Presented at 2018 Irrigation Show & Education Conference, Dez 3-7, 2018
Long Beach Convention Center, Long Beach, California, USA

PERFORMANCE OF IRRIGATED BLACK PEPPER

Gustavo Haddad Souza Vieira. Full Professor. PhD.
IFES *campus* Santa Teresa, Rod. ES 080, km 93, São João de Petrópolis, Santa Teresa-ES, Brazil. 29.660-000. e-mail: ghsvieira@gmail.com

Géssica Monteiro dos Santos. Agronomy undergraduate student.

IFES *campus* Santa Teresa – Rod. ES 080, km 93, São João de Petrópolis, Santa Teresa-ES, Brazil. 29.660-000.

Marcelo Rodrigo Krause. MSc student.
Universidade Federal de Viçosa. Campus Universitário, Viçosa-MG, Brazil. 36570-900.

Milena Monteiro dos Santos. Agronomy undergraduate student.

IFES *campus* Santa Teresa – Rod. ES 080, km 93, São João de Petrópolis, Santa Teresa-ES, Brazil. 29.660-000.

Paola Alfonsa Vieira Lo Monaco. Full Professor, PhD.

IFES *campus* Santa Teresa – Rod. ES 080, km 93, São João de Petrópolis, Santa Teresa-ES, Brazil. 29.660-000.

Abstract: *This study aimed to evaluate irrigation depths in the performance of black pepper (Piper nigrum), in São Mateus-ES, Brazil. We performed the experiment with five treatments and four replications, with depth irrigation replacement being varied according to the crop evapotranspiration (ETc). In the first year we evaluated: number of leaves per plant (NLP), plants height (PH), stem diameter (SD) and leaf temperature (LT). The best results were, respectively, 52.5 leaves per plant; 173.1 cm and 13.5 mm, with 100% replacement of ETc, at 199 days after planting. For leaf temperature, we observed lowest values in the 100% treatment. In the second year we evaluated the number of bunches per plant (NBP) and the productivity of fresh grains (PFG) and dry grains (PDG). For the NBP and PDG variables, the best results occurred in the depths of 75% and 100%, respectively. We recommend 100% of ETC replacements for the first and second year.*

Keywords: water, efficiency, yield, development, leaf temperature, evapotranspiration.

INTRODUCTION

Black pepper (*Piper nigrum* L.) is a climbing plant, belonging to Piperaceae family, of high productivity and one of the most valued spices in the world, with great economic value and also known as Indian pepper or black gold (Lima et al., 2010).

Introduced in Brazil in the seventeenth century in the state of Bahia, and then brought to the States of Paraíba, Maranhão and Pará (Pedeag, 2016), black pepper presented economic importance only in 1993 year, when it was reintroduced in the state of Pará by the Japanese people. Currently, it has a major presence in the municipalities of the North of Espírito Santo state, making it the second largest producer and exporter at the national level, behind only Pará. The plantations in the North of the State are concentrated in the municipalities of São Mateus and Jaguaré, with more than 75% of cultivated area and production (Ramos, 2015).

Lima et al. (2010) state that Brazil is one of the largest producers of black pepper, oscillating between the second and third position in the world market. Due to the good adaptation of the different types of soil, there are several commercially accepted cultivars of black pepper in Brazil, among them Bragantina, also known as Panniyur, which has a denomination of the original cultivar in India (Lemos et al. 2014; Oliveira et al., 2007)

The black pepper is the most used spice by Brazilian cuisine. It is mainly used in industrialized products (salami, sausage, mortadella, ham etc) and for food seasoning. Brazil consumes only 10% in the form of whole grains, the other 90% are used in the form of milled grains, in mixtures with other condiments (Duarte and Albuquerque, 2005).

Grain productivity is indicative of the profit for the producer, being directly related to the profitability of the crop. Therefore, irrigated crops tend to be more profitable, since they can present a longer period of grain filling (flowering until maturation) and green leaf area to perform photosynthesis and remobilize the reserves, providing a greater supply of grain assimilates (Gomes, 2016 and Maehler et al., 2003).

According to Bonomo et al. (2013), irrigation management is a very important technique from an economic and environmental point of view in an irrigated agricultural activity, because through proper irrigation management, one can save water, energy, increase crop productivity and improve product quality. Therefore, irrigation practices are important to ensure production in the regions most susceptible to water deficit. Based on this, it is essential to know the water requirement of the black pepper, cultivated under different irrigation depths, so that it has a good productivity and a better use of the applied water, avoiding excess or water deficit.

The objective of this study was to evaluate the effect of irrigation depths on the initial development and productivity of black pepper cultivar bragantina and to identify the percentage of irrigation that provides the best water use efficiency.

MATERIAL AND METHODS

The cultivation was carried out in a field in the municipality of São Mateus, Espírito Santo state, Brazil, at coordinates 18° 44' S and 40° 06' W, in a altitude of 77 m in relation to sea level, as shown in Figure 1.

Figure 1. Location of the experiment.

The experimental design was a randomized block design (RBD), containing five treatments and four replications. Four useful rows were planted, spaced 2.5 m between rows and 2 m between plants. Six plants were planted for each treatment, two plants were considered as borders and four useful plants, totaling 144 plants in the experiment, being 96 useful plants.

Pepper seedlings were planted in December 2016 and conducted until the beginning of April 2018 for 470 days. The period was divided into two phases, the first of which from planting until 199, called Year 1 (Vegetative stage), and the second, from day 200 to day 470, called Year 2 (Productive stage). The local soil has sandy texture, field capacity of 18%, permanent wilting point of 9% and apparent density of 1.15 g cm^{-3}. The effective root system depth considered was 0.4 m and the water availability factor of the crop (f factor) was 0.4.

For irrigation depths variation, we installed different numbers of emitters per plant, so that all irrigations occurred at the same time. The treatments consisted of different irrigation depths, proportional to crop evapotranspiration (ETc), as follows: T1: 25% of ETc (1 emitter); T2: 50% (2 emitters); T3: 75% (3 emitters); T4: 100% (4 emitters); and T5: 125% (5 emitters). A localized irrigation system microspray type was used, working with pressure of 100 kPa and flow rate of 10 L h^{-1}. Figure 2 shows images of the experimental area, on planting (A and B) and the production (C) stages.

Figure 2. Experimental area at planting time and in the production stage.

After the installation of the irrigation system and the plots demarcation, we assessed the irrigation system, and calculated the CUC (Christiansen Uniformity Coefficient) and the emitters flow rate (Thompson and Ross, 2011). For the evaluation of the irrigation system efficiency, treatment 4 (T4 - 4 emitters) was used as a reference, applying the 100% irrigation depths related to the crop evapotranspiration. In the evaluation, a 1,000 mL beaker and measuring cups were used, evaluating 16 emitters in total, measuring the volume of water collected from each emitter in a time of 20 seconds.

Irrigation management was performed using a spreadsheet (Figure 3), determining the black pepper water demand, using coefficients of adjustment (soil moisture coefficient - K_S and coefficient due to the location of the irrigation - K_L) on the reference evapotranspiration (ETo). The values of K_S were calculated with the logarithmic model (Mantovani et al, 2009). The percentage of wetted area was 40%, resulting in a K_L of 0.63, calculated by the method of Keller and Bliesner (1990). The gross irrigation depths were calculated by means of a water balance, in which the inputs of water were irrigation and rainfall and the exit was crop evapotranspiration (ETc).

	A	B	C	D	E	F	G	H	I	J	K
1	**Irrigation scheduling using the Hargreaves-Samani method for ETo calculation**										
2	Spreadsheet developed by Gustavo Haddad Souza Vieira										
3	ghsvieira@gmail.com			Yellow cells = data entry					Crop	Black Pepper	
4		**Graus**	**Minutos**	**Equipamento**							
5	**Latitude**	18	45	Emitter flowrate		40	L/h		Kc initial	0.6	
6	Hemisphere	S		Emitter spacement		2	m		Kc medium	0.7	
7	altitude (z)	79	m	Lateral lines spacement		2.5	m		Kc final	0.9	
8	**Soil**			CUC		93	%		Plants spacing	2	m
9	Field capacity	18	%		**Net irrigation**	16.6	mm		Rows spacing	2.5	m
10	Permanent wilti	9	%		**Gross irrigation**	17.8	mm		PAW (%)	40	%
11	Bulk density	1.15	g/cm^3		**CAD**	41.4	mm		PAS (%)	20	%
12	f factor	0.4			**Aplication rate**	8.0	mm/h		K_L	0.63	
13	Soil root depth	40	cm								
14	**Date**	**Tmax (ºC)**	**Tmin (ºC)**	**Kc**	**ETc (mm/day)**	**Irrigation time (min)**	**Rainfall (mm)**	**Recommended irrigation time (min)**	**Measured soil moisture (%)**	**Calculated soil moisture (%)**	
15	12/29/16	34.90	24.10	0.6	2.3	21.0		0			
16	12/30/16	34.80	24.30	0.6	2.2	10.0		8		17.8	
17	12/31/16	32.40	23.30	0.6	2.0	10.0		14		17.6	
18	1/1/17	34.40	23.80	0.6	2.2			32		17.1	
19	1/2/17	35.00	23.90	0.6	2.3	65.0		0	14.7	18.0	
20	1/3/17	34.30	24.80	0.6	2.1	142.0		0		18.0	
21	1/4/17	34.10	23.60	0.6	2.2			18		17.5	
22	1/5/17	32.80	24.10	0.6	2.0			34		17.1	

Figura 3. Spreadsheet used to calculate evapotranspiration and water balance.

For the ETo estimation method, the available meteorological elements (maximum and minimum air temperatures) were used, following the model of Hargreaves and Samani (Allen et al., 1998). The temperature data used to perform the experiment were obtained on a maximum and minimum thermometer installed in the farm. The values of Kc used were 0.6 in the initial stage (21 days), 0.7 in the intermediate stage (314 days) and 0.9 in the final stage (136 days).

In the first year, we evaluated the number of leaves per plant (NLP), the plant height (PH), the stem diameter (SD) and the leaf temperature (LT), following the methodology described by Vieira et al. (2014), at 64, 138 and 199 days after planting (DAP). In the second year, we evaluated at 353, 409, 445 and 470 DAP, measuring the number of bunches per plant (NBP), the productivity of fresh grains (PFG) (kg ha^{-1}) and the productivity of dry grains (PDG) (kg ha^{-1}). Leaf temperature values were compared graphically with the maximum temperature recorded on the day of measurement.

To obtain the values of the water demand, the values of the water depths applied in the two cycles of the crop were summed for all treatments. From the data obtained from the productivity of the dry grains, we calculated the water use efficiency for each treatment.

To verify the assumptions for validation of the analysis of variance, the evaluated variables were submitted to the normality test (Shapiro Wilk). As the variables met the assumptions, it was adopted as a procedure the decomposition of the degrees of freedom of the treatments in regression models by the orthogonal polynomials method, being the choice of the model based on the coefficient of determination and the level of significance. For all procedures, the significance of variance analysis was presented in the graphs.

RESULTS AND DISCUSSION

Figure 4 shows the calculated and measured soil moistures, irrigation, rainfall and soil water limits (field capacity, permanent wilting point, and safety soil moisture) during the experimental period for the T4 treatment (100% of ETc). In this treatment, the soil moisture was, in the majority of experimental period, kept above the safety limit, however, in some moments there was a decrease of soil moisture to values below the limit. The measured moisture values served as a reference for adjustments of the values used in the irrigation management at the beginning of the experiment and for validation of the calculations from the third month.

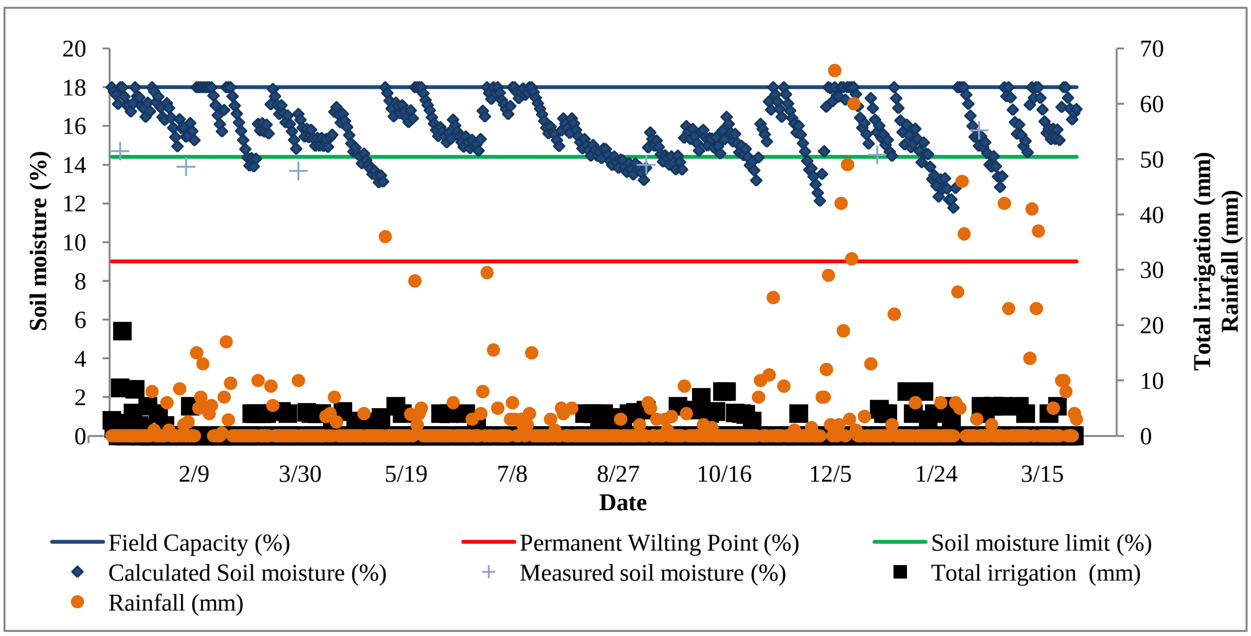

Figure 4. Calculated and measured soil moistures, irrigations performed, rainfall and soil water limits during the experimental period, for T4 treatment (100% ETc).

In the figures 5 (A), (B), (C) and (D), we can see the number of leaves per plant (NLP), the plant height (PH), the stem diameter (SD) and the leaf temperature (LT). According to the results, it can be observed that there was a linear behavior for all the variables NLP, PH, and SD, for the evaluations at 138 and 199 DAP, where the best means were obtained in the water depth referring to 100% of the crop evapotranspiration. For the TF variable, the highest value was obtained in the 25% depth at 64 DAP.

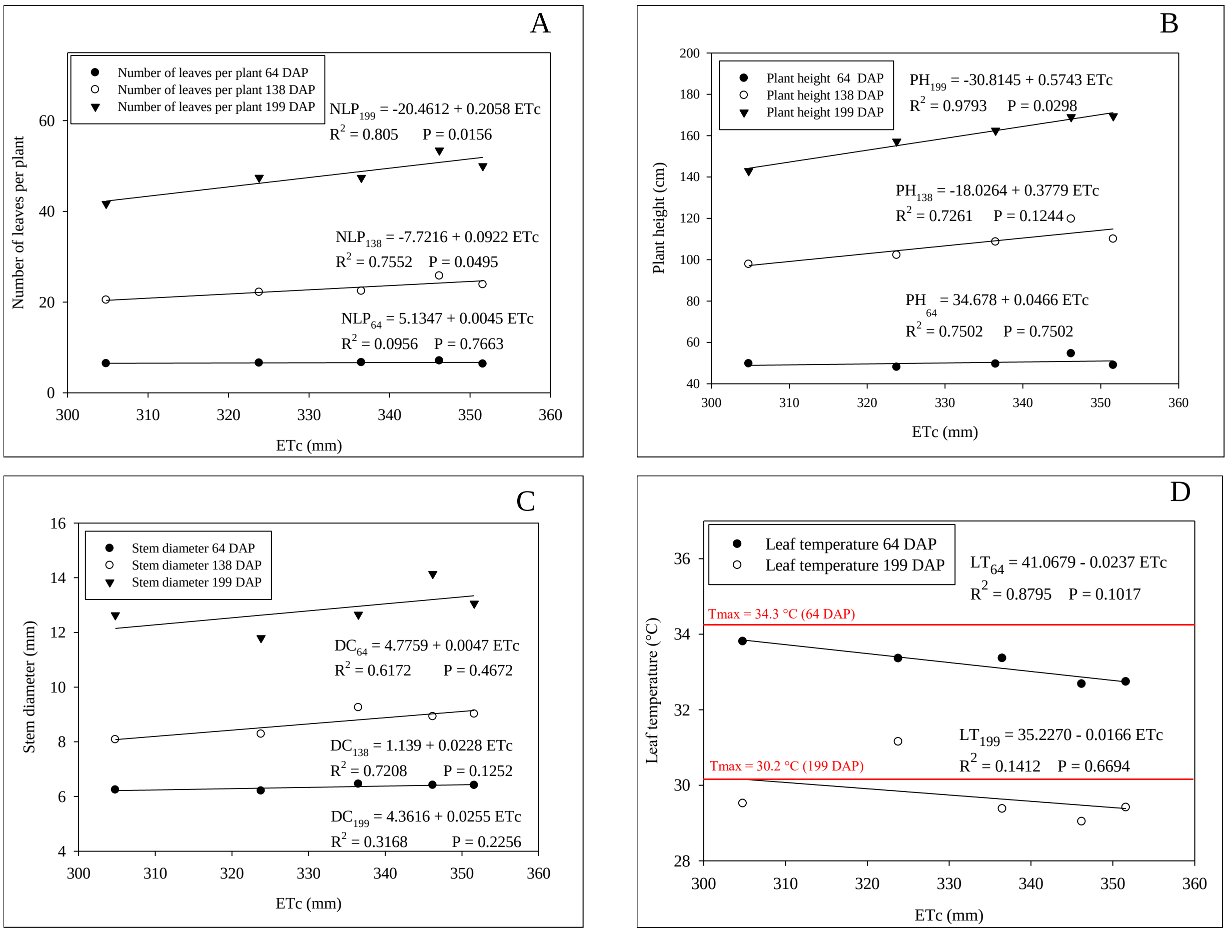

Figure 5: Number of leaves per plant (A), plants height (B), stem diameter (C) and leaf temperature (D) of black pepper plants submitted to different irrigation depths.

For the variables NLP, PH and SD, the evaluations at 64 DAP did not present significant results, because at this initial stage, the plants were in the stage of adaptation to the field, therefore irrigation did not influence its initial development, since the contact between the surface of the roots and the soil provided a surface area for the absorption of water (Lacerda, 2007). Therefore, transplanted plants demand greater protection against water losses as soon as they go into the field, because in this period, the new roots that are being emitted will restore their root-soil connection, which may take a few days until this process occurs totally, causing then a water stress.

According to Gobbo Neto and Lopes (2007), there are physiological factors, such as photosynthesis, stomatal behavior (opening and closing), reserve mobilization, leaf expansion and growth, which are considered critical when they are submitted to water stress. Thus, one of the first processes that are affected in the plant with water deficit is the division and the cellular expansion, where the growth of the leaves and stems diminish considerably before it becomes severe, causing the stomata to close and cause a photosynthesis decreasing (Duarte , 2012).

It was verified that 25 and 52.5 leaves per plant were obtained at 138 DAP and 199 DAP, respectively. A similar result was found by Martins et al. (2006), working with Conilon coffee (*Coffea canephora*), and observed that the increase of the applied depth provided greater fresh matter production of the plants and that the low availability of the same caused a smaller roots development.

At 138 DAP, an average plant height of 116 cm was obtained and at 199 DAP, it was obtained 173 cm. Alves et al. (2000), when working with Conilon coffee (*Coffea canephora*), observed that the mean height values of the plants maintained an upward trend as a function of the applied irrigation depth, which is similar to the results found in this study, where the highest plant height was found in treatments applying 100 to 125% ETc at 199 DAP.

We measured, at 138 DAP, 9.2 mm of SD and at 199 DAP, 13.5 mm. Rodrigues et al. (2009), when working with castor beans, observed that there was an increase in the SD, with greater sensitivity in the initial phase of growth, deducing that plants cultivated without water restriction should be more resistant to tipping due to the sturdier stalks. It was also noticed that, the smaller the depth applied, the smaller the diameter of the stem, a result similar to that found in this study.

It was verified that, for the variable LT at 138 and 199 DAP, there was no adjustment for the different levels of the polynomials ($P > 0.5$). Comparing the leaf temperature values with the maximum air temperature recorded on the days of measurements, a closer approximation is observed in the treatments with the lowest irrigation depths (lower ETc values). These results corroborate with those of Trentin et al. (2011) in a greenhouse study with sugarcane, cultivar RB 86-7515, in which plants maintained under adequate water supply had lower temperatures, when compared to those under conditions of severe water stress and high solar radiation.

According to Dias and Marenco (2007), the increase in leaf temperature also caused a reduction in stomatal conductance, a process in which the stomata open allowing the vapor escaping and the diffusion of the carbon dioxide from the atmosphere to the interior of the leaf, this being the raw material of photosynthesis. Another factor that contributed to the variation in the stomatal and transpiratory behavior of the plant is the variation of the angle of exposure of the leaves to the solar rays, being, therefore, an important mechanism of defense of the plants, that occurs mainly in periods of water stress, decreasing the leaf temperature and, consequently, stomatal transpiration (Oliveira et al., 2005). The opening of the stomata is also related to the water condition of the soil and not only by solar radiation. Apparently, the plant seeks to reduce leaf area to reduce transpiration without abruptly affecting water absorption capacity by roots (Lacerda, 2007). In order to use leaf temperature in irrigation management, as an indicator of crop water conditions, as recommended by Lobo et al. (2004), it is necessary to establish water stress indexes, which determine the momentum and irrigation depth.

The number of bunches per plant (NBP), productivity of fresh grains (PFG) and productivity of dry grains (PDG) are presented in Figures 6 (A), (B) and (C). According to the results, the linear model was chosen due to the higher values of significance for all variables, where the best means were obtained near the depth of 100% ETc.

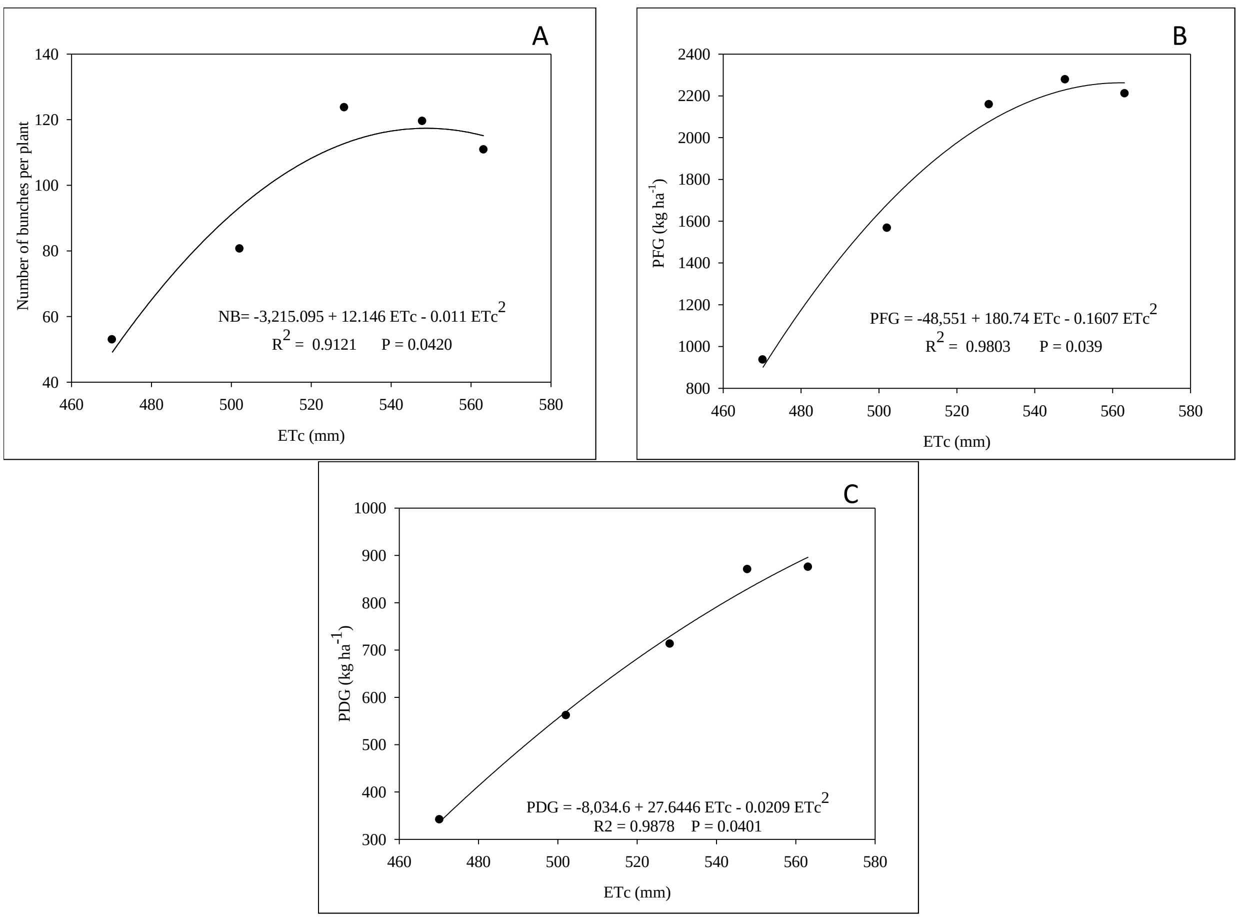

Figure 6. Number of bunches per plant (A), productivity of fresh grains (B) and productivity of dry grains (C) of black pepper plants submitted to different ETc.

The lowest averages were obtained in the depth of 25% ETc, with the productivity increasing proportionally to the increase of the applied depth, up to the 100% ETc. These higher averages occurred due to the water supply in quantities adequate to the needs of the crop, mainly in the pre-flowering stages until the ripening of the grains, when the water stress could affect the translocation of sap in the plant and its productivity.

For the NBP, the reduction of the observed productivity was due to the low applied depths. According to Santos and Carlesso (1998), the limitation of the water availability in the soil during the pre-flowering period affects the development of vegetative structures of the plants, reducing the biomass production capacity by the crop. In this way, the low depths applied in the pepper affected the production of inflorescences or permanence of the same in the plant, occurring the abortion.

Another important factor that interferes directly in the production is the amount of leaf area present in the evaluated plants. According to Martins et al. (2006), the increase of the applied depths provides greater production of fresh matter of the plants, that is, the larger the depth applied, the greater the leaf area, providing greater photosynthesis, that is, greater production of chemical energy. However, when submitted to high temperatures and low water availability, as in the case of treatments with 25% and 50% ETc, they tend to close their stomata, reducing stomatal conductance and consequently reducing the raw material of photosynthesis (Dias and Marenco, 2007).

For the PFG and PDG variables, the highest averages were also obtained on the 100% ETc depth. This is due to the higher water availability for the processes of cell expansion and, consequently, formation of the grain. On the other hand, the lowest rates of accumulated matter is the result of the low water availability for the initial process of grain formation, occurring low cell expansion, which can be limited to small grains or few grains per bunch, which justifies the low productivity in treatments with the smallest depths. Parallel to this process, the production of photosynthesis provides greater amounts of photoassimilates that are used in the formation and development of grains, in which after completing cell expansion, accumulation of dry matter occurs in the developing grains.

Bergamaschi et al. (2004), when working with maize plants, reported that the reduction in the harvest was a consequence of the lack of rainfall that occurred in December and January, when the great majority of the corn plantations of the Espírito Santo State was in the critical period, that is, from the pennon formation to the beginning of grain filling. Similar fact was reported by Bassoi et al. (2011), when evaluating grapevine plants, where they observed that the water deficit between anthesis (opening of flowers) and veraison (beginning of berries ripening) decreases the final size of the berry irreversibly, even if there is a wetting after the veraison. This fact corroborates Santos and Carlesso (1998), who affirm that the grain formation phase is the phase of greater dependence on assimilates. According to the author, this dependence is due to the low reserve that the plant has, and may not complete the grain development, that is, the grain reaches maturity with low dry matter rate or is detached from the plant before of maturation.

Table 1 presents data of crop evapotranspiration, irrigation depths applied during the cycle, crop productivity and water use efficiency, ie the relationship between yield (obtained by PDG) and crop evapotranspiration, for each treatment, in the second year.

Table 2. Treatments and applied depths, water demand and water use efficiency in the second year of crop development in each treatment

Treatment	**T1**	**T2**	**T3**	**T4**	**T5**
Perncentual depth (%)	0.25	0.50	0.75	1.00	1.25
Irrigation depth (mm)	47	94	141	188	235
Effective rainfall (mm)	426.5	414.7	397.2	373	348.7
Total water depth (mm)	473,5	508.7	538.2	561	583.7
Productivity(kg ha^{-1})	342.6	562.7	713.8	870.3	875.2
Crop evapotranspiration (mm)	470.2	502.1	528.3	547.8	563.2
Water use efficiency (kg m^{-3})	0.073	0.112	0.135	0.159	0.155

It can be observed that, as the irrigation depths increase and consequent higher crop evapotranspiration, the crop yield increases, reaching values of up to 875.2 kg ha^{-1} for the evapotranspiration of 563.2 mm. This productivity is lower than the average found in commercial crops in Brazil (2,230 kg ha^{-1}); however, it is worth mentioning that the crop cycle was reduced, harvesting only the first bunches. The best efficiency of water use occurred in the 100% replacement of the ETc, with the production of 0.159 kg of dry pepper per 1,000 L of evapotranspirated water.

CONCLUSIONS

In the first year of cultivation of Bragantina pepper, the application of irrigation depths for 100% ETc treatment is recommended to achieve higher plant height, stem diameter and number of leaves per plant, as well as smaller ones leaf temperatures. From the second year of cultivation, the irrigation depth that provided the highest averages for the number of bunches per plant (NBP), productivity of fresh grains (PFG) and productivity of dry grain (PDG) was the irrigation depths of 100% of ETc. The total evapotranspiration that promoted the highest PDG was 563.2 mm, with a yield of 875.2 kg ha^{-1}.

ACKNOWLEDGMENT

To Ifes *campus* Santa Teresa for the financial, operational and infrastructure available for the experiment and for providing scholarship to the students. To Prodif-Ifes for the financial support in the trip to present this paper.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, M. Smith, 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO (56). 300 pp.

Alves, M.E.B.; M.A. Faria, R.J. Guimarães, J.A. Muniz, E.L. Silva. 2000. Coffee plant growth under different irrigation and fertirrigation depths. Revista Brasileira de Engenharia Agrícola e Ambiental. 4(2):219-225.

Bassoi, L.H.; S.O. Goncalves, A.R.L Santos, J.A. Silva, M.A.C. Lima. 2011. Influence of irrigation management on aspects of ecophysiology and production of grapevine cv. Syrah. Irriga. 16:395-402.

Bergamaschi, H.; G.A. Dalmago, J.I. Bergonci, C.A.M. Bianchi, A.G. Müller, F. Comiran, B.M.M. Heckler. 2004. Water distribution in the critical period of corn and grain production. Pesquisa Agropecuária Brasileira. 39:831-839.

Bonomo, D.Z., R. Bonomo, F.L. Partelli, J.M. Souza, M. Magiero, 2013. Vegetative development of the Conilon coffee plant submitted to different irrigation depths. Revista Brasileira de Agricultura Irrigada. 7(2):157-169.

Dias, D. P., R.A. Marenco. 2007. Photosynthesis and photoinhibition in mahogany and acariquara as a function of luminosity and leaf temperature. Pesquisa agropecuária brasileira. 42(3):305-311.

Duarte, M.L.R., F.C. Albuquerque. 2005. Black pepper Production System. Embrapa Eastern Amazon. Brazil.

Duarte, A.L.M. 2012. Effect of water on growth and nutritive value of forage plants. Pesquisa & Tecnologia.9:1-6.

Gobbo Neto, L., N.P. Lopes. 2007. Medicinal plants: factors influencing the content of secondary metabolites. Química nova. 30(2):374-381.

Gomes, D.G. Growth and production of Runner IAC 886 peanut under different irrigation depths. 2016. Doctorate Thesis. Escola Superior de Agricultura “Luiz de Queiroz.

Keller, J., R.D. Bliesner. 1990. Sprinkle and trickle irrigation, pp. 652, Van Nostrand Reinold, New York.

Lacerda, C.L. Part I, 2007. Soil-water-plant relationships in natural and agricultural environments of the Brazilian Northeast. Recife, PE, Brazil.

Lemos, O.D., C.R. Tremacoldi, M.C., Poltronieri. 2014. Good agricultural practices to increase productivity and quality of black pepper in the State of Pará. Embrapa Brasília, DF, Brazil. Also at https://www.infoteca.cnptia.embrapa.br/bitstream/doc/994882/1/CartilhaPimenta.pdf

Lima, J.S.S., R.B., Oliveira, W. Rocha, P.C. Oliveira, W.Z. Quartezani. 2010. Spatial analysis of soil chemical attributes and production of the black pepper (*Piper nigrum* L.). Idesia. 28:31-39.

Lobo, F.A., M.A., Oliva, M. Resende, N.F. Lopes, M. Maestri. 2004. Infrared thermometry to schedule irrigation of common bean. Pesquisa Agropecuária Brasileira. 39(2):113-121.

Maehler, A.R., J.A. Costa, J.L.F.; Pires, L. Rambo. 2003. Grain quality of two soybean cultivars as a function of soil water availability and plant arrangement. Ciência rural. 33(2):13-218.

Mantovani, E.C.; S. Bernardo, L.F. Palaretti. 2009. Irrigation: principles and methods. 3.ed. pp;355. UFV, Viçosa, MG, Brazil.

Martins, C.C., E.F. Reis, C. Busato, J.E.M. Pezzopane. 2006. Initial growth of Conilon coffee (*Coffea canephora* Pierre) under different irrigation depths. Engenharia na Agricultura. 14(3):193-201.

Oliveira A.P., E.U. Alves, J.A. Silva, A.U. Alves, A.N.P. Oliveira, F.A.P. Leonardo, M.F. Moura, I.S. Cruz. 2007. Productivity of black pepper as a function of cattle manure. Horticultura Brasileira. 25:408-410.

Oliveira, A.D., de; E. J. Fernandes, T.J.D. Rodrigues. 2005. Stomatal conductance as an indicator of water stress in beans. Engenharia Agrícola. 25:86-95.

Pedeag. 2016. Strategic plan for the development of Capixaba Agriculture: Black pepper. Also at http://www.incaper.es.gov.br/pedeag/setores08.htm

Ramos, A.L.R. 2015. Black pepper conjuncture of Espírito Santo. Conag: Companhia Nacional de Abastecimento. Also at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/15_08_26_16_06_06_conjuntura_de_pimenta-do-reino_2015_.pdf

Rodrigues, L.N., A.R. Nery, P.D. Fernandes, N.E.M. Beltrão, H.R. Gheyi. 2009. Growing and production of berries of the castor bean irrigated with domestic wastewater. Revista Brasileira de Engenharia Agrícola e Ambiental. 13(0):825–835.

Santos, R.F., R. Carlesso. 1998. Water deficit and the morphological and physiological processes of plants. Revista Brasileira de Engenharia Agrícola e Ambiental. 2(3):287-294.

Thompson, K.K.; G.A. Ross. 2011. Performance audits. Chapter 14 in Irrigation. 6 ed. pp. 567-612, Irrigation Association, Falls Church, VA.

Trentin, R., S. Zolnier, A. Ribeiro, A.J. Steidle Neto. 2011. Transpiration and leaf temperature of sugarcane unde different values of matric potential. Engenharia Agrícola. 31(6):1085-1095.

Vieira, G.H.S.; E.C. Mantovani, G.C. Sediyama, F.T. Delazari. 2014. Morpho-physiological indicators of water stress on sugarcane as a function of irrigation depths. Bioscience Journal. 30:65-75.