presented by FAO

Cultivation systems	Development stage							
	I	SD_I	II	SD_{II}	III	SD_{III}	IV	SD_{IV}
Intercropping	0.79	0.19	1.06	0.17	1.10	0.12	1.01	0.13
Monoculture	0.67	0.13	0.92	0.19	1.27	0.13	0.81	0.23
FAO	0.70	-	0.95	-	1.20	-	0.90	-
Adjusted FAO	0.82	-	1.01	-	1.12	-	0.55	-

In the simulation of the requirement of supplementary irrigation for the corn crop in the winter of Rio de Janeiro, Carvalho et al. (2006) found corn Kc ranging from 0.57 to 0.71, for stage I; 0.9 to 1.12, for stage III and 0.63 to 0.86, for stage IV, which are similar to the values found for the monoculture (Table 2). Using the same research structure adopted in the present study, Souza et al. (2012) found Kc values of corn irrigated by sprinklers of 0.76, 0.82, 1.04 and 0.58 for the stages I, II, III and IV, respectively. These values differ from those found in the present study for the monoculture, since the planting periods and corn cultivar used were different, indicating the necessity to conduct studies of this nature.

Conclusions

1. The Kc values of 'BRS Caatingueiro' corn planted in monoculture and intercropped with jack bean were different from those presented by FAO (56).

2. The intercropped planting demanded greater water depth in comparison to the monoculture, especially in stages I and II, when the intercropping was in active growth.

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