University of São Paulo
Luiz de Queiroz College of Agriculture

Nutrient demand for vegetation and fruiting of *Coffea arabica* L.

Laís Teles de Souza

Dissertation presented to obtain the degree of Master in Science. Area: Crop Science

Piracicaba
2018

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Agronomist

Nutrient demand for vegetation and fruiting of *Coffea arabica* L.

versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **JOSÉ LAÉRCIO FAVARIN**

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1. Café 2. Manipulação fonte-dreno 3. Carga de frutos 4. Crescimento vegetativo 5. Dose de nutrientes I. Título

Dedicated to

My parents: Ademir Teles and Sirléia de Freitas

My sisters: Tamires Teles and Priscilla Teles

My fiancé: César Augusto

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First, I would like to thank God, because “For everything comes from him and exists by his power and is intended for his glory. All glory to him forever.” (Romans 11, 36).

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Thank you very much

CONTENT

RESUMO

Demanda de nutrientes para vegetação e frutificação do *Coffea arabica* L.

A demanda de nutrients do cafeeiro (*Coffea arabica L.*) depende da carga de frutos e da intensidade da variação anual do crescimento vegetativo. No entanto, as doses de nutrientes recomendadas para a cultura são baseadas apenas na produtividade de frutos, especialmente produtividades de lavouras antigas. Portanto, o objetivo principal desta pesquisa foi determinar a relação fonte-dreno, por meio do efeito da carga de frutos no crescimento vegetativo, para compreender a demanda nutricional do café. As hipóteses foram (i) a biomassa vegetativa anual teria uma forte relação linear negativa em função da carga de frutos, (ii) a concentração média de nutrientes seria variável na parte vegetativa da planta devido à quantidade de frutos e (iii) a demanda de nutrientes variaria em anos de alta e baixa produção devido às diferentes proporções entre frutificação e vegetação anual. O experimento foi realizado de novembro de 2015 a junho de 2016 em Jacuí - MG, Brasil. O delineamento experimental foi inteiramente casualizado com um fator (carga de frutos), seis níveis do fator (100%, 80%, 60%, 40%, 20% e 0%) e cinco repetições. Após o florescimento, no início de novembro de 2015, as seis cargas de frutos foram aplicadas manualmente e a base do último par de folhas totalmente expandidas foi marcada com um arame indicador em todos os ramos das plantas. No início de junho de 2016, durante o período de colheita do café, os ramos foram cortados a partir do arame indicador e caracterizados. As variáveis analisadas foram: número de nós, área foliar, massa seca da vegetação, massa seca de frutos, volume de frutos e concentração de macro e micronutrientes na vegetação e na frutificação. O estudo revelou que a carga de frutos afeta fortemente o crescimento vegetativo de *Coffee arabica* L. Para cada litro de fruto produzido a planta deixa de vegetar ~ 103 g de massa seca. Além disso, as concentrações dos macronutrientes N, P, K, Mg e S e os micronutrientes Mn, Fe, Cu e Zn na vegetação e na frutificação não dependeram da carga de frutos. A demanda de nutrientes de uma dada densidade de plantas varia em anos de alta e baixa produção devido às diferentes proporções de produção de massa entre frutificação e vegetação anual.

Palavras-chave: Café; Manipulação fonte-dreno; Carga de frutos; Crescimento vegetativo; Dose de nutrientes

ABSTRACT

Nutrient demand for vegetation and fruiting of *Coffea arabica* L.

Coffee (*Coffea arabica L.*) nutrient demand depends on fruit load and intensity of the annual variation of vegetative growth. However, nutrient rates recommended for this crop are based only on bean yield, manily yields of old crops. Therefore, this research aimed to determine the source-sink relationship, through the effect of fruit load on vegetative growth, to understand coffee nutritional demand. The hypotheses were (i) the annual biomass of stem, branches and leaves should have a strong negative linear relationship regarding fruit load, (ii) the average nutrients concentration changes in the vegetative plant part due to the number of fruits, and (iii) the plant nutrient demand varies in years of high and low production due to the different proportions between fruiting and annual vegetation. The study was carried out from November 2015 to June 2016 in coffee trees in the municipality of Jacuí - MG, Brazil. The experimental design was completely randomized with one factor (fruit load), six factor levels (100%, 80%, 60%, 40%, 20% and 0%) and five replicates. After flowering, in early November 2015, six fruit loads were manually imposed and the base of the last pair of fully expanded leaf was labeled with wire on all branches of the trees. In early June 2016, during the coffee harvest, branches were cut from the wire-label and characterized. The variables analyzed were: numbers of nodes, leaf area, dry vegetation yield, dry bean yield, volume of fruits and concentration of macro and micro nutrients in vegetation and fruiting. The study revealed that fruit load strongly affects vegetative growth in *Coffee arabica* L. For each liter of fruit produced, ~ 103 g of dry vegetation yield decreases per tree. Furthermore, the concentration of the macronutrients N, P, K, Mg and S and the micronutrients Mn, Fe, Cu and Zn in vegetation and fruiting not dependent on fruit load. Nutrient demand of a given plant density varies in years of high and low production due to the different yield proportions of mass between fruiting and annual vegetation.

Keywords: Coffee; Source-sink manipulation; Fruit load; Vegetative growth; Nutrient rate

FIGURE LIST

TABLE LIST

1. INTRODUCTION

A better understanding of source-sink relationship and its effect on nutritional demand of plants can be useful to predict the effects of agronomic practices that affect fruit load or vegetative biomass, or both. In the coffee crop (*Coffea arabica* L.), particularly in non-shaded fields, trees tend to flower heavily and berries act as priority sinks (DaMatta et al. 2008). Due to great demand, photoassimilates allocated to attend fruit development may be more than four times higher than that allocated to branch growth during the annual production cycle (Vaast et al. 2005, DaMatta 2004). Therefore, fruit load has a major effect on dry matter production (Cannell 1985), as the coffee plant needs to deal with the sinks at the same time.

Plant nutrient demand depends on fruit load and the intensity of annual variation of vegetative growth (Riaño-Herrera et al. 2004, Malavolta et al. 2002). Overall, nutrients demand on coffee beans yield is obtained by beans biomass (dry beans) and nutrient concentration (g kg^{-1} of grains biomass) (Raij et al. 2004). However, the annual vegetative biomass growth (stem, branches and leaves) and average concentration of the nutrients based on fruit load are factors that need further investigation.

In the past ten years, high yields (>5 Mg ha^{-1}) have been reported by coffee growers (Sakai et al. 2015, Silva, Teodoro, and Melo 2008, Silva et al. 2011); however, the amount of extra nutrients that must be supplied is not clear. Previous studies have not taken into account the current crop yield, for example, recommendations for Minas Gerais (Guimarães et al. 1999) and São Paulo (Raij et al. 1996) state, Brazil's largest coffee producers, most likely overestimate nutrients rates of nitrogen (N) and potassium (K) to achieve the yields targets. More effort should be placed to meet crop demands and reduce fertilizer costs, which account for over 20% of coffee crop expenses (CONAB 2017).

The usual practice is to set N and K rates across the years. Regardless of fruit production (high or low), the sink-grain demand is assumed to be equivalent to the annual vegetative sink (Corrêa et al. 1986; Matiello et al. 2015). This assumption may not be the best strategy to provide nutrients, since biomass amount and nutrients concentration differ between vegetative and reproductive sinks. (Malavolta et al. 2002; Laviola et al. 2004).

Moreover, nowadays, higher plant densities are used, compared to previous management practices (Pavan et al. 1999; Paulo et al. 2005; Pereira et al. 2011). Many growers and other professionals believe the demand for nutrients is proportional to yield beans, and high rates of nutrients are supplied without scientific description. This is partially true, but they are neglecting that vegetation has an inverse relationship to fruit load, similarly to nutrient needs. Furthermore, increasing plant density compromises soil fertility (Pavan et al. 1999), affecting the fertilization rate. In addition, the increase of coffee trees in rows impairs light interception of solar radiation, reducing the production of fruits per plant. The differentiation of floral bud in this case is smaller because there is an endogenous increase of gibberellins (Kumar 1978; DaMatta and Rena 2002).

Corrêa et al. (1986) proposed nutrient demmand considering vegetation and fruiting based on expected yield in number of bags (60 kg): 4.5 kg N per bag, 0.5 kg P_2O_5 per bag and 4.3 kg of K_2O per bag. This presupposes an error, because the authors assigned fixed values for the demand of simultaneous vegetation (2.2 kg of N per bag, 0.2 kg of P_2O_5 per bag and 2.7 kg of K_2O per bag), disregarding the vegetation variation due to fruit load. In other words, if fruit load were different from these values, the nutritional demand would be different for both sinks.

This research aimed to determine the source-sink relationship through the effect of fruit load on vegetative growth to better understand coffee nutritional demand. Therefore, the hypotheses were (i) the annual biomass of stem, branches and leaves should have a strong negative linear relationship due to fruit load, (ii) the average nutrients concentration changes in the vegetative part of the plant due to the number of fruits, and (iii) the plant nutrient demand varies in years of high and low production due to the different proportions between fruiting and annual vegetation.

2. MATERIAL AND METHODS

2.1. Plant material and growth conditions

The study was carried out from November 2015 to June 2016 on Arabica (*Coffea arabica* L.) trees at the São Pedro Farm in Jacuí - MG, Brazil (21°6'32.32"S; 46°41'11.79"W and 1098 m above sea level), with local climate classified as Cwb - Humid subtropical with dry winters and temperate summers (Köppen). The rainfall in the experimental period was 1892 mm (Figure 1) and avarage temperature was 19.1ºC. The coffee plants, cv. Catuaí Amarelo, were in their third production cycle and 3.5 x 0.7 m spacing.

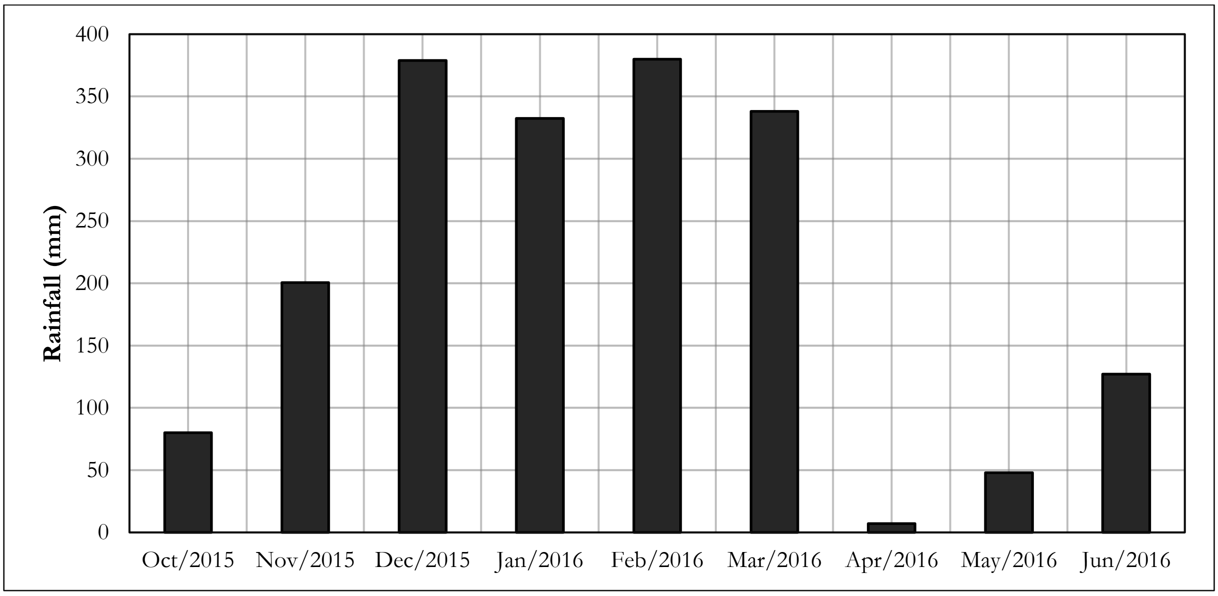

Figure 1. Mean rainfall along the months of field measurements.

The soil is classified as an Oxisol (US Taxonomy) and its chemical constitution was characterized according Table 1 before the installation of experiment and after harvest. Subsequently, the first fertilization was characterized to provide the required elements according to recommendations for the state of Minas Gerais (Guimarães et al. 1999).

Table 1. Soil chemical properties of field experiments. Values describes 0-20 cm depth.

Before experiment installation										
pH	**O.M**	**P**	**K**	**Ca**	**Mg**	**H+Al**	**Al**	**H**	**SB**	**CTC**
$CaCl_2$ 0.01mol L^{-1}		resin	NH_4Cl	NH_4Cl	NH_4Cl					
	g dm^{-3}	mg dm^{-3}	------------------------------------- $mmol_c$ dm^{-3} -------------------------------------							
5.1	19	6	2.1	18	5	25	0	25	25.1	50.1
V%	**B**	**Cu**	**Fe**	**Mn**	**Zn**	**S**	**Ca/Mg**	**Mg/K**	**Ca/K**	**K in CTC**
	Hot water	DTPA	DTPA	DTPA	DTPA	Fost.Calcium				
%	--------------------------- mg dm^{-3} ---------------------------									%
50	0.1	0.7	67	6.4	1.1	14	3.6	2.4	8.6	4.2
After harvest										
pH	**O.M**	**P**	**K**	**Ca**	**Mg**	**H+Al**	**Al**	**H**	**SB**	**CTC**
$CaCl_2$ 0.01mol L^{-1}		resin	NH_4Cl	NH_4Cl	NH_4Cl					
	g dm^{-3}	mg dm^{-3}	------------------------------------- $mmol_c$ dm^{-3} -------------------------------------							
4.3	27	6	2.7	10	4	28	6	22	17	45
V%	**B**	**Cu**	**Fe**	**Mn**	**Zn**	**S**	**Ca/Mg**	**Mg/K**	**Ca/K**	**K in CTC**
	Hot water	DTPA	DTPA	DTPA	DTPA	Fost.Calcium				
%	--------------------------- mg dm^{-3} ---------------------------									%
37	0.96	0.8	58	6.4	1.3	2	2.5	1.48	3.7	6

The crop was unsheded and clean-weeded. The plants were submitted to best agricultural practices for commercial coffee bean production, including integrated pest management.

2.2. Experimental design

The experimental design was completely randomized with one factor (fruit load), six factor levels (100%, 80%, 60%, 40%, 20% and 0%) and five replicates (Figure 2). The manipulation of the fruit load was used to obtain several loads under the same climate and crop condition. Therefore, 30 trees were selected based on uniformity and vigor. After flowering in early November 2015, six fruit loads were manually imposed and the base of the last pair of fully expanded leaf was labeled with wire in all tree branches.

At harvest, in June 2016, fruit loads (%) were converted into fruits volume per plant (L) obtained through a volumetric vessel. This unit was used to relate the other observed variables.

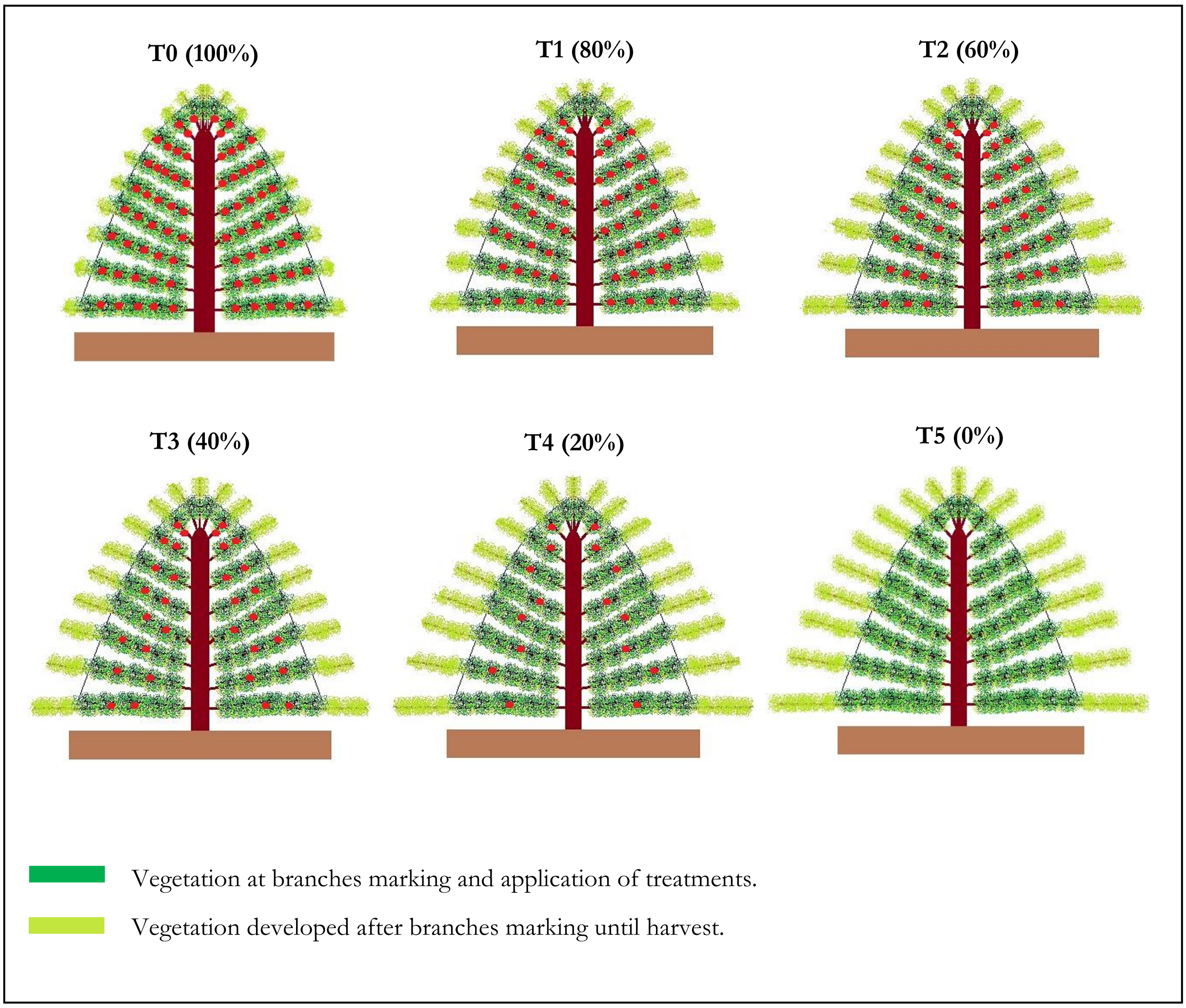

Figure 2. Treatment desgin.

2.3. Crop yield and measurements

In early June 2016, during harvest, branches were cut from the wire-label and characterized. The numbers nodes per branch were recorded per tree. Leaf area was measured through LI-3100 area meter (Li-Cor, Lincoln, NE). Stem, branches and leaves dry matter were recorded to obtain annual dry vegetation yield for each fruit load. Total fruit production per each tree was harvested to obtain the volume and dry fruiting yield.

The materials were dried in an oven at 60º C for 72 h and separated into vegetative biomass (stem, branches and leaves) and fruits (outer skin, parchment with pulp and bean with silver skin). Subsequently, the materials were ground for quantification of P, K, Ca, Mg, S, Cu, Fe, Mn and Zn by X-ray diffraction (EDXRF, Shimadzu, São Paulo). To determine total-N concentration, the plant material was subjected to digestion with sulphuric acid (Jackson 1985), and N was determined according to the analytical semi-micro Kjeldahl method (Bremner 1965).

2.4. Statistics

The datasets were subjected to residual normality and variance homogeneity tests. If assumptios were met, the Analysis of Variance (ANOVA) F-test would be performed considering <0.05 of probability through SAS software version 9.2 (SAS Institute, 2009). When F probability was significant, the means were fitted to linear regression using SigmaPlot software version 10.0 (Systat Software 2006).

3. RESULTS

Fruit load significantly affected leaf area, dry vegetation yield, dry bean yield, beans volume, number of new nodes and vegetation Ca concentration; however, no significant effect was observed in other nutrients evaluated in vegetation and fruiting. The average concentrations of K and N were the highest in vegetation and fruiting compared to the other nutrients. Between both parts of the plant, K concentration was similar. Likewise, P concentration was similar in both parts of the plant, 1.53 g kg^{-1} dry matter for vegetation and 1.39 g kg^{-1} dry matter for fruiting.

The average concentrations of secondary macronutrients were: ~ 2.59 g kg^{-1} S and 2.36 g kg^{-1} Mg dry matter vegetation and 1.44 g kg^{-1} S and 1.43 g kg^{-1} Mg dry matter fruiting. For micronutrients, the average concentrations were: ~ 263.20 g Mn, 247.10 mg Fe, 9.90 mg Cu, 18.30 mg kg^{-1} Zn dry matter vegetation and 56.10 mg Mn, 131.60 mg Fe, 12.00 mg Cu, 6.80 mg kg^{-1} Zn dry matter fruiting (Table 2).

Table 2. Summary of analysis of variance of fruit load effects on variables. Variables: leaf area, dry vegetation yield, dry bean yield, volume of fruits per plant (Volume), new nodes per tree (Nodes), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mg), iron (Fe), cuprum (Cu) and zinc (Zn). Abreviations: DM = dry matter and ns = not significant.

	Average	*P*		Average	*P*	Average	*P*
				---------- Vegetation ----------		---------- Fruiting ----------	
				g kg^{-1} DM		g kg^{-1} DM	
Leaf area (m² per tree)	6.08**	0.0029	N	15.48^{ns}	0.842	13.58^{ns}	0.161
Dry vegetation yield (g per plant)	702.46**	0.0016	P	1.53^{ns}	0.217	1.39^{ns}	0.053
Dry bean yield (g per plant)	737.64**	<.0001	K	18.00^{ns}	0.050	18.94^{ns}	0.284
Volume (L per plant)	2.97**	<.0001	Ca	**	0.003	2.38^{ns}	0.188
Nodes (number per tree)	865.22*	0.0189	Mg	2.36^{ns}	0.104	1.43^{ns}	0.852
			S	2.59^{ns}	0.920	1.44^{ns}	0.118
				mg kg^{-1} DM		mg kg^{-1} DM	
			Mn	263.20^{ns}	0.408	56.10^{ns}	0.654
			Fe	247.10^{ns}	0.496	131.60^{ns}	0.216
			Cu	9.90^{ns}	0.452	12.00^{ns}	0.488
			Zn	18.30^{ns}	0.939	6.80^{ns}	0.240

* Significant at 5% and ** significant below 1% of probability of error by the F test.

The relationship between fruit load and fruit volume was strong and positive linear (P<0.0001). The average fruit volume per tree ranged between 0 and 5.68 liters across treatments and increased with the percentage of fruit load (Fig. 3).

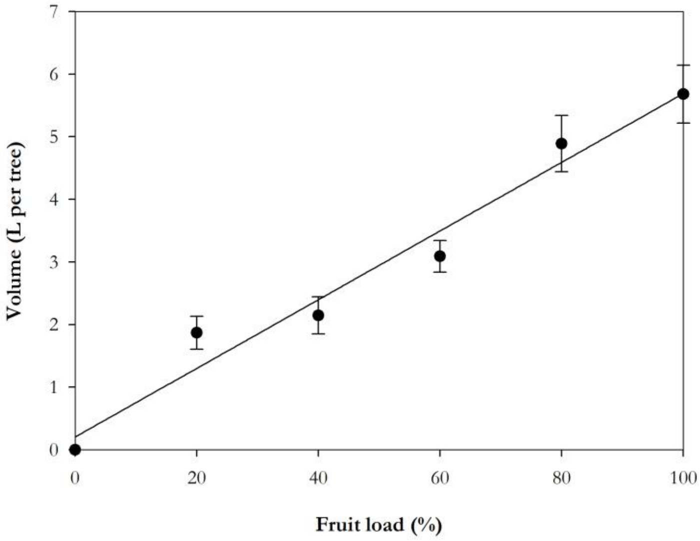

Figure 3. Effect of fruit load on volume of mature fruits of field-grown coffee (*Coffea arabica*) trees. Each point representes the mean of five replicates ($y = 0.2032+0.0549x$ with $R^2 = 0.96$ where y = mean volume of mature fruits and x = fruit load berry per tree). Vertical bars denote the standard error.

Fruit load significantly affect Ca concentration in vegetation. High fruit load, which corresponds to a low amount of dry vegetation yield, increases Ca concentration in vegetation, which ranged from 6.32 g kg^{-1} of vegetation dry matter for lower fruit loads to 11.41 g kg^{-1} of vegetation dry matter for higher fruit loads (Fig. 4).

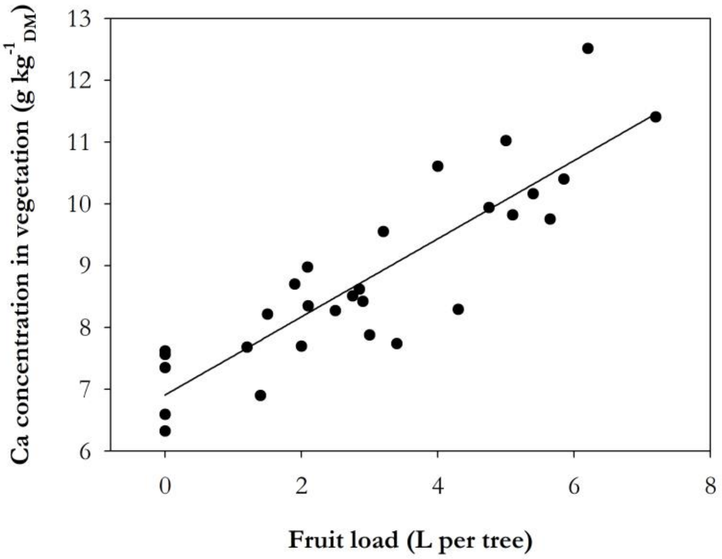

Figure 4. Effect of fruit load on Ca concentration in vegetation (g kg^{-1} dry matter). Data are all observations of five replicates collected from each coffee tree. $y = 6.9072+0.6324x$ with $R^2 = 0.77$ where y = Ca concentration in vegetation (g kg^{-1} dry matter) and x = fruit load (liter per tree).

High fruit load greatly decreased leaf area and number of nodes in new branches. Leaf area of no fruit load achieved 8 m^2 per tree and 4 m^2 with full fruit load, while the number of nodes achieved 1104 with no fruit load and 560 with full fruit load (Fig. 5).

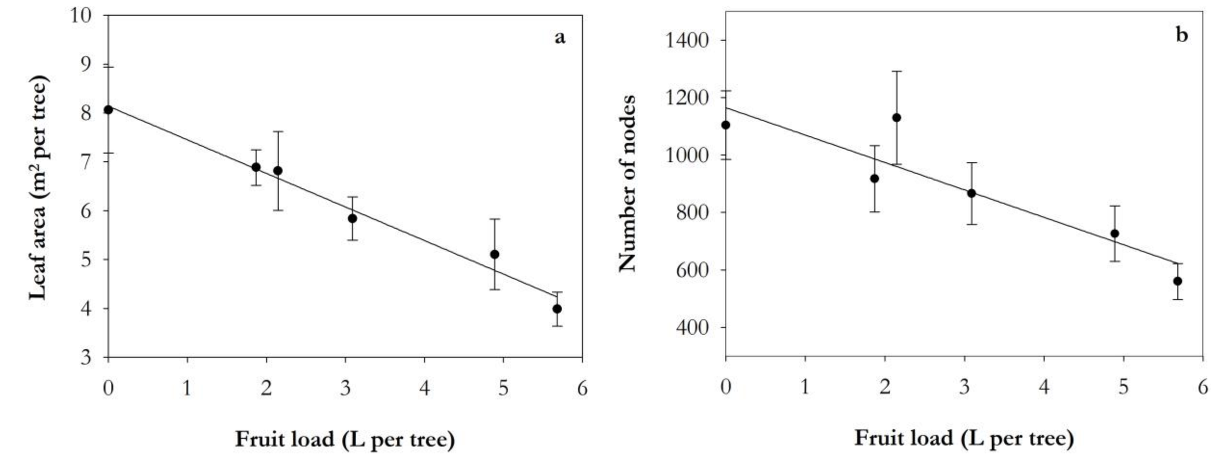

Figure 5. Effect of fruit load on new leaf area (a) and number of nodes in new branches (b) of field-grown coffee trees. Data are means of five replicates collected from coffee tree of each treatment. Vertical bars show the standart error for trees in each group. y = 8.1361-0.6872x with R^2 = 0.97 for leaf area (a) and y = 1164.7620-95.3937x with R^2 = 0.78 for number of nodes (b), where y = leaf area (m^2 per tree) or number of nodes per tree and x = fruit load (liter per tree).

Fruit thinning significantly ($P<0.001$) increased dry vegetation yield (282%) and decreased dry bean yield (377%). Dry vegetation yield per tree ranged from 1204 g in lower fruit loads to 315 g in higher fruit loads (Fig. 6a), and dry bean yield per tree ranged from no yield in lower fruit loads to 1510 g in higher fruit loads. In the 100% fruit load treatment (~6 L per tree), dry matter accumulation by fruits accounted for more than three times the volume accumulated by vegetation over the annual production cycle (Fig. 6).

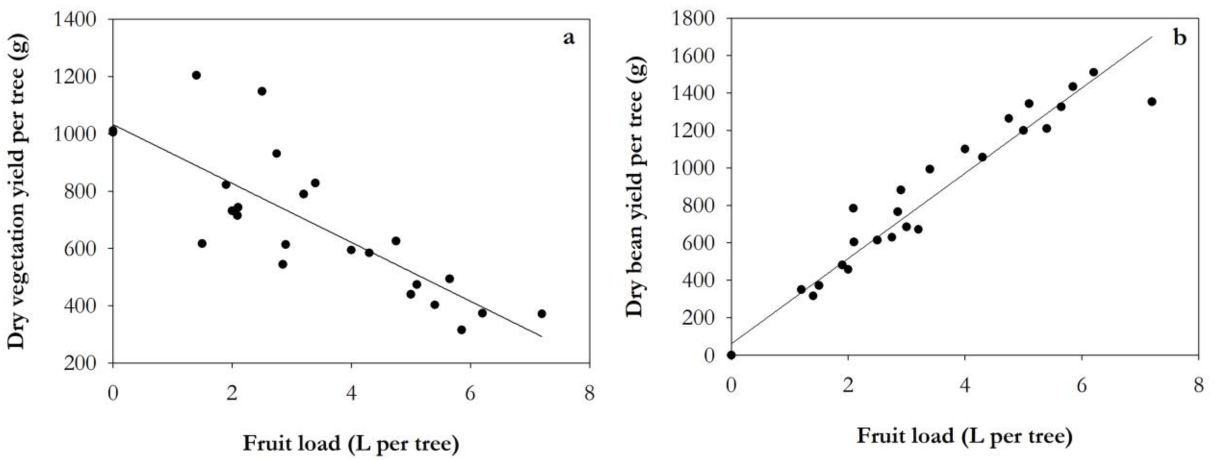

Figure 6. Dry vegetation yield (a) and dry bean yield (b) per tree regarding fruit load. Data are all observations of five replicates collected from each coffee tree. y = 1032.5280-102.8417x with R^2 = 0.66 for vegetation (a) and y = 60.7371+227.6214x with R^2 = 0.95 for beans (b), where y = dry vegetation or bean yield per tree (g) and x = fruit load (liter per tree).

Nutrient demand of the studied crop was calculated for bean yield of 6600 kg ha^{-1}, as an example, based on the data presented (Table 3). The crop demanded ~114 kg ha^{-1} N, 12 kg ha^{-1} P, 156 kg ha^{-1} K, 30 kg ha^{-1} Ca, 13 kg ha^{-1} Mg, 13 kg ha^{-1} S, 687 g ha^{-1} Mn, 1213 g ha^{-1} Fe, 97 g ha^{-1} Cu and 69 g ha^{-1} Zn.

Table 3. Annual nutrient demand for 3600 kg ha^{-1} bean yield* of the commercial crop where the experiment was carried out.

Nutrient	Fruiting (kg ha^{-1})	Vegetation (kg ha^{-1})	Total (kg ha^{-1})
		kg ha^{-1}	
N	97.78	16.62	114.40
P	10.01	1.64	11.65
K	136.37	19.33	155.70
Ca	17.14	12.50	29.63
Mg	10.30	2.53	12.83
S	10.37	2.78	13.15
		g ha^{-1}	
Mn	403.92	282.61	686.53
Fe	947.52	265.33	1212.85
Cu	86.40	10.63	97.03
Zn	48.96	19.65	68.61

* processed coffee

4. DISCUSSION

4.1. Fruit production versus vegetative growth and properties of vegetative organs

This study illustrates the effect of fruit thinning on vegetative growth, bean yield and the vegetative and fruiting nutrient concentration. Fruit thinning strongly modulated bean yield and branch growth. The removal of fruits at a very early stage stimulated branch growth and production of additional apical leaves. Comparison of the total yield of vegetation with full fruit load versus vegetation with no berries clearly revealed the influence of fruits on dry matter accumulation (Table 2; Fig. 6a). Therefore, other vegetation properties, such as leaf area and number of nodes, were also affected (Table 2; Fig. 5). Bean yields in fruit thinning was reduced (Table 2, Fig. 3 and 6b). These results also indicate coffee tree source-sink interactions, which are modulated by carbon assimilation and partitioning during growth and development. Moroever, the trend of the plant to develop larger sink demand by fruits, to the detriment of young apical vegetative branch parts, determine the production level in the following year (Fig. 6).

The effect of fruit load on vegetative growth is consistent with previous observations for coffee (Cannell 1971; Kumar and Tieszen 1976; Amaral et al. 2001; Vaast et al. 2005; Franck et al. 2006; DaMatta et al. 2008; Chaves et al. 2012). The same effect was also reported in the other fruit tree species, for example apple (Meland 2009), sweet cherry (Whiting and Lang 2004) and olive (Haouari et al. 2012). For obvious reasons, new leaf area and number of nodes decreased according dry yield vegetation reduction with increased fruit load. It results in a strong biennial fruiting pattern, which ultimately leads to tree degeneracy (Cannell 1985; DaMatta et al. 2010). There are indications that a leaf area of approximately 15 cm^2 (Vaast et al. 2005) or 20 cm^2 (Cannell 1985) is needed to support each fruit to avoid restraining the vegetative growth of the coffee tree. This area, however, can be considered variable in coffee trees qith many fruits (DaMatta et al. 2008).

4.2. Nutrient concentration

In this study, we observed no effect of fruit thinning on nutrient concentration in vegetation and fruiting, except for Ca in vegetation (Table 2). Previous studies suggested that quantatitavely macronutrient concentration of plant shoot should be N> K>Ca>Mg>P>S for adequate growth (Epstein 1965; Marschner 1995; Raij 2011). However, in this study, macronutrient concentration was registered as K>N>Ca>Mg>S>P for vegetation and K>N>Ca>P>S>Mg for fruiting. Coffee plants have high N and K requirements (Catani and Moraes 1958; Malavolta et al. 1963; Catani et al. 1967); however, K plays a major role in coffee plant physiology especially during fruit growth and maturation. The quantity of K exported at harvest exceeds that of N (Mitchell 1988).

Ca concentration in vegetation increased with fruit load (Fig. 4), although this also corresponds to the low amount of dry vegetation yield (Fig. 6). This result confirmed that coffee plants absorb excessive Ca quantities when they grow in acidic soils with limestone correction, which provides high Ca amounts (Willson 1985). The Ca content in the soil of this experiment (18 $mm_c\ dm^{-3}$, Table 1) was far above the ideal (4 - 7 $mm_c\ dm^{-3}$), according to Raij et al. 1996. Ca has a structural function in the stabilization of the cell wall and plasma membrane. It has a recognized role in processes of cell division and elongation, in polymerization of proteins, and as an enzyme regulator. In addition, Ca moves inside the plant through the xylem, mainly with transpiration water, and is not carried by the phloem (Malavolta et al. 1997; Brady and Weil 2013).

Unlike our expectations, the average nutrients concentration did not vary in the vegetative plant part due to the quantity of fruits, except for Ca. On the other hand, we proved that nutrient demand of the same plant population varies in years of high and low production due to the different proportions between fruiting and annual vegetation.

4.3. Comparison between nutrient demand in plant biomass (current research study) and nutrient rate recommended by Brazilian official manuals

N, P and K annual demand for coffee was calculated based on the results presented in this study and compared to nutrients rate recommended by Brazilian official manuals (Raij et al. 1996; Guimarães et al. 1999). Nutrient use efficiency was not built into the nutrient demand calculation. According to the presented data, N total demand (vegetation plus fruiting) ranged from 75 to 118 kg ha^{-1} from 600 to 3600-4800 kg ha^{-1} of yield bean. Guimarães et al. (1999) recommend 140 to 340 kg ha^{-1} N (Table 4) and Raij et al. (1996) recommend 120 to 250 kg ha^{-1} (Table 5) for crops with 25 - 30 g kg^{-1} N content (average concentration) in leaves for yield bean from 600 to 3600 - 4800 kg ha^{-1}.

Table 4. Coffee nitrogen demand (kg ha^{-1}) based on the current study and rates recommended in Guimarães et al. (1999).

Bean yield		Current study			Guimarães et al. (1999)		
					N content in leaves (g kg^{-1})		
		Fruiting	Vegetation	Total	<25	25-30	31-35
kg ha^{-1}	Bags ha^{-1}	N (kg ha^{-1})					
600	**10**	16	59	**75**	200	**140**	80
600-1200	**20**	35	49	**84**			
1200-1800	**30**	54	39	**93**	250	**175**	110
1800-2400	**40**	66	33	**99**	300	**220**	140
2400-3000	**50**	79	26	**105**	350	**260**	170
3000-3600	**60**	92	20	**111**	400	**300**	200
3600-4800	**70**	104	13	**118**	450	**340**	230

Table 5. Coffee nitrogen demand (kg ha^{-1}) based on the current study and rates recommended in Raij et al. (1996).

Bean yield		Current study			Raij et al. (1996)		
		Fruiting	Vegetation	Total	N content in leaves (g kg^{-1})		
					<26	26-30	>30
kg ha^{-1}	Bags ha^{-1}	N (kg ha^{-1})					
<600	**10**	16	59	**75**	150	**120**	70
600-1200	**20**	35	49	**84**	180	**120**	70
1200-1800	**30**	54	39	**93**	210	**140**	90
1800-2400	**40**	66	33	**99**	240	**160**	110
2400-3600	**50**	79	26	**105**	300	**200**	140
2400-3600	**60**	92	20	**111**			
3600-4800	**70**	104	13	**118**	360	**250**	170
3600-4800	**80**						

P_2O_5 total demand (vegetation plus fruiting) ranged from 17 to 27 kg ha^{-1} from 600 to 3600 - 4200 kg ha^{-1} of yield bean. Guimarães et al. (1999) recommends 0 to 20 kg ha^{-1} P_2O_5 (Table 6) and Raij et al. (1996) recommends 20 to 50 kg ha^{-1} P_2O_5 (Table 7) for crops with high and 13 - 30 P content in soil and yield bean from 600 to 3600 - 4800 kg ha^{-1}.

Table 6. Coffee phosphorus demand (kg P_2O_5 ha^{-1}) based on the current study and rates recommended in Guimarães et al. (1999).

Bean yield		Current study			Guimarães et al. (1999)				
		Fruiting	Vegetation	Total	P content in soil[1]				
					Very low	Low	Medium	Good	Very good
kg ha^{-1}	Bags ha^{-1}	P_2O_5 (kg ha^{-1})							
<600	**10**	3.7	13.3	**17**	30	20	10	**0**	0
600-1200	**20**	8.2	11.1	**19**	40	30	20	**0**	0
1200-1800	**30**	12.6	8.9	**22**	50	40	25	**0**	0
1800-2400	**40**	15.6	7.4	**23**	60	50	30	**15**	0
2400-3600	**50**	18.5	5.9	**24**	70	55	35	**18**	0
2400-3600	**60**	21.5	4.5	**26**	80	60	40	**20**	0
3600-4800	**70**	24.4	3.0	**27**					

[1] according to Guimarães et al. (1999)

Table 7. Coffee phosphorus demand (kg P_2O_5 ha^{-1}) based on the current study and rates recommended in Raij et al. (1996).

Bean yield		Current study			Raij et al. (1996)			
		Fruiting	Vegetation	Total	P content in soil (mg dm^{-3})			
					0-5	6-12	13-30	>30
kg ha^{-1}	Bags ha^{-1}	P_2O_5 (kg ha^{-1})						
<600	**10**	3.7	13.3	**17**	40	20	**20**	0
600-1200	**20**	8.2	11.1	**19**	50	30	**20**	0
1200-1800	**30**	12.6	8.9	**22**	60	40	**20**	0
1800-2400	**40**	15.6	7.4	**23**	70	50	**30**	0
2400-3600	**50**	18.5	5.9	**24**	80	60	**40**	20
2400-3600	**60**	21.5	4.5	**26**	90	70	**50**	30
3600-4800	**70**	24.4	3.0	**27**				

K_2O total demand (vegetation plus fruiting) ranged from 109 to 194 kg ha^{-1} from 600 to 3600 - 4800 kg ha^{-1} of yield bean. Guimarães et al. (1999) recommends 150 to 350 kg ha^{-1} K_2O (Table 8) and Raij et al. (1996) recommends 100 to 250 kg ha^{-1} K_2O (Table 9) for crops with 1.2 mmolc dm^{-3} K content in soil and yield bean from 600 to 3600 - 4800 kg ha^{-1}.

Table 8. Coffee potassium demand (kg K_2O ha^{-1}) based on the current study and rates recommended in Guimarães et al. (1999).

Bean yield		Current study			Guimarães et al. (1999)		
		Fruiting	Vegetation	Total	K content in soil (mg dm^{-3})		
					60	120	200
kg ha^{-1}	Bags ha^{-1}	K_2O (kg ha^{-1})					
<600	**10**	27	82	**109**	200	**150**	100
600-1200	**20**	59	69	**127**	200	**150**	100
1200-1800	**30**	91	55	**146**	250	**190**	125
1800-2400	**40**	112	46	**158**	300	**225**	150
2400-3600	**50**	133	37	**170**	350	**260**	175
2400-3600	**60**	154	28	**182**	400	**300**	200
3600-4800	**70**	175	19	**194**	450	**350**	225

Table 9. Coffee potassium demand (kg K_2O ha^{-1}) based on the current study and rates recommended in Raij et al. (1996).

<table>
<tr><th colspan="2" rowspan="3">Bean yield</th><th colspan="3">Current study</th><th colspan="4">Raij et al. (1996)</th></tr>
<tr><th rowspan="2">Fruiting</th><th rowspan="2">Vegetation</th><th rowspan="2">Total</th><th colspan="4">K content in soil (mmolc dm^{-3})</th></tr>
<tr><th>0-0.7</th><th>0.8-1.5</th><th>1.6-3.0</th><th>>3.0</th></tr>
<tr><th>kg ha^{-1}</th><th>Bags ha^{-1}</th><th colspan="7">-- K_2O (kg ha^{-1}) --</th></tr>
<tr><td>**<600**</td><td>**10**</td><td>27</td><td>82</td><td>**109**</td><td>150</td><td>100</td><td>**50**</td><td>20</td></tr>
<tr><td>**600-1200**</td><td>**20**</td><td>59</td><td>69</td><td>**127**</td><td>180</td><td>120</td><td>**70**</td><td>30</td></tr>
<tr><td>**1200-1800**</td><td>**30**</td><td>91</td><td>55</td><td>**146**</td><td>210</td><td>140</td><td>**90**</td><td>40</td></tr>
<tr><td>**1800-2400**</td><td>**40**</td><td>112</td><td>46</td><td>**158**</td><td>240</td><td>160</td><td>**110**</td><td>50</td></tr>
<tr><td>**2400-3600**</td><td>**50**</td><td>133</td><td>37</td><td>**170**</td><td rowspan="2">300</td><td rowspan="2">200</td><td rowspan="2">**140**</td><td rowspan="2">80</td></tr>
<tr><td>**2400-3600**</td><td>**60**</td><td>154</td><td>28</td><td>**182**</td></tr>
<tr><td>**3600-4800**</td><td>**70**</td><td>175</td><td rowspan="2">19</td><td>**194**</td><td rowspan="2">360</td><td rowspan="2">250</td><td rowspan="2">**170**</td><td rowspan="2">100</td></tr>
<tr><td>**3600-4800**</td><td>**80**</td><td></td><td></td></tr>
</table>

5. CONCLUSIONS

- Fruit load strongly affects vegetative growth in *Coffee arabica* L. High fruit load provides lower vegetative growth. For each liter of fruit produced, ~ 103 g of dry vegetation yield decreases per tree.
- The concentration of macronutrients N, P, K, Mg and S and micronutrients Mn, Fe, Cu and Zn in the vegetative (stem, branches and leaves) and fruiting stages are not dependent on fruit load.
- Nutrient demand, consequently the fertilization rate, of a given plant density varies in years of high and low production, due to the different proportions of mass between fruiting and annual vegetation.
- The knowledge of nutrient demand by the *Coffee arabica* L. tree helps professionals to calculate fertilizer rates for the crop according to nutrient content available in the soil.

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APPENDICES

APPENDIX A.	Dry vegetation yield: stem, branches and leaves that grew from the indicator wire until harvest.
APPENDIX B.	Dry bean yield: whole fruit (with outer skin, parchment with pulp and bean with silver skin).
APPENDIX C.	Bean volume: whole mature fruit harvested.
APPENDIX D.	Leave area: leave area that grew from the indicator wire until harvest.
APPENDIX E.	Bags: 60 kilograms of dry grain processed (without outer skin and parchment with pulp).
APPENDIX F.	Bean yield: coffee processed (without outer skin and parchment with pulp).