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Review

The nutritional efficiency of *Coffea* spp. A review

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Reduced soil fertility has been surpassed by the supply of mineral nutrients, which results in increased rates of plant production and costs. In this context, the optimization of plants' nutritional efficiency is critical to increase productivity and reduce the cost of agricultural production systems. The nutritional efficiency of plants is conditioned by numerous factors and the growing environment. Therefore, the knowledge of genetic basis and mode of inheritance can assist in selecting genotypes with desirable agronomic characteristics coupled with nutritional efficiency and genetic variability. The trend of expanding agricultural frontiers has increased interest in the use of genotypes with the potential to adapt to adverse conditions of soil fertility. Within crops, the coffee beans are the second most traded commodity in the world. In this sense, optimization of nutritional efficiency of the coffee has a positive impact on the sum of efforts to make sustainable activity. This review aimed to present a systematic analysis of the nutritional efficiency of the coffee.

Key words: Nutrient absorption and utilization, root length, genetic variability.

INTRODUCTION

In the world, coffee is grown in about 80 countries. It is the second most traded commodity in the world after oil, generating approximately U$ 90,000 million per year and involves about 500 million people in its management from cultivation to final product for consumption. The genus *Coffea* comprises more than 100 species, with particular relevance to *Coffea arabica* L. and *Coffea canephora* Pierre ex Froehner, which together are responsible for about 99% of the production of coffee beans in the world (DaMatta and Ramalho, 2006; Ramalho et al., 2013; Martins et al., 2014). Based on global demand, there must be awareness of farmers for the activity to be more sustainable, without harming the environment while ensuring a better quality of life for future generations. However, this awareness is connected to adopting numerous cultivation techniques and management of crops ground especially in an increase in the use of efficiency of raw materials, so that the increased production of coffee is not coupled to a similar increase in magnitude in fertilizer use.

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The exploration of a coffee with low energy consumption and sustainable environment has stimulated research to identify mechanisms responsible for the greater nutritional efficiency, with the aim of utilizing them by selection and other methods of plant breeding. Moreover, there has been extensive genetic diversity due to a series of physiological, morphological and biochemical mechanisms developed by various species of plants, and also the coffee, when subjected to adverse conditions of soil fertility (Moura et al., 1999; Cardoso, 2010; Soares, 2013; Martins et al., 2013a, 2013b, 2014). As absorption, transportation and redistribution of nutrients have genetic control, it is possible to improve and/or select cultivars for more efficient utilization of nutrients (Gabelman and Gerloff, 1983; Amaral et al., 2011a; Fageria and Moreira, 2011).

Numerous morphological and physiological mechanisms contribute to the efficient use of nutrients, for example: extensive root system (which allows the exploration of large soil volume); high ratio between roots and shoots; root system's ability to modify the rhizosphere (enabling it to overcome low nutrient levels); increased absorption or utilization efficiency of nutrients; the ability to maintain normal metabolism with low nutrient content in tissues and high photosynthetic rate (Gabelman and Gerloff, 1983; Blair, 1993; Fageria and Baligar, 1993; Fageria, 1998; Fageria and Moreira, 2011). The low productivity of crop plants in the world's many soils is due, in large part, to excess or deficiency of mineral elements. Acidity, alkalinity, salinity and erosion promote degradation and low fertility soils; therefore, correction and soil fertilization, and the use of appropriate management techniques are essential to achieve yields. However, in general, the recovery efficiency of nutrients applied as fertilizer is low: about 50% N, less than 10% for P and approximately 40% for K (Baligar and Fageria, 1998).

Overall, this context implies the need to select plants efficient in the absorption and utilization of nutrients applied to the soil. Thus, optimizing the nutritional efficiency of coffee is of great importance for increased productivity, particularly in tropical soils (Fageria, 1989; Furtine Neto et al., 1998). The study of mineral nutrition of plants may contribute to diagnose the correct requirement of soil and plant in the production process, avoiding misapplication of fertilizers, controlling restrictions productivity to ensure the sustainability of agriculture. This review aimed to present a systematic analysis of the nutritional efficiency of coffee.

CONCEPTS OF NUTRITIONAL EFFICIENCY

Numerous concepts on nutritional efficiency are reported in the literature, ranging from conceptualization of the nutrient, species and the researcher. Therefore, the mechanisms of acquisition and utilization of nutrients should be interpreted to prevent errors in relation to increased productivity. The term nutritional efficiency is used to characterize plants in their ability to absorb and utilize nutrients. Nutritional efficiency is also related to economic output per unit of fertilizer applied and the absorption, translocation and use efficiency of nutrients (Baligar and Fageria, 1998). In the context agronomic nutritional efficiency refers to the ability to produce low supply of a nutrient based on standard genotype (Graham, 1984). Physiological, nutritional efficiency can be related to the efficiency of a genotype to absorb soil nutrient, distribute it and use it internally (Goddard and Hollis, 1984). The genotypic differences in nutritional efficiency occur for several reasons, which are related to the absorption, transport and utilization of nutrients by plants (Marschner, 1995). These genotypic differences involved in the mineral nutrition of plants can be explained by morphological and physiological aspects related to the absorption of nutrients (Gabelman and Gerloff, 1983). Plants can be grouped into "effective" and "ineffective" (Vose, 1987), and "responsive" or "non-responsive" in relation to converting nutrients in dry matter (Blair, 1993; Ciat, 1978; Fox, 1978; Amaral et al., 2012; Martins et al., 2013a; Christo et al., 2014).

Nutritional efficiency can be expressed and calculated in five different ways (Fageria, 1998): agronomic efficiency (for example yield increase per unit of nutrient applied - $kg.kg^{-1}$); physiological efficiency (for example biological yield obtained (grain + senescent leaves in crops) per unit of nutrient accumulated - $kg.kg^{-1}$); efficiency in the production of grains (for example production of grain obtained by the accumulated nutrient unit - $kg.kg^{-1}$); recovery efficiency (for example the quantity of nutrient uptake per unit of nutrient applied - $kg.kg^{-1}$); use efficiency (unit of dry matter per unit of nutrients in leaf tissues - $kg.kg^{-1}$]. Most efficient plants in the absorption, translocation and use of nutrients are essential to crops in soils with low natural supply, since they are more adaptable and show better performance (Caldeira et al., 2002). This suggests the need to understand these concepts. The increased efficiency of nutrient absorption may be acquired by: i) adequate geometry and distribution of the root system; ii) chemical changes in the rhizosphere and exudation of substances capable of solubilizing nutrients; iii) presence of mycorrhizae; iv) tolerance to conditions of low pH or high levels of exchangeable aluminum; v) faster rate of absorption under conditions of low nutrient concentrations (Souza, 1994; Fageria, 1998; Fageria and Moreira, 2011). Factors such as root hairs, mycorrhizae and root morphology may lead to differences in the absorption efficiency of nutrient between varieties grown in soil and, consequently, differences in plants' nutritional efficiency.

The efficiency of translocation is largely dependent on the ability of absorption and movement of the ions through the roots and also the ability of the system to release the absorbed ions to xylem vessels (Taiz and Zeiger, 2012). The movement of ions through the roots and their release into the xylem involve several steps that limit the release to the shoots, probably being the basis of genotypic differences in absorption and movement of nutrients (Gerloff and Gabelman, 1983). Thus, the study of mineral nutrition of a species is related to: i) the occurrence of variations in long-distance transport; ii) the occurrence of differences in the accumulation and release of vacuolar level; and iii) the relative proportion of the metabolic and non-metabolic nutrient fractions (Furttini Neto, 1994). The use efficiency can be defined as biomass production per nutrient unit, divided into two components; (1) acquisition efficiency corresponds to the total nutrient by the plant nutrient unit supplied and (2) utilization efficiency, concerning the matter produced by total dry on the plant nutrient unit. Overall, use efficiency of nutrients has been reported as well as the ability of plants to produce maximum quantities of dry matter with minimal investment in applied nutrient unit (Swiader et al., 1994).

Although the efficiency of utilization of nutrients is present in one genotype ability to produce well on nutrient-poor, results show that under suitable nutrient levels there is a tendency of not obtaining effective genotypes similar to efficient production genotypes (Gerloff, 1976). Results report that the use efficiency figures the nutritional efficiency index which shows greater variability between individuals of the same species; for example wheat genotypes exhibit wide variability in the efficiency of internal P utilization and consequent variation in biomass production (Fageria and Baligar, 1999). Similar results were also found for the efficiency of nitrogen utilization in cocoa plants (Ribeiro et al., 2008).

SYSTEMATIC ANALYSIS OF THE NUTRITIONAL EFFICIENCY OF *COFFEA* spp.

The literature is vast in relation to information on mineral nutrition of coffee, but there are few studies on the nutritional efficiency of culture. In comparative study of Arabica coffee cultivars, it was found that the Catuaí is less demanding on nutrients for variety Mundo Novo, mainly beacuse it has lower requirement for magnesium and zinc (Matiello, 1991); however, the Catuaí variety has low efficiency in the use of nitrogen and sulfur (Correa et al., 1983); but has high efficiency in utilization of copper, in relation to variety Mundo Novo. An extensive study on the nutritional efficiency of Arabica coffee plants in relation to nitrogen and potassium nutrients was able to discriminate, based on utilization efficiency of N and K, some varieties of Arabica coffee. This enabled the efficient selection and expansion of the genetic basis of culture in Brazil (Pereira, 1999). Studies on the efficiency in the production of fruits and relative allocation of nutrients in cultivars of Arabica coffee (Acaiá IAC-474/19, Icatu Amarelo IAC-3282, Rubi MG-1192 and Catuaí Vermelho IAC-99) fertilized with different amounts of fertilizer indicate that the efficiency of the use of nutrients for fruit production was different among cultivars only in scenarios that simulated the pattern of nutrient application on land and 140% of the standard recommendation. There was a trend of superiority of the Rubi MG 1192 and Catuaí Vermelho IAC 99, mainly in higher fertilization levels (140% of the standard recommendation). This better use of nutrients for fruit production may explain the better performance of these cultivars for productivity in these levels of fertilization (Amaral et al., 2010).

The results report that the efficiency in the production of roots per unit of nutrient (N, P, K, Ca, Mg and S) of Acaiá (IAC 474-19) is different (lowest) from Ruby (MG - 1192). This suggests a possible genetic variability for numerous variables, directly or indirectly, related to the indices of nutritional efficiency of the coffee (Amaral et al., 2011b). To be inefficient in the absorption and utilization of zinc, nutritional efficiency of coffee in relation to mineral nutrient zinc has been investigated (Souza et al., 2001; Reis and Martinez, 2002; Zabini, 2004). With the study of three varieties of Arabica coffee, it was possible to confirm that Catuaí variety uses zinc absorbed with higher efficiency compared to Icatu; and variety Mundo Novo has reduced capacity utilization of zinc, which can be a limiting factor in the production of grain soils lacking this element (Souza et al., 2001).

In studies of nutritional efficiency, usually genotypes are grown in different scenarios of mineral nutrient supply. To study the selection, characterization and differential tolerance to zinc deficiency progeny of Arabica coffee, for intermediate parameters of nutritional efficiency, four progenies of Arabica coffee were subjected to different scenarios of supply of zinc. This study revealed that the progeny UFV 4066-5 showed low demand and was efficient in environment with low supply of zinc; UFV 4066-3 was demanding and efficient in the environment with a high supply of zinc; progeny *Caturra Vermelho* was intermediate in the requirement and nutritional efficiency of zinc; the IAC 4376-5 was undemanding and nutritionally inefficient for zinc. This leads to the conclusion that there is variability in the absorption of this micronutrient between progenies of arabica coffee (Zabini, 2004).

Recently, similar experiments were developed with the aim of investigating the efficiency use of zinc for coffee genotypes (MG H-419-1, MG-1192, MG-6851, MG-1474, MG-1190, IAC 1669-33, IAC-476, IAC 785-15, IPR-102, San Ramon and São Bernardo,) grown in contrasting doses of the element in the nutrient solution (0.0 and 6.0 mmol L^{-1}). The results show that the IPR-102 variety was the most efficient in the use of zinc; varieties San Ramon and São Bernardo had low efficiency. The MG-1192 (Rubi) had high and low utilization efficiency of zinc when grown in doses 0.0 and 6.0 mmol L^{-1}. The MG-6851 (Oeiras) showed low efficiency of use of 6.0 mmol L^{-1}. The other varieties were moderately efficient in the use of the element (Pedrosa et al., 2013). Among the macro-nutrients required the absence of nitrogen is the most limiting to the development of the coffee plants; for implication in expanding leaf area and growth of vegetation. Due to this importance, studies have been conducted to ascertain the nutritional efficiency of coffee in relation to nitrogen, especially the test aimed to highlight the nutritional efficiency of genotypes and genetic divergence in different scenarios of nitrogen supply (adequate supply -7.5 mmol L^{-1}; reduced supply - 1.0 mmol L^{-1}; in nutrient solution) (Cardoso, 2010). Among the 20 cultivars only four (Obatã IAC-1669/20, Araponga MG-1, Tupi IAC-1669/33 e Catucaí IAC-785/15) were classified into the effective use of nitrogen and further responsive to the addition of this element; analogously cultivars San Ramon and São Bernardo were inefficient and unresponsive in relation to nitrogen supply. The results were promising evidences of the existence of genetic variability among cultivars of Arabica coffee in relation to the cultivation of nitrogen-constrained environment, highlighting the possibility of exploitation in plant breeding programs to obtain efficient cultivars to N (Cardoso, 2010).

Potassium has fundamental implications for the production of coffee beans, especially in the regulation of water loss and grain filling and ripening. By this fact there are studies focusing on highlighting the implications of the nutritional efficiency of coffee plants. In this context, studies were conducted to highlight the extent of genetic diversity among cultivars of arabica coffee with nutritional efficiency for potassium in different scenarios (adequate supply, 4.0 mmol L^{-1}; reduced supply, 1.5 mmol L^{-1}) in nutrient solution (Soares, 2013). The cultivation in scenario with low potassium supply indicated wide genetic variability among cultivars of Arabica coffee for indices of nutritional efficiency, associated with high genotypic coefficients of determination. This indicates the possibility of obtaining successes in breeding program for environments with low potassium supply in the soil (Soares, 2013). It was possible to group the 11 cultivars of arabica coffee in five groups of genetic similarity. Scientific advancement entails the finding of a large group of cultivars with high efficiency of absorption and utilization of potassium (Paraíso MG H-419/1, IPR-102, Rubi MG-1192, Catucaí IAC-785/15, IPR 103, Catuaí Amarelo IAC-62, Obatã IAC-1669/20, Araponga MG-1, Catuaí Vermelho IAC-15, Pau Brasil and Caturra Vermelho). The result shows nine cultivars with high nutritional efficiency (Obatã IAC-1669/20, Caturra Amarelo, IPR-102, Catuaí Vermelho IAC-15, Rubi MG-1192, Araponga MG-1, Tupi IAC-1669/33, Catucaí IAC-785/15 and Caturra Vermelho). Furthermore, cultivars of Arabica coffee Araponga MG-1, Tupi IAC-1669/33 and Catucaí IAC-785/15 can be considered efficient and responsive to addition of potassium in the crop environment (Soares, 2013).

Reports of studies on nutritional efficiency of plants of the species *C. canephora* are scarce in the literature. The study of Reis and Martinez (2002) shows that Conilon coffee supersedes the efficiency of absorption and trans-location of phosphorus and zinc compared to Arabica coffee (Catuaí). But in comparison, Conilon is more efficient in the use of P and Zn. The nutritional efficiency (absorption, translocation and utilization) of Conilon coffee for phosphorus was systematically studied in test that aimed to promote the interaction of 13 genotypes (CV-01, CV-02, CV-03, CV-04, CV-05, CV-06, CV-07, CV-08, CV-09, CV-10, CV-11, CV-12 and CV-13) at different supply levels of phosphorus (0, 50, 100 and 150% of recommended phosphorus for Conilon coffee) (Martins et al., 2013a; Martins et al., 2013b; Martins et al., 2013d). The results indicate that genotypes conilon exhibit significantly different behavior depending on the levels of supply of P_2O_5 in the soil. This behavior highlights the finding that the variables of vegetative growth (number of leaves, stem diameter, plant height and leaf area), of dry matter (leaves, stem and roots) and phosphorus use efficiency of genotypes increase linearly with the supply of P_2O_5 in the soil (Martins et al., 2013b; Martins et al., 2013d). The absorption efficiency of phosphorus in most genotypes of coffee conilon presents adjustment of the quadratic model. This implication in efficiency absorption is maximum between 75 and 100% of the nutrient supply in the soil. The translocation efficiency of phosphorus genotypes conilon coffee is differentiated with linear behavior and quadratic. The use efficiency of phosphorus increases with linear characteristic for genotypes conilon coffee depending on the supply of soil P_2O_5 (Martins et al., 2013b).

The results show that regardless of the supply of phosphorus in the soil, conilon coffee has high efficiency in the translocation of phosphorus; occasionally about 75 to 95% of absorbed phosphorus is translocated into the leaves by conilon coffee (Martins et al., 2013b). The CV-02 and CV-13 genotypes were classified as non-efficient and non-responsive, and coffee conilon CV-04, CV-05 and CV-08 are classified as efficient and responsive supplier of phosphorus in the soil (Martins et al., 2013a). Much of the differential behavior of genotypes conilon coffee in relation to vegetative vigor and nutritional efficiency was due to genetic variation (Martins et al., 2013a; Tomaz et al., 2013). Commonly vegetative growth and differentiated nutritional efficiency are under the same conditions of soil fertility, for cultivars of the same species (Fageria, 1989). In the culture of conilon, there is wide genetic (Ferrão et al., 2008) and phenotypic variability (Fonseca et al., 2004) between different materials, reinforcing the above. Studies regarding nutritional efficiency of conilon coffee in relation to the supply of N and K have preliminary results. In relation to potassium supply, there is no evidence that the conilon coffee is highly responsive to the supply of potassium in the soil, because the genotypes CV-01, CV-02, CV-03 and CV-05 presented high efficiency of absorption and utilization of potassium, independent of K in the soil (Machado et al., unpublished data). The interaction between genotypes (CV-01, CV-02, CV-03, CV-04, CV-05, CV-06, CV-07, CV-08, CV-09, CV-10, CV-11, CV-12 and CV-13) and different levels of nitrogen rates (0, 50, 100 and 150% of the recommended nitrogen for conilon coffee) revealed that the absorption and translocation efficiency of nitrogen of genotypes increased with the supply of nitrogen in the soil; however, the maximum efficiency of nitrogen utilization of genotypes is linked to the supply of 50 to 75% of the recommended nitrogen supply. The results indicate that the genotypes have lower translocation efficiency of nitrogen, between 40 to 85%, when compared to translocation of phosphorus. CV-03, CV-07 and CV-08 genotypes were classified as non-efficient and non-responsive and genotypes CV-01, CV-04 and CV-09 weree classified as efficient and responsive to the supply of nitrogen in the soil.

The nutritional efficiency can be changed under the influence of cultivation techniques used in coffee. So one of the issues widely investigated was the nutritional efficiency of arabica coffee plants grafted under the hypothesis that the nutritional efficiency of grafted seedlings of *C. arabica* grafts of *C. canephora* can differ from conventional seedlings. The nutritional efficiency and the use of N, P, S, Ca, and Mg by plants of coffee vary depending on the combination of scion / rootstock (Tomaz et al., 2003). Studies were directed to verify the nutritional efficiency in relation to N, P and K in the coffee, from four combined genotypes graft (Catuaí Vermelho IAC-15, Oeiras MG-6851, H 419-10-3-1-5 and H 514-5-5-3) and four rootstock (Apoatã LC-2258, Conilon coffee, Emcapa-8141 e Mundo Novo) in hydroponics. The results demonstrate the existence of distinct nutritional efficiency (absorption, translocation and use) of N, P and K in each combination of rootstock and graft (Tomaz et al., 2004). Overall, the rootstocks Apoatã LC 2258 and Mundo Novo showed excellent performance in relation to nutritional efficiency. It was observed that MG 6851 Oeiras and H 419-10-3-1-5 had no benefit by grafting, showing high efficiency in nutrient utilization (Tomaz et al., 2004). The efficiency of absorption and utilization of N, P and S has been studied in plants of *C. arabica* grafted on *C. canephora* (Tomaz et al., 2009) and evaluated at 18 months of age. It was concluded that the use efficiency of N, P and S (Tomaz et al., 2009) and K, Ca and Mg (Tomaz et al., 2008) varied depending on the combination of rootstock and graft as already evidenced (Tomaz et al., 2004). The variety Catuaí Vermelho IAC-15 combined with rootstocks ES-26 and ES-23 showed higher use efficiency of N, P and Mg than ungrafted plants of Catuaí IAC-15. Furthermore, variety Oeiras MG 6851 showed low absorption efficiency of K and Mg in relation to plant not grafted, regardless of the combination studied.

In general, higher rates of translocation of nutrients, except for S, are observed in seedlings of *C. arabica* grafted on *C. canephora* (Dominghetti et al., 2010). The influence of grafting on the absorption and use of micronutrients was also studied, since small changes in foliar concentrations of drugs can be potentially limited for many metabolic processes.

As observed for macronutrients (Tomaz et al., 2004; Tomaz et al., 2008; Tomaz et al., 2009), the nutritional efficiency of coffee plants to B, Zn, Cu and Mn shows variation with the combination graft and rootstock used. Combining Catuaí Vermelho IAC-15 and rootstocks ES-26 and ES-23 benefited the efficiency of use of B and Zn (Tomaz et al., 2011). Another study that can be reported is the influence of increasing levels of silicon in the soil on the nutritional efficiency of arabica coffee, modifying indexes of Icatu and Mundo Novo, and maintaining the nutritional efficiency of Catuaí unchanged (Pozza et al., 2009).

CONCLUSION

Overall, there is consent in relation to the concept of nutritional efficiency to characterize plants in their ability to absorb and utilize nutrients. Numerous studies show the differential behavior between species or genotypes of the same species in relation to the efficiency of absorption, translocation and use of nutrients. This differential behavior is explained by genetic variability, which can be conceptualized as a hereditary trait genotype that shows significant difference compared to the other genotype (for indexes of nutritional efficiency), under ideal or adverse conditions. We present the existence of genetic variability among coffee genotypes of the same species, for absorption and use efficient of nutrients; however, it is necessary to better understand the mechanisms of absorption and utilization of nutrients, and also the nature and genetic inheritance in relation to efficiency.

There are reports that enable one to point clearly that the grafting in coffee modifies indices of nutritional efficiency for some essential mineral nutrients in plant metabolism. The arabica coffee has satisfactory indexes for absorption and use efficiency of nitrogen in potassium; however, these rates may vary from those genotypes, implying that they are classified as efficient and responsive. The conilon coffee has satisfactory absorption, translocation and use efficiency of nitrogen and phosphorus, which also allows us to observe genetic differences that enable the selection of effective and responsive genotypes indices.

Conflict of interests

The authors have not declared any conflict of interest.

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