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Determination of water demand and crop coefficient in intercropping system of lettuce and radish

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Abstract

Determining water requirement, as well as crop coefficients, are essential informations for the management of irrigation and consequently efficiency in the use of water resources. The study aimed to determine the evapotranspiration and the culture coefficients of lettuce and radish in a monoculture system and intercropping in a protected environment. The lettuce cultivar used was Vanda and for radish hybrid 19 was used. The reference evapotranspiration was estimated by the Penman-Monteith method (FAO 56) using data from the automatic weather station and the crop evapotranspiration was determined by direct method using lysimeters of constant water table. The water demand for lettuce and radish in the intercropping system was 170 mm, being less than the lettuce monoculture which was 190 mm and higher than the radish monoculture which was 121 mm. The obtained average values of crop coefficient were 0.96, 1.85, and 1.50 for lettuce and 0.85, 1.28, and 1.10 for the radish in the initial, intermediate and final stages, respectively. The intercropped cultivation showed lower water consumption than the lettuce monoculture. The coefficient values of lettuce and radish in a monoculture system were higher than the standard values recommended by FAO, emphasizing the importance of conducting regional studies

Keywords: irrigation management, *Lactuca sativa L.*, lysimeters, *Raphanus sativus*

Introduction

Irrigated agriculture demands a high amount of water for plant production, considering the needs of plants for physiological maintenance and development. For this reason, it is essential to adopt mechanisms that favor increasing the efficiency of water use. The search for managements that enable the ecologically correct and sustainable production of food has become a constant concern (Coutinho et al., 2020; Santos et al., 2018a).

The production of vegetables in a intercropping system, especially for small producers, is a cultivation system with good efficiency, which can be indicated as a sustainable model of production, as it presents better use of water, light and nutrients when there is complementarity between the crops (Andreani Junior et al., 2016; Daniel et al., 2020).

The knowledge of the total water demand for the crop during the cycle is not sufficient for the success of efficient water management, being essential studies that identify the requirements in each stage of development, being an important component in the calculation of water requirement considering the edaphoclimatic conditions (Andrade Junior et al., 2018; Andrean et al., 2022).

Several studies report crop coefficient values for lettuce (*Lactuca sativa*) and radish (*Raphanus sativus*) in a protected environment and in the field in a monoculture system (Alves et al., 2017; Andreani Junior et al., 2020; Silva et al., 2018), however, for systems intercropped between these species, information is limited.

The study aimed to determine the evapotranspiration and crop coefficients (Kc) of lettuce and radish, grown in a protected environment, in a monoculture and intercropping system in the northwest region of the State of Paraná.

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Material and methods

The experiment was conducted at Technical Irrigation Center (CTI) in State University of Maringá (UEM), located in Maringá, Paraná, Brazil (23°25'S and 51°57'W with 542 m of altitude). The region's climate is classified as Cfa type, subtropical mesothermal, with an average rainfall of 1500 mm, maintaining an average temperature of 22 to 23° C, characterized by hot, humid summers and dry winters (Nitsche et al., 2019).

The conduction of the experiment was carried out in a protected environment, in which the structure is 25 m long, 7 m wide and 3.5 m in height, with the sides covered with white anti-aphid screen and the arch ceiling covered with foil of low density polyethylene (150 μm thick).

As it is a deterministic analysis, the values collected represent the reality in the period, the place and the condition in which the cultures were conducted. The experiment does not fit into any statistical design, as direct readings of evapotranspiration of the lettuce and radish culture were carried out.

The soil, classified as NITOSSOLO VERMELHO distroférrico according to the Brazilian Soil Classification-SiBCS (Santos et al., 2018b), with clayey texture, average density of 1.34 mg m^{-3}. The soil presented as chemical parameters: pH $CaCl_2$: 6.2; pH SMP: 6.9; organic carbon: 15 g dm^{-3}; phosphorus: 75.47 mg dm^{-3}; potassium: 0.42 $cmol_c$ dm^{-3}; calcium: 7.43 $cmol_c$ dm^{-3}; magnesium: 2.27 $cmol_c$ dm^{-3}; hydrogen: 2.47 $cmol_c$ dm^{-3}; cation exchange capacity: 10.12 $cmol_c$ dm^{-3}; base saturation: 80.39%; boron: 0.32 mg dm^{-3}; copper: 16.80 mg dm^{-3}; zinc: 11.88 mg dm^{-3}; iron: 102.42 mg dm^{-3}; and manganese: 124.86 mg dm^{-3}.

The cultures were arranged in spacing of 0.30 x 0.25 m for lettuce and 0.15 x 0.05 m for radish. The radish was sown between the lettuce rows. The lettuce that was used is the cultivar Vanda (Sakata Seed Sudamerica™), which has adaptations to tropical growing conditions. The seedlings were produced in expanded polystyrene trays, of 200 cells, with coconut fiber substrate and sheltered in a greenhouse until transplanting, which occurred when they had four definitive leaves. Hybrid radish N°19 (Sakata Seed Sudamerica™) was sown on the same day as the lettuce transplant, with a thinning afterwards when the plants were 0.05 m tall.

The evapotranspiration of cultures (ETc) were determined by means of constant water table lysimeters installed inside the protected environment, conformed describe by Andrean et al. (2022). The readings of the evapotranspirated water volume and water replenishment in the feeding tank were performed daily, at 8 am.

The reference evapotranspiration (ETo) was determined by the climatic method, with the data of air temperature, relative humidity, wind speed and incident solar radiation measured using a DAVIS weather station installed inside the protected environment. The ETo calculation was obtained by Equation 1 according to the Penman-Monteih methodology parameterized in FAO bulletin 56 (Allen et al., 1998).

$$ETo = \frac{0.408\Delta\,(Rn - G) + \gamma\,\frac{900}{Tmed+273}\,u2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34u2)} \quad \text{(Equation1)}$$

On what:

ETo - reference evapotranspiration (mm d^{-1});

Δ - slope of the vapor pressure curve (kPa $°C^{-1}$);

Rn - daily radiation balance (MJ m^{-2} d^{-1});

G - daily heat flow in the soil (MJ m^{-2} d^{-1});

γ - psychometric constant (kPa $°C^{-1}$);

Tmed - average daily air temperature (°C);

u2 - average daily wind speed at 2 m high (m s^{-1});

es - saturation pressure of the average daily water vapor (kPa); and,

ea - average daily steam pressure (kPa).

Crop coefficients (Kc) were determined by having the values of ETc and ETo, according to Equation 2 below:

$$Kc = \frac{ETc}{ETo} \quad \text{(Equation 2)}$$

The culture of lettuce in a monoculture system had its phenological stages grouped in periods of seven days (Santana et al., 2016). And the radish culture cycle in a monoculture system was divided into four phenological stages: stage I = sowing to germination (5 days); stage II = crop development (10 days), stage III = fruit formation (7 days), and stage IV = maturation (6 days) (Allen et al., 1998; Alves et al., 2017). Regarding the phenological stages of intercropping, the main crop phases, lettuce, were considered. For data analysis was used MS Excel™.

Results and Discussion

In the monoculture system, lettuce and radish cultures had total ETc equal to 190 and 121 mm, respectively. While in the intercropped system of lettuce and radish the ETc was 170 mm, showing that the water consumption in the intercropped system was lower than the consumption of the lettuce monoculture. The ETc crop cycle of lettuce and radish in monoculture and in intercropping are shown in (**Figure 1**).

The ETc values of the lettuce started to increase from the second week after transplanting, reaching a maximum value of 20 DAT (Figure 1). The average leaf area of the lettuce in this period was 525 cm^2 in the monoculture system, while the average leaf area value of the radish was 79 cm^2. An increase in the average air temperature and a reduction in the relative humidity of the air can be seen (**Figure 2**).

(**Figure 3**) depicts the relationship between global solar radiation and crop evapotranspiration, since as there is an increase in solar radiation rates on the surface, there is an increase in ETc.

The Kc values of lettuce, as well as radish, determined in the present study were higher than the values recommended by FAO bulletin 56 in all phenological stages (**Table 1**).

In the intercropping system of lettuce and radish the average values of crop coefficients were: 0.94; 1.63 and 1.70 for the initial, intermediate and final stages, respectively.

It is important to note that the initial measurements of ETc are subject to the effects of variations and it is recommended to perform a refinement in the initial phase, as the crop is in the process of stabilization and there may be variation in the frequency of soil wetting (Allen et al., 1998). Therefore, ETc values were considered from the verification of the stabilization of cultures in the area (5 days after transplanting and sowing).

The evapotranspiration of lettuce culture in a tropical region averages 158 mm during the cycle, varying from 124 to 208 mm according to the growing season, with the summer being the period with the highest evapotranspiration (Silva et al., 2018). For the radish culture, the evapotranspiration determined by means of drainage lysimeter was 143.54 mm during cultivation (Costa et al., 2020).

It can be seen in Figure 1 that the radish culture in the monoculture system showed the lowest ETc values, as it is a culture with less water demand when compared to lettuce. However, the culture of lettuce in the monoculture system showed the highest ETc values up to 24 days after transplanting (DAT), showing that up to this period the system of intercropping had less water demand.

At the end of the cycle there was an inversion, in which the ETc values of the intercropping system became slightly higher than that of lettuce in the monoculture system, this fact may have occurred due to the simultaneous development of the culture of lettuce and radish, possibly associated increase in the total leaf area responsible for the transpiration of cultures. This behavior was also observed by Daniel et al. (2020) in which the evapotranspiration of corn intercropped with crotalaria was increased according to the morphological development of the crops. It is observed that the lowest values of evapotranspiration of the lettuce culture occurred in the initial phase, since the root system and the leaf area of the plants are incipient. The water demand in this phase occurs mainly due to the evaporation of water from the soil, the superficial humidity and the evaporative demand of the atmosphere, being only a small portion due to the transpiration of the plants (Teixeira et al., 2007).

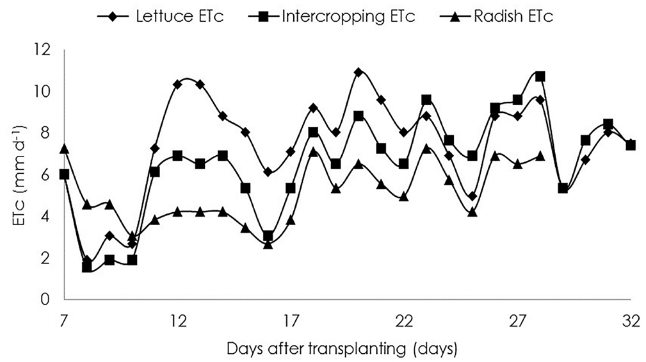

Figure 1. Comparison of the evapotranspiration of lettuce and radish in a monoculture system with a intercropping of both cultures in a protected environment.

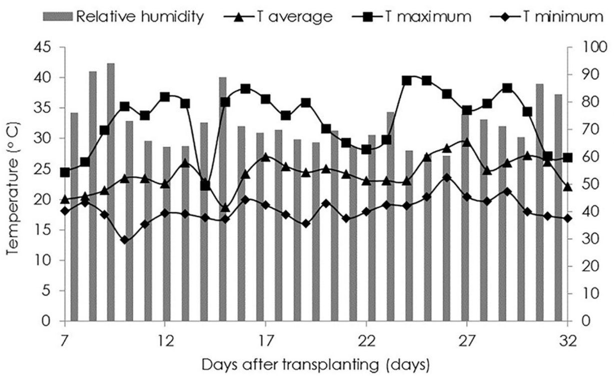

Figure 2. Maximum, average, minimum temperature and average relative humidity inside the protected environment during the experimental period.

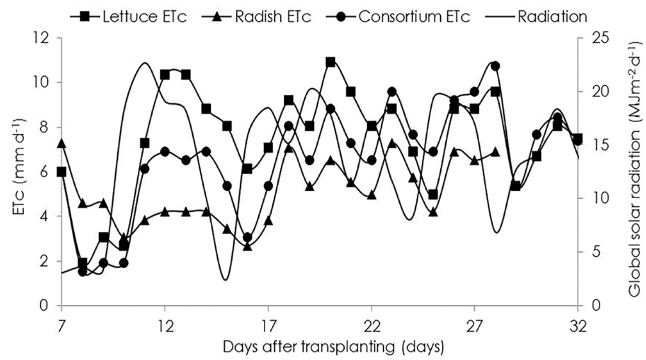

Figure 3. Variation of global solar radiation and evapotranspiration of lettuce and radish in a monoculture system and intercrop in a protected environment during the experimental period.

Table 1. Average values of lettuce and radish crop coefficients drip irrigated in a protected environment

Phase	Lettuce			Radish		
	Duration (days)	Determined	FAO	Duration(days)	Determined	FAO
Initial	7	0.96	0.70	6	0.85	0.70
Intermediate	12	2.10	1.00	10	1.28	0.90
Final	9	1.50	0.95	5	1.44	0.85

Regarding the radish culture, it is noted that the maximum ETc occurred during stage III, which comprises the formation of the bulbs. This same behavior was obtained by Alves et al. (2017) when determining the evapotranspiration of the radish culture through drainage lysymetry in Arapiraca, AL, Brazil.

The climatic variables that most affect evapotranspiration are air temperature, relative humidity, global solar radiation and wind speed, with a different degree of impact on the process (Mantovanelli et al., 2020). Therefore, when dealing with a protected environment, the wind speed becomes negligible, especially when the sides are partially or totally closed.

The variations in air temperature are a consequence of the radiation balance on the surface, influencing the evapotranspiration process, since the solar radiation absorbed by the atmosphere and the heat emitted by the cultivated surface increase the air temperature. The heated air surrounding the plants transfers energy to the crop in the form of a sensitive heat flow, increasing evapotranspiration rate (Teixeira & Lima Filho, 2004).

The balance of radiation comprises the balance between the downward and upward radioactive fluxes of short wave (BOC) and long wave (BOL), which act on the surface and depend on the global solar radiation, temperature and surface emissivity, of the albedo, presenting temporal variation and spatial that impact heat and mass exchanges in the lower atmosphere (Silva et al., 2011).

The relative humidity of the air can affect the evapotranspiration of the crops, since the increase in relative humidity reduces the gradient of concentration present in the interaction between plant tissue and atmosphere, and mediated by the saturation of air vapor (Almeida et al., 2016; Taiz et al., 2017).

The increase in air temperature implies a decrease in the relative humidity of the air, which represents an increase in the saturation deficit. When there is an increase in air temperature, the energy level of the molecules increases and also the difference between the current vapor pressure and the saturation pressure, resulting in greater evapotranspiration. More water molecules leave the evapotranspiration surface and are incorporated into the air (Pereira et al., 1997).

In protected environments, cultivation conditions are altered by the formation of a microclimate that acts directly on plant development and on the properties that influence evapotranspiration, with solar radiation being the most affected, depending on the characteristics of the material used for coverage (Oliveira et al., 2017). Part of the energy is converted into heat, boosting the sweating process and changing the temperature of plant tissues with harmful consequences for metabolic processes, which can induce stomatal closure, reducing sweating, due to the increase in the air saturation deficit inside the greenhouse (Taiz et al., 2017).

From the relationship between ETc and ETo, the mean values of the crop coefficient (Kc) of lettuce and radish were calculated in a monoculture and intercropping system for each phenological stage. It is observed the occurrence of the lowest Kc values in the initial stage for both lettuce and radish culture. Over time, Kc assumed values greater than 1.0, with ETc greater than ETo, due to the growth vegetative value of crops.

Frequent soil wetting conditions, such as the irrigation performed in the present study, can result in a substantial increase in Kc values at the initial stage (Allen et al., 1998) justifying the values found for lettuce and radish culture when compared to values proposed by FAO.

According to Figure 1 that the ETc values of lettuce and intercropping are lower in the initial phase when compared to the radish culture. This fact may occur due to the lesser area of the soil discovered, since the lettuce crop is in greater development. Reflecting in this way, the initial Kc values of the lettuce in the monoculture and consortium system are similar, because in this phase the water demand of the consortium was more influenced by the lettuce culture.

In the final phase, the average Kc value of the intercropping system is higher in relation to the monoculture of lettuce and radish, as in this period the crops were in full development, with a larger leaf area, reflecting the inversion of ETc values, which to have an increase in the consortium system (Figure 1).

This behavior is in accordance with the results described by Fietz et al. (2019), in which the corn consortium with brachiaria showed Kc values higher than single cultivation in the initial and final stages. The Kc values varied from approximately 0.8 to 1.4 for the culture of lettuce grown in the field in the Southwest region of Paraná (Nunes et al., 2009). The crop coefficient of lettuce grown in a protected environment in the region of Tangará da Serra, MT, Brazil, ranged from 0.6 to 1.4 (Santos et al., 2015). Average Kc values of lettuce cultivated in the field ranged from 0.54 to 1.21 for the region of Uberaba, MG, Brazil (Santana et al., 2016).

The radish crop coefficient determined using field drainage lysimeters showed values: 0.45 for the initial stage, 0.75 for the intermediate stage and 0.65 for the final stage (Alves et al., 2017). The reported divergences reflect the importance of local determination of crop coefficient. In addition, the vast majority of studies have outliers when compared to the values provided as standard by FAO. As a result, the underestimation or overestimation of the amount of water that must be replaced in the system.

The Kc values tabulated by FAO bulletin 56 are useful as a general guide and for comparison purposes and should be used wherever possible local observations and consider cultivar, climatic conditions, soil, irrigation system and cultural practices (Lozano-Menezes et al., 2017). It is noteworthy that in a protected environment, climatic variables undergo some changes, which may interfere with water demand and, consequently, with Kc values.

However, even though the FAO methodology in Bulletin 56 presents good accuracy in estimating evapotranspiration and adjustment coefficients for different climatic regions, currently the genetic improvement and cultivation practices have undergone a great evolution, justifying the need for current regional work to the determination of evapotranspiration in local conditions, since the use of general coefficients may not reflect the conditions in a real way (Santana et al., 2018).

Analyzing the information generated and available regarding evapotranspiration and crop coefficients, it is possible to verify the need for their judicious use for planning and decision making. This information can support government and private actions regarding the use of water resources in agriculture and technical assistance policies to optimize agricultural production and consequently contribute to food security.

Conclusion

The intercropped cultivation showed lower water consumption than the lettuce monoculture. The coefficient values of lettuce and radish in a monoculture system were higher than the standard values recommended by FAO, emphasizing the importance of conducting regional studies.

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