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REGULAR ARTICLE

Nutrient accumulation in bean and fruit from irrigated and non-irrigated *Coffea canephora* cv. Conilon

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ABSTRACT

The amount of nutrients present in husks and beans from Conilon coffee fruits directly influence the crop nutritional management, as well as its use as a complement to conventional fertilization. The present study aimed to quantify the concentration and accumulation of nutrients in husks, beans and whole fruit in irrigated and non-irrigated plants from the cropped genotype C. canephora cv. Conilon Clone 02, from clonal variety EMCAPA 8111. The experiment consisted of two treatments (irrigated and non-irrigated) in a completely randomized design with 28 replicates under field conditions, in southern Bahia, Brazil. During harvesting stage, 50 fruits per plant, in two consecutive harvests, were collected to quantify the dry matter and accumulation of nutrients in the husks, beans and fruits. The fruits from irrigated coffee plants showed higher N, P, K, Ca, Mg, Cu and Mn accumulation than non-irrigated plants. The huskand beans from irrigated coffee plants showed higher Ca, Zn and Cu and N, P, Ca, Mg, S, Cu and Mn accumulation, respectively, than non-irrigated coffee. Regarding the nutrient accumulation, K followed by N, and Ca were the most represented macronutrients in coffee husk. N followed by K and P, and N followed by K and Ca were the most represented macronutrients in beans and fruit, respectively. Fe and B were the micronutrients found in higher contents in husk, beans and fruits from Conilon coffee.

Keywords: *Coffea canephora*; Drought; Fertilizer; Nutrients accumulation

INTRODUCTION

The genus *Coffea* includes at least 124 species (Davis et al., 2011), among which *Coffea arabica* and *C. canephora* are the most important species used in the coffee production (Davis et al., 2012). World coffee bean production reached *ca*. 141.8 million bags (of 60 kg) in 2014, being ca. 40% from *C. canephora* (ICO, 2015). Brazil is the second largest producer of *C. canephora*, with *ca*. 13.0 million bags of coffee beans produced in 2014 (ICO, 2015).

The Conilon coffee (*Coffea canephora* Pierre ex A. Froehner) is frequently grown in regions with drought incidence, which has led growers to invest more in irrigation systems. These systems potentiate the buds production (Carvalho et al., 2006), increases the number of reproductive branches per plant (Nazareno et al., 2003) and the number of flowers in *C. arabica* (Massarirambi et al., 2009), while provides better fruit development and filling (Pezzopane et al., 2010). Therefore, irrigation ensures high productivity (Scalco et al., 2011; Bonomo et al., 2013; Sakai et al., 2015), and a final product with better beverage quality (Fernandes et al., 2012). However, others climatic factors can also affect significantly the coffee beverage quality (Santos et al., 2015).

The Conilon coffee shows great productive potential linked to high nutritional requirement and accumulates large amounts of nutrients in tissues (Bragança et al., 2007;

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Serrano et al., 2011; Partelli et al., 2014.). The retained nutrient amounts by coffee plants changes according to the location, time of year, age, organs and the tissues within the same plant (Bragança et al., 2007) and maturation cycle (Partelli et al., 2014).

The coffee's fruiting process comprises a sequence of physiological events and morphological changes ranging from flower induction to fruit maturation, having a high demand for mineral nutrients (Carelli et al. 2006; Bragança et al, 2007; Melo et al. 2011; Partelli et al., 2014). During development, fruits are strong sinks for minerals and carbohydrates, therefore competing with other plant organs and often leading to nutritional deficiencies in those organs of the same coffee plant (Reindeer and Maestri, 1985; Carvalho et al., 1993; Laviola et al., 2008).

Physically adequate soil for coffee production can display low availability of some nutrients due to either actual deficiency or factors which limit the absorption, frequently leading to deficiency symptoms in coffee crops (Martinez et al., 2003; Partelli et al., 2006; Laviola et al., 2007a). An alternative to acceptable nutrition of crops is the use of organic nutrient sources, such as coffee husk (Serrano et al., 2011). Additionally, it has low cost, especially when the produced coffee is locally processed.

The need for renewable options, available *in-situ* and lower cost for the supply of nutrients for the crop is increasingly important due to the need for more sustainable agriculture (Chemura, 2014). By knowing the amounts of allocated nutrients in Conilon coffee tissues, valuable information can be gathered to assist the planning of the coffee crop fertilization program, as well as its use as a complement to conventional fertilization. Therefore, this study aims at to quantify the concentration and accumulation of nutrients in the husk, beans and fruits from irrigated and non-irrigated Conilon coffee trees.

MATERIALS AND METHODS

Plant material and experimental conditions

The experiment was performed in southern Bahia, Brazil (42'13 "S latitude and 39 ° 25'28"W longitude) at an altitude of 108 m. Five year old plants from *C. canephora* cv. EMCAPA 8111 genotypes Clone 02 (Bragança et al., 2001) grown under field conditions and spaced 3.5 x 1.0 m. According to Köppen classification, the climate is Aw, tropical with a dry and rainy season during the winter and summer, respectively (Köppen, 1931; Alvares et al., 2014). The soil is classified as Oxisol (sandy loam dystrophic Yellow Latosol) according to Embrapa (2013). Chemical and physical characteristics of the soil, at 0-20 cm layer were: P: 28.5 mg dm^{-3}; K: 105 mg dm^{-3}; Ca: 4.15 $cmol_c$ dm^{-3}; Mg: 1.55 $cmol_c$ dm^{-3}; S: 15.5 mg dm^{-3}; B: 1.49 mg dm^{-3}; Cu: 1.9 mg dm^{-3}; Fe: 450 mg dm^{-3}; Mn: 20.0 mg dm^{-3}; Zn: 4.2 mg dm^{-3}; pH: 6.25; $H^+ + Al^{3+}$: 2.85 $cmol_c$ dm^{-3}; organic matter: 4.55 dag kg^{-1}; total sand: 730 g kg^{-1}; silt: 110 g kg^{-1}; clay: 160 g kg^{-1}; field capacity: 0.19 cm^3 cm^{-3} and permanent wilting point: 0.13 cm^3 cm^{-3}.

A completely randomized design with two treatments (irrigated and non-irrigated) with 28 replicates under field conditions were used. The management practices on the crop consisted in weeds control through herbicides and clipping, preventive phytosanitary management, liming, fertilization and irrigation (only on irrigated treatment). To implement the non-irrigated treatment, irrigation of the respective plot was suspended in March of 2011 in order to allow the plants acclimation to drought. In the irrigated treatment, surface drip irrigation was used with one line of emitters per plants lines, spaced every 0.5 m and flow of 2.0 L h^{-1}.

The air temperatures (maximum, mean and minimum), global solar radiation, rainfall and relative humidity of the air were collected at an automatic weather station located at a distance of 800 m from the experimental area (Fig. 1). The meteorological data were used to determine the reference evapotranspiration (ETo) according to the Penman-Monteith model (Allen et al., 1998). The irrigation management was adopted through water balance, based on crop evapotranspiration (ETc), rainfall measured at the site and water storage characteristics of soil. A daily soil water balance (for both irrigated and non-irrigated conditions) was calculated to identify water deficit periods (Fig. 1).

Both irrigated and non-irrigated treatments were fertilized annually with: N - 500 kg ha^{-1}; P_2O_5 - 100 kg ha^{-1}; K_2O - 400 kg ha^{-1}. The fertilizer was split and applied weekly on irrigated plants, through fertigation, whereas the fertilizer was split 10 times over the two years on non-irrigated plants. The coffee crop was conducted according to programmed cycle pruning system with four orthotropic branches (Verdin Filho et al., 2014).

Nutrient accumulation measurements

The fruit samples were collected during the harvest of 2012 and 2013 (two harvests), being collected 14 samples per treatment (one per plant) in each harvest. During the harvest, 50 coffee fruits were collected in each plant, being selected only mature fruits (consisting of two beans). Harvested fruits were dried in an oven with forced air at 70 ºC for 72 h. Thereafter, the fruits were processed aiming at to separate the beans and husk. Afterward, these fruit parts were weighed on a precision balance to obtain the

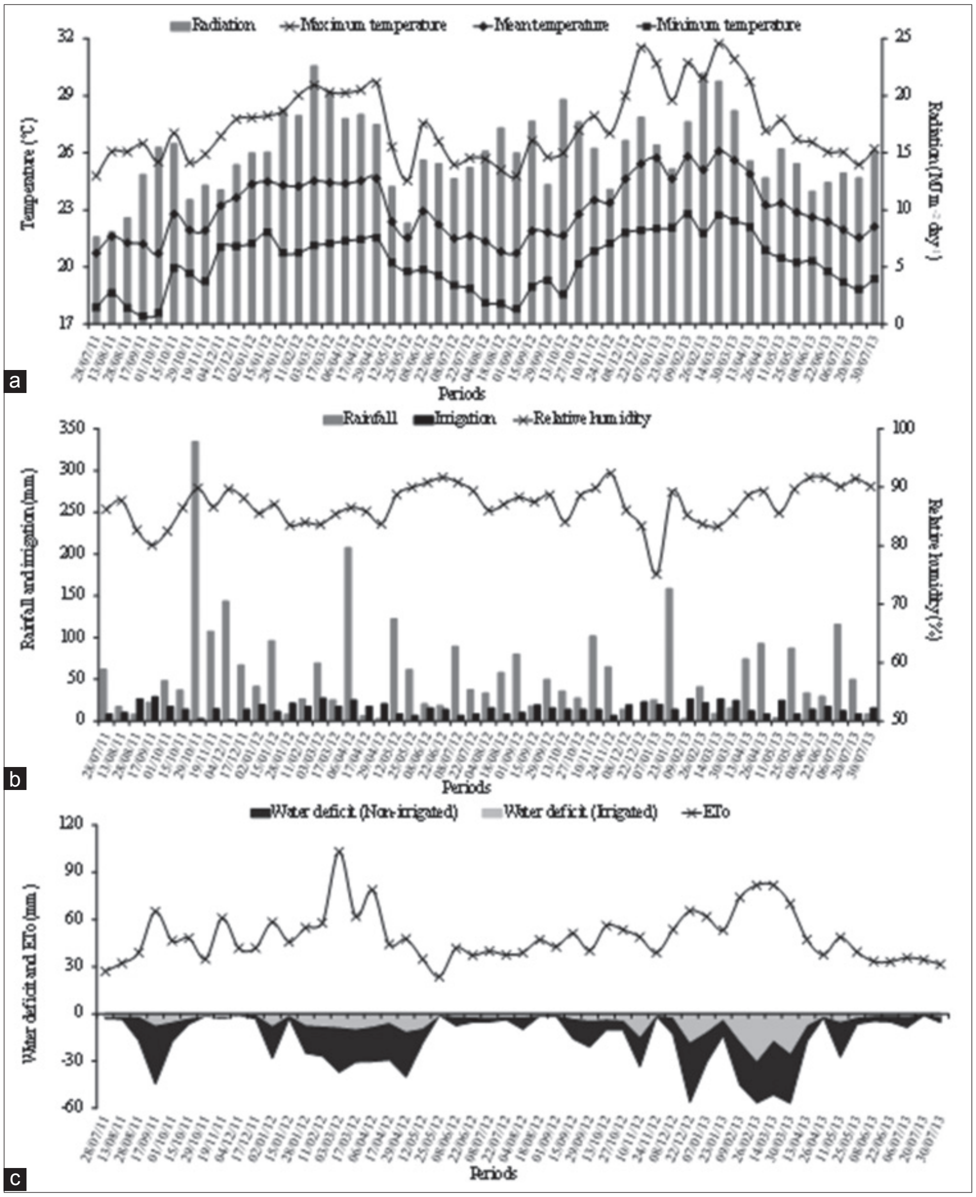

Fig 1. Global solar radiation, maximum, mean and minimum air temperatures (a); rainfall, irrigation and relative humidity (b); water deficit (in non-irrigated and irrigated treatments) and total reference evapotranspiration (ETo) (c), determined during the experimental period between July 2011 and July 2013.

straw, bean and total fruit dry mass. Thereafter, the samples (straw, bean and fruit) were finely ground in a wiley mill and used to macro (N, P, K, Ca, Mg and S) and micronutrients (Fe, Zn, Cu, Mn and B) analysis following the methodology described by Silva et al. (2009).

The amount of husk and bean dry mass in a processed bag of 60 kg of coffee was estimated, considering the relationship found between bean and straw from fruit. Accumulation of macro and micronutrients in the husk and beans were calculated by dry mass x the concentration of each nutrient. Macro and micronutrients accumulated in the fruits were obtained from the sum of the macro and micronutrients contained in the husk and bean. All data were submitted to a one-way ANOVA, followed by a mean using the Student's t–test, using Genes software (Cruz, 2013). A 95% confidence level was adopted for all tests.

RESULTS AND DISCUSSION

The maintenance of an adequate mineral nutrition and of the balance between the several minerals is crucial to plant development. Such preservation of adequate mineral contents and balance within the plant is determinant for the expression of stress tolerance mechanisms on coffee (Ramalho et al., 2013), and assume a particular importance under predicted future conditions of climate changes and global warming (Martins et al., 2014), which are expected to simultaneously alter temperature and water availability to main crops, including to coffee (Rodrigues et al., 2016).

The concentration and accumulation of nutrients in Conilon coffee showed no statistical differences between water treatments in husk, beans and the whole fruit (Table 1). Fruit dry mass production of Conilon coffee is not mainly influenced by the drought (non-irrigated plants) at the end of fruits physiological maturity stage (Table 1). The production of one ton (1000 kg) processed Conilon coffee resulted in production of 520.7 and 536.7 kg of husks by irrigated and non-irrigated plants, respectively (Table 1). Therefore, for each produced bag, the husk biomass represented *ca*. half of processed bean biomass, representing *ca*. 35% and. 65% of total fruit biomass, respectively, what agrees with Matiello et al. (2010) who claim that 2 kg Conilon coffee beans yields 1.3 kg of processed coffee. To the high yield of genotype 02 found here it would have contributed that only with perfect coffee fruit were used, that is, from flowers which undergone complete syngamy with fertilization of the two ovules of flower. Additionally, the genotype 02 shows low proportion of "moca" beans (Pereira, 2015). These values are somewhat higher than those found for *C. arabica* genotypes that showed values in the range of *ca*. 43% to 59% of coffee beans yields to processed coffee (Gaspari-Pezzopane et al., 2005; Matiello et al., 2010; Palva et al., 2010).

As regards the mineral contents in the fruit tissues, the macronutrient concentration of husk and beans showed no statistical difference between the irrigated and non-irrigated treatments, except for P concentration in the husk where non-irrigated plants presented a 33.3% higher value than irrigated plants (Table 2). This contrasted with the impact of extreme temperatures in mineral contents at leaf level (Ramalho et al., 2013; Martins et al., 2014), and might be linked to the strong sink effect of the fruits that could withdraw minerals from other plant organs, together with the mineral availability provided by the applied fertilization in the present experiments.

The largest macronutrients concentrations in the coffee husk, in decreasing order, were K, N and Ca, whereas in beans were N, K and P. These macronutrients in the husk and beans showed no statistical difference between water availability treatments (Table 2). Regarding to micronutrients, Fe was by far the most represented mineral both in husk and in beans (Table 2). Therefore, the incorporation of husk in the soil would constitute an important source of some minerals, with emphasis to N and K among macronutrients, and Fe and B among micronutrients.

Considering the whole fruit, there is a significant accumulation of Ca, Zn and Cu in husk from irrigated coffee (Table 3). Unlike, larger accumulated amount of P, S and Fe were found in the husk from non-irrigated plants. There was larger N, P, Ca, Mg and S accumulation in the beans from irrigated plants than non-irrigated plants. Regarding the fruit, irrigated plants showed greater accumulation of N, P, K, Ca, Mg, Cu and Mn, however, lower B accumulation (Table 3). The K macronutrient was found in larger quantity in the husk from one coffee fruit, followed by the N and Ca (Table 3). Unlike, the N, followed by K were the nutrients that showed the largest accumulation in both beans and fruit.

Fe was the most abundant micronutrient in the husk, beans and whole fruit (Table 3), what agrees with the finding of Bragança et al. (2007). Furthermore, Covre et al. (2013) observed that Fe was the most represented micronutrient in some tissues of six months old seedlings of Conilon

Table 1: Husk, bean and whole fruit dry matter from irrigated and non-irrigated Conilon coffee

Treatment	Dry matter per fruit (mg fruit^{-1})		
	Husks	Beans[1]	Fruit
Irrigated	99.3a	193.9a	293.2a
Non-irrigated	96.8a	182.9a	279.7a
CV(%)	21.1	11.8	12.0
Treatment	**Dry matter per ton of fruits (Kg ton^{-1})**		
	Husks	**Beans**	**Fruit**
Irrigated	520.7	1000.0	1520.7
Non-irrigated	536.7	1000.0	1536.7

The values represent the mean (n=28). Means followed by the same letter do not differ at 5% probability by "t" test. [1]Just fruit consisting of two beans was considered

Table 2: Macronutrients and micronutrients concentrations in husk and beans from irrigated and non-irrigated Conilon coffee

Treatment	Macronutrients (g kg^{-1})					
	N	P	K	Ca	Mg	S
Husks						
Irrigated	12.8a	0.8b	17.6a	4.5a	0.8a	1.8a
Non-irrigated	12.5a	1.2a	16.5a	4.0a	0.8a	2.2a
CV (%)	9.4	26.6	9.4	32.3	40.2	64.3
Beans						
Irrigated	26.7a	2.7a	16.9a	2.1a	1.3a	1.8a
Non-irrigated	25.8a	1.8a	17.0a	1.5a	1.3a	1.6a
CV (%)	10.6	73.7	18.1	68.1	44.1	22.7
Treatment	**Micronutrients (mg kg^{-1})**					
	Fe	**Zn**	**Cu**	**Mn**	**B**	
Husk						
Irrigated	48.2a	7.67a	6.67a	9.17a	27.3a	
Non-irrigated	56.3a	6.50a	5.33a	9.00a	29.3a	
CV (%)	74.90	77.90	57.90	19.30	36.90	
Beans						
Irrigated	55.0a	6.67a	13.2a	9.50a	12.3a	
Non-irrigated	59.0a	7.33a	11.8a	7.83a	21.3a	
CV (%)	49.20	52.00	70.40	20.80	61.80	

The values represent the mean (n=6). Means followed by the same letter do not differ at 5% probability by "t" test

Table 3: Amount of nutrients found in husk, beans and whole fruit from irrigated and non-irrigated Conilon coffee, per fruit

Treatment	Accumulation of macronutrients (mg fruit^{-1})					
	N	P	K	Ca	Mg	S
Husk from one fruit						
Irrigated	1.28a	0.08b	1.76a	0.45a	0.08a	0.18b
Non-irrigated	1.22a	0.12a	1.60a	0.39b	0.08a	0.21a
CV (%)	20.5	20.2	20.5	20.5	20.9	20.4
Beans from one fruit[1]						
Irrigated	5.16a	0.53a	3.27a	0.41a	0.25a	0.34a
Non-irrigated	4.71b	0.34b	3.09a	0.26b	0.23b	0.30b
CV (%)	11.7	11.0	11.9	13.6	11.3	12.1
Fruit						
Irrigated	6.44a	0.61a	5.03a	0.86a	0.33a	0.52a
Non-irrigated	5.93b	0.46b	4.69b	0.65b	0.31b	0.51a
CV (%)	11.3	11.0	11.9	13.6	11.4	12.2
Treatment	**Accumulation of micronutrients (μg fruit^{-1})**					
	Fe	**Zn**	**Cu**	**Mn**	**B**	
Husks from one fruit						
Irrigated	4.82b	0.77a	0.67a	0.92a	2.85a	
Non-irrigated	5.48a	0.63b	0.52b	0.88a	2.73a	
CV (%)	20.4	20.6	20.8	20.4	20.4	
Beans from one fruit						
Irrigated	10.75a	1.34a	2.55a	1.84a	2.39b	
Non-irrigated	10.65a	1.29a	2.16b	1.43b	3.89a	
CV (%)	11.9	11.9	11.6	11.6	13.1	
Fruit						
Irrigated	15.46a	2.06a	3.21a	2.76a	5.12b	
Non-irrigated	16.22a	1.97a	2.67b	2.30b	6.74a	
CV (%)	12.0	12.0	11.1	11.8	13.6	

The values represent the mean (n=28). Means followed by the same letter do not differ at 5% probability by "t" test. [1]Just fruit consisting of two beans was considered

coffee, whereas Marré (2012) reported that this mineral showed the highest micronutrient contents in fruits of some Conilon genotypes with different maturation cycles.

The results obtained for N are in accordance with Arzolla et al. (1963), who states that the coffee bean has a larger amount of N compared to husk. On the other hand, our data differ from that obtained by preview cited authors as they found greater K amount in the husk than bean. This difference may be related to the studied species. Except for Ca and B, the analyzed nutrients are in greater quantity in the bean than husk. However, the coffee husk can present large quantity of carbohydrates, proteins, tannins + polyphenols (Lima et al., 2014).

N is one of the more required nutrients for production at many coffee regions (Malta et al., 2003), which is the most accumulated macronutrient by the coffee Conilon trees and seedlings (Bragança et al., 2008; Covre et al., 2013), which demonstrates the high demand for nitrogen by the coffee plants. The N accumulation in the Conilon coffee fruits presents significant increases between rapid expansion, filling and maturation stages (Covre and Partelli, 2013; Partelli et al., 2014).

Among the micronutrients, Fe had a larger accumulation in the fruit, husk and beans (Table 3), a fact also observed by Sarruge et al. (1966), in arabica coffee. B was the second largest accumulated micronutrient in husk and one single coffee bean followed by Mn (Table 3). On the other hand, Sarruge et al. (1966) observed that Mn was the second most micronutrient accumulated in the coffee husk followed by B, however they observed that Zn was the second most micronutrient accumulated by beans, whereas in the present study, Zn was only the fourth most micronutrient accumulated in Conilon coffee beans. According to Bragança et al. (2007), B is the third most micronutrient accumulated by Conilon coffee. Accordingly, it was found that the proportion of B and Zn accumulation in fruit was higher compared to the other micronutrient during the initial growth stage of fruit expansion (Laviola et al., 2007b). This would be related to the importance of these nutrients in the cell division process and stabilization of new cell membranes (Marenco and Lopes, 2005; Laviola et al., 2007b). The differences observed between the results from this study and preview cited reports seems to be related to plant genetics/evaluated fruit, local effect and management, as well as soil fertility, water availability, among others.

Amongst minerals, K showed the largest mineral accumulation in husk (and the second in beans) for both water treatments, considering the production of one processed ton (1000 kg) (Table 4). In the beans, N was the highest accumulated mineral. Considering the entire fruit N and K are the highest accumulated macronutrients, without clear differences between water availability treatments.

Regarding the micronutrients, in the husk Fe was the most accumulated mineral (followed by B), with non-irrigated plants showing a 20% higher value than the irrigated plants. In the bean, Fe was also the greatest accumulated micronutrient. B accumulated *ca*. 73% more under water shortage conditions than in well-watered conditions. As a consequence, when considering the whole fruit, Fe and B were the most accumulated micronutrients, although the non-irrigated plants showed a tendency to higher values of both elements (Table 4).

Nutrients are accumulated by the fruit during its development, from ovule fertilization in different amounts. To produce one processed ton (1000 kg) of Conilon coffee, there was the following descending order of nutrient accumulation in the coffee husk: K> N> Ca> S> P> Mg and Fe> B> Mn> Zn> Cu. In coffee beans,

Table 4: Amount of nutrients found in husk, beans and whole fruit equivalent to one ton (1000 Kg) from irrigated and non-irrigated Conilon coffee

Treatment	Accumulation of macronutrients per ton of fruits (Kg ton^{-1})					
	N	P	K	Ca	Mg	S
Husks						
Irrigated	6.7	0.4	9.2	2.3	0.4	0.9
Non-irrigated	6.7	0.6	8.8	2.2	0.4	1.2
Bean						
Irrigated	26.7	2.7	16.9	2.1	1.3	1.8
Non-irrigated	25.9	1.9	17.0	1.5	1.3	1.6
Fruit						
Irrigated	33.3	3.2	26.0	4.4	1.7	2.7
Non-irrigated	32.6	2.5	25.8	3.6	1.7	2.8
Treatment	**Accumulation of micronutrients per ton of fruits (g ton^{-1})**					
	Fe	**Zn**	**Cu**	**Mn**	**B**	
Husks						
Irrigated	25.1	4.0	3.5	4.8	14.2	
Non-irrigated	30.2	3.5	2.9	4.8	15.7	
Bean						
Irrigated	55.0	6.7	13.2	9.5	12.3	
Non-irrigated	59.0	7.3	11.8	7.8	21.3	
Fruit						
Irrigated	80.1	10.7	16.6	14.3	26.6	
Non-irrigated	89.2	10.8	14.7	12.7	37.1	

The values represent the mean (n=28)

the accumulation order was N> K> P> Ca> S> Mg and Fe> B> Cu> Mn> Zn and by the coffee fruits was N> K> Ca> P> S> Mg and Fe> B> Cu> Mn> Zn (see Table 4). These results are very relevant, because it can be used for calculating the nutrients export according to crop productivity and to calculate what part of the crop requirement nutrition can be provided by use of husk as a nutrients source for the Conilon coffee plants.

During the coffee fruiting stage, the fruits are preferred sinks among the parts of a plant for nutrient, leading often to the deficiency in other organs of plants (Reindeer and Maestri, 1985; Carvalho et al., 1993; Laviola et al., 2008), requiring the providing through of fertilization. Coupled with high demand for fertilizers, it's the high its cost, which makes the supply of the correct amount of nutrients for crop a limitation for farmers (Serrano et al., 2011). The use of organic sources, such as coffee husk, can be an alternative to reduce the amount of mineral fertilizers provided to the coffee plantations and can reduce the fertilization cost.

The coffee husk is a byproduct generated during the coffee processing, which is discarded in many properties, or is used for feeding stoves during the drying process of coffee beans in rotary dryers. The results of this study reinforce the use of straw as fertilizer, as it has large amounts of nutrients. Thus, the coffee straw/husk when applied to the crops can constitute an excellent complement of nutrients source, as well as of organic matter added to the soil. According to Fernandes et al. (2013), the coffee straw/husk can be used as a N, P, K and S source, with consequent reduction of the need of chemical fertilization regarding these nutrients, and promoting yield enhancements up to 25%. Finally, decomposition of the coffee straw/husks can improve the soil physical structure, providing CTC and soil pH increases (Pace et al., 1996).

CONCLUSIONS

In conclusion, irrigated coffee plants showed larger accumulation of most macronutrients and some micronutrients (mainly Cu, Mn and Zn) in fruits, beans and husk. K followed by N and Ca were the most macronutrients found in coffee straw, whilst N followed by K and P, and N followed by K and Ca were the most macronutrients found in the beans and fruit respectively. Fe and B are the most micronutrients that accumulate in the straw, beans and fruits from Conilon coffee plants.

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Authors' contributions

Study concept and management: (A. M. C., F. L. P.). Conducted the experiments: (A. M. C., F. L. P.). Analysis and interpretation of data: (A. M. C., F. L. P., H. B., H. D. V., W. P. R., J. C. R.). Wrote the manuscript: (A. M. C., F. L. P., H. B., H. D. V., W. P. R., J. C. R.). Review of manuscript at final version (F. L. P., W. P. R., J. C. R.).

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