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Exploring the nutritional efficiency of genotypes of *Coffea arabica* L. from different parental lineages in contrasting environments for N availability

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The different responses of improved genotypes to alterations of the availability of nutrients indicate that it is possible to modulate the nutritional efficiency by exploring the interaction between the intrinsic response of a genotype and the level of nutrient supply. The objective of this research was to assess the response of genotypes of *Coffea arabica* L., from different parental lineages, to contrasting environments for N supply, using parameters of growth and nutritional efficiency indexes to explore a possible increase in the nutritional efficiency. The experiment followed a 3×3 factorial scheme, in a completely randomized design, with 3 improved genotypes (Acauã, Katipó and Topázio) and 3 environments with different levels of N availability in the soil (50, 100 and 200% of the recommended supply). The growth and nutritional efficiency of *C. arabica* is influenced by the effects of the intrinsic differences among genotypes and can be modulated by changes in the environment, based on the response to different supplies of N in the soil. Genotypes from different parental linages are able to present highly contrasting responses to the fertilization with N, indicating a high variability to be explored. Among the studied genotypes, Topázio presents higher accumulation of biomass and high nutritional efficiency for absorbing, translocating and using N in environments with low fertility; while Acauã presents higher efficiency in environments with higher N supply.

Key words: Coffee, genotypes, mineral nutrition, variability.

INTRODUCTION

The coffee industry stands out for its great importance to Brazilian socioeconomic development, being one of the main Brazilian exports. The species *Coffea arabica* L. currently covers an area of 1.74 million ha, corresponding to 80% of the total area of coffee plantations in Brazil, which may be responsible for a production of over 36

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million bags of coffee in the current year (Conab-Companhia Nacional de Abastecimento, 2019). There is a constant need for new technologies aimed to increase the coffee productivity in a more sustainable manner, such as the use of newer and improved cultivars, new pruning practices and rational fertilization programs (Prezotti and Bragança, 2013; Martins et al., 2015; Rodrigues et al., 2017).

The ongoing breeding programs in Brazil have developed and recommended several new cultivars of *C. arabica* along the past decades. These cultivars present higher crop yield, often associated to other agronomic advantages, such as higher beverage quality, resistance to plant diseases and tolerance to environmental stresses (Oliveira and Pereira, 2008). Therefore, a considerable number of improved genotypes are available for commercial plantations, also representing a valuable genetic source for the improvement of other agronomic traits still unexplored by the current breeding programs.

Beside the use of improved cultivars, the fertilization management is another important research object, since the fertilization is responsible for a high proportion of the production costs of coffee plantations, and the highly productive genotypes tend to also have high nutritional demands, especially during the stages of flowering and fruit formation (Fonseca et al., 2015; Sakiyama et al., 2015). Among the nutrients, N must be highlighted in the fertilization programs for coffee, since it is highly required in the metabolism, allowing the vegetative growth and photosynthetic process, and is highly mobile in the soil; therefore, this nutrient is commonly subjected to losses by lixiviation or volatilization in Brazilian edaphoclimatic conditions (Malavolta, 1993; Sakiyama et al., 2015; Taiz et al., 2017).

The nutritional efficiency may vary according to the species and even among genotypes of the same species. In the agronomic context, the nutritional efficiency is related to the ability of a given genotype to absorb, distribute and use the nutrient in order to grow and yield in relation to the given supply of nutrients (Baligar and Fageria, 1997). Parameters of nutritional efficiency have been used to discriminate genotypes of different plant species worldwide (Muurinen et al., 2006; Rozane et al., 2007; Beche et al., 2014).

For *C. arabica*, parameters of nutritional efficiency have been successfully used to identify differences among coffee genotypes in Brazil (Martins et al., 2015; Rodrigues et al., 2015). These studies also report different responses of improved genotypes to alterations in the availability of nutrients. This indicates that it is possible to modulate the nutritional efficiency by exploring the interaction between the intrinsic response of a genotype and the level of nutrient supply in order to enhance the fertilization programs. The objective of this research was to assess the response of genotypes of *C. arabica*, from different parental lineages, to contrasting environments for N supply, using parameters of growth and nutritional efficiency indexes to explore a possible increase in the nutritional efficiency.

MATERIALS AND METHODS

Local and soil conditions

The experiment was executed in protected environment, in a greenhouse, located in the experimental area of the Center of Agrarian Sciences and Engineering of the Federal University of Espírito Santo (CCAE-UFES), in the municipality of Alegre, Espírito Santo State, Southeast Region of Brazil. The site is located at 20°45' S latitude and 41°33' W longitude, and present average altitude of 277.41 m over sea level. Homogeneous samples of a red-yellow Oxisol were collected at a depth of 10 to 40 cm, discarding the first 10 cm in order to reduce the effect of the presence of organic matter, more present on surface layers. The soil was analyzed to determine its physical and chemical characterization (Table 1). After characterization, the soil was dried in shade and homogenized in a 2.0 mm mesh sieve before being separated into 10 dm³ samples, standardized by weighing in precision scale, using the soil density. The samples were transferred to sealed plastic pots, capable of holding 12 dm³ of total internal volume.

Experimental design

The experiment studied the interaction between the effects of the genotypic differences and environmental modifications regarding the availability of nutrients in the soil, following a 3×3 factorial scheme. The factors corresponded to three coffee genotypes cultivated under conditions of three levels of N availability in the soil: 50, 100 and 200% of the recommended supply. The trial was arranged in a completely randomized design (CRD) with three repetitions and one plant per experimental pot (14 dm³ of capacity).

Selection of genotypes

Three genotypes of *C. arabica* L. were selected based on their recommendation as cultivars of above-average crop yield for the region of this study and by their contrasting parental origins and ripening cycles. The selected genotypes were Acauã, Katipó and Topázio, which present desirable agronomic traits (Table 2), such as potential to good beverage quality or some level of resistance to common stresses. The seedlings were acquired in certified nurseries, selected to compose a homogeneous group regarding size, leafiness, phytosanitary and nutritional aspects. At the stage of three fully developed pairs of leaves, the seedlings were transplanted to the prepared plastic pots.

Cultivation practices

According to the results of the physical and chemical characterization of the soil, its fertility was correct and the nutritional availability of all nutrients, excepted N, was raised to the levels considered adequate to protected environments, based on the recommendations of Novais et al. (1991). The fertilizations with phosphorus and potassium were performed in a single application previously to transplanting of the seedlings, using KH_2PO_4 salt diluted in water and mixed in the entire soil samples. The irrigation was performed daily, in order to maintain adequate levels of soil moisture for the development of the plants. Phytosanitary management was performed according to its eventual need, applying only manual control strategies to evade chemical interventions. All the practices were planned in accordance with the

Table 1. Physical and chemical characteristics of the soil used as substrate.

Characterization	Parameter	Value
Texture	Sand proportion (g kg^{-1})[1]	47.0
	Silt proportion (g kg^{-1})[1]	6.0
	Clay proportion (g kg^{-1})[1]	47.0
Density	Soil density (kg dm^{-3})[2]	1.20
	Particle density (kg dm^{-3})[3]	2.81
	Porosity (m^3)[4]	0.57
Fertility	pH[5]	6.37
	P (mg dm^{-3})[6]	5.65
	K (mg dm^{-3})[7]	83.00
	Ca ($cmol_c$ dm^{-3})[8]	3.73
	Mg ($cmol_c$ dm^{-3})[8]	0.63
	Al ($cmol_c$ dm^{-3})[8]	0.00
	H+Al ($cmol_c$ dm^{-3})[8]	3.63
	Sum of bases ($cmol_c$ dm^{-3})[9]	4.83
	Potential cation-exchange capacity ($cmol_c$ dm^{-3})[9]	8.46
	Effective cation-exchange capacity ($cmol_c$ dm^{-3})[9]	4.83
	Base saturation (%)[9]	57.1

[1]Pipette method (slow mixing); [2]Graduated cylinder method; [3]Ethyl alcohol method; [4]Based on soil and particle density; [5]pH in water (relation 1:2.5); [6]Extracted by Mehlich-1 and determined by colorimetry; [7]Extracted by Mehlich-1 and determined by flame photometry; [8]Extracted with 1 mol L^{-1} potassium chloride and determined by titration; [9]Calculated parameter (Embrapa, 1997).

Table 2. Characteristics of the studied genotypes.

Genotype	Acauã	Katipó 245-3-7	Topázio MG1190
Progenitor	Sachimor IAC 1668	Caturra Vermelho	Catuaí Amarelo
	Mundo Novo IAC 388-17	Híbrido Timor	Mundo Novo 515
Crop yield	High	High (early years)	High
Ripening	Late	Early	Intermediate
Plant height	Short	Short	Short to average
Vigor	High	Average	High
Fruit coloration	Dark red	Red	Yellow
Beverage quality	Good	Good	Good

Source: Ferrão et al. (2005); Queiroz et al. (2007); Carvalho (2008); Sakiyama et el. (2015).

current recommendations for Arabica coffee cultivation (Reis and Cunha, 2010).

Alteration of N supply

The N fertilizations started 30 days after transplanting the seedling to the prepared pots, and were performed in four proportional parcels, separated by 30-days intervals between them. The different levels of N supply were applied to each designed plot following the levels of 50, 100 and 200% of the recommended levels (Novais et al., 1991), which resulted respectively in the addition of 1.11, 2.22 and 4.44 g of $CO(NH_2)_2$ salt per pot. The urea salt was diluted in distilled water and applied over the soil surface, distant 10 cm around the plant collar.

Evaluation of growth and nutritional efficiency

After 180 days of cultivation under conditions of different N supplies, the plants were cut; separating leaves, stems and roots; separated in paper bags, which were then dried in laboratory drying oven, with forced air circulation at 65°C (STF SP-102/2000 CIR), until their mass achieve constant weight. After drying, the plant organs were weighed on analytical balance (Shimadzu AUW-220D; precision: 0.00001 g) to obtain the measures of roots dry matter (RDM), above-ground dry matter (ADM, as the sum of leaves and stems) and total dry matter (TDM, as sum of roots and above-ground dry matter).

The dried tissues were triturated in Wiley-type mill (Cienlab EC-430, 8 blades, 1725 rpm, using a 0.42 mm mesh stainless steel sieve) to obtain a homogeneous powder. Triplicate samples of 0.5 g of the powder were transferred to Taylor tubes (25 mm × 200 mm) and submitted to sulfuric digestion (H_2SO_4), in order to quantify the organic N content of roots (RNC), above-ground (ANC) and total (TNC) (Silva, 1999). The determined values of dry matter and N content were used to estimate the following indexes of nutritional efficiency: N absorption efficiency (NAE), based on the total nutrient content and the root dry matter (Swiader et al., 1994); N translocation efficiency (NTE), based on the above-ground and total nutrient content (Li et al., 1991); and N use efficiency (NUE), based on the total dry matter and total nutrient content (Siddiqi and Glass, 1981).

Data analysis

The collected data was subjected to analysis of variance ($p \leq 0.05$), using the F-test to identify the existence of significant interactions among the factors and the unfolding of levels for each factor was performed according to the statistical need, using the Tukey's test ($p \leq 0.05$). The analyses were done using the statistical software Sisvar (Ferreira, 2011).

RESULTS AND DISCUSSION

The response of the genotypes to the cultivation in environments with different N supplies showed the existence of significant interaction between the effects of both genotypic and environmental effects over the determination of the growth and nutritional efficiency of the plants.

Similar responses were observed among the genotypes for the root growth, although with different magnitudes (Figure 1a). The high availability of N in the environment with 200% of the recommendation did not cause an increase in root development (RDM). The abundant supply of the nutrient may have made it promptly available for the root system, not requiring a larger growth for the plant to support its nutritional demand. The promotion of the root development in conditions of low supply, as observed for Topázio (Figure 1b), may be explained by the nutritional deficiency inducing the root growth in order to explore larger volumes of soil and acquire the nutrient to sustain the metabolism and the growth of the aerial organs (Neto et al., 2016).

The genotypes also presented different responses for the accumulation of dry matter on above-ground organs (Figure 1c, d) and in total biomass production (Figure 1e f). Acauã presented the lowest means for both ADM and TDM when cultivated with only 50% of the N supply (Figure 1d and f). This genotype achieved similar means to others when cultivated in environments with N supply under the recommended level; however, it never achieved the same above-ground and total biomass accumulation than Topázio in any of the scenarios (Figure 1c and e). The genotype Topázio was described by Carvalho et al. (2012) as being well adapted to different environments, presenting vigorous growth and high yield under different conditions. This genotype presented high accumulations of biomass regardless of the differences among the three studied environments. It is reported that genotypes of *C. arabica*, subjected to cultivation in modified environments for nutrient availability in the soil, can present high genetic variability for growth (Rodrigues et al., 2017), which could justify the different patterns of biomass allocation observed among the three genotypes in response to the N supply. Martins et al. (2015) explains that even older parental genotypes used in the breeding of the species, such as Mundo Novo and Catuaí, present different responses regarding their nutritional efficiencies, which can be modulated by modifications in the nutritional availability of the environment in which they are cultivated.

Different responses in terms of concentrating the absorbed N along the different organs were also observed among the genotypes (Figure 2a, c and e). The genotypes Acauã and Katipó showed gains in the accumulation of N in the all vegetative organs as the N availability increased in the soil (Figure b, d and f). The genotype Topázio, however, accumulated higher amounts of N on the aerial organs regardless of the fertilization (Figure 2d) and in the roots under condition of low supply of N (Figure 2b), resulting in higher N content in the plant in the environment with 50% of the N supply, probably due to a robust activity of its root system.

The different responses among the genotypes for root N content reaffirm this particular pattern, as the concentration of this nutrient for the genotypes Acauã and Katipó, at the level corresponding to 100 and 200% of N supply, surpassed Topázio, which in turn was superior to all others at the level of 50% of N supply (Figure 2a). For the concentration in above-ground organs, the genotype Topázio presented higher means for the environments with up to 100% of the N supply; however, to the environment with 200% of the N supply, the genotypes achieved similar concentration of this nutrient (Figure 2c).

There is a noticeable inversion of patterns among genotypes for the total N content of the plants. While Topázio exceeded the N concentration of all other genotypes at the level of 50% of the nutrient supply, this genotype had similar concentration than Acauã at 100% and was surpassed by all genotypes when cultivated in the environment with 200% of N supply. The genotype Acauã present gains in N content, accumulating more of this nutrient as the availability in the soil increases, presenting the higher TNC at the environment with 200% of the N supply (Figure 2e). The ability of the coffee genotypes to absorb and utilize nutrients is linked to intrinsic characteristics of the genotype (Martins et al., 2013a; Rodrigues et al., 2015), which may explain the differentiated response of the genotypes regarding the uptake and accumulation of N in the plant tissues (Table 2). As well as the different nutritional efficiencies that each genotype presented in the modified environments (Figure 3).

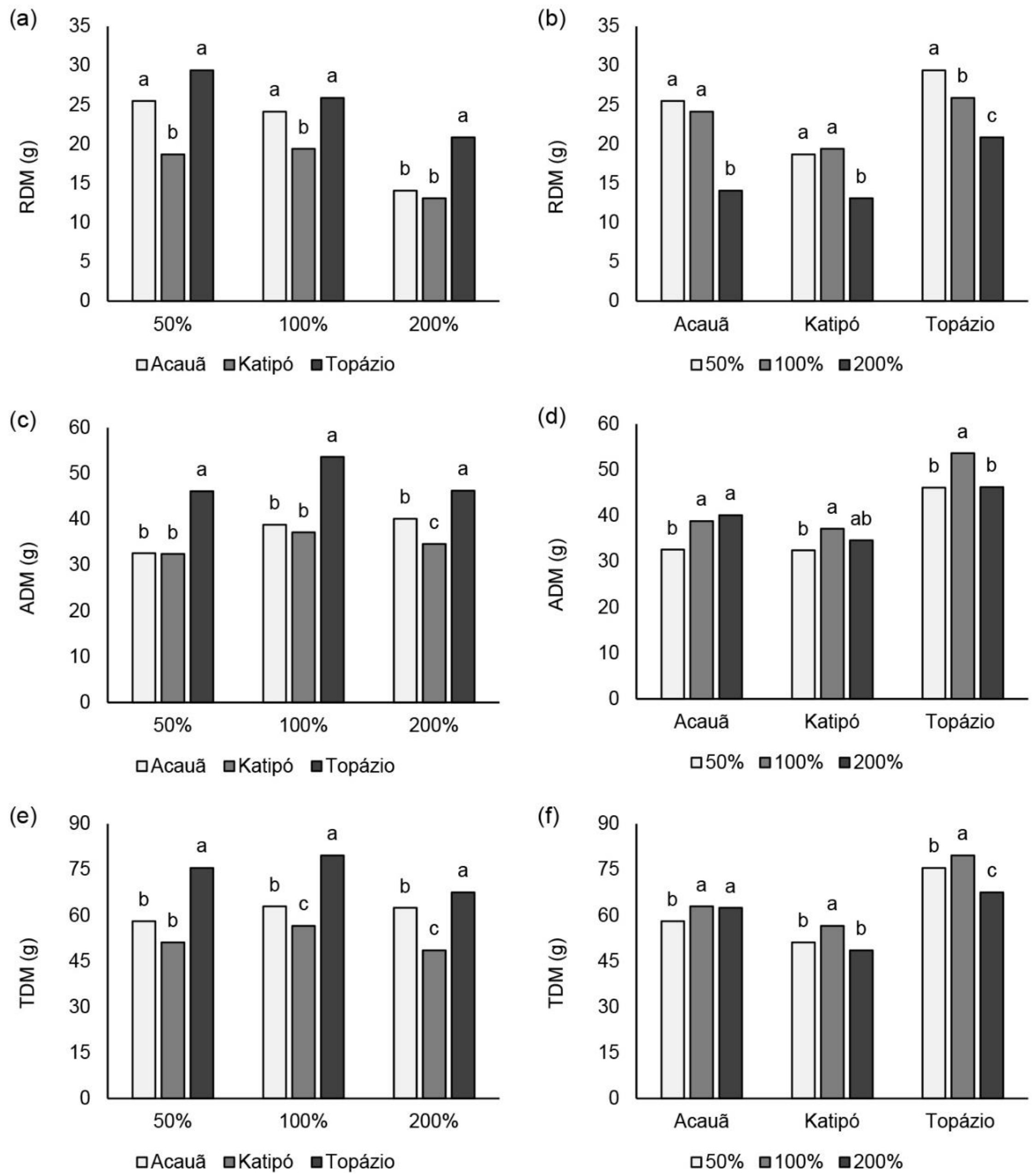

Figure 1. Means of roots dry matter from unfolding the interaction for genotypes *C. arabica* (a) and N supply (b), dry matter of above-ground organs for genotypes (c) and N supply (d), and total dry matter for genotypes (e) and N supply (f) (means followed by the same letter do not differ by the Tukey test at 5% of probability).

For N absorption efficiency, gains were observed for the genotypes Acauã and Katipó in the nutrient uptake as more of it was supplied in the fertilization, while the genotype Topázio kept similar efficiency regardless of the availability of N in the soil (Figure 3b). Swiader et al., (1994) relate the absorption efficiency to the ability of a genotype to acquire the nutrient from the soil in relation to its available root system, which reaffirms the vigorous growth and activity of the roots of Topázio as an important factor to maintain its nutritional efficiency in different soil conditions. Between the genotypes Acauã and Katipó, the gains in N absorption efficiency with the increase on its availability is shaper for Katipó, which ended up being the genotype with the highest efficiency at the environment with 200% of N supply (Figure 3a).

Variability for the nutritional efficiency among genotypes of other species of coffee have been reported in several other researches (Amaral et al., 2011; Martins et al., 2013a, b; 2016; Colodetti et al., 2015; Tomaz et al., 2011), including differences for the efficiency in absorb

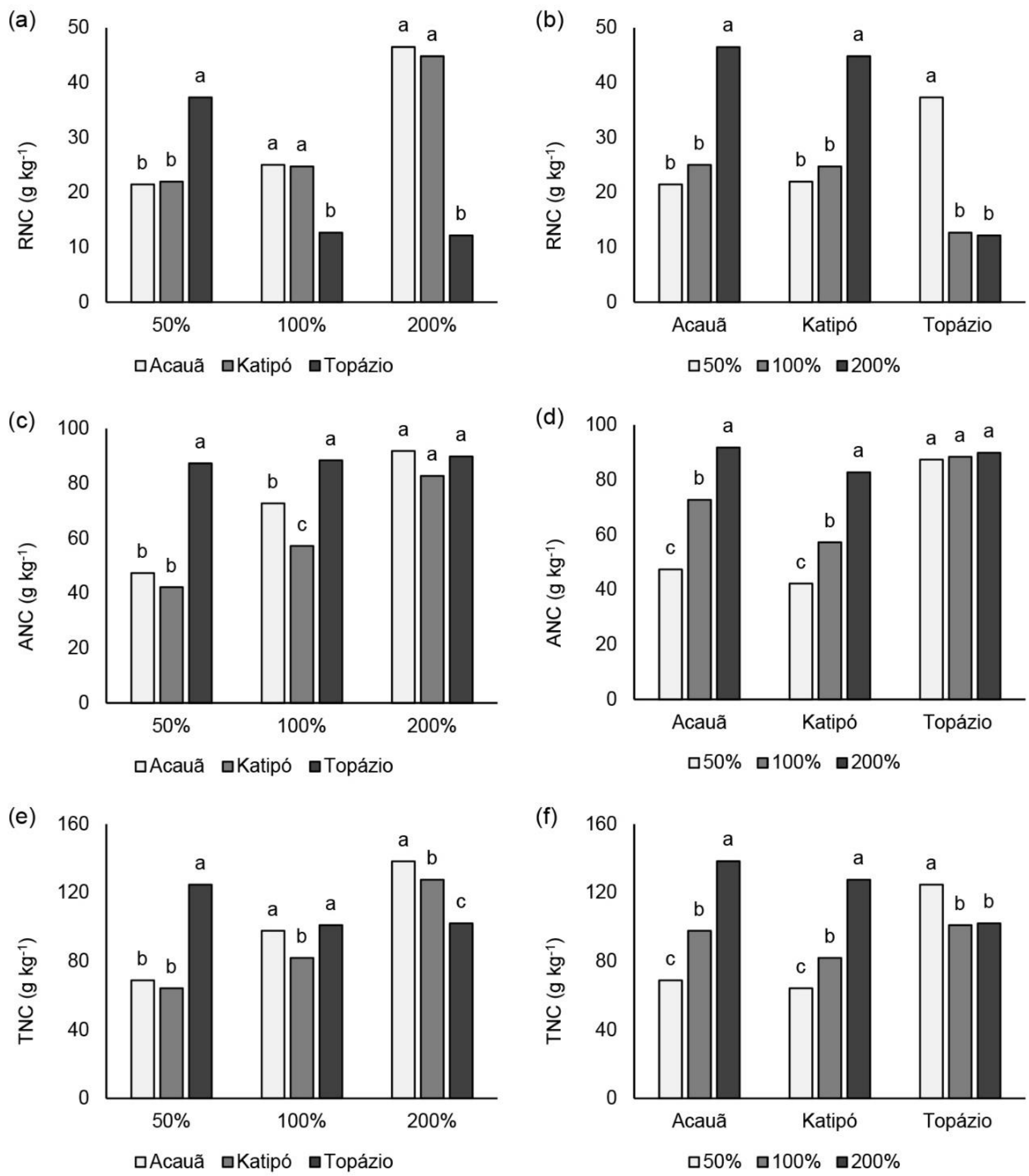

Figure 2. Means of roots N content from unfolding the interaction for genotypes *C. arabica* (a) and N supply (b), N content of above-ground organs for genotypes (c) and N supply (d), and total N content for genotypes (e) and N supply (f) (means followed by the same letter do not differ by the Tukey test at 5% of probability).

and utilize N (Colodetti et al., 2014; Machado et al., 2016). Fageria (1998) relates the different efficiencies observed in among genotypes of one species with the ability of one specific genotype to adapt its root system to stress conditions, which supports the patterns of efficiency observed for Topázio. Analyzing the efficiency of N translocation, it is possible to observe differentiated responses among the genotypes for each environment (Figure 3c). Overall, it is possible to observe a relative superiority of the genotype Topázio and lower efficiency of the genotype Katipó, in all three scenarios of N availability.

The change of N supply had no effect over the translocation efficiency for the genotype Katipó (Figure 3d). However, Acauã presented the higher efficiency when cultivated with the recommended supply (100%) and Topázio presented higher efficiency for the environments with the recommended supply or above.

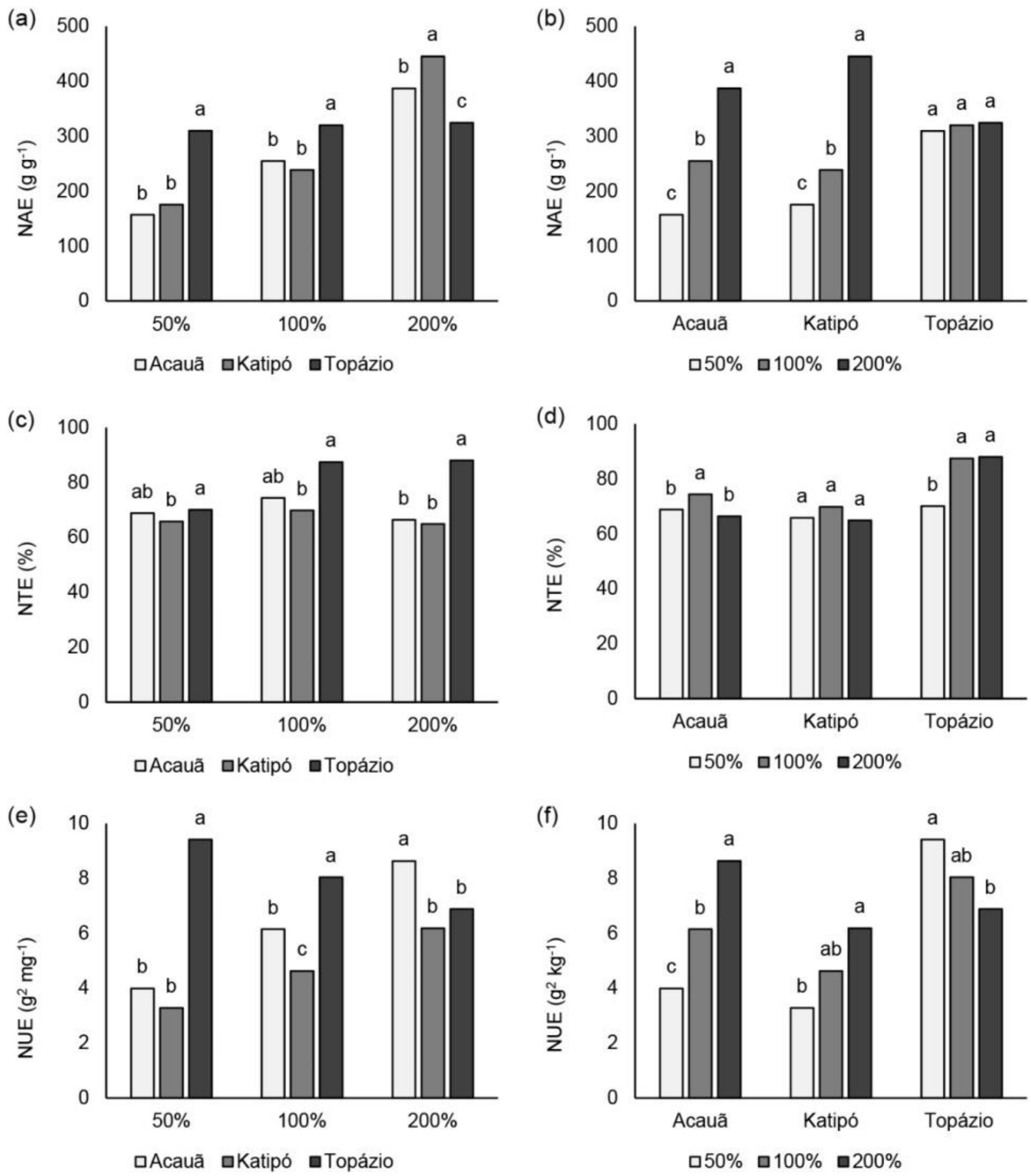

Figure 3. Means of N absorption efficiency from unfolding the interaction for genotypes *C. arabica* (a) and N supply (b), N translocation efficiency for genotypes (c) and N supply (d), and N use efficiency for genotypes (e) and N supply (f) (means followed by the same letter do not differ by the Tukey test at 5% of probability).

The translocation efficiency, according to Li et al. (1991) relates to the amount of nutrient contained in the aerial organs of a plant with the amount of nutrients in the plant as a whole. Thus, the NTE is directly related to the ability of the plant to carry the absorbed nutrients from root system to its aerial systems to sustain the metabolism of the photosynthetically active tissues (Martins et al., 2015). Higher capacity to translocate N can be related to the productivity of a plant, since higher N contents in aerial organs tend to sustain a greater chloroplast synthesis, increasing the overall photosynthetic yield of this plant (Faquin, 2005; Epstein and Bloom, 2006; Taiz et al., 2017).

A considerable variability was observed among genotypes for the N use efficiency (Figure 3e). In the environments with N supply of 100% and bellow, the genotype Topázio is highlighted by its higher efficiency and capacity to convert biomass. For the environment with high supply (200%), the genotype Acauã surpass the efficiency of all others. This fact indicates that Topázio may be efficient to utilize the available nutrient and convert I to produce biomass even in environments with low availability, while Acauã probably presents higher nutritional demands and becomes more efficient in soils of higher fertility.

The N use efficiency presented two distinct patterns among the studied genotypes. For the genotype Topázio, highest use efficiency occurred at the 50% of N supply, decreasing as the supply increased in the soil. In contrast, the genotypes Acauã and Katipó presented higher efficiencies as the levels of N available in the soil increased (Figure 3f). The use efficiency is related to the amount of biomass which the plant is capable of producing by the amount of nutrient available in the tissues (Siddiqi and Glass, 1981). Therefore, it can be inferred that a genotype which is able to produce more biomass requiring a smaller amount of nutrient tends to be more efficient to use of this nutrient, which is a highly desirable agronomic trait (Tomaz et al., 2008).

Considering the overall different behavior of the genotypes, it becomes possible to explore their efficiency traits in a more rational way. For breeding programs, the contrasting patterns make it possible to use these genotypes in efforts to improve the nutritional efficiency both for environments with intense use of fertilization, exploring Acauã; or soils with low natural fertility, exploring the traits of Topázio. For nutritional management, the response of each genotype makes it possible to funnel efforts to supply the plantation with adequate amounts of fertilization in order to explore the efficiency to reduce costs.

Conclusion

The growth and nutritional efficiency of *C. arabica* is influenced by the effects of the intrinsic differences among genotypes and can be modulated by changes in the environment, based on the response to different supplies of N in the soil. Genotypes from different parental linages are able to present highly contrasting responses to the fertilization with N, indicating a high variability to be explored among genotypes. Among the studied genotypes, Topázio presents higher accumulation of biomass and high nutritional efficiency for absorbing, translocating and using N in environments with low fertility; while Acauã presents higher efficiency in environments with higher supplies of N.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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