DEVELOPMENT AND PRODUCTION OF FERTIGATED COFFEE TREES IN THE WEST REGION OF BAHIA, BRAZIL

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ABSTRACT: The aim in the present study was to evaluate the effects of different split fertigation and doses on the development and production of drip irrigated coffee in the western region of the state of Bahia, Brazil. The study was performed at the Café do Rio Branco Farm, in Barreiras, BA, Brazil, in adult coffee trees aged approximately 3.5 years from the variety *Catuaí IAC 144*. A 3 x 3 factorial design was adopted, with three levels of nitrogen and potassium fertilization (900/800, 600/500 and 300/250 kg ha^{-1} year^{-1} N and K_2O) in three monthly split fertigation (two, four and eight times). Stem and crown growth, productivity, yield and sieve were evaluated. The doses of 600/500 and 900/800 kg ha^{-1} year^{-1} N/K_2O and the splits in two and eight times provided the highest productivities of coffee. A higher split fertigation was observed on the effect of N and K_2O doses in coffee development variables (crown diameter and plant height). There was no effect of split fertigation and doses in the classification by sieves of coffee beans.

Index terms: *Coffea arabica* L., irrigation, nitrogen, potassium.

DESENVOLVIMENTO E PRODUÇÃO DO CAFEEIRO FERTIRRIGADO NA REGIÃO OESTE DA BAHIA

RESUMO: Este trabalho foi realizado com o objetivo de avaliar os efeitos de diferentes doses e parcelamentos da fertirrigação no desenvolvimento e na produção do cafeeiro irrigado por gotejamento na região Oeste da Bahia. O trabalho foi conduzido na fazenda Café do Rio Branco, localizada em Barreiras - BA, em cafeeiros adultos, com aproximadamente 3,5 anos de idade, da variedade Catuaí IAC 144. Foi adotado um esquema fatorial 3 x 3, sendo três níveis de adubação nitrogenada e potássica (900/800, 600/500 e 300/250 kg ha-1 ano-1 de N e K2O) em 3 parcelamentos mensais de fertirrigação (2, 4 e 8 vezes). Foram avaliados o crescimento do caule e copa, a produtividade, o rendimento e peneira. As doses de 600/500 e 900/800 kg ha-1 ano-1 de N/K2O e os parcelamentos em dois e oito vezes proporcionaram as maiores produtividades do cafeeiro. Observou-se efeito maior do parcelamento da fertirrigação, sobre o efeito das doses de N e K2O, nas variáveis de desenvolvimento do cafeeiro (diâmetro de copa e altura de planta). Não houve efeito das doses e parcelamento da fertirrigação na classificação por peneira dos grãos do café.

Termos para indexação: *Coffea arabica* L., irrigação, nitrogênio, potássio.

1 INTRODUCTION

Irrigation is characterized as part of a set of techniques used to guarantee the economic production of coffee, with adequate management of natural resources (MANTOVANI; VICENTE, 2015).

The water requirement of the coffee tree is a limiting factor in bean yield and quality, being the minimum limit required by the coffee tree during a cycle is 800 mm (VENANCIO et al., 2016). Associated with water consumption is the phenomenon of mass flow, responsible for large part of plant's absorption of nutrients. Based on this, research correlating the supply of water and fertilizer arose from the fertigation. Currently, fertigation has been intensively used in coffee growing through irrigation systems that apply water and conventional fertilizers, saving labor force and with better fertilizer distribution in the area.

The benefits of the fertigation technique are limited due to the scarcity of specific scientific information for the coffee tree, especially in relation to the doses and split number required in the year (SOBREIRA et al., 2011).

Fernandes et al. (2007) evaluated coffee fertigation in Uberaba, MG, Brazil, after four harvests and observed that the used fertilizer sources both in fertigation and in conventional soil application did not show significant differences in terms of coffee productivity and quality.

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Lima et al. (2016), in Araguari, MG, Brazil, evaluated the vegetative and productive parameters of coffee as a function of different sources, doses and forms of nitrogen application and observed that agricultural urea applied through fertigation was not better in the vegetative and productive parameters of the coffee tree in relation to the applied conventionally, and that the conventionally applied ammonium nitrate can be considered as the best source of N when all the variables are analyzed together.

Coelho et al. (2009), in an experiment performed in Lavras, MG, Brazil, did not observe an effect of the split number of N, P and K (4, 12, 24 and 36 applications) applied through fertigation in the coffee productivity.

Although there are publications on the application of fertilizers through irrigation water, it is verified that there is still a need for research on fertilizer doses for the coffee tree, since there are several variables involved in the use of this technique.

The aim in the present study was to evaluate the effects of different doses and split fertigation by dripping on production and development of coffee tree in western Bahia region, Brazil.

2 MATERIAL AND METHODS

The experiment was installed in adult coffee plantations, aged approximately 3.5 years, *Catuaí Vermelho IAC 144* variety, spaced 3.80 x 0.5 m with drip irrigation at Fazenda Café do Rio Branco (11°48'01" S; 45º35'50" W; 735 m altitude) municipality of Barreiras, BA, Brazil. The analyzed period was from November 2004 to May 2008.

Soil texture analysis is presented in Table 1. Field capacity value was determined from the 5 kPa tension as a function of the soil texture in the experiment. For the permanent wilting point, the moisture corresponding to the 1540 kPa tension was adopted. Soil moisture values corresponds to the field capacity and permanent wilting point, in the 0-60 cm profile, were 27.01 and 17.63% volume, respectively.

Urea was used as source of nitrogen and potassium chloride with potassium source.

The crop evapotranspiration (ETc) was estimated using the coefficients of adjustment ("kc" crop, "kl" landscape and "ks" soil) on reference evapotranspiration (ETo), according to the methodologies described by Mantovani et al. (2009) and Mantovani and Vicente (2015). The gross irrigation depth was calculated through a water balance using the Irriplus software (MANTOVANI et al., 2009), in which the inputs of water were the irrigation and the effective rainfall, and the outputs, crop evapotranspiration (ETc) and percolation depth, besides the depth considered for the root system.

The method for estimating the ETo used by Irriplus is the Penman-Monteith-FAO 56 model (ALLEN et al., 1998; PEREIRA et al., 2015). The meteorological data used to perform the experiment were obtained from an automatic agrometeorological station, Davis brand, Vantage Pro model, located on the property.

In the experiment, the values of the crop coefficient (Kc), percentage of shaded area (P) and effective depth of the root system were 1.0, 50% and 0.60 m, respectively, were used.

The experiment used drip irrigation, with flow emitters 2.3 L h^{-1}, spaced every 0.75 m.

Harvests were performed manually. Coffee production of the plot was determined after each harvest, and two 5 L samples were taken to determine the yield and sieve of each treatment. The productivity result was calculated in 60 kg bags of processed coffee per hectare (bg ha^{-1}).

To evaluate the vegetative development, the plant height and crown and stem diameter were considered. For measuring the crown diameter, the perpendicular length to the planting line was determined as reference. The evaluations were performed on December 10, 2005 and September 19, 2007.

The development variables (plant height, crown and stem diameter), sieve classification and yield of coffee fruits were performed by analysis of variance by F test at 5% probability. Means were compared using the Tukey test at 5% probability.

3 RESULTS AND DISCUSSION

In Figure 1 are observed the soil moisture content estimated by Irriplus, the safe soil moisture (moisture relative to the soil water availability factor), the irrigation depths and the rainfall occurred throughout the experiment during the analyzed period (November 2004 to May 2008). The total applied irrigation depth was 3,029 mm (135, 1083, 645, 919 and 247 mm for the years 2004, 2005, 2006, 2007 and 2008, respectively) and accumulated rainfall was 3,715 mm (321, 1075, 1210, 588 and 522 mm for the years 2004, 2005, 2006, 2007 and 2008, respectively).

TABLE 1- Particle size composition, texture classification and soil specific weight.

Depth (cm)	Particle size composition (%)			Soil density (g/cm^3)	Texture classification
	Sand	Silt	Clay		
0-20	65.53	2.23	32.24	1.57	Sandy clay loam
20-40	63.37	2.86	33.78	1.57	Sandy clay loam
40-60	57.20	2.83	39.97	1.47	Sandy clay

The experiment was set up in a 3 x 3 factorial design with three levels of nitrogen and potassium fertilization, in three split fertigation (Table 2), and the randomized block design with four replicates. The experimental plots consisted of 20 plants (10 m).

TABLE 2 - Description of the different treatments of N and K_2O levels and splits, Barreiras, BA, Brazil

Treatment	Doses (kg ha^{-1} $year^{-1}$)		Split	No. monthly applications
	N	K_2O		
1	900	800		2
2	600	500	every 15 days	2
3	300	250		2
4	900	800		4
5	600	500	1 per week	4
6	300	250		4
7	900	800		8
8	600	500	2 per week	8
9	300	250		8

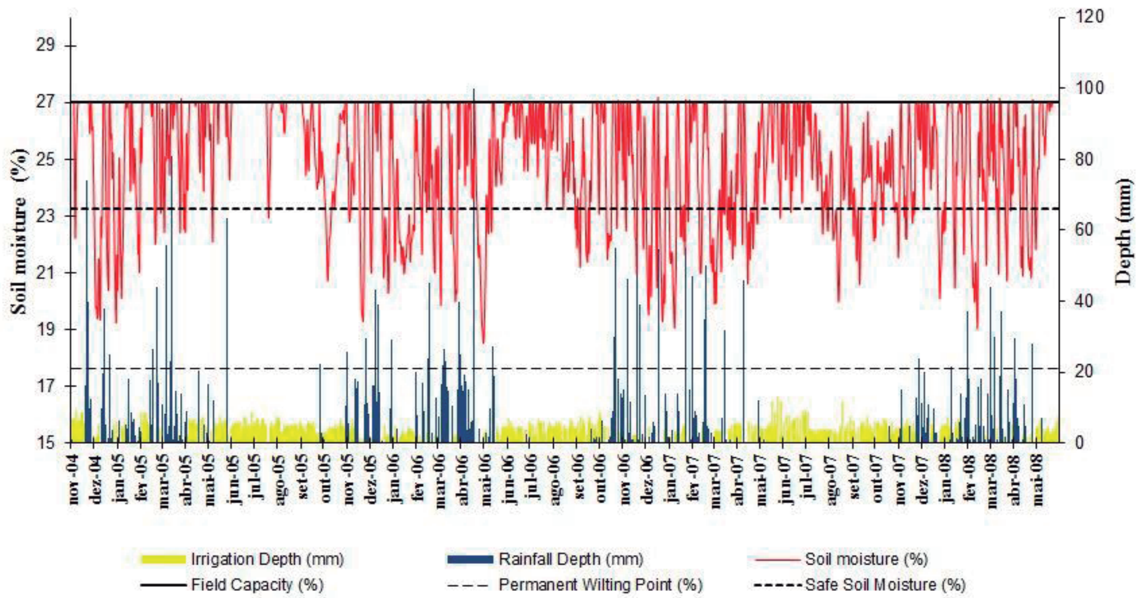

FIGURE 1 - Soil (volumetric) moisture estimated by the Irriplus software, applied irrigation depths and rainfall for the experiment.

There was an isolated effect among the different doses ($p < 0.05$) for coffee productivity, in bg ha^{-1} for the harvests 2005, 2006, 2008, and for the average of the four studied harvests (Table 3).

The doses 600/500 and 900/800 (N/K_2O) differed from the dose 300/250 in the average of four harvests, being that the dose 600/500 provided the highest average productivity, occurring the same in the 2006 and 2008 harvests. The dose of 600/500 N/K_2O, according to the obtained productivity (60.9 bg ha^{-1}) corroborates Santinato (2005) for the western region of Bahia, Brazil, which observed the requirements of 574 kg ha^{-1} N and 454 kg ha^{-1} K_2O for obtaining similar productivity. For the same region, Guerra et al. (2007) state that the doses of 500-600 kg/ha N and K_2O, generally applied in crops with productive potential from 60 to 70 bg/ha, are consistent with the research results obtained at Embrapa Cerrados and are adequate to meet the needs of coffee trees.

The four harvest average did not present higher productivity at the 900/800 dose (Table 3) because of the nutrient leaching.In a study performed on coffee plantations in the western Bahia, Brazil, Bortolotto et al. (2012) verified that the nitrogen leaching corresponding to 104.5 kg ha^{-1} at the dose of 800 kg ha^{-1} N applied as urea was associated with concentrated rainfall.

The found results contrast with the obtained by Rena, Nacif and Guimarães (2003) in Patrocínio, MG, Brazil. The authors observed that doses of 1000-1200 kg ha^{-1} $year^{-1}$ of 20-5-20 (200-240 kg ha^{-1} $year^{-1}$ N and K_2O) were sufficient to meet the demands of coffee, although it is worth mentioning that the productivity under dry conditions obtained by the authors was 31.0 bg ha^{-1}, almost half of that obtained in the present experiment.

There was also an isolated effect of the fertigation frequency ($P < 0.05$) on coffee yield, in bg ha^{-1}, for all the crops except for the 2006 harvest and the average of four harvests (Table 4).

Split in two monthly applications provided higher productivity than the other splits, not statistically differing from the split fertigation applied eight times a month for the average of four harvests.

Coelho et al. (2009), in Lavras, MG, Brazil, observed that the split application of fertilizers did not result in differences on coffee productivity. Karasawa, Faria and Guimarães (2002) and Vilella and Faria (2003) in Lavras, did not observe a significant effect of split nutrient.

Sant'ana (2015) observed in Lavras that the average productivity of the 2010, 2011, 2012 and 2013 harvests were not influenced by the split nitrogen and potassium fertilization (four applications in Nov, Dec, Jan and Feb and 12 monthly applications), although observing higher leaching with lower splits. Lima et al. (2016) also did not observe effect of urea fertigation (weekly splits from September of each year until July of the following year) in relation to conventional fertilization split in three applications (November, January and March of all evaluated years).

TABLE 3 - Productivity, in bags per hectare, of fertigated coffee trees subjected to different doses of N and K_2O

Doses (kg ha^{-1} $year^{-1}$) (N/K_2O)	Productivity (bg ha^{-1})				
	2005	2006	2007	2008	Average
600/500	52.2 AB	68.9A	58.9 A	67.3 A	60.9 A
900/800	53.7 A	64.5 A	54.9 A	66.1 AB	60.4 A
300/250	49.1 B	50.7 B	61.3 A	55.5 B	53.3 B

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 4 - Productivity, in bags per hectare, of coffee tree subjected to different monthly split fertigation, in Barreiras, BA, Brazil

Split (monthly)	Productivity (bg ha^{-1})				
	2005	2006	2007	2008	Average
2	56.1 A	62.6 A	63.0 A	62.1 AB	60.9 A
8	53.3 AB	61.6 A	51.6 B	69.3 A	58.5 AB
4	45.6 B	59.9 A	55.6 AB	57.8 B	55.2 B

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

In the analyses, interaction between doses and monthly split fertilization was significant (P <0.05) for coffee productivity in the 2005 and 2007 harvests and for the average of four harvests (Table 5).

Similar results were found by Leite Júnior and Faria (2016), obtaining a productivity average of 63.5 bags for the most productive year and 38 bags for the lowest productive year, thus concluding that fertigation make possible to stagger production and increase productivity.

Treatment 2 (600/500 kg ha^{-1} year^{-1} N/K_2O with two monthly splits) showed the highest productivity in the average of four studied harvests (65.6 bg ha^{-1}). Treatment 3 (300/250 kg ha^{-1} year^{-1} N/K_2O with two monthly splits) provided higher productivities in the 2005 and 2007 harvests, but lower than the treatment 2 on average. The higher productivities in the 2005 and 2007 harvests for treatment 3 can be explained by the more efficient use of nitrogen, as observed by Bruno et al. (2015), in Barreiras, MG, Brazil, where the dose of 200 kg N ha^{-1} year^{-1} urea showed the lowest losses and greater N recoveries by coffee.

In Table 4 is noted that split is more relevant in the years of low productivity (2005 and 2007) and the dose in the years of high productivity (2006 and 2008), although observing interaction between dose and split.

The results corroborate with the presented by Bruno et al. (2011), demonstrating that it is possible to reduce the nitrogen dose from 600kg ha^{-1} year^{-1} to 200 kg ha^{-1} without decreasing coffee yield. It should be highlighted that the authors evaluated only one harvest, i.e., the effect on future harvests were not evaluated.

For the analyses of coffee development (crown diameter and stem height), a statistical difference ($p < 0.05$) was observed in the first evaluation between the doses and splits for the crown diameter and between the splits and stem height.

TABLE 5 - Productivity, in bags per hectare, of coffee tree subjected to different monthly doses and split fertigation

Doses (kg ha^{-1} year^{-1}) (N/K_2O)	Monthly split		
	2	4	8
	Productivity 2005 (bg ha^{-1})		
900/800	50.0 A a	51.2 A a	59.8 A a
600/500	54.8 AB a	42.4 B a	59.4 A a
300/250	63.3 A a	43.2 B a	40.9 B b
	Productivity 2006 (bg ha^{-1})		
900/800	67.4 A a	67.1 A a	59.1 A a
600/500	77.1 A a	64.2 A a	65.5 A a
300/250	43.3 A a	53.5 A a	55.2 A a
	Productivity 2007 (bg ha^{-1})		
900/800	50.5 A b	64.8 A a	56.3 A a
600/500	61.3 A b	55.8 A ab	47.7 A a
300/250	77.1 A a	46.3 B b	50.87 a
	Productivity 2008 (bg ha^{-1})		
900/800	67.0 A a	61.0 A a	70.4 A a
600/500	69.2 A a	60.5 A a	79.0 A a
300/250	50.0 A a	52.0 A a	64.5 A a
	Average productivity (bg ha^{-1})		
900/800	58.7 A b	61.0 A a	61.4 A a
600/500	65.6 A a	55.8 B a	61.4 AB a
300/250	58.4 A b	48.8 B b	52.9 AB b

Averages followed by the same capital letter on the row and same lowercase letter on the column within each harvest do not differ among themselves by Tukey test (P<0.05)

In the second evaluation, a statistical difference ($p < 0.05$) was verified between the doses only for the crown diameter. In Tables 6, 7 and 8 are presented the results of the first and second biometric measurements of the experiment.

It is observed in Table 6 that the 600/500 dose of N and K_2O provided the largest crown diameter in the first evaluation, while the best result was observed at the 300/250 dose in the second evaluation. The results are similar to the found by Nazareno et al. (2003) and Rezende et al. (2010), which observed a response to N and K for crown diameter and growth in number of plagiotropic branches, demonstrating the synergistic effect of adequate water availability and better nutrient distribution in fertilizers, concluding that fertigation is a good alternative to be used in the formation of coffee plants to the detriment of conventional fertilization.

In the first evaluation, the largest crown diameter of coffee tree was provided by split fertigation eight times per month (Table 7), differing only from the splits applied four times. The small difference between the average crown diameter for the first and second crop (191.9 and 189.0 cm, respectively) may be correlated with the fact that the first evaluation was performed in the rainy season in contrast to the second one at the end of the dry period of the year.

For stem development (Table 8), it is noted that split fertigation applied eight times provided the highest average stem growth (67.2 cm) in 21 months.

The effect of the monthly split on the yield, in liters of coffee per acre ($p<0.05$), was observed in the 2008 harvest (Table 9).

TABLE 6 - Average crown diameter of coffee in centimeters as a function of the different doses of N and K_2O in the two evaluations

Doses (kg ha^{-1} year^{-1})	Crown diameter (cm)	
N/K_2O	1st evaluation	2nd evaluation
900/800	191.4 AB	185.7 B
600/500	197.2 A	188.6 AB
300/250	187.2 B	192.5 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 7 - Crown diameter of coffee in centimeters as a function of the different monthly splits of N and K_2O in the two evaluations

Split (monthly)	Crown diameter (cm)	
	12/10/2005	9/19/2007
2	191.5 AB	186.9 A
4	186.8 B	188.6 A
8	197.4 A	191.3 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 8 - Stem height of coffee in centimeters as a function of the different monthly splits of N and K_2O in the two evaluations

Split (monthly)	Stem height (cm)	
	12/10/2005	9/19/2007
2	213.0 A	266.0 A
4	209.4 AB	267.1 A
8	203.3 B	270.5 A

Averages followed by the same letter on the column do not differ among themselves by Tukey test ($p<0.05$)

TABLE 9 - Yield (L bg^{-1}) of coffee necessary to produce one processed bag

Split (monthly)	Yield (liters of coffee per processed bag)
4	531 A
2	518 AB
8	512 B

Averages followed by the same letter do not differ among themselves by Tukey test ($p<0.05$)

The split four times a month provided the best yield. It can be observed in Table 4, for the 2008 harvest, that the split four times per month also provided the lowest productivity in relation to the other splits. The yield is affected considerably by water deficit occurring in the expansion of the coffee bean (October-December), which did not occur throughout the experiment. Such difference in the yield can be explained by the greater easiness in filling the coffee bean by the treatments subjected to the split four times a month, since were produced in smaller amount.

There were no significant effects of treatments on the percentage of beans classified in the 16-mesh sieve or above. The percentage found was 46.3%, translating into a good coffee percentage for export, since exporters prefer larger beans, thus automatically eliminating defects. This value is consistent with that presented by Custódio, Gomes and Lima (2007).

4 CONCLUSIONS

The doses of 600/500 and 900/800 kg ha^{-1} $year^{-1}$ N/K_2O provided the highest productivities of coffee;

Split fertigation applied two and eight times a month was superior in productivity;

A higher split fertigation was observed on the effect of N and K_2O doses in coffee development variables (crown diameter and plant height).

There was no effect of split fertigation and doses in the classification by sieves of coffee beans;

Split fertigation applied four times a month resulted in a better yield, in liters of coffee per acre, for the 2008 harvest, although this same split provided lower productivity than the others.

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