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Arugula production as a function of irrigation depths and potassium fertilization

Elis M. de Freitas¹, Luan B. Giovanelli², Fábio T. Delazari³,
Márcio L. dos Santos³, Silvio B. Pereira² & Derly J. H. da Silva³

¹ Universidade Federal dos Vales do Jequitinhonha e Mucuri/Centro de Ciências Agrárias/Departamento de Agronomia. Viçosa, MG. E-mail: elis_stavanato@hotmail.com

² Universidade Federal de Viçosa/Centro de Ciências Agrárias/Departamento de Engenharia Agrícola. Viçosa, MG. E-mail: luan.giovanelli@ufv.br; silviopereira.ufv@gmail.com

³ Universidade Federal de Viçosa/Centro de Ciências Agrárias/Departamento de Fitotecnia. Viçosa, MG. E-mail: fabio.delazari@ufv.br (Corresponding author); marcio.luizufv@gmail.com; derly@ufv.br

Key words:

Eruca sativa L.
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plant nutrition

ABSTRACT

Arugula is a vegetable that has gained more highlight in the consumption, being rich in potassium, sulfur, iron, omega-3 and vitamins A and C. Availability of water and nutrients are limiting factors for production of this crop. In this context, the objective of this study was to evaluate the production of arugula subjected to different irrigation depths and potassium fertilization. The experiment was conducted between August and September 2015. The experimental design was completely randomized in split-plot scheme. Irrigation depths L_1 , L_2 , L_3 and L_4 (25, 50, 75 and 100% of crop evapotranspiration, respectively) represented the plots and potassium doses K_1 and K_2 (200 and 400 kg ha⁻¹, respectively) represented the subplots. Although the highest yield was obtained with highest irrigation depth and highest potassium dose, it is recommended the cultivation of arugula with the lowest irrigation depth and the lowest potassium dose, considering the higher value of water use efficiency for this treatment.

Palavras-chave:

Eruca sativa L.
fita gotejadora
nutrição de plantas

Produção da rúcula em função da lâmina de irrigação e da adubação potássica

RESUMO

A rúcula é uma hortaliça que tem ganhado cada vez mais destaque na alimentação, sendo rica em potássio, enxofre, ferro, ômega-3 e vitaminas A e C. É uma cultura que possui, como fatores limitantes para sua produção, a disponibilidade de água e de nutrientes, contexto no qual se objetivou, neste trabalho, avaliar a produção da rúcula submetida a diferentes lâminas de irrigação e doses de adubação potássica. O experimento foi conduzido entre agosto e setembro de 2015. O delineamento experimental utilizado foi o inteiramente casualizado, no esquema de parcelas subdivididas. As parcelas foram representadas pelas lâminas de irrigação L_1 , L_2 , L_3 e L_4 (25, 50, 75 e 100% da evapotranspiração da cultura, respectivamente), e as subparcelas pelas doses de potássio K_1 e K_2 (200 e 400 kg ha⁻¹, respectivamente). Embora a maior produtividade tenha sido obtida com a maior lâmina de irrigação e maior dose de potássio, recomenda-se o cultivo da rúcula com a menor lâmina e menor dose, haja vista o maior valor de eficiência do uso da água para este tratamento.



INTRODUCTION

Arugula (*Eruca sativa* L.), also called rocket salad, is an herbaceous vegetable from the *Brassicaceae* family (Borges et al., 2014). It has small size and reaches height of 15 to 20 cm at the point of harvest, with elongated leaves with deeply cut blades, dark green color and spicy taste, rich in potassium, sulfur, iron and vitamins A and C (Gonzalez et al., 2006).

According to Carvalho et al. (2012), arugula has gained more and more space on the table of the Brazilian population and prominence in the market, because of its nutritional composition. Still according to these authors, it is a crop highly sensitive to water deficit and irrigation is a very important practice for its good development and better yield.

Another relevant factor in arugula production is its nutrition. It is known that the adequate supply of nutrients from the stage of plantlet until harvest favors the success of the production of any vegetable. For arugula, any nutritional imbalance can be irreversible due to the short growth period (Cecílio Filho et al., 2014).

In this context and in relation to the availability of nutrients, potassium has become important because, according to Silveira et al. (2015), it participates in the synthesis of sugars and proteins in the process of photosynthesis to obtain energy, in the translocation of carbohydrates and proteins and in water absorption.

Considering the importance of the arugula crop and the absence of information on its water-nutritional requirement, the present study aimed to evaluate the production of arugula subjected to different irrigation depths and potassium fertilization doses.

MATERIAL AND METHODS

The experiment was conducted at the Research Vegetable Garden of the Federal University of Viçosa (UFV), in Viçosa, MG, situated at 20° 45' 14" S, 42° 52' 53" W and altitude of 648 m, between August and September 2015.

After physical analysis of the soil in the experimental area, it was classified as sandy clay loam (Lemos & Santos, 2005), showing values of 33.00 g 100g⁻¹ of clay, 19.00 g 100g⁻¹ of silt and 48.00 g 100 g⁻¹ of sand. The values of volumetric moisture at field capacity and permanent wilting point were 0.36 and 0.22 m³ m⁻³, respectively. The chemical analysis exhibited the following characteristics of the soil: pH: 6.3, using a pH meter; base saturation (V): 52%; mean content of organic matter, determined by the Walkley-Black method: 3.1 dag kg⁻¹; available contents of P and K, extracted with Mehlich I: 24.6 and 120.0 mg dm⁻³, respectively; exchangeable contents of Ca²⁺ and Mg²⁺, extracted with 1.0 mol L⁻¹ KCl: 3.1 and 0.8 cmol_c dm⁻³, respectively; potential acidity (H+Al), extracted with 1.0 mol L⁻¹ calcium acetate at pH 7.0: 4.0 cmol_c dm⁻³ and CEC at pH 7.0, determined through the sum of Ca²⁺ + Mg²⁺ + K⁺ + (H+Al): 8.2 cmol_c dm⁻³.

The experimental design was completely randomized (CRD) in split-plot scheme, with five replicates, and each replicate consisted of three plants. Plots were represented by the irrigation depths L₁, L₂, L₃ and L₄, referring to 25, 50, 75 and 100% of crop evapotranspiration (ETc), respectively.

The subplots contained the treatments corresponding to the potassium doses K₁ and K₂, referring to 200 and 400 kg ha⁻¹ of K₂O, respectively. The dose K₂ was adopted according to the recommendation of Porto et al. (2013), in a study that points out the maximum water use efficiency by arugula when subjected to this dose, while the dose K₁ was adopted by the authors to study the behavior of arugula in a nutritional condition below the recommended one.

Sowing was performed on August 21, 2015, on trays with 200 cells and the substrate for plants 'Carolina, Padrão II', EC = 1.5 mS cm⁻¹ ± 0.3, using three seeds per cell of the cultivar 'Astro'. Transplanting occurred on September 2, when the seedlings reached the first pair of true leaves. 400 seedlings were transplanted at spacing of 0.10 x 0.20 m and arranged in 4 beds (1 m wide x 2 m long). Each bed received one irrigation depth and the potassium doses. The experimental plots had total area of 0.7 m², evaluation area of 0.3 m² and were separated by 30 cm. Arugula plants were harvested on September 28.

A drip tape was used, operating with flow rate of 1.72 L h⁻¹, at pressure of 10.0 mwc, and Christiansen Uniformity Coefficient (CUC) of 98.7%. The drippers on the tape were spaced by 0.30 m. On the beds, the tapes were spaced by 0.40 m, resulting in an application intensity of 14.35 mm h⁻¹.

Irrigation frequency of two to three days was used in the management of irrigation depth, with water demand calculated by the estimate of crop evapotranspiration (ETc), constituting the treatments. Eqs. 1 and 2 were used to estimate crop evapotranspiration (Allen et al., 2006; Angeli et al., 2016).

$$ETc = ETo \times Kc \quad (1)$$

$$Kc = (Kcb \times Ks) + Ke \quad (2)$$

where:

- ETc - crop evapotranspiration, mm d⁻¹;
- ETo - reference evapotranspiration, mm d⁻¹;
- Kc - crop coefficient;
- Kcb - basal crop coefficient;
- Ke - soil evaporation coefficient; and,
- Ks - stress coefficient.

The arugula cycle was divided into phenological stages based on the growth period or vegetative period, related to the shading of the area, in which each stage assumed a different value of crop coefficient (Kc). The calculations used coriander Kcb values, because of the lack of information on arugula. The initial, intermediate and final Kcb values were 0.15, 1.10 and 0.70, respectively (Silva et al., 2013).

Along the experiment, the irrigation depths applied in the treatments referring to 25, 50, 75 and 100% of crop evapotranspiration (ETc) were 19.7, 39.5, 59.2 and 79.0 mm, respectively.

The daily data of maximum, mean and minimum temperature (°C) and relative air humidity (%), solar radiation (W m⁻²) and reference evapotranspiration (ETo, in mm d⁻¹), used for irrigation management are presented in Figure 1. These data were obtained using a meteorological station installed in the experimental area.

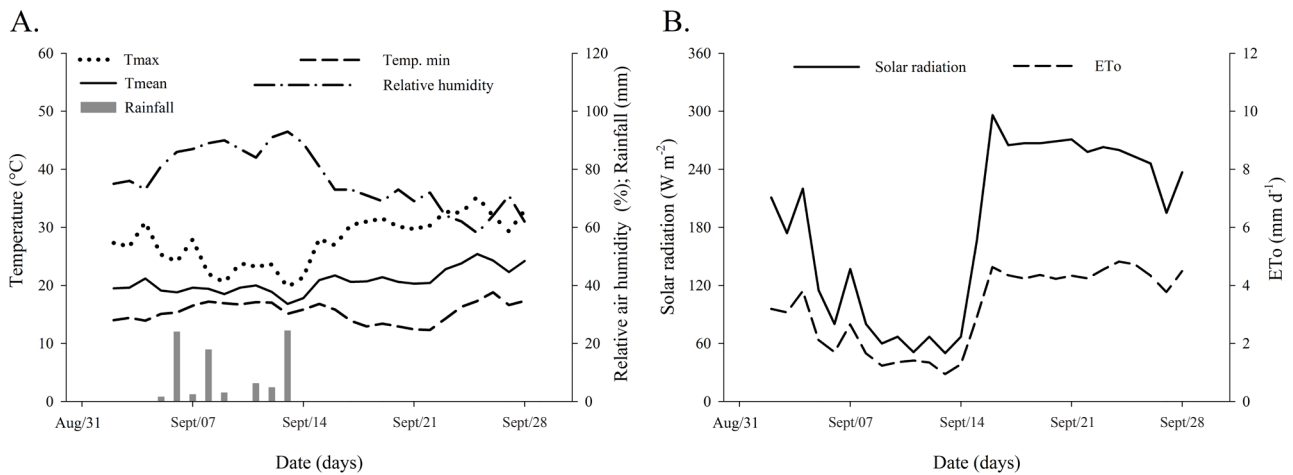


Figure 1. Daily values of maximum, mean and minimum temperature, relative air humidity and rainfall (A) and solar radiation and reference evapotranspiration (B) for the period of arugula cultivation

Soil acidity was not corrected, because the pH of the soil of the experiment (6.3) was within the ideal range (5.5 to 6.5) recommended to maintain ideal levels of macro and micronutrients for cultivated plants (Ribeiro et al., 1999). At transplanting, the soil received 600 kg ha⁻¹ of P₂O₅ in the form of single superphosphate (18% P₂O₅) and 400 kg ha⁻¹ of N in the form of ammonia sulfate (20% N). Potassium fertilization was split using KCl (59% of K₂O) as source of K. In the treatment K₁ (200 kg ha⁻¹ of K₂O), half of the dose was applied at planting and the other half split into two applications - at 8 and 16 days after transplanting (DAT). For the treatment K₂ (400 kg ha⁻¹ of K₂O), 42.25% of the recommended dose was applied at planting and the rest split into two similar applications, at 8 and 16 DAT.

After reaching the commercial size of 20 to 30 cm, the 15 central plants of each treatment were harvested and their heights were measured. After harvest, leaves were passed in the leaf area integrator LAI 3010 (Licor Inc., Lincoln, NE, USA) and the fresh matter was quantified. Water use efficiency (WUE) was also evaluated, defined by the relationship between production and the applied water volume, expressed in kg m⁻³. On the day of harvest, leaf temperature was measured with an

infrared thermometer and chlorophyll index was determined with a ClorofiLog device (Falker, Porto Alegre, RS, Brazil).

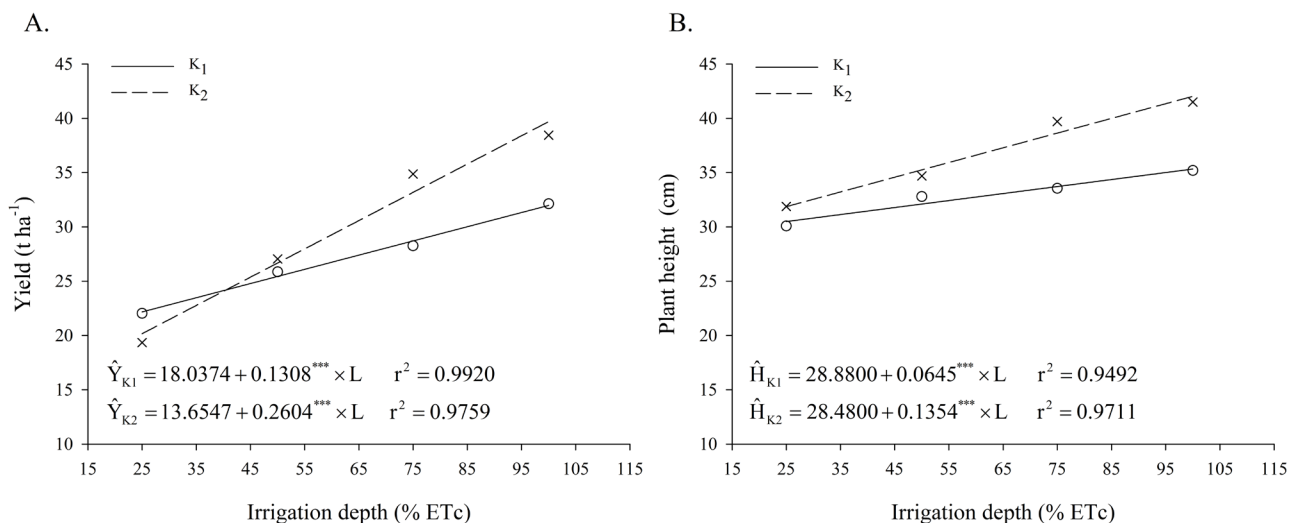
The data were analyzed through regression analysis. The equations were fit for each K dose correlating the irrigation depths with the evaluated characteristics. The regression models were selected based on the significance of the regression coefficients using the t-test at 0.1 probability level.

RESULTS AND DISCUSSION

The responses of arugula yield and height to the irrigation depths for each K dose are presented in Figure 2.

It is observed in Figure 2 that the increment of 1% in ETc promoted a yield increase of 0.1308 t ha⁻¹ in the treatments that received the dose K₁ and 0.2604 t ha⁻¹ in those that received the dose K₂.

The plant responded positively to the increment in K doses as the irrigation depths increased. For lower irrigation depths (25 and 50% of ETc), the supply of K little influenced yield. For the irrigation depth of 25%, for instance, twice the K dose led to lower yield. This behavior can be attributed to the fact that potassium chloride is a salt, which may have increased the



***Significant at 0.1 probability level by t-test

Figure 2. Response of arugula yield (A) and height (B) as a function of the applied irrigation depth (% ETc) for each potassium dose

osmotic potential of the soil under low water supply condition, compromising the absorption of water and nutrients by plant roots.

Maximum yield (39.7 t ha⁻¹) was obtained for the irrigation depth L₄ and potassium dose K₂. This maximum yield occurred probably because the water contents in the soil were adequate for the crop, which allowed greater absorption of water and nutrients. The water deficit caused by the application of the lowest irrigation depths damaged the development of the plants.

The first and most sensitive response to water deficit is the decrease in turgor and, associated with this event, the reduction of the process of plant growth in extension (Chaves Filho & Stacciarini-Seraphin, 2001; Larcher, 2006). Under water deficit condition, there is a restriction to biomass accumulation, which damages the number of leaves both in the initial and later stages, limiting the dimension of individual leaves and, consequently, total leaf area, number and growth rates of branches and stem growth (Osório et al., 1998).

Another hypothesis that may have contributed to the increment in yield as K doses and irrigation depths increased is the relationship between K and N, the water supply and the dynamics of K⁺ in the soil. K can act in the better use of other nutrients in the plant, such as N, which was observed in the treatments that received the highest irrigation depths. With greater K availability, there is a better assimilation of N, which acts in the increase of photosynthetic activity due to the higher chlorophyll indices. Hence, the use of N allows the increase in its absorption, assimilation and nutrition and, consequently, in plant yield (Viana & Kiehl, 2010).

According to Figure 2B, the variable plant height followed a behavior similar to that of yield. As the irrigation depth increased for both K doses, plant height increased. The highest K dose (K₂), associated with the highest irrigation depth (L₄), resulted in the highest value of plant height (42 cm).

The increment of 1% in ETc caused an increase of 0.0645 cm in plant height in the treatment K₁ and 0.1354 cm in the treatment K₂, being almost two times higher in the treatment with the highest K dose.

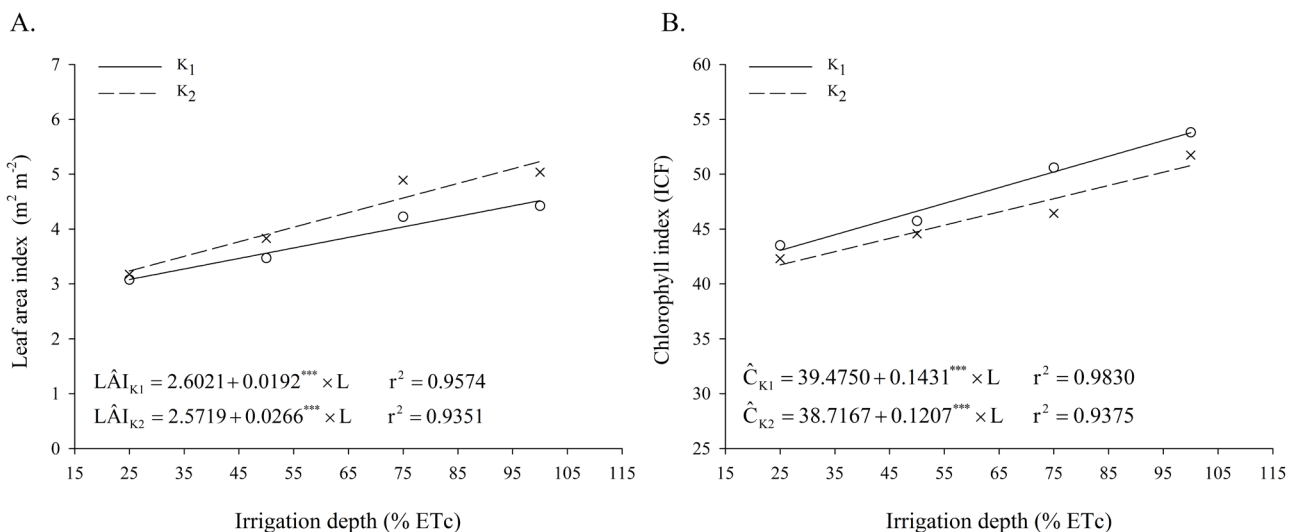
K is an essential macronutrient for higher plants and the third element that most limits plant growth, with important role in the translocation of compounds elaborated in the plant tissue (Marenco & Lopes, 2005). It is appropriate to point out that leafy vegetables deserve attention with respect to water use, because the plants are strictly sensitive to water regime and the lack of water can compromise plant growth, while its excess can damage root respiration and lead to the occurrence of diseases.

The responses of the variables leaf area index and chlorophyll as a function of the irrigation depths for each K dose are presented in the figure below.

According to Figure 3, when the irrigation depth L₁ was applied, in comparison to L₄, for both K doses, there was an increment in leaf area index. The greater supply of K promoted an increase in the variation of leaf area index from 0.0192 to 0.0266 m² m⁻² for each 0.01 increase in the ETc applied in the treatments.

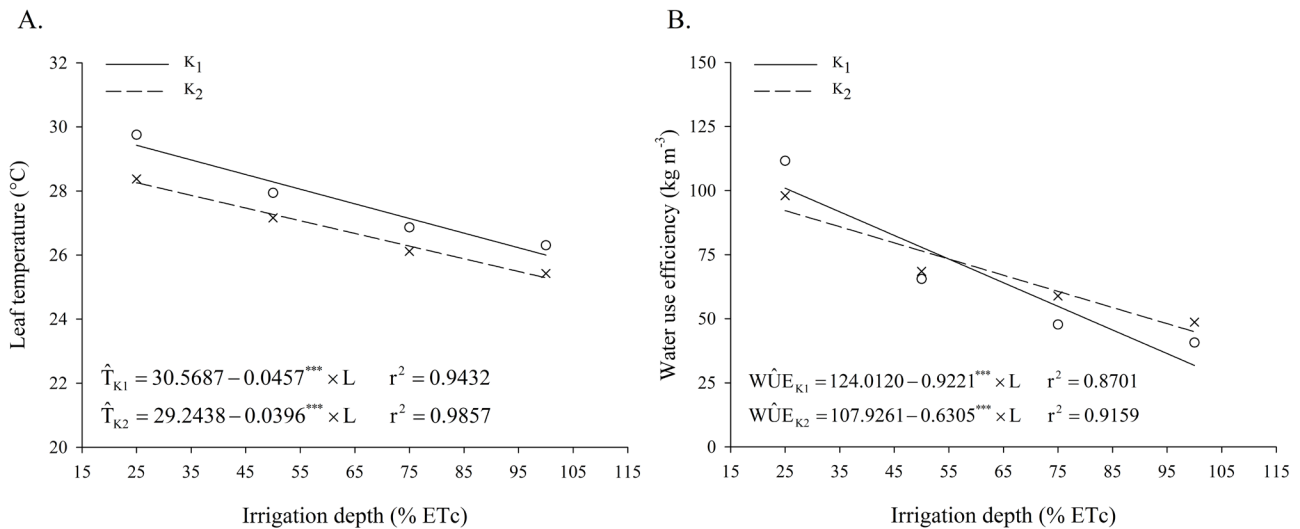
The highest value of leaf area index (5.2 m² m⁻²) was observed in the irrigation depth L₄ for the dose K₂. These results allowed to infer that plants under water deficit showed reduced leaf area and leaf area index, a condition evidenced by plants subjected to the irrigation depth L₁. Leaf area is an important factor in the production and determines the use of water by plants and their yield potential is severely inhibited when exposed to water deficit (Fernández et al., 1996). Water stress limits not only the size of individual leaves, but also the number of leaves, because it decreases the number and growth rates of the branches (Taiz et al., 2015).

The regression analysis for the characteristic chlorophyll index (CI) is presented in Figure 3B. For both K₁ and K₂ doses, the chlorophyll index decreased always when the water deficit, caused by the application of the lowest irrigation depths, was accentuated. Gonçalves et al. (2010) and Jangpromma et al. (2010) also observed reduction in the chlorophyll index of plants subjected to water stress, in comparison to plants satisfactorily irrigated. The highest value of chlorophyll was observed in the treatment L₄K₁, related to the irrigation depth of 100% ETc and K dose equal to 200 kg ha⁻¹ of K₂O.



***Significant at 0.1 probability level by t-test

Figure 3. Response of leaf area index (A) and chlorophyll index (B) as a function of the applied irrigation depth (% ETc) for each potassium dose



***Significant at 0.1 probability level by t-test

Figure 4. Response of leaf temperature (LT) and water use efficiency (WUE) as a function of the applied irrigation depth (% ETc) for each potassium dose

It should be pointed out that the application of the dose K₁ promoted higher values of CI in comparison to K₂, for all irrigation depths, which can be explained by the fact that the chlorophyll index is dimensionless and proportional to values measured at the laboratory, as g chlorophyll g⁻¹ leaf or g chlorophyll area⁻¹ of the leaf. Since the dose K₁ contributed to lower yield increments (Figure 2A) and leaf area index (Figure 3A), as the irrigation depths increased, compared with the dose K₂, the divider of the ratios - g chlorophyll g⁻¹ leaf or g chlorophyll area⁻¹ of the leaf - used to calculate CI, tends to be smaller, increasing the values of CI.

The responses of the variables leaf temperature and water use efficiency as a function of the irrigation depths for each K dose are presented in Figure 4.

Based on the results, there was a decrease in temperature with the increase of irrigation depths for both K doses. The highest temperature was observed in the treatment L₁K₁, related to the irrigation depth of 25% of ETc and dose of 200 kg ha⁻¹ of K₂O.

Under water stress, plants exhibit higher leaf temperature, in comparison to those cultivated under full water availability conditions (Testi et al., 2008). Trentin et al. (2011) observed that leaf temperature is closely associated with the process of transpiration. As it increases, there is a reduction in leaf temperature due to the dissipation of energy in the form of latent heat.

Since the lowest K dose promoted lower plant development, reducing height (Figure 2B) and leaf area index (Figure 3A), compared with the highest dose, there was lower transpiration of the plants in these treatments, increasing leaf temperature, as explained above.

As to the water use efficiency (WUE, Figure 4B), the increase in irrigation depths caused lower water use efficiency at both K doses, but at the highest irrigation depths - L₃ and L₄ - the dose K₂ was more efficient in the use of water, while at the lowest irrigation depths L₁ and L₂ - the dose K₁ was more efficient.

The decrease in water use efficiency as the irrigation depths increased indicates that the increase in yield was not proportional to the increment in water supply. For the dose K₁,

the increase of four times in the irrigation depth (25 to 100% of ETc) promoted only an increment of approximately 1.5 times in the value of yield, while at the dose K₂ this increase in the irrigation depth promoted only an increment of approximately two times in the value of yield. The dose K₂ led to higher WUE values for the lowest irrigation depths, because there was a greater increment of yield in these treatments with the increase in the applied irrigation depth, compared with the dose K₁.

Coelho et al. (2005) claim that water use efficiency can be increased by reducing the applicable irrigation depth (evapotranspiration) in such a way to not drastically reduce yield. According to these authors, this alternative would lead to the maintenance of a high efficiency of the irrigation system, increasing water use efficiency by the reduction in the actual irrigation depth necessary during the stages of growth and development considered not critical for the plants, without significant damage to the expected potential yield.

CONCLUSIONS

1. Maximum values of yield, plant height and leaf area index were obtained with the application of the highest irrigation depth and highest potassium dose.
2. The lowest potassium dose, associated with the lowest irrigation depth, promoted the highest values of leaf temperature and water use efficiency and, when associated with the highest irrigation depth, increased the value of chlorophyll index.
3. Although the highest yield was obtained with the highest irrigation depth and highest potassium dose, it is recommended to cultivate arugula with the lowest irrigation depth and lowest dose, because of the higher water use efficiency for this treatment.

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