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COEFICIENTE DE PRODUTIVIDADE – KY DO FEIJÃO CARIOCA (*Phaseolus vulgaris* L. TAA DAMA.) PARA O MUNICÍPIO DE BOTUCATU-SP*

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1 RESUMO

A irrigação apresenta-se como ferramenta fundamental para a segurança hídrica no campo. Estudos sobre o uso racional da água na irrigação são importantes, devido a economia de água e energia. Nesse sentido, a determinação dos coeficientes de resposta hídrica (Ky) surge como alternativa para realizar o manejo da irrigação. O objetivo deste trabalho foi determinar os valores de Ky em diferentes fases fenológicas do feijão carioca cultivar TAA DAMA. Foi instalado um experimento em casa de vegetação, onde adotou-se o delineamento inteiramente casualizado, constituído por 4 tratamentos e 12 repetições. Os tratamentos consistiram na aplicação de déficit hídrico em diferentes estádios fenológicos: T1: controle (não houve déficit hídrico); T2: estádio vegetativo; T3: estádio de floração e T4: estádio de enchimento de grão. Foram analisados a produtividade dos tratamentos. Os dados obtidos foram submetidos à análise de variância e ao teste Tukey a 5% de probabilidade. Foi possível concluir que a fase de enchimento de grão, aos 82 (DAP), obteve a maior perda de produtividade da cultura, com um decréscimo de 52,2% de produtividade em relação ao controle. Assim os valores de Ky nas fases vegetativa, floração e enchimento de grãos foram 1,37, 1,69 e 1,85 respectivamente.

Palavras-chave: coeficiente de resposta hídrica (Ky), evapotranspiração, tensiômetria, Hargreaves Samani.

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PRODUCTIVITY COEFFICIENT – KY OF CARIOCA BEAN (*Phaseolus vulgaris* L. TAA DAMA.) **FOR THE MUNICIPALITY OF BOTUCATU-SP**

2 ABSTRACT

The irrigation presents itself as a fundamental tool for water security in agriculture. Studies on the rational irrigation water use are of importance for a good productivity, while at the same time ensuring water and power costs. In this sense, a determination of water response coefficients (Ky) appears as an alternative to carry out irrigation management. The objective of this work was to determine the Ky values for different bean phenological phases. An experiment was installed in a greenhouse, the experimental design was in a completely randomized design, consisting of 4 treatments and 12 repetitions. The treatments were application of water deficit, a different phenological stages: T1: control (there was no water up to deficit at any time); T2: vegetative stage; T3: flowering stage; T4: grain filling stage. It was measured the productivity. The collected data had an analysis of variation and Tukey test at 5% probability. It was possible to conclude that the grain filling stage, at 82 days after sowing, was the phase that obtained the greatest loss of productivity, resulting in a 52.2% decrease in productivity compared to the control. Thus, Ky values in the vegetative, flowering and grain filling stages were 1.37, 1.69 and 1.85 respectively.

Keywords: water response coefficient (Ky), evapotranspiration, tensiometer, Hargreaves Samani.

3 INTRODUCTION

Crop productivity is directly linked to three main interacting factors: soil, plants, and the atmosphere. The relationships among these factors affect crop production, which is influenced by the environmental conditions of the growing site. This interaction is called the water response factor or productivity coefficient (Ky). (SILVA et al., 2009).

Owing to the wide variation in environmental conditions, the uneven distribution of rainfall strongly affects the water supply in arable land. Therefore, irrigation is a fundamental tool for ensuring water security in the field, considering that rainwater alone is not sufficient to meet the water demand of crops.

Since irrigation plays an important role in agriculture, its management must be carried out appropriately, taking into account crop evapotranspiration, and excessive irrigation should not occur, resulting in negative impacts such as water waste, salinization, compaction, soil erosion and high energy consumption (PITOL LUCAS et al., 2015). Deficient irrigation should also not occur, as it affects the biochemical and physiological processes of plants, leading to problems such as loss of turgor, wilting, burning of plants, increased entry of pathogens and, consequently, significant losses in productivity (SANTOS; CARLESSO, 1998).

According to Silva et al. (2012), plants are able to express their greatest productive potential when they are not subjected to water stress at any time, that is, when actual evapotranspiration (ETr) is equal to maximum evapotranspiration (ETm). However, if the water supply is less than the plant's evapotranspiration demand, a water deficit will occur; thus, the plant's yield will be lower, depending on the amount of water supplied. Crop productivity decreases as the severity of the water deficit increases and is strongly influenced by the phenological phase in which water stress occurs (ALMEIDA, 2016).

To relate productivity to the amount of water supplied to a given crop during its cycle, Doorenbos and Kassam (1979) proposed the water yield response coefficient Ky through an equation in which the reduction in relative yield is linked to a relative reduction in evapotranspiration.

$$\left(1-\frac{Yr}{Ym}\right)=Ky\left(1-\frac{ETr}{ETm}\right) \quad (1)$$

where Ky is the water yield response coefficient; Yr is the actual yield (kg ha^{-1}); Ym is the maximum or potential yield (kg ha^{-1}); ETr is the actual crop evapotranspiration (mm); and ETm is the maximum crop evapotranspiration (mm).

To assess the decline or increase in productivity as a function of water supply for a given crop, the Ky coefficient is used to predict productivity on the basis of plant water deficit. In crop phenological phases where Ky < 1.0, the plant is more tolerant to water stress, resulting in proportionally smaller productivity reductions with reduced water use, enabling the optimization of irrigation costs. In phases where Ky > 1.0, greater sensitivity to water stress is identified, resulting in proportionally greater productivity reductions with reduced water use, indicating the need for irrigation in satisfactory quantities to meet crop evapotranspiration. When Ky = 1, the yield reduction is directly proportional to the reduction in water use.

In this context, it is possible to plan water use in crops, managing the timing of higher or lower irrigation depths on the basis of Ky values at each crop stage, effectively optimizing field costs and consequently promoting greater profits for the producer. Therefore, this study was conducted to determine the production water response factor (Ky) for the carioca bean cultivar TAA DAMA in the municipality of Botucatu, São Paulo, for which there are no references in the technical or scientific literature.

4 MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Lageado Experimental Farm of the School of Agricultural Sciences - UNESP/Botucatu Campus, São Paulo State. Asbestos pots with a capacity of 50 L were used, and the soil used was classified as Dystrophic Red Latosol with a loamy texture.

To carry out this experiment, carioca bean seeds (*Phaseolus vulgaris* L.), cultivar TAA DAMA, were treated with the Cruizer 350 FS insecticide and the Vitavax fungicide Thiram 200 SC.

Irrigation was carried out via a drip system with dripper buttons at a flow rate of 4.0 L h^{-1}. The soil water content was determined with tensiometers installed at depths of 15 cm, and the average value was used to calculate the irrigation depth. The soil water retention curves were determined for the same depths according to the methodology of Embrapa (2007).

A randomized statistical design was adopted for the distribution of treatments, with four treatments and twelve replicates. The plants in Treatment 1 were irrigated, and the soil was maintained at field capacity. throughout the crop cycle. Irrigation was applied when the soil tension reached 26 kPa (35% of CAD), and the irrigation was continued for the time determined according to the irrigation system used until the tension returned to 6 kPa (field capacity) with a moisture content of 0.211 cm^3 cm^{-3}, which was the control. The other treatments suffered a water deficit in only one development phase: vegetative, flowering, and grain filling. At the time of water deficit application, the treatments were not irrigated until the soil water tension reached 70 kPa, resulting in a moisture content of 0.104 $^{cm^{3}{}^{-3}}$. The treatments were designed as follows: T1: Control (did not suffer a water deficit at any time); T2: suffered a water deficit only in the vegetative phase (Figure 1); T3: suffered a water deficit only in the flowering phase (Figure 2); T4: suffered a water deficit only during the grain-filling phase (Figure 3).

Treatments were started at 35 DAP (days after planting); before this period, all the treatments were irrigated equally, being maintained at field capacity.

Figure 1. Water stress in the vegetative phase

Source: SANTOS, RM (2021).

Figure 2. Water stress during the flowering phase

Source: Santos (2021).

Figure 3. Water stress during the grain-filling phase

Source: Santos (2021).

At 90 DAP, productivity analysis was performed, the number of pods per plant was determined, and the quantity of grains per pod and their respective weights were determined when the moisture content reached 15%.

To obtain the ETr and ETm values, which constitute the Ky equation, it is first necessary to estimate the ETo (reference evapotranspiration) and ETc (crop evapotranspiration) values.

To estimate ETo, the model proposed by Hargreaves and Samani (1985) was used according to the following equation:

$$ETo = 0{,}0023 * Ra\ (Tméd + 17{,}8) * (Tmáx - Tmin)^{0{,}5} \quad (2)$$

where Ra represents the radiation at the top of the atmosphere, MJ m^{-2} d^{-1} represents the value tabulated according to the latitude of the location and day of the year, and T_{max}, T_{min} and T_{med} represent the maximum, minimum and average air temperatures in °C, respectively.

The Hargreaves Samani equation was initially proposed for use in arid and semiarid climate regions (ADEBOYE et al., 2009; SENTELHAS, GILLESPIE; SANTOS, 2010; SUBBURAYAN; MURUGAPPAN; MOHAN, 2011). Bernardo, Soares, and Mantovani (2006) noted possible overestimated ETo values under humid climates and underestimated values under high wind speed conditions. The climate of Botucatu is Cwa, mesothermal (subtropical and temperate), with hot, rainy summers and cold, dry winters (ROSSI et al., 2018). However, Shahidian et al. (2011), studying the use of the Hargreaves and Samani equation (1985) for the calculation of ETo in greenhouses, concluded that such an equation results in satisfactory ETo estimates when used inside a greenhouse since the wind speed in greenhouses is negligible.

To estimate ETc, the following equation was used:

$$ETc = ETo * Kc \qquad (3)$$

where ETc represents crop evapotranspiration; ETo represents reference evapotranspiration; and Kc represents the crop coefficient.

The Kc values used were those proposed by Doorenbos and Kassam (1979) (Table 1).

Table 1. Values of the crop coefficient (Kc)

Phase	Development stage	Duration (days)	DAP	Kc	Phase
1	Initial development	35	1 - 35	0.4	V0 - V3
2	Vegetative	15	35 - 50	0.65	V3 - V4
3	Flowering	13	50 - 63	1.05	R5 - R6
4	Grain filling	24	63 - 87	0.9	R7 - R8
5	Maturation	3	87-90	0.85	R9

DAP: Days after planting; Kc: crop coefficient.

Source: SANTOS, RM (2021).

The ETr estimate was performed according to the following equation:

$$ETr = ETc * Ks \qquad (4)$$

where ETr is the actual evapotranspiration; ETc is the crop evapotranspiration; and Ks is the effect of the soil water deficit obtained through tensiometric data.

To calculate Yr, the productivity values of the treatments that experienced water stress in a phenological phase were obtained, namely, T2, T3 and T4.

The maximum yield value (Ym) was obtained according to the productivity obtained in treatment 1 (control), in which the soil remained at field capacity throughout the crop cycle, according to the methodology proposed by Embrapa (2010).

5 RESULTS AND DISCUSSION

This study highlights the high productivity that can be achieved by managing water use in irrigation, where the highest productivity achieved was in treatment 1 (control), with 4983.2 kg ha $^{-1}$ (Table 2), which was 73.89% higher than the country's average productivity in the 2020/21 harvest.

According to ANA (2021), the use of different types of irrigation systems has been increasing, with average annual growth reaching 216,000 hectares in 2019, 66% higher than that in 2011. In this sense, there is a significant expansion in the use of irrigation in crops and the need for their management, given that the average productivity of beans in Brazil remains low, even with the increased use of irrigation in the country.

In this sense, the Ky coefficients address issues of water management in the phenological phases of carioca beans to achieve higher productivity.

In the vegetative phase, Steduto et al. (2012) reported that the Ky coefficient value can vary from 0.38 to 0.56. In the present study, the Ky value in this phase was 1.37 (Table 2). This difference in value may have been influenced by the crop's adaptation to local environmental conditions and the TAA DAMA cultivar used. In the T2 treatment, there was a 30.2% reduction in productivity. This highlights the high sensitivity of crops to water deficit in the vegetative phase. Therefore, if the crop is irrigated in subsequent phases at levels where ETr reaches or is close to the ETc values, the crop can establish physiologically, but such a deficit will compromise final productivity.

In any case, 3479.8 kg ha $^{-1}$ (Treatment 2) is 62.6% higher than the average productivity obtained in the 2020/21 harvest.

Table 2. Ky coefficient values

Treatment	ETr (mm/day)	ETm (mm/day)	(1-ETr/ETm)	Yr (kg ha $^{-1}$)	Ym (kg ha $^{-1}$)	(1-Yr/Ym)	Ky
1	326.1	415.35	0.215	4983.2	4983.2	0.000	0.00
2	323.9	415.35	0.220	3479.8	4983.2	0.302	1.37
3	323.8	415.35	0.220	3125.4	4983.2	0.373	1.69
4	298.45	415.35	0.281	2384.4	4983.2	0.522	1.85

* Average values of maximum evapotranspiration (ETm, mm), actual evapotranspiration (ETr, mm), relative evapotranspiration deficit ([(1 – ETr/ETm), mm), actual productivity (Yr, kg ha $^{-1}$), maximum productivity (Ym, kg ha $^{-1}$) and relative yield decline ([(1 – Yr/Ym)], ha $^{-1}$) in different stages of carioca beans analyzed at Botucatu-SP.
Source: SANTOS, RM (2021).

In the flowering phase of the crop, the Ky value stated in the FAO 66 document varies from 1.35 to 1.75 (STEDUTO et al., 2012). In the present research, the value obtained was 1.69 (Table 2), which is consistent with the value proposed by FAO 66, representing a high level of sensitivity of the crop to water stress in this phase, resulting in a 37.3% decrease in final productivity.

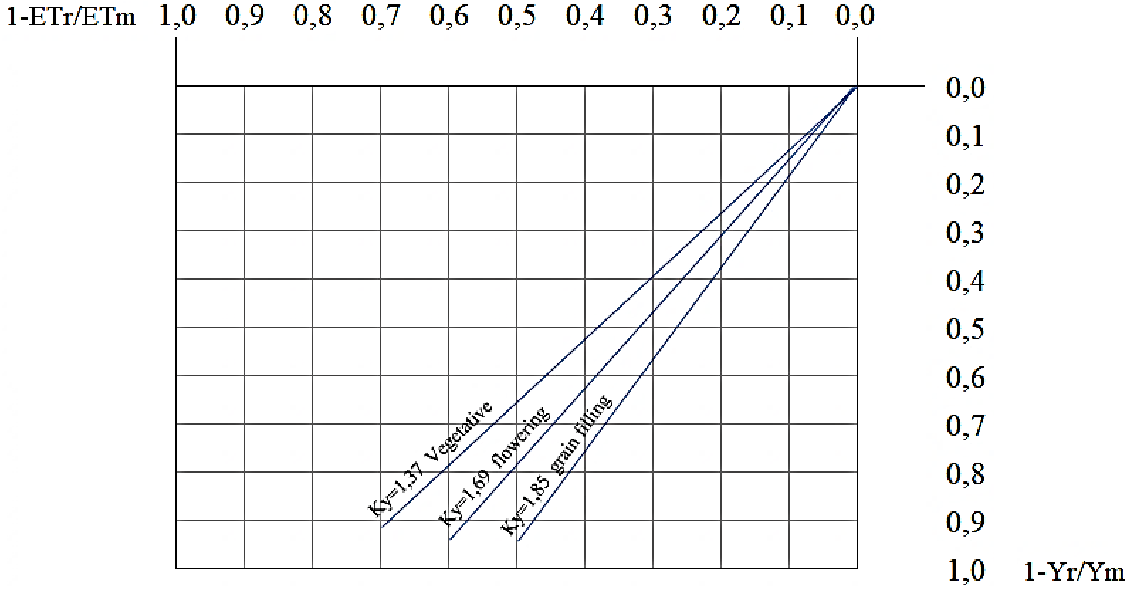
In the grain-filling phase, the Ky value proposed by FAO66 ranges from 0.87--1.44 (STEDUTO et al., 2012). In the present study, a value of 1.85 was obtained (Table 2), resulting in a 52.2% decrease in productivity, classifying this phase as highly sensitive to water deficit. This variation may have occurred because of the genetic material of the TAA DAMA cultivar, which is highly sensitive to water stress during this phase.

In their research on water deficiency in different phases of cowpea, Bezerra et al. (2003) concluded that the grain-filling phase was the phase that suffered the most from water deficit, resulting in the lowest productivity, corroborating the results of the present research, where the Ky value was 1.85. Thus, the Ky value is consistent with the low productivity obtained in Treatment 4 (Table 2).

The Ky values were determined from linear relationships because the relative yield (Yr/Ym) is linearly related to the relative evapotranspiration (ETr/ETm); that is, when changes in the independent variable occur, the dependent variable consequently changes.

In Figure 4, the differences in the Ky values are noted; the steeper the slope of the linear function is, the greater the Ky value, and the greater the reduction in yield in a given reduction in evapotranspiration resulting from the water deficit applied in the specific period.

Figure 4. Linear water production functions for the carioca bean cultivar TAA DAMA with water deficits occurring during the vegetative period, flowering and grain filling



Source: SANTOS, RM (2021).

Considering that there is no research defining the Ky value for the TAA DAMA cultivar, this article is the first bibliographic source available to producers in the Botucatu-SP region.

6 CONCLUSION

The productivity of the carioca bean cultivar TAA DAMA grown in Botucatu is strongly related to the availability of water during the cycle. The Ky values were all greater than 1.0, varying in the following decreasing order: grain filling (1.85), flowering (1.69), and vegetative (1.37). **The phase that showed the greatest sensitivity to water deficit was grain filling, resulting in a 52.2% decrease in productivity.** Owing to the sensitivity of the carioca bean cultivar TAA DAMA to water stress, supplemental irrigation is recommended for the Botucatu-SP region at all phenological stages of the crop.

7 REFERENCES

ADEBOYE, OB; OSUNBITAN; ALREADY; ADEKALU, KO; OKUNADE, FROM Evaluation of FAO - 56 Penman Monteith and temperature based models in estimating reference evapotranspiration using complete and limited data application to Nigeria. **Agricultural Engineering International** , Beijing, v. 11, n. 1291, p. 1-25, 2009.

ALMEIDA, BM **Water deficit and excess in corn crops in a protected environment** . 2016. Thesis (Doctorate in Agricultural Systems Science/Engineering) – Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, 2016.

ANA. **Irrigation Atlas** : water use in irrigated agriculture. 2nd ed. Brasília, DF: ANA , 2021.

BERNARDO, S.; SOARES, AA; MANTOVANI, EC **Irrigation Manual** . 8th ed. Viçosa, MG: UFV, 2006.

BEZERRA, FML; ARARIPE, MAE; TEÓFILO, EM; CORDEIRO, LG; SANTOS, JJA Cowpea and water deficit in its phenological phases. **Agronomic Science Journal** , Fortaleza, v. 34, n. 1, p. 13-18, 2003.

DOORENBOS, J.; KASSAM, AH **Effects of water over crop yield** . Rome: FAO, 1979. (Irrigation and Drainage paper , no. 33).

EMBRAPA. **Determination of the soil water retention curve in the laboratory** . Teresina: EMBRAPA , Nov. 2007.

EMBRAPA. **Irrigation Management Strategies: Calculation Examples** . Sete Lagoas: Embrapa, Sept. 2010.

HARGREAVES, G.H.; SAMANI, ZA Reference crop evapotranspiration from ambient air temperature . **Applied Engineering in Agriculture** , Chicago, Vol. 1, no. 2, p. 1-12, 1985.

LUCAS , DDP; HELDWEIN, AB; MALDANER, IC; TRENTIN, R.; DILL HINNAH, F.; SILVA, JR Water surplus in different soils and sunflower sowing times in Rio Grande do Sul. **Brazilian Agricultural Research Journal** , Brasília, DF, v. 50, n. 6, p. 431-440, 2015.

ROSSI, TJ; ESCOBEDO, JF; SANTOS, CM; ROSSI, LR; SILVA, MBP; DAL PAI, E. Global, diffuse and direct solar radiation of the infrared spectrum in Botucatu/SP/Brazil . **Renewable and Sustainable Energy Reviews** , Belfast, vol. 82, part. 1, p. 448-459, 2018.

SANTOS, RF; CARLESSO, R. Water deficit and the morphological and physiological processes of plants. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 2, n. 3, p. 287-294, 1998.

SANTOS, RM **Productive response of carioca beans (*Phaseolus vulgaris* L. TAA DAMA.) under water deficit in different phenological phases** . 2021. Dissertation (Master's in Agronomy/Agricultural Engineering) – Faculty of Agricultural Sciences, São Paulo State University, Botucatu, 2021.

SENTELHAS, PC; GILLESPIE, T.J.; SANTOS, EA Evaluation of FAO Penman - Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. **Agricultural Water Management** , Amsterdam, v. 97, no. 5, p. 635-644, 2010.

SHAHIDIAN, S.; SERRALHEIRO, RP; TEIXEIRA, JL; SERRANO, J.; SANTOS, FL; GUIMARÃES, RC **Use of the Hargreaves Samani equation for calculating ETo in greenhouses** . *In:* IBERIAN CONGRESS OF AGROENGINEERING, 6th, 2011, Évora. **Article** [...]. Évora: University of Évora, 2011 . p. 1-11.

SILVA, BB; BRAGA, AC; BRAGA, CC; OLIVEIRA, LMM; GALVÍNCIO, JD; MONTENEGRO, SMGL Evapotranspiration and estimation of water consumption in irrigated perimeter of the Brazilian Semi-Arid region by remote sensing . **Brazilian agricultural research** , Brasília, DF, v. 47, n. 9, p. 1218-1226, 2012. Available at: https://www.scielo.br/pdf/pab/v47n9/06.pdf . Accessed on: January 13, 2021.

SILVA, LL; COSTA, RF; CAMPOS, JHBC; DANTAS, RT Influence of Precipitation on agricultural productivity in the State of Paraíba. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 13, n. 4, p. 454-461, 2009.

STEDUTO, P.; HSIAO, TC; FERERES, E.; RAES, D. **Crop yield response to water** . Rome; FAO, 2012. (Irrigation and Drainage Paper, n. 66).

SUBBURAYAN, S.; MURUGAPPAN, A.; MOHAN, S. Modified Hargreaves Equation for Estimation of Eto in a Hot and Humid Location in Tamilnadu State, India. **International Journal of Engineering Science and Technology** , Tehran , vol. 3, n .1, p. 592-600 , 2011.