DOI: 10.37856/bja.v95i2.4243

COFFEE PRODUCTION IN THE BRAZILIAN SAVANNAH: CONSIDERATIONS ABOUT NITROGEN NUTRITION

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ABSTRACT

The Brazilian savannah, locally called "*cerrado*", is a forest and shrub type ecosystem that occupied vast areas of very flat relief, mainly distributed in the central part of the country. In the mid 1970ies, this region was recognized as unfertile with little possibility of agricultural use. From there on, a large part of this biome was occupied by extensive agricultural production, due to the advances in technology. The coffee crop is very important for the Brazilian agribusiness, and in recent years, part of its cultivation has been shifted from the traditional growing areas (e.g. São Paulo and southern of Minas Gerais) to some savannah areas (e.g. northwestern of Minas Gerais and western of Bahia). The Brazilian savannah has quite different edaphoclimatic conditions than the traditional coffee regions, and therefore crop management should be re-evaluated, including those concerning the nitrogen. This paper aims to review some studies already carried out on nitrogen fertilization in savannah coffee plantations.

Keywords: cerrado, nitrogen loss, *Coffea arabica*

PRODUÇÃO DE CAFÉ NO CERRADO: CONSIDERAÇÕES SOBRE NUTRIÇÃO NITROGENADA

RESUMO

A savana brasileira, chamada localmente de "*cerrado*", é um ecossistema do tipo florestal e arbustivo, que ocupava vastas áreas de relevo muito plano na parte central do país. Em meados da década de 1970, essa região era reconhecida como infértil, com pouca possibilidade de uso agrícola. A partir de então, grande parte desse bioma foi ocupado pela produção agrícola extensiva, graças aos avanços da tecnologia. A cafeicultura é muito importante para o agronegócio brasileiro e, nos últimos anos, parte do cultivo foi deslocado das áreas tradicionais (e.g. São Paulo e sul de Minas Gerais) para certas áreas de cerrado (e.g. noroeste de Minas Gerais e oeste da Bahia). O cerrado possui condições edafoclimáticas muito diferentes das regiões cafeeiras tradicionais e, portanto, o manejo das culturas deve ser reavaliado, inclusive o referente ao nitrogênio. Este trabalho objetiva revisar alguns estudos já realizados sobre a adubação nitrogenada em cafezais de cerrado.

Palavras-chave: Cerrado, perda de nitrogênio, *Coffea arabica*

"CERRADO": THE BRAZILIAN SAVANNAH

The main vegetation patterns of Brazil are the tropical rain forests ("*Amazônia*" and "*Mata Atlântica*"), subtropical grassland ("*Pampa*"), tropical wetland ("*Pantanal*"), semi-arid prairie ("*Caatinga*") and the savannah ("*Cerrado*"). The savannah is the second largest Brazilian biome, distributed mainly in the center of the country (Figure 1), occupying over 200 million hectares (24% of country´s total area) (IBGE, 2004a). This savannah type vegetation consists of grassland, shrub and tree, belonging to a very characteristic soil-plant ecosystem that is similar to other types of tropical savannahs found around the globe. This ecosystem occupies mostly vast areas of plateau, and it is classified by the Brazilian Environmental Ministry into three categories: i. "*Campestre*" (with essentially herbaceous species and some shrubs not taller than 3 m); ii "*Savânico*" (with some tall trees and shrubs spread on grassland); and iii. "*Florestal*" (with large trees and continuous or discontinuous canopy) (BRASIL, 2007).

The fundamental factors considered to determine a "*Cerrado*" biome are: climate, soil and incidence of fire. The fire is common and regular in savannah, and the natural vegetation is adapted to it, as well as to a dry season. These areas present strong seasonality, with a rainy season from October to March and with a dry period from April to September. The rainfall ranges from 600 to 2200 mm, and the temperature from 22 to 27ºC. Most of the soils are profound, range from sandy to sandy loams, with very low pH (4.0 to 5.0), high concentration of exchangeable aluminum, high phosphorus fixation capacities, poor in macronutrients, and presents very low cation exchange capacity and low available water for plants (IBGE, 2004b). The detailed climatic characterization of the "*Cerrado*" biome can be found in Silva et al. (2008).

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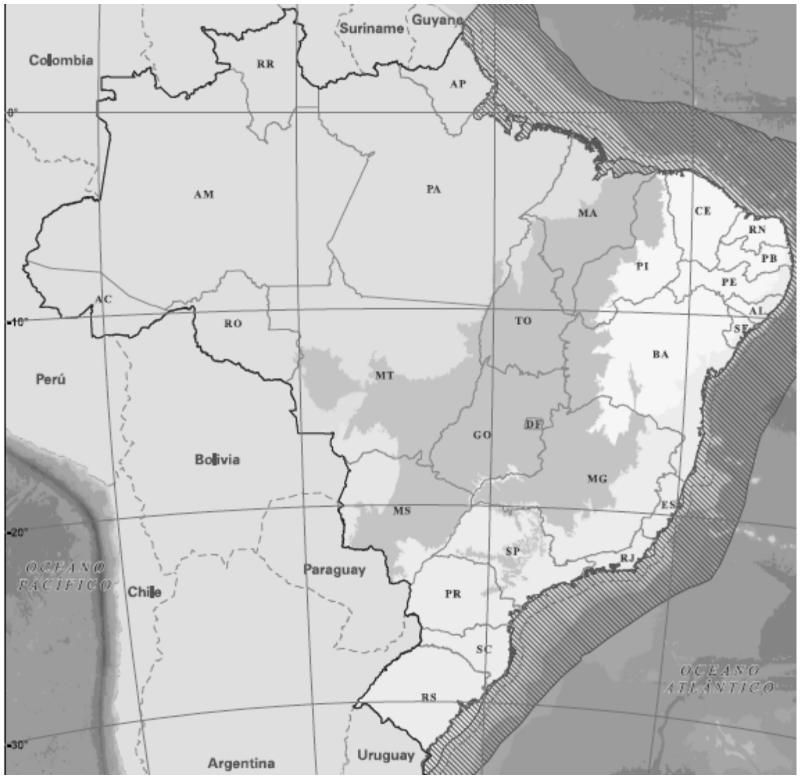

Brazilian states acronyms: AC = Acre, AL = Alagoas, AP = Amapá, AM = Amazonas, BA = Bahia, CE = Ceará, ES = Espírito Santo, GO = Goiás, MA = Maranhão, MT = Mato Grosso, MS = Mato Grosso do Sul, MG = Minas Gerais, PA = Pará, PB = Paraíba, PR = Paraná, PE = Pernambuco, PI = Piauí, RJ = Rio de Janeiro, RN = Rio Grande do Norte, RS = Rio Grande do Sul, RO = Rondônia, RR = Roraima, SC = Santa Catarina, SP = São Paulo, SE = Sergipe, TO = Tocantins and DF = Distrito Federal.

Figure 1. A schematic view of the Brazilian "*Cerrado"* biome (darker area in the center of the country). Source: Adapted from http://mapasinterativos.ibge.gov.br/sigibge/

AGRICULTURE IN THE "*CERRADO"*

The savannah extends from north to south of Brazil and constitutes the current agricultural frontier. Therefore, the landscape is quickly changing due to increasing farming activities, established since 1970ies (SANO et al., 2010). Between 2002 and 2013, the savannah natural vegetation was replaced by agricultural activities (perennial crops, annual crops, pastures and forestry) at a rate of 0.41% per year, i.e. 772 thousand hectares per year. In 2013 around 54% of the original savannah area remained intact, while the agricultural activity occupied 43%, which corresponds to 88.5 million hectares (BRASIL, 2015; SANO et al., 2019).

In the mid of 1970ies the savannah ecosystems were recognized as unfertile with very little possibility of use for farming. From there on, more than half of this area has been used as pastureland and extensive production of maize, soybean, cotton, sugarcane and coffee. In 1975 the savannah land use had its turning point due to territory occupation policies with the 'II

National Development Plan'. This plan was intended to promote some economy sectors in the different regions of the country. In this context, the "*Cerrados* Development Program" was created, with the Brazilian Government offering credit and infrastructure, focusing the agriculture and livestock. In 1979, the "*Programa de Cooperação Nipo-brasileira para Desenvolvimento dos Cerrados – PRODECER"* was created, a program with partnership among the private initiative, the Brazilian and the Japanese governments. The main objective of *PRODECER* was the production of export commodities, especially soybeans. Thus, in just over 40 years both the savannah landscape and the way of practicing agriculture in Brazil underwent profound changes (BRASIL, 2015).

Many authors emphasize that the major problems of carrying out agriculture in the savannah areas are related to water and nutrient availability (e.g. HARIDASAN, 2008; HUNKE et al., 2015). The soil water availability is a problem because these areas are located in high temperature zones, leading to great evapotranspiration rates and water losses mostly in the dry season. As previously mentioned, the savannah rainfall presents strong seasonality in the temporal distribution, including "veranicos", which are drought periods within the rainy season. This characteristic makes the irrigation an essential practice for agricultural production. Since savannah has a very good water supply, this resource has been explored extensively to ensure high crop yield, but sometimes this resource is not properly used. This biome is positioned over plateaus, and it performs an important role in the water distribution to eight hydrographic regions. The water originated in savannah areas flows to several watersheds, mainly to the Araguaia, São Francisco, Parnaíba and Paraguay rivers, making the water resources from this ecosystem very important to other biomes (LIMA, 2011). In Brazil, irrigation uses up to 67% of the available water, in an area of 6.95 million ha, of which around 1 million is within the "*Cerrado"* biome (ANA, 2017; LIMA, 2011). The irrigation is concentrated in some zones of the savannah, and this fact added to water use inefficiency is causing conflicts on water use policies and environmental damages (LIMA, 2011).

The second problem of agriculture in savannah areas is the poor soil fertility. Since crop roots cannot reach great depths due to high soil acidity, exchangeable aluminum and low calcium, the explored layer by roots is limited, being short in water and essential nutrients. Therefore, some agricultural practices are essential for increasing the productivity in this region, such as liming to increase the pH and gypsum application to improve the calcium/magnesium

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content and to reduce aluminum toxicity in the sub-surface layers. Build up soil fertility is important as well, and is achieved by phosphate, potash and micronutrient fertilizations, and through organic matter management. Nitrogen (N) is also an important limiting factor for savannah agricultural production (BUOL, 2009; HARIDASAN, 2000, 2008). A review about the savannah soil fertility, since before agricultural exploitation until nowadays can be can be found in Lopes and Guilherme (2016).

Despite the significant and increasing agricultural and livestock production in the savannah region, several authors point out that exploitation can lead to water, soil and nutrient depletion (GOMES et al., 2019; HUNKE et al., 2015). Therefore, to maintain not only the "*Cerrado"* biome sustainability but also the agriculture, it is essential to adopt appropriate crop management alternatives in order to minimize negative impacts on the entire agroecosystem. A deep discussion about the advance of the agricultural frontier in the brazilian savannah, and its consequences, can be found in Silva (2018).

THE BRAZILIAN COFFEE

Coffee has always been an important commodity for the Brazilian agribusiness, producing beans from both commercial species: *Coffea arabica* L., known as 'Arabica coffee' and *Coffea canephora*, known as 'Robusta' or 'Conilon' coffee. According to the latest statistical survey of 'Food and Agriculture Organization of the United Nations', the Brazil is the largest coffee producer and was responsible for 29% of the 9.2 million Mg of green coffee produced around the world in 2017 (FAOSTAT, 2017). In 2019, the country produced more than 2.9 million Mg of green coffee, collecting around US$ 5 billion just from exports of 2.4 million Mg. The state of Minas Gerais is the largest coffee producer and alone was responsible for almost half of the Brazilian coffee produced in 2019 (CONAB, 2019; CECAFE, 2020).

The geographic distribution of coffee production has been changing over time. Historically very important coffee growing regions, such as those of São Paulo and Paraná, have been losing relevance, and the cultivation was gradually gaining prominence in different regions like Minas Gerais and Bahia regarding Arabica coffee production, and Rondônia and Espírito Santo concerning Robusta (VOLSI et al., 2019).

In the savannah coffee growing there is a strong tendency towards corporate farms, which are more competitive and with professional management (VOLSI et al., 2019).

Currently, about 70% of coffee bean produced in Brazil is from the Arabica species, which occupies 81% of the 2 million hectares of the total country's coffee plantation area. The largest Arabic green coffee producers are the States of Minas Gerais (1.46 million Mg), São Paulo (258 thousand Mg), Espírito Santo (180 thousand Mg) and Bahia (72 thousand Mg) (CONAB, 2019). The localization of all these coffee producing states can be observed in Figure 1.

Regarding Arabic coffee production in the savannah, Minas Gerais northwest and Bahia's west stand out. The savannah of the State of Minas Gerais currently has a total area of more than 225 thousand ha, while Bahia has 11.5 thousand ha (CONAB, 2020). In 2019, a year of negative biennial cycle at arabica species, the coffee farms in Minas Gerais and Bahia savannah produced respectively 276 thousand Mg and 18 thousand Mg of green coffee (CONAB, 2019). For 2020, which is a year of positive biennial cycle, coffee production in the savannah of Minas Gerais is estimated as 360 thousand Mg, while in the Bahia savannah it will be 28.2 thousand Mg (CONAB, 2020).

The coffee productivity in the savannah is also a highligh because, while the national average in 2019 was 1.38 Mg per hectare of Arabica green coffee, in the Minas and Bahia savannah it was 1.5 and 1.98 Mg per hectare, respectively (CONAB, 2019). These data illustrate the great potential of the coffee crop in the "*Cerrado*" biome, which has been explored by farmers applying high technology.

More details about the plant coffee management in savannah (e.g. varieties, breaking dormancy of flower buds, irrigation and mechanized harvesting) can be found in the Fernandes et al. (2012) review paper.

COFFEE PRODUCTION IN "*CERRADO*"

Approximately 57% of the area in Minas Gerais state corresponds to the "*Cerrado*" biome, and half of this area is occupied by agricultural activities and 48% has natural coverage (BRASIL, 2015; SANO et al., 2019). This region corresponds to the microregions of "Triângulo Mineiro", "Alto Paranaíba" and northwest (ORTEGA, 2008).

The climatic conditions favored the coffee production with average temperature from 18 to 23 ^{o}C, altitude from 800 to 1300 m and rainfall index of 1600 mm per year (ORTEGA, 2008). The state of Minas Gerais has more than 1 million hectares equipped for irrigation (ANA, 2017);

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in 2020 the 'Cerrado Coffee Growers Federation' estimates that 85 thousand ha of coffee plantations in the savannah have irrigation equipment for drought periods (FCC, 2020).

After the severe frosts of the 1970s that devastated plantations in Paraná and west of São Paulo, the savannah from Minas Gerais intensified coffee production, with the implementation of the 'Coffee Renovation and Invigoration Plan' by the government. Until this date coffee was produced only for own consumption, and from then on there was an intense development of this activity for commercialization. This development was based on incentives for migration of farmers from the south and southeast of Brazil, financing land for new producers, and placing better agricultural credit policies (ORTEGA, 2008). The result is that today the coffee produced in these areas is basically for exportation, having been the first demarcated coffee producing region in the country, the so called 'Denomination of Origin' (FCC, 2020; ORTEGA; JESUS, 2011).

The savannah of Minas Gerais is specialized to produce 'natural coffee', which means that the beans are dried with intact fruit skin, just with the sun heat. This methodology is applied in few places around the world, generally places with dry winter and mild temperature during harvest time (ORTEGA, 2008). Better information about the characterization and rural territorial productive arrangement of coffee production in this region can be found in Ortega and Jesus (2011).

In Bahia, the savannah occupies just over a quarter of the entire state territory, and is located mainly in the western portion of the state. Agriculture covers 31% of the savannah area and the natural landscape 67% (BRASIL, 2015; SANO et al., 2019). Farmers have explored this area mainly through technologies such as irrigation, fertigation and mechanization. The savannah of the State of Bahia is one the most important food and feed producer of the region known as MATOPIBA, which includes the Maranhão, Tocantins, Piauí and Bahia states, and is considered the great national agricultural frontier today (ANA, 2017; SANO et al., 2019).

In the west of Bahia, the annual rainfall is approximately 1200 mm, with a defined dry season from May to September and the average temperature of 24 ºC (SEI, 2009). Irrigation extends the cropping season and is essential for perennial crops like the coffee plant. According to the latest survey on Brazilian irrigated agriculture, Brazil is among the ten largest irrigators in the world, with almost 7 million hectares equipped for irrigation, and may reach up to 10 million hectares by 2030 (ANA, 2017). However, according to the last haverst yearbook for western Bahia in this region there is a predominance in non-irrigated production, with only 6.5% of irrigated area (around 160 thousand hectares). In the irrigated area prevails the use of the central pivot system (90%) which makes Bahia the third state with the largest installed central pivot area (Figure 2) (ANA, 2017; AIBA, 2019). Since the savannah of the State of Bahia is located on very flat land (Figure 3) with good fresh water availability, this kind of irrigation system has, up to now, been proved to be quite suitable.

Figure 2. View of a central pivot system equipped with Low Energy Precision Application (LEPA) sprinklers, in a commercial coffee plantation. Barreiras, Bahia State, Brazil.

Figure 3. View of the extensive coffee crop plantation in the "*cerrado*" region. Barreiras, Bahia State, Brazil.

Fertigation is widely used by local coffee growers, as it allows simultaneous applications of water and nutrients. Fertigation is traditionally performed using Low Energy Precision Application (LEPA) sprinklers (Figure 4) that concentrate water application over the plant, avoiding the interrow.

Figure 4. View of the Low Energy Precision Application (LEPA) sprinklers in operation.

NITROGEN FERTILIZATION IN "*CERRADO"* COFFEE PLANTATIONS

The N nutrition is quite critical for any plantation established on "*cerrado"* soil, because N is the nutrient with the highest demand, affecting plant growth and development. Urea is the most consumed N fertilizer worldwide, accounting for 48% of total N fertilization (IFA, 2020). Urea is widely used in fertigation projects especially because of the high solubility in water, high N content (45%), and lowest price in relation to other N sources (ESPÍRITO-SANTO, 2004). After applied, the urea [$CO(NH_2)_2$] is hydrolyzed by the urease enzyme and is transformed into carbon dioxide (CO_2) and ammonia (NH_3). This last one can be lost to the atmosphere or be converted into nitrite (NO_2^-) and immediately to nitrate (NO_3^-), with the possible release of nitrous oxide (N_2O) (MOREIRA; SIQUEIRA, 2006). The anion nitrate is highly mobile in the soil, and under sandy soil conditions with excessive rainfall or irrigation can easily be leached out of the root zone and reach the water table (BORTOLOTTO et al., 2012; BORTOLOTTO et al., 2013; CAMERON et al., 2013; PADILLA et al., 2018). Water excess also favors the nitrate denitrification, transforming it into the gaseous forms N_2 and N_2O due to the anaerobic environment of microsites, even in well-drained soils (CAMERON et al., 2013). Some of the main N losses in crop production happen through emission of nitrous oxides and by nitrate leaching down to the water table. The N losses consequences are reduction in ecosystem biodiversity, soil and water body eutrophication, and production of gases, which contribute to the greenhouse effect and reduction of the ozone layer (BATTYE et al., 2017; SHIBATA et al., 2017).

The savannah region of the Bahia State has unique conditions of soil and climate, highly different from the traditional coffee producer regions in Brazilian southeast. This new coffee growing region requires specific management practices, especially regarding N fertilization.

In recent years, farmers strive to make more efficient the use of the fertilizers, shifting the focus from increasing yield at any cost to the development of more sustainable agricultural practices. In any farming activity, management practices affect severely the N uptake by plants, and consequently its losses, determining crop productivity and economic profit. In tropical agroecosystems, between 7-58% of the N applied to crops is absorbed in the first growing season, and in average 50% of N fertilizer is lost, unaccounted for, in the soil or crop (DOURADO-NETO et al., 2010). On the other hand, a study that focused on the N use efficiency in the savannah agriculture, presented results that suggest that N exports by products

DOI: 10.37856/bja.v95i2.4243

surpass their replacement in a regional scale, which can lead to soil degradation (TÔSTO et al., 2019). These results show how diverse and challenging agriculture in the tropics is, in particular regarding the N management.

For woody perennial crops like coffee plants, the N dynamics are even more intricate, and scientific information is still scarce. For this plant, the challenge of finding the appropriate rate and major N demand stages is even greater. This is due to the significant variation in the N need in different phenological stages of the plant, and occurs differently during each crop cycle, year after year (BRUNO et al., 2011). In such a scenario, to achieve maximum productivity with reduced N fertilizer inputs is a huge challenge, despite being a possible goal to be achieved.

The nitrogen fertilization recommendations for coffee plants at full production stage, in the State of Minas Gerais (RIBEIRO et al., 1999), range from 200 to 450 kg ha^{-1} N, varying according to the expected yield, respectively from 1.2 to 3.6 Mg ha^{-1}. This recommendation, in addition to being two decades old, does not take into account the particularities of the savannah environment, nor the technologies adopted by farmers in these areas. This situation shows the urgent need for research regarding the N behavior in coffee plantations of the savannah region of the Minas Gerais State.

Several particularities about the area and the management techniques must be taken into account for the efficient N coffee plant nutrition. Plant species previously grown in the area, as well as the kind of management adopted for coffee plantations, are essential to be known for N soil maintenance, as shown in a study carried out in Minas Gerais by Cerri et al. (2017). These authors noted that the cultivation of coffee without pruning, in areas that were previously pastures, significantly reduced the N soil stock. In the 0-10 cm soil layer, the N stock fell from 3.17 Mg ha^{-1} N present in the pasture to 1.82 Mg ha^{-1} N found in the coffee plantation. Under the same conditions, in the layer of 0-30 cm of soil, the drop was from 7 to 3.72 Mg ha^{-1} N. The pruning of the coffee trees allowed the maintenance of the N stock of the soil previously cultivated under pasture in the 0-10 cm layer, which presented 3.08 Mg ha^{-1} N. However, in the 0-30 cm layer, even with pruning there was a decrease in the N stock from the initial 7 Mg ha^{-1} N to 4.61 Mg ha^{-1} N in the coffee plantation.

In the Minas Gerais savannah the coffee productivity was higher when the entire N rate was applied during the winter, reaching 3.5 Mg of beans per ha. Probably this occurs because the temperature drop paralyzes the aerial part growth, but not the root system. Thus, the roots accumulate N compounds that will be transferred to the aerial part in the next summer, contributing to the coffee bean production (DIAS et al., 2011).

Lima et al. (2016) tested the use of different N fertilizer rates (201 and 300 kg ha^{-1} of N), sources (urea, polymerized urea and ammonium nitrate), and methods of application (conventional and fertigation) in coffee trees in the savannah of Minas Gerais. The yield ranged from 3 to 6 Mg ha^{-1} green coffee, but it did not differ statistically in relation to the rates, sources, or method of application observing the mean values of four consecutive harvests. However, the authors observed that the use of 300 kg ha^{-1} of urea applied thorough fertigation improved fruit ripening homogeneity.

The fact that the crop is irrigated or rainfed influences the N use efficiency, reflecting in its yield and economic performance. The fertigated coffee plantations in the savannah of Minas Gerais had the highest productivity (2.6 Mg ha^{-1}) when 178% of the recommended fertilization for rainfed coffee trees was used (around 600 kg ha^{-1} N). However, the greatest economic return occurred when 141% of the recommended rate (around 485 kg ha^{-1} N) was used, resulting in a yield of 2.5 Mg ha^{-1} (ASSIS et al., 2018).

In the late 2000s Bahia coffee farmers have been applying N rates of the order of 600–800 kg N ha^{-1} $year^{-1}$. These rates are far above those recommended in the traditional region of coffee plantations (BRUNO et al., 2011). As commented before, most of farmers in the savannah of Bahia State use fertigation systems. It is interesting because this kind of management opens the possibility of splitting the nutrient rates. All N in the soil, either in the organic or mineral form, becomes quickly nitrate, which is liable to leaching. So, the N leaching minimization can be achieved by splitting the N rate, which possibly increases its availability to the plants. However, the use of huge quantities of this nutrient and the disregard about the moments of great N demand by the coffee plant may become this management inefficient.

The N behavior in the savannah of the Bahia State coffee plants was observed in detail in a large study using ^{15}N-labeled urea applied via fertigation, presented in different papers by Bortolotto et al. (2012; 2013), Bruno et al. (2011; 2015) and Pinto et al. (2017a,b). Rates of 0, 200, 400, 600 and 800 kg N $ha^{-1}year^{-1}$ were applied in full production coffee plants, during the 2008/2009 harvest season. Each rate was divided equally into 26 portions, distributed every 14 days, over the cropping cycle. At the beginning of the experiment, the coffee plants were 7 years old, and had until then received a dose of 600 kg N $ha^{-1}year^{-1}$. Regarding N leaching as nitrate

DOI: 10.37856/bja.v95i2.4243

($N-NO_3^-$), only coffee plants that received 400 and 800 kg N ha^{-1} were evaluated, while the N leaching in 200 and 600 kg N ha^{-1} rates were estimated.

About the absorption changes in plant compartments over time, Bruno et al. (2011) concluded that fruit filling is the period of greatest N consumption by leaf and fruit. Therefore, the fertilizer use could be more efficient if it is applied only up to the beginning of fruit maturation. Moreover, the data indicated that it is possible to decrease the usual rate of 600 to 200 kg N ha^{-1} without decreasing coffee bean production, at least in those conditions.

Evaluating the ^{15}N-urea balance and efficiency, Bruno et al. (2015) observed that the most efficient rate was 200 kg N ha^{-1} $year^{-1}$ that produced 13 kg of green coffee per kg of N applied as fertilizer. The less effective rate was 800 kg N ha^{-1} $year^{-1}$, which produced only 4 kg of green coffee per kg of N applied. The percentage of N derived from fertilizer recovered in the entire coffee plant was around 61, 37, 41 and 27%, respectively for 200, 400, 600 and 800 kg ha^{-1}N. Therefore, adult plants that received a high N fertilizer rate during previous years do not increase the coffee production with the N fertilizer rates increasing. Around 2.5, 15, 46 and 104 kg ha^{-1} of $N-NO_3^-$ leached was derived from fertilizer, respectively from the rates of 200, 400, 600 and 800 kg ha^{-1} of N.

Bortolotto et al. (2012) applied a sequential monthly water balance using three scenarios: i) rainfall + irrigation the full year, ii) rainfall only; and iii) rainfall + irrigation only in the dry season. The result was that association of high N rates and high rainfall plus irrigation, presented in the 'scenario i', was the main cause for leaching. It is important to state that 'scenario i' was the most applied scenario by coffee producers the late 2000s, because this scenario makes it possible to fertigate equaly over the whole cropping cycle, facilitating daily management.

Using the climatologic water balance to evaluate the $N-NO_3^-$ leaching, Bortolotto et al. (2013) found the monthly average of 5.4 and 25 mg L^{-1} $N-NO_3^-$ for fertilizations of 400 and 800 kg ha^{-1} of N. During that entire coffee production cycle, 24 (400 kg ha^{-1} of N) and 153 kg ha^{-1} (800 kg ha^{-1} of N) were leached as $N-NO_3^-$. The authors highlighted the possibility of groundwater pollution and a cost/benefit problem for applications higher than 400 kg ha^{-1} of N.

Approaching the environmental impacts of N loss in the same study place, Pinto et al. (2017 a) used modeling techniques to simulate N from nitrate leaching and plant N uptake, in different scenarios. The most efficient N recovery was associated with N rates between 200 and 400 kg N ha^{-1} y^{-1}, split during the crop cycle into at least seven applications. For the rates between 200 and 300 kg N ha^{-1} y^{-1}, the N recovery was efficient with or without split application. Finally, the most environmental friendly N management strategy occurred when the application of 200 to 300 kg N ha^{-1} y^{-1} was made, using at least seven splits.

In addition to the environmental problem, the economic harm linked to N losses should also be considered. Since N fertilizers are derived from petroleum, their prices are established based on this commodity, which fluctuates considerably during the last years (MACROTRENDS, 2020). The financial harm generated by N fertilizer losses should be a matter of more concern, since a reduction in the surplus for the potential balance (supply minus total demand) of N fertilizers from 2020 to 2022 in the world is foreseen. In Latin America the potential balance of N in 2022 is predicted to be negative in almost 5,000 thousand tonnes (FAO, 2019). In this context, Pinto et al. (2017b) studied the monetary expenditure related to N losses in the same coffee plantation in the savannah of the Bahia State mentioned above. These authors observed that, from the lowest to the highest application rate, the average annual monetary losses due to N leaching by pivot management ranged from around 45 to 140 thousand US-dollar, and due to volatilization plus denitrification varied between 22 to 50 thousand US-dollar, (May 5, 2020 quotation, Commercial Dollar = 5.5933). The prospect is not merely an eminent environmental crisis, but also a possible crisis in the N fertilizers supply, indicating the urgent need of a more rational use of this resource. So, the adequacy of N applications in agricultural enterprises has to be based on scientific information that indicate the best management practices to be adopted, having in mind the maximum efficiency.

It should be noted, however, that all the information presented by Bruno et al. (2011; 2015), Bortolotto et al. (2012; 2013) and Pinto et al. (2017a,b) refers to full production coffee plants (7-8 years old), and coffee trees at the beginning of their growing cycle probably have different behavior in N use and losses.

FINAL REMARKS

The "*cerrado*" has soil and climatic characteristics very different from other biomes, and in recent decades has been explored by man through agriculture. However, the rational management of its natural resources and the inputs used are essential for a sustainable agriculture establishment. Some studies about N fertilization in the Brazilian savannah coffee plantation show that high N input is not necessary to maintain the coffee production, at least in adult trees. The N leaching dynamic is relevant in the savannah area, and it is the main route of loss. The N fertilizer management in coffee plants of savannah areas must be deeply studied to base the efficient use of this nutrient, preventing negative environmental impact and economic losses.

REFERENCES

ANA - AGÊNCIA NACIONAL DE ÁGUAS (BRASIL). 2017. **Atlas irrigação**: uso da água na agricultura irrigada, Brasília: ANA, 86 p. Available at: <http://atlasirrigacao.ana.gov.br/> Accessed on: Jun.18, 2020.

ASSIS, G.A.; MELO, M.R.P.; SOARES, M.A.; ASSIS, F.A.; MARTINS, W.E.R.; SILVA, L.R. 2018. Levels of nitrogen and potassium fertilization in coffee fertigated and response function. **Ciência Agrícola**, Rio Largo, vol. 16, n. 3, p. 65-73. Available at: <http://www.seer.ufal.br/index.php/revistacienciaagricola/article/view/5607> Accessed on: Jun. 10, 2020.

AIBA - ASSOCIAÇÃO DOS AGRICULTORES E IRRIGANTES DA BAHIA. 2019. **Harvest Yearbook for Western Bahia**: 2017/2018, Luís Eduardo Magalhães: AIBA, 64 p. Available at: <http://aiba.org.br/anuario/> Accessed on: Jun. 18, 2020.

BATTYE, W.; ANEJA, V.P.; SCHLESINGER, W.H. 2017. Is nitrogen the next carbon? **Earth's Future**, Washington, vol. 5, p. 894-904. Available at: <https://doi.org/10.1002/2017EF000592> Accessed on: Jun. 15, 2020.

BORTOLOTTO, R.P.; BRUNO, I.P.; DOURADO-NETO, D.; TIMM, L.C.; SILVA, A.N.; REICHARDT, K. 2013. Nitrate leaching through climatologic water balance in a fertigated coffee plantation. **Revista Ceres**, Viçosa, vol. 60, n. 6, p. 785-792. Available at: <https://doi.org/10.1590/S0034-737X2013000600006> Accessed on: Jun. 15, 2020.

BORTOLOTTO, R.P.; BRUNO, I.P.; REICHARDT, K.; TIMM, L.C.; AMADO, T.J.C.; FERREIRA, A.O. 2012. Nitrogen fertilizer (^{15}N) leaching in a central pivot fertigated coffee crop. **Revista Ceres**, Viçosa, vol. 59, p. 466-475. Available at: <https://doi.org/10.1590/S0034-737X2012000400006>. Accessed on: 15 Jun. 2020.

BRASIL. Ministério do Meio Ambiente. 2007. **Mapeamento de Cobertura Vegetal do Bioma Cerrado**: Relatório Final, Edital Probio 02/2004, Projeto Executivo B.02.02.109. Brasília: MMA, 93 p.

BRASIL. Ministérios do Meio Ambiente. 2015. **Mapeamento do Uso e Cobertura do Cerrado: Projeto TerraClass Cerrado 2013**. Brasília: MMA, 67 p. Available at: <https://www.mma.gov.br/biomas/cerrado/projeto-terraclass.html> Accessed on: Jun. 12, 2020.

BRUNO, I.P.; REICHARDT, K.; BORTOLOTTO, R.P.; PINTO, V.M.; BACCHI, O.O.S.; DOURADO-NETO, D.; UNKOVICH, M.J. 2015. Nitrogen balance and fertigation use efficiency in a field coffee crop. **Journal of Plant Nutrition**, vol. 38, p. 2055-2076. Available at: <https://doi.org/10.1080/01904167.2014.958168> Accessed on: Jun. 1, 2020.

BRUNO, I.P.; UNKOVICH, M.J.; BORTOLOTTO, R.P.; BACCHI, O.O.S.; DOURADO-NETO, D.; REICHARDT, K. 2011. Fertilizer nitrogen in fertigated coffee crop: Absorption changes in plant compartments over time. **Field Crops Research**, Amsterdam, vol. 124, p.369-377. Available at: <https://doi.org/10.1016/j.fcr.2011.07.004> Accessed on: Jun. 3, 2020.

BUOL, S.W. 2009. Soils and agriculture in central-west and north Brazil. **Scientia Agricola**, Piracicaba, vol. 66, n. 5, p. 697-707. Available at: <http://dx.doi.org/10.1590/S0103-90162009000500016>. Accessed on: May. 15, 2020.

CAMERON, K.C.; DI, H.J.; MOIR, J.L. 2013. Nitrogen losses from the soil/plant system: a review. **Annals of Applied Biology**, vol. 162, p. 145–173. Available at: <https://doi.org/10.1111/aab.12014>. Accessed on: 18 Jun. 2020.

CERRI, C.C.; MOREIRA, C.S.; ALVES, P.A.; TOLEDO, F.H.R.B.; CASTIGIONI, B.A.; RODRIGUES, G.A.A.; CERRI, D.G.P.; CERRI, C.E.P.; TEIXEIRA, A.A.; CANDIANO, C.A.C.; REIS, M.R.; D'ALESSANDRO, S.C.; TURELLO, L. 2017. Soil carbon and nitrogen stocks due to land use change in coffee areas at Minas Gerais state. **Coffee Science**, Lavras, vol. 12, n. 1, p. 30-41. Available at: <https://doi.org/10.25186/cs.v12i1.1194> Accessed on: Jun. 5, 2020.

CONAB - COMPANHIA BRASILEIRA DE ABASTECIMENTO. 2019. **Acompanhamento da safra brasileira de café**: Safra 2019, Quarto levantamento. Brasília: CONAB, p. 1-44. Available at: <https://www.conab.gov.br/info-agro/safras/cafe> Accessed on: Jun. 18, 2020.

CONAB - COMPANHIA BRASILEIRA DE ABASTECIMENTO. 2020. **Acompanhamento da safra brasileira de café**: Safra 2020, Primeiro levantamento. Brasília: CONAB, p. 1-58. Available at: <https://www.conab.gov.br/info-agro/safras/cafe> Accessed on: Jun. 18, 2020.

CECAFE - CONSELHO DOS EXPORTADORES DE CAFÉ DO BRASIL. 2020. **Relatório Mensal**: Janeiro de 2020. São Paulo: CECAFE, 19 p. Available at: <http://www.sapc.embrapa.br/arquivos/consorcio/informe_estatistico/CECAFE_Relatorio_Mensal_JANEIRO_2020.pdf> Accessed on: Jun. 15, 2020.

DIAS, K.G.L.; GUIMARAES, P.T.G.; REIS, T.H.P.; OLIVEIRA, C.H.C. 2011. Adubação realizada no inverno e produtividade de cafeeiros no cerrado mineiro. **VII Simpósio de Pesquisa dos Cafés do Brasil**. Araxá: Consórcio Pesquisa Café, 4 p. Available at: <http://www.sapc.embrapa.br/arquivos/consorcio/spcb_anais/simposio7/170.pdf> Accessed on: May. 1, 2020.

DOURADO-NETO, D.; POWLSON, D.; ABU BAKAR, R.; BACCHI, O.O.S.; BASANTA, M.V.; THI CONG, P.; KEERTHISINGHE, G.; ISMAILI, M.; RAHMAN, S.M.; REICHARDT, K.; SAFWAT, M.S.A.; SANGAKKARA, R.; TIMM, L.C.; WANG, J.Y.; ZAGAL, E.; VAN KESSEL, C. 2010. Multiseason recoveries of organic and inorganic nitrogen-15 in tropical cropping systems. **Soil Science Society of America Journal**, vol. 74, p. 139-152. Available at: <https://doi.org/10.2136/sssaj2009.0192> Accessed on: Jun. 15, 2020.

ESPÍRITO-SANTO, J.A. 2004. Cafeicultura no oeste da Bahia. In: ZAMBOLIM L. (Ed.), **Efeitos da irrigação sobre a qualidade e produtividade do café**. Viçosa: UFV, p. 319-335.

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. 2019. **World fertilizer trends and outlook to 2022**. Rome: FAO, 28 p. Available at: <http://www.fao.org/3/ca6746en/CA6746EN.pdf> Accessed on: Feb. 20, 2020.

FAOSTAT - FOOD AND AGRICULTURE ORGANIZATION CORPORATE STATISTICAL DATABASE. 2017. **Crop Data Production Coffee Green 2017**. Available at: <http://www.fao.org/faostat/en/#data/QC> Accessed on: Mar. 3, 2020.

FCC - FEDERAÇÃO DOS CAFEICULTORES DO CERRADO. 2020. **Região do Cerrado Mineiro**: Denominação de origem. Available at: <https://www.cafedocerrado.org/index.php?pg=regiao#group1> Accessed on: Feb. 28, 2020.

FERNANDES, A.L.T.; PARTELLI, F.L.; BONOMO, R.; GOLYNSKI, A. 2012. The modern coffee planting in the Brazilian savannah. **Pesquisa Agropecuária Tropical**, Goiânia, vol. 42,

n. 2, p. 231-240. Available at: <https://doi.org/10.1590/S1983-40632012000200015>. Accessed on: Jan. 22, 2020.

GOMES, L.; SIMÕES, S.J.C.; DALLA NORA, E.L.; DE SOUSA-NETO, E.R.; FORTI, M.C.; OMETTO, J.P.H.B. 2019. Agricultural expansion in the Brazilian Cerrado: increased soil and nutrient losses and decreased agricultural productivity. **Land**, Basel, vol. 8, p. 1-26. Available at: <https://doi.org/10.3390/land8010012> Accessed on: Jun. 18, 2020.

RIBEIRO, A. C.; GUIMARAES, P. T. G.; ALVAREZ V. V. H. 1999. **Recomendações para o Uso de Corretivos e Fertilizantes em Minas Gerais** - 5º Aproximação. Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais, 359 p.

HARIDASAN, M. 2000. Nutrição mineral de plantas nativas do cerrado. **Revista Brasileira de Fisiologia Vegetal**, Lavras, vol. 12, p. 54-64. Available at: <https://files.cercomp.ufg.br/weby/up/284/o/v12n1p54.pdf> Accessed on: Apr. 12, 2020.

HARIDASAN, M. 2008. Nutritional adaptations of native plants of the Cerrado biome in acid soils. **Revista Brasileira de Fisiologia Vegetal**, Lavras, vol. 20, p. 183-195. Available at: <https://doi.org/10.1590/S1677-04202008000300003> Accessed on: Apr. 12, 2020.

HUNKE, P., MUELLER, E. N., SCHRÖDER, B., ZEILHOFER, P. 2015. The Brazilian Cerrado: assessment of water and soil degradation in catchments under intensive agricultural use. **Ecohydrology**, vol. 8, p. 1154-1180. Available at: <https://doi.org/10.1002/eco.1573> Accessed on: Jun. 15, 2020.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2004 (a) **Mapa de Vegetação do Brasil** – 3ª. Edição. Brasília: IBGE.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2004 (b) **Mapa de Biomas do Brasil** - 1ª. Aproximação. Rio de Janeiro: IBGE.

IFA - INTERNATIONAL FERTILIZER INDUSTRY ASSOCIATION. **Databases and charts**: Consumption. Available at: <https://www.ifastat.org/databases/plant-nutrition> Accessed on: Feb. 14, 2020.

LIMA, J.E.F.W. 2011. Situação e perspectivas sobre as águas do Cerrado. **Ciência e Cultura**, São Paulo, vol. 63, p. 27-29. Available at: <http://dx.doi.org/10.21800/S0009-67252011000300011> Accessed on: Jun. 18, 2020.

LIMA, L.C.; GONÇALVES, A.C.; FERNANDES, A.L.T.; SILVA, R.O.; LANA, R.M.Q. 2016. Growth and productivity of coffee irrigated according to different sources of nitrogen. **Coffee Science**, Lavras, vol. 11, n. 1, p. 97-107. Available at: <https://doi.org/10.25186/cs.v11i1.987> Accessed on: Jun. 10, 2020.

LOPES, A.S.; GUILHERME, L.R.G. 2016. A career perspective on soil management in the Cerrado Region of Brazil. **Advances in Agronomy**, vol. 137, p. 1-72. Available at: <https://doi.org/10.1016/bs.agron.2015.12.004> Accessed on: Jun. 18, 2020.

MACROTRENDS. **Crude Oil Prices**: 70 year historical chart. 2020. Available at: <https://www.macrotrends.net/1369/crude-oil-price-history-chart> Accessed on: Feb. 21, 2020.

MOREIRA, F.M.S.; SIQUEIRA, J.O. 2006. **Microbiologia e Bioquímica do Solo**. Lavras: Editora UFLA. p. 338-364.

ORTEGA, A. C. 2008. Café do Cerrado: Certificação de origem e desenvolvimento territorial rural. **VII Colóquio Ibérico de Estudos Rurais. Cultura, Inovação e Território**. Coimbra: CIER, vol. 1. p. 1-20.

ORTEGA, A.C.; JESUS, C.M. 2011.Território, certificação de procedência e a busca da singularidade: o caso do café do Cerrado. **Política & Sociedade**, vol. 10, n. 19, p. 305-330.

Available at: <https://doi.org/10.5007/2175-7984.2011v10n19p305>. Accessed on: 18 Jun. 2020.

PADILLA, F.M.; GALLARDO, M.; MANZANO-AGUGLIARO, F. 2018. Global trends in nitrate leaching research in the 1960–2017 period. **Science of the Total Environment**, vol. 643, p. 400-413. Available at: <https://doi.org/10.1016/j.scitotenv.2018.06.215> Accessed on: Apr. 10, 2020.

PINTO, V.M.; BRUNO, I.P.; VAN LIER, Q.J.; DOURADO-NETO, D.; REICHARDT, K. 2017 (a). Environmental benefits of reducing N rates for coffee in the Cerrado**. Soil & Tillage Research**, vol. 166, p. 76-83. Available at: <https://doi.org/10.1016/j.still.2016.10.006> Accessed on: Jun. 18, 2020.

PINTO, V.M.; BRUNO, I.P.; VAN LIER, Q.J.; DOURADO-NETO, D.; REICHARDT, K. 2017 (b). Excessive use of nitrogen causes monetary loss for coffee growers in the cerrado. **Coffee Science**, Lavras, vol. 12, n. 2, p. 176-186. Available at: <https://doi.org/10.25186/cs.v12i2.1205> Accessed on: Jun. 18, 2020.

SANO, E.E.; ROSA, R.; BRITO, J.L.S.; FERREIRA, L.G. 2010. Land cover mapping of the tropical savanna region in Brazil. **Environmental Monitoring and Assessment**, Dordrecht, vol. 166, p. 113-124. Available at: <https://doi.org/10.1007/s10661-009-0988-4> Accessed on: Jun. 15, 2020.

SANO, E.E.; ROSA, R.; SCARAMUZZA, C.A.M.; ADAMI, M.; BOLFE, E.L.; COUTINHO, A.C.; ESQUERDO, J.C.D.M.; MAURANO, L.E.P.; NARVAES, I.S.; OLIVEIRA FILHO, F.J.B.; SILVA, E.B.; VICTORIA, D.C.; FERREIRA, L.G.; BRITO, J.L.S.; BAYMA, A.P.; OLIVEIRA, G.H.; BAYMA-SILVA, G. 2019. Land use dynamics in the Brazilian Cerrado in the period from 2002 to 2013. **Pesquisa Agropecuária Brasileira**, Brasília, vol. 54, e00138, 2019. Available at: <http://dx.doi.org/10.1590/s1678-3921.pab2019.v54.00138> Accessed on: Jun. 10, 2020.

SHIBATA, H.; GALLOWAY, J.N.; LEACH, A.M.; CATTANEO, L.R.; NOLL, L.C.; ERISMAN, J.W.; GU, B.; LIANG, X.; HAYASHI, K.; MA, L.; DALGAARD, T.; GRAVERSGAARD, M.; CHEN, D.; NANSAI, K.; SHINDO, J.; MATSUBAE, K.; OITA, A.; SU, M.; MISHIMA, S.; BLEEKER, A. 2017. Nitrogen footprints: Regional realities and options to reduce nitrogen loss to the environment. **Ambio**, vol. 46, p. 129–142. Available at: <https://doi.org/10.1007/s13280-016-0815-4> Accessed on: Jun. 18, 2020.

SILVA, C.M. 2018. Between Fenix and Ceres: the great acceleration and the agricultural frontier in the Brazilian Cerrado. **Varia Historia**, Belo Horizonte, vol. 34, n. 65, p. 409-444. Available at: <https://doi.org/10.1590/0104-87752018000200006> Accessed on: Jun. 15, 2020.

SILVA, F. A. M.; ASSAD, E. D.; EVANGELISTA, B. A. 2008. Caracterização climática do bioma Cerrado. In: SANO, S. M.; ALMEIDA, S. P.; RIBEIRO, J. F. (Ed.). **Cerrado**: ecologia e flora. Brasília: EMBRAPA. p. 71-88.

SEI - SUPERINTENDÊNCIA DE ESTUDOS ECONÔMICOS E SOCIAIS DA BAHIA. 2009. **Estatística dos municípios baianos**: vol. 3 – Território de Identidade Oeste Baiano. Salvador: SEI. 270 p. Available at: <https://www.sei.ba.gov.br/index.php?option=com_content&view=article&id=2441&Itemid=284> Accessed on: Jan. 19, 2020.

TÔSTO, K.L.; PACHECO, F.S.; GOMES, L.; MIRANDA, M.; OLIVEIRA, S.M.L.; PESSI, D.D.; COX, C.; OMETTO, J.P.H.B. 2019. Nitrogen use efficiency: a local and regional approach for Brazilian agriculture. **Revista Ra'e Ga**, vol. 46, n. 3, p. 125 - 139. Available at: <http://dx.doi.org/10.5380/raega.v46i3.67095> Accessed on: Jun. 18, 2020.

VOLSI, B.; TELLES, T.S.; CALDARELLI, C.E.; CAMARA, M.R.G.D. 2019. The dynamics of coffee production in Brazil. **PLoS One,** vol. 14, n. 7, e0219742. Available at: <https://doi.org/10.1371/journal.pone.0219742>. Accessed on: Jun. 18, 2020.

Received in: June 18, 2020
Accepted in: August 1, 2020