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GREENHOUSE GAS EMISSIONS IN BRAZILIAN COFFEE PRODUCTION

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1 INTRODUCTION

Coffee is one of the most important productive chains in the Brazilian agribusiness, as it generates foreign exchange and economic development. Brazil is the world's largest producer and exporter of coffee and the second largest consumer market of coffee. In 2017, coffee ranked fifth on the export agenda, made US $ 5.2 billion and created about 8 million direct and indirect jobs in Brazil (MAPA, 2017).

The most produced coffee species in Brazil are *Coffea arabica* and *Coffea canephora*. The states of Minas Gerais, São Paulo, Espírito Santo, Bahia and Paraná are the main producers and represent 98.27% of the national production of *C. arabica* (CONAB, 2017). The state of Minas Gerais account for 70.56% of this production. *C. Canephora*'s largest growing areas are in the states of Espírito Santo, Bahia and Rondônia, which account for 58.38%, 22.23% and 18.11% of production, respectively (CONAB, 2017).

As Brazil is the largest producer and exporter of coffee and the second largest consumer market in the world. Brazilian coffee ranks fifth in Brazilian exports. Given the relevance of the coffee production chain, there are several discussions about greenhouse gas emissions (GHG) in the sector and their impacts on climate change. GHG emissions inventories are necessary to create emission mitigation strategies, as well as to improve the relations of stakeholders with the various stages of the chain.

2 RESEARCH PROBLEM AND OBJECTIVE

The production of Arabica emitted about 1.40 million tons of CO2e. This represented 70% of total GHG emissions in the Brazilian coffee production. Therefore, the question of this research is how does temperature, rainfall, altitude, soil characteristics, tree species and shade density could impact GHG emissions? And also, could be possible to measure then to be proposed to improve coffee production and minimize GHG emissions?

Considering the importance of the coffee production chain in Brazilian socioeconomics and its GHG emissions, this study aimed to estimate the GHG emissions in the Brazilian Arabica coffee-beans production and to verify how more efficient management techniques can avoid these emissions during the crop production in crop year. It is based on the premise that the quantification of emissions (expressed in CO2 equivalent) can make it possible to choose realistic mitigation targets and allow a worldwide standard of comparison.

3 THEORETICAL FRAMEWORK

The cultivation of coffee, like any other agricultural crop, emits greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Maina et al.; 2015). Among the sectors that emit more GHG (Noponen et al., 2013), Brazilian agriculture emits about 7.5 million tons (SEEG, 2016).

From the 1970s, nontrivial changes have continuously occurred in rainfall regimes and in the processes of desertification, which have directly increased GHG emissions (Mora et al., 2018; IPCC, 2006; Tzilivakis et al., 2005). Climate change is of concern to the international community (IPCC, 2006; Tzilivakis et al., 2005), affecting agricultural activity and altering the growing areas of various crops (Maina et al., 2016). Therefore, many of the GHG emissions result from anthropogenic actions that directly increase global temperature, alter the global climate, and interfere with the entire life cycle on Earth (Montzka et al.,2011; Mora et al.,2018).

The demand for sustainable produced coffee has increased among industries and consumer markets in recent decades (Maina et al., 2016, ABNT NBR ISSO 14064, 2015). The coffee production chain considers environmental issues a great deal and seeks clean production systems that respect the environment (Maina et al., 2016).

Achieving the goal of halting 2°C from rising temperatures and minimizing the effects of climate change necessarily means reducing GHG emissions (GHG Protocol, 2010, Smith et al., 2007). In this context, GHG emissions inventories are required in all agricultural production systems. Particularly in coffee cultivation, efficient production and management techniques can make the production chain more sustainable throughout the product cycle (Relatório Internacional de Tendências do Café, 2017).

Considering the importance of the coffee production chain in Brazilian socioeconomics and its GHG emissions, this study aimed to estimate the GHG emissions in the Brazilian Arabica coffee-beans production and to verify how more efficient management techniques can avoid these emissions during the crop production in crop year. It is based on the premise that the quantification of emissions (expressed in CO_2 equivalent) can make it possible to choose realistic mitigation targets and allow a worldwide standard of comparison (Montzka et al., 2011).

4 METHODOLOGY

This study used the data provided by the *Campo Futuro* project for inventories of coffee production. The project partners with the Confederation of Agriculture and Livestock of Brazil (CNA), the National Rural Apprenticeship Service (SENAR) and the Market Intelligence Center (CIM) of the Federal University of Lavras.

Delphi Methodology was used to collect data information with the coffee farms. The methodology consists of meetings with farmers and rural workers who provide information on crop management, harvesting and post-harvesting, general expenses, financial values, costing interest and inventory.

The properties chosen for this study were the most representative of each region in terms of areas of cultivation, productivity, inputs and machinery. Data collection was performed using the ABC costing and operational cost methods proposed by Matsunaga et al. (1976).

In 2017, production costs of Arabica were collected in 10 representative municipalities (Apucarana / PR, Brejetuba / ES, Caconde / SP, Capelinha / MG, Franca / MG, Guaxupé / MG, Luís Eduardo Magalhães / BA, Manhumirim / MG, Monte Carmelo / MG and Santa Rita do Sapucaí / MG). In Brazil, the state of Minas Gerais is the largest producer of Arabica (*Sul de Minas, Cerrado, Triangulo Mineiro and Zona da Mata*), followed by São Paulo (*Mogiana and Centro Oeste Paulista*), Paraná (*Norte Pioneiro*), Bahia (*Planalto and Cerrado*), Espírito Santo and Rondônia.

The CO_2 emission per sck of coffee (60 kg dry and with 12% humidity) produced in the 2017 and 2016 harvest was used as a functional unit to standardize a GHG measurement. The parameters used in the comparison considered the productive phase of the coffee plantations (e.i. pre-planting, planting and initial phase of cultivation were not considered). Only the productive phase of the plant was considered. Thus, a comparison parameter was obtained for the emissions during a crop year.

Among the possible environmental impacts inherent to coffee cultivation, we chose to evaluate the Global Warming Potential, which consists of the sum of all GHGs emitted (CO_2, CH_4 and N_2O) converted into carbon dioxide equivalent (CO_2e) per sck (60kg) of coffee produced in a crop year. Global Warming Potential (GWP) was used for 100 years according to the time horizons of the Intergovernmental Panel on Climate Change (IPCC) Assessment

Report 5 (AR5) (Myhre et al., 2013) to facilitate the comparison of results with other studies (Florindo et al., 2017) (Table 2).

The estimated GHG emission equations used in this study were developed based on the IPCC methodology described in 2006 in the IPCC Assessment Reports and in the agriculture methodology of the Green House Gas Protocol (GHG Protocol, 2014).

The emissions of CO_2, CH_4 and N_2O related to coffee production systems were considered in the calculations. The values were converted into kilograms of carbon dioxide equivalent (CO_2e) in the defined functional unit. The emissions were estimated based on data from modal farms and aid from equations and emission factors provided by the IPCC (IPCC, 2006).

The addition of calcitic limestone ($CaCO_3$) or dolomitic limestone ($CaMg\ (CO_3)_2$) to the soil cultivated with coffee leads to the emission of carbon dioxide (CO_2) (Raij et al., 1985). In soils cultivated with coffee, liming is applied to correct the acidity caused by nitrogen fertilizations (Guimarães and Lopes, 1986).

The original equation proposed by the IPCC (2006) considers the calcitic and dolomitic carbonates for the calculation of emissions from the liming practice. However, only dolomitic limestone was observed in Brazilian plantations through panel-type surveys with the modal properties. Therefore, the original equation was adequate to this reality (*Eq. 1)* (Table 1).

The emission of CO_2 from urea applications is described by *Eq. 2* (Table 1). When applied to the soil, urea is converted to ammonium (NH_4^+), hydroxyl ion (OH^-) and bicarbonate (HCO_3^-). The CO_2 is lost in the industrial production process. The bicarbonate is transformed into CO_2 and H_2O like liming in soils (IPCC, 2006). Subsequently, this product can react with H^+ ions resulting in CO_2. The enzyme urease also acts on the hydrolysis of urea, producing ammonium carbonate ($(NH_4)_2CO_3$). It then converts to ammonia and CO_2, both released into the atmosphere (Oliveira, 2015).

The emission of N_2O according to IPCC (2006) comes from synthetic nitrogen fertilizers, organic fertilizers, crop residues and nitrogen mineralization and is associated with land use change and management. Synthetic and organic nitrogen fertilizers were considered. No emissions from crop residues or mineralization were considered.

Table 1 - Equations used to calculate CO_2e emissions and description of variables

Equations used for calculations	Description of the variables of the equations
Emission of CO_2 from the application of limestone: *(Eq.1)* $CO_2=(M_{Dolomític}*EF_{Dolomític}*(44/12)$	Where: $M_{Dolomític}$= quantity of dolomitic limestone applied to the soil (tons); $EF_{Dolomític}$= standard emission factor for dolomitic limestone (0.13 according to IPCC 2006); *(44/12)*= conversion of C into CO_2
Emission of CO_2 from the application of Urea: *(Eq2):* $CO_2e=(MUrea*EFUrea)*(44/12)$	Where: CO_2= direct CO2 emissions in tons of CO_2 (tCO_2); *MUrea*= amount of urea applied to soil (tons); *EFUrea*= standard emission factor for urea (0.20 according to IPCC 2006); *(44/12)*= conversion of C into CO_2
Emission of CO_2e from the application of synthetic nitrogen fertilizers: *(Eq.3):* $CO_2e=(F_{SN}*EF_1*(44/28)*298$	Where: CO_2e= direct emissions of N_2O in tons of CO_2e (tCO_2e); F_{SN} = amount of synthetic nitrogen applied to the soil (tons); EF_1= standard emission factor for nitrogen applied to soil (0.01 according to IPCC 2006); *(44/28)*= conversion of N into N_2O; *298*= global warming potential of N_2O over CO_2
Emission of CO_2e from the application of organic fertilizers: *(Eq.4):* $CO_2e=(F_{ON}*EF_1)*(44/28)*298$	Where: CO_2e = direct emissions of N_2O in tons of CO_2e (tCO_2e); F_{ON} = amount of organic nitrogen applied to the soil (tons); EF_1 = standard emission factor for nitrogen applied to soil *(44/28)* = conversion of N into N_2O; *298* = global warming potential of N_2O over CO_2

Emission of CO_2e from the use of pesticides: *(Eq5):* $CO_2e=(QHerbicide*EFHerbicide)+(QInsecticide*EFInsecticide)+(QFungicide*EFFungicide)$	Where: *CO_2e* = direct GHG emissions in tons of CO_2e (tCO_2e);*QHerbicide*=amount of applied herbicides (tons); *QInseticid2*= Amount of insecticides applied (tons); *QFungicide*= Amount of applied fungicides (tones); *EFHerbicide*= emission factor for applied herbicides; *EFInseticide*= emission factor for applied insecticides; *EFFungicide*= emission factor for applied fungicides.
Emission of CO_2e from mechanized operations: *(Eq.6)*: $CO_2e=H*HP*0,12*[0,92*(EFCO_2Diesel+EFCH4Diesel+EFN2ODiesel)+0,08*EFCO2Biodiesel]$	Where: *CO_2e*= direct GHG emissions, in kilograms of CO_2e ($kgCO_2e$); *H*= operating time, in hours; *HP*= engine power in horsepower (hp); *0,92*= percentage of diesel in diesel marketed in Brazil; *$EFCO_2Diesel$*= CO_2 emission factor for diesel; *$EFCH_4Diesel$*= CH_4 emission factor for diesel; *$EFN_2ODiesel$*= N_2O emission factor for diesel; *0,08*= percentage of biodiesel in diesel oil marketed in Brazil; *$EFCO_2Biodiesel$*= CO_2 emission factor for biodiesel.

Source: Prepared by the authors based on the IPCC (2006); GHG Protocol (2014).

The *Eq.3* (Table 1) was used to calculate the emissions of synthetic nitrogen fertilizers. The role of synthetic nitrogen fertilizers is to provide nutrients to plants. Nitrogen fertilization can increase up to 30% the production of coffee in traditional areas of cultivation (Sanzonowicz et al.,2003).

In coffee cultivation, synthetic nitrogen plays important roles in photosynthetic activity, leaf area expansion, vegetative growth and flower bud formation (Cerri, 2009). Nitrogen uptake by plants occurs in the form of ammonium (NH_4^+) and nitrate (NO_3^-) (Carmo et al., 2005). The most common forms of N_2O emission occur via denitrification (reaction carried out by anaerobic bacteria) (Giacomini, 2005)[1] and within soil pores occupied by water and atmospheric temperature[2] (Jantalia et al., 2006). In the agricultural sector, nitrous oxide (N_2O) accounts for approximately 87.2% of the emissions into the atmosphere (Cerri et al.,2009).

Organic fertilizers are waste from animals, plants, agroindustry or others. They are commonly applied to the soil to increase the availability of plant nutrients and increase crop productivity (CFSEMG, 1999). The *Eq.4* was used to calculate CO2e from organic fertilizer applications.

During coffee cultivation, it is recommended to apply organic fertilizers to the soil during periods of higher demand for nutrients. It should be noted that incorrect applications disregarding the oxidation rate of ammoniacal nitrogen ($N\text{-}NH_4^+$) in nitrate ($N\text{-}NO_3^-$) result in losses of nitrogen by leaching or volatilization (Minogue et al., 2012) and thus the emission of N_2O increases.

Estimated GHG emissions from pesticide use are related to indirect emissions. Emission factors used to calculate emissions from pesticide use are shown in Table 2.

Table 2 - Emission factors for the use of pesticides.

Pesticide	Emission factor (kg CO_2e / kg product)
Herbicide	10,26
Inseticide	16,68
Fungicide	10,11

Source: Ecoinvent DataBase (2017); GHG Protocol (2014).

The emission of GHG from pesticides is related to the production and transport of the pesticides and can be calculated with *Eq.5* (Table 1). This phase counts the total carbon dioxide emitted directly or indirectly by an activity or accumulated during the life stages of a product (Wiedmann and Minx 2008).

The sources of GHG emissions are the automotive equipment or machines used in rural properties, such as tractors, harvesters and others. These sources emit carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The quantities emitted depend on the type of equipment or machinery used and the composition of the fuels they use (GHG PROTOCOL, 2014).

Fuel consumption may vary depending on the machinery used, its conditions, operator and type of work (Molin and Milan, 2002). The calculation of GHG emissions from the consumption of diesel oil eliminates the need to regionalize mechanized operations (GHG PROTOCOL, 2014). The emission factors used in this study are presented in Table 3.

According to Law No. 13,263 of March 23, 2016, the mandatory percentage of biodiesel added to diesel sold anywhere in the country corresponds to 8% of the total fuel volume (Brasil, 2016).

The fuel consumption of an automotive engine is obtained by multiplying the net power of the engine by the factor 0.163 L kW^{-1} h^{-1} used in diesel engines. The value of 0.12 L cv^{-1} h^{-1} was obtained by converting the factor to use horsepower (hp) in the calculation. Thus, GHG emissions from mechanized operations can be estimated by *Eq. 6* (Molin and Milan, 2002).

Table 3 - Emission factors for the consumption of diesel oil in mechanized operations

Fuel	Emission factor (kg CO_2/L)		
	CO_2	CH_4	N_2O
Diesel	2,681	0,0003	0,00002
Biodiesel	2,499	-	-

Source: Brazilian Program GHG Protocol (2014); IPCC (2006).

Noponen et al. (2013) suggest the management of inputs in coffee cultivation is likely to be altered. The variation in inputs and outputs of nutrients such as Nitrogen (N) may be indicative of sustainability and efficiency in coffee plantations.

The ideal amount of N required to produce a sack of coffee and to keep the plant in its vegetation state is 6.2 kg per sack per hectare (Favarin et al.; 2013). It is observed that the nitrogen applications overstepped the nutritional needs of the coffee plantations in all the regions studied in the years 2016 and 2017. It is also observed that N waste ranged from 1.5 kg / sck to 2.95 kg / sck in the analyzed regions (Figure 5).

Emissions from the production of Arabica were calculated in the modal regions. Then, the emissions were extrapolated to producing regions of Brazil. Information from Luis Eduardo (Table 4).

Table 4 - Regions and municipalities used to represent the CO_2e emissions to calculate the total Brazilian emissions

Brazilian Regions	Municipalities considered for calculation of CO_2e in Brazil
Northeast (BA)	Luís Eduardo Magalhães/BA
Midwest (MT and MS)	Monte Carmelo/MG
South	Apucarana/PR
Southeast (MG)	
South of Minas	Média (Guaxupé/MG + Santa Rita do Sapucaí/MG)
Cerrado	Monte Carmelo/MG
Wood zone (Zona da Mata)	Manhumirim/MG
North	Capelinha/MG
Southeast	Brejetuba/ES
Southeast (RJ)	Manhumirim/MG
Southeast (SP)	Média (Franca/SP + Caconde/SP)
Others (*)	Average Emissions

Source: Elaborated by the authors based on the CONAB (2018).

Coffee farms can achieve "carbon-neutral" or even "carbon-negative" status throughout their productive life cycle. However, other variables such as temperature, precipitation, altitude, soil properties, cultivated species, shading and management also influence the carbon emissions in the coffee areas (Maina et al., 2015; Noponen et al.; 2013).

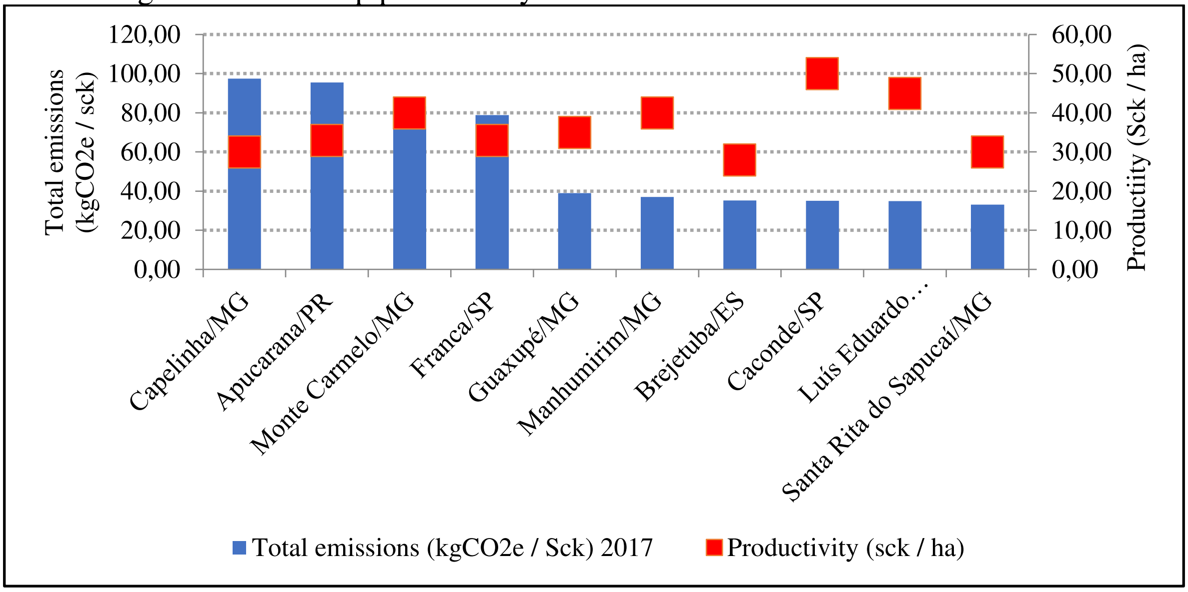
Through the methodology described and based on the information presented in this work, we identified the main sources of GHG emissions in coffee cultivation. With them, the calculation of emissions was carried out considering appropriate forms of nitrogen fertilization and management, according to technical and scientific recommendations. With an adequate management of the coffee, it was possible to estimate the Brazilian emissions avoided in the 2016/2017 harvest.

5 RESULTS AND DISCUSSION

Identifying the agricultural practices that emit most GHG is essential to design alternatives that mitigate the effects of GHG on climate change (Maina et al., 2016; Relatório Internacional de Tendências do Café, 2017).

Estimates of GHG emissions for *C. Arabica* on representative properties are presented in Figure 2. The municipalities of Brejetuba /ES (48.69 kgCO_2e / sck), Luis Eduardo Magalhães / BA (48.91 kgCO_2e / sck) and Manhumirim / MG (50.13 kgCO_2e / sck) presented the lowest levels of GHG emissions. Capelinha farms were the ones that emitted most GHG (97.50 kgCO_2e / sck), followed by the farms in Apucarana / PR (86.61 kgCO_2e / sck) and Franca / SP (78.84 kgCO_2e / sck). The results suggest that gains in productivity can reduce GHG emissions per unit produced, suggesting greater efficiency in the crop (Figure 2).

Figure 2 - Emissions (kgCO_2e / sck) of the municipalities chosen for *Coffea arabica* considering the level of crop productivity in 2017.



Source: Elaborated by the authors based on data of Campo Futuro (2017)

It should be noted that the biennial coffee cycle[3] is an important productivity issue and affects coffee production in Brazil. For that reason, the year 2017 presented a production 21% lower than the year 2016. Brazil produced 37.4 million sacks of Arabica in 2017 and 43.3 million sacks in 2016 (Figure 3). In years of low production volume (negative biennial cycle) there is a lower volume of GHG emissions. In 2017, the production of Arabica emitted 2.01

million tons of CO_2e. According to the Greenhouse Gas Emission and Removal Estimation System, in 2017 the emissions levels of agriculture were 71.5 million tons of CO_2e. In relative terms, this means that Arabica production contributed 2.81% of GHG emissions in Brazilian agriculture in 2017 (Figure 3).

In 2016, a year of high production volume (positive biennial cycle), the Arabica cultivation emitted 2.70 million tons of CO_2e. According to Greenhouse Gas Emission and Removal Estimation System (2017), the emissions levels of agriculture in 2016 were 68.7 million tons of CO_2e. This means a contribution of 3.93% of the emissions to Brazilian agriculture. The negative biennial cycle implies a reduction of CO_2e emissions by 25.5% from 2016 to 2017 (Figure 3).

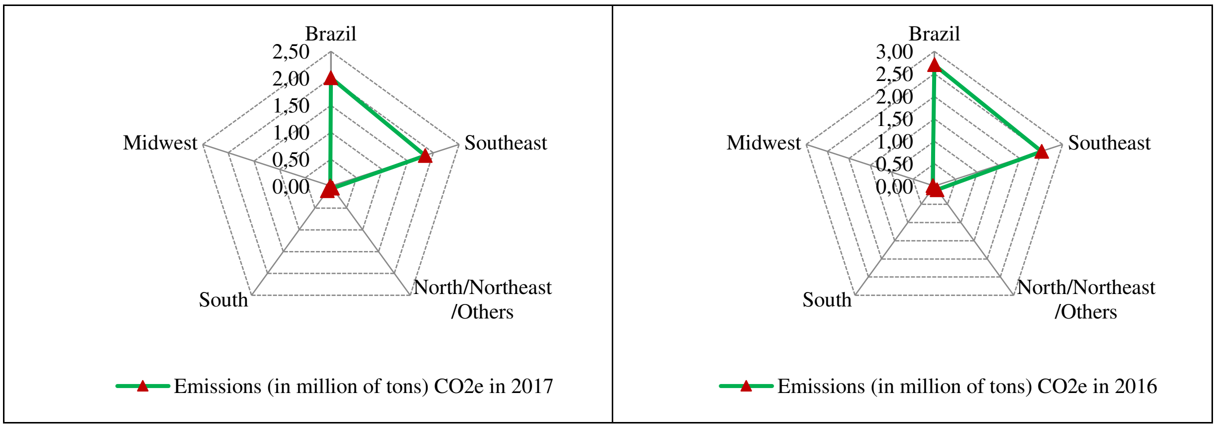
The contribution of coffee cultivation to GHG emissions is small compared to other agricultural activities. In addition, coffee cultivation is a perennial production system with many trees. Therefore, coffee cultivation has the potential to sequester and store large amounts of GHG (Kandji et al., 2006; Mutuo et al., 2005; Soto-Pinto et al., 2010; Noponen et al.; 2013).

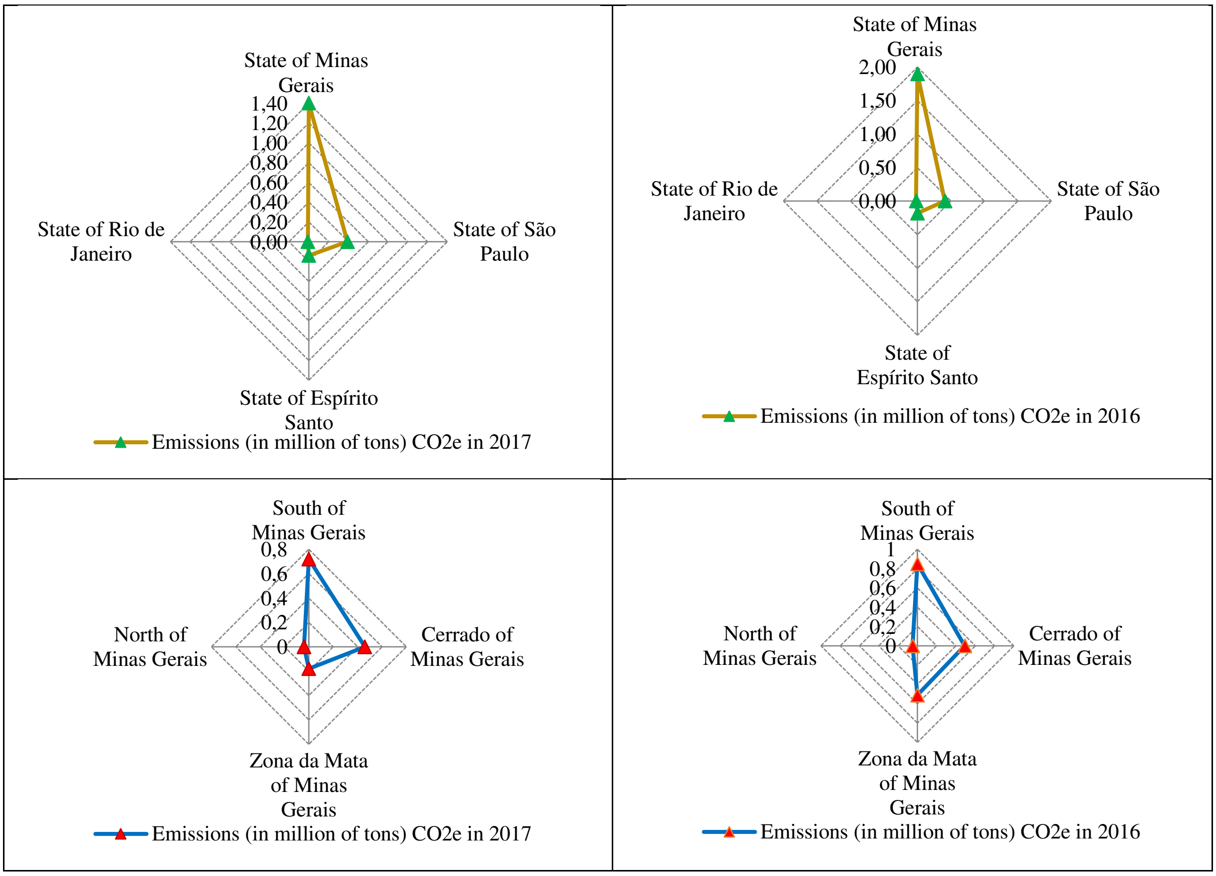
The Southeast region is the main producer of Arabica in Brazil (92.89%) and accounted for the largest volume of emissions. In 2017, this region emitted 1.84 million tons of CO_2e, which represented 91.5% of total GHG emissions in coffee cultivation. In 2016, Southeast Brazil emitted 2.51 million tons of CO_2e due the positive biennial cycle (Figure 4). Other Brazilian coffee regions showed much lower emissions.

In Southeast Brazil, Minas Gerais is the main producer state and the largest GHG emitter. In 2107, the state emitted about 1.40 million tons of CO_2e only in Arabica cultivation. This value represented 70% of total GHG emissions in Arabica's Brazilian production. In 2016, the volume of emissions was higher due to the positive biennial cycle.

The largest volume of emissions (0.72 million tons of CO_2e) was verified in the south of Minas Gerais, which accounted for 35.8% of total GHG emissions in Arabica's Brazilian production. Zona da Mata is also representative in GHG emissions and accounted for 0.46 million tons of CO_2e. This volume represented 32.8% of total GHG emissions in Arabica's Minas Gerais production and 22.9% in Arabica's Brazilian production.

Figure 3 - Total emissions of CO_2e (million tons) in Brazil, Brazilian regions and Minas Gerais in 2017 and 2016.





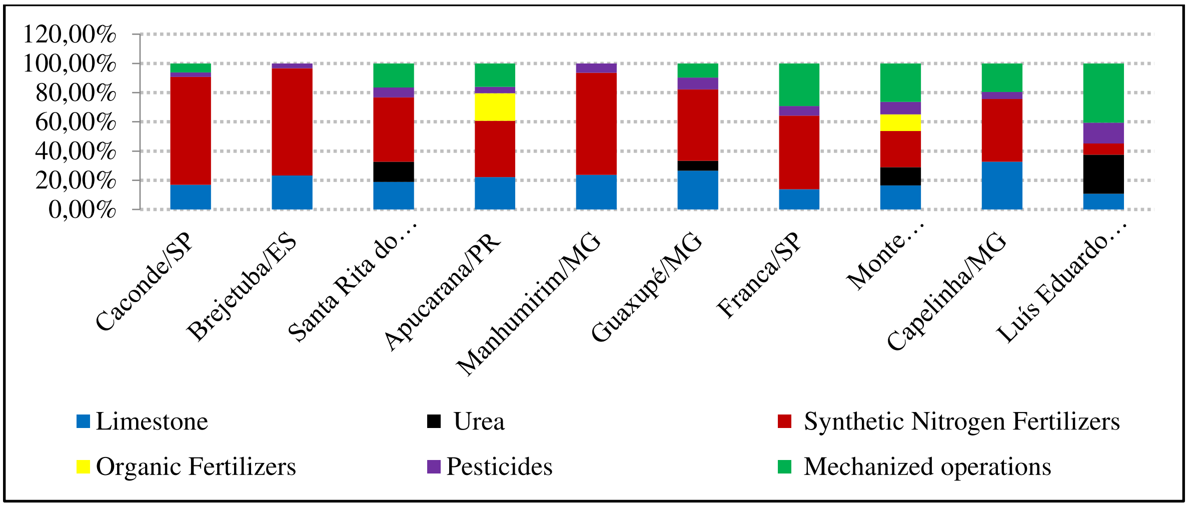
Source: Prepared by the authors based on data from Campo Futuro (2017) and CONAB (2017).

The Figure 4 shows the contribution of each source of GHG emission in coffee cultivation. The GHG emissions from synthetic nitrogen fertilization represent 46% of the total. This input is used in all coffee regions analyzed in this study. In Caconde / SP (73.83%), Brejetuda / ES (73.30%) and Manumirim / MG (69.78%) synthetic nitrogen fertilization is responsible for most GHG emissions.

Liming is used to correct soil acidity in all coffee regions analyzed in this study. This practice was responsible for 21% of the total GHG emissions. Capelinha/MG (32.59%), Guaxupé/MG (26.48%) and Manhumirim/MG (23.77%) showed the largest GHG emission in liming practice. Among all analyzed regions, Capelinha/MG (31.78 $kgCO_2e$/sck) showed the largest GHG emission while Luís Eduardo Magalhães/BA (5.30 $kgCO_2e$/sck) showed the smallest GHG emission in liming practice (Figure 4).

The use of soil acidity correctives is important in Brazilian soils, which undergo intensive nutrient leaching, removal of cationic nutrients and use of fertilizers. Emissions due to organic fertilization were observed only in Apucarana/PR (16.40 $kgCO_2e$/sck) and Monte Carmelo/MG (8.33 $kgCO_2e$/sck). Emissions due to urea fertilization accounted for 5.2% of the total. Luís Eduardo Magalhães/BA (13.04 $kgCO_2e$/sck) was the major emitter, followed by Monte Carmelo/MG (9.17 $kgCO_2e$/sck), Santa Rita do Sapucaí/MG (8.56 $kgCO_2e$/sck) and Guaxupé/MG (3.56 $kgCO_2e$/sck) (Figure 4).

Figure 4 - Contribution (%) of GHG emission sources from *Coffea Arabica* production in the main coffee producing regions in Brazil



Source: Elaborated by the authors based on data from Campo Futuro (2017).

Mechanized operations represent 18% of the total GHG emissions and are present in almost all regions, except Brejetuba/ES and Manhumirim/MG (Figure 4). Pesticides contribute to 6.2% of the GHG emissions and are applied in all regions analyzed in this study. This agricultural input is indispensable to control pests, diseases and weeds. Organic fertilizers accounted for 3.79% of the total GHG emissions (Figure 4).

Among fertilizers, nitrogen fertilizers are mainly responsible for GHG emissions in coffee cultivation, since they release nitrous oxide (N_2O) into the atmosphere. According to PNUMA (2017), nitrous oxide causes a thermal absorption in the Earth's surface with high heat retention in atmosphere (about 300 times greater than CO_2). It contributes to the greenhouse effect that increases global temperatures, with a direct impact on Earth's climate change.

In 2015, the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) aimed at containing the increase in global averages by 2100 to below 2° C (pre-industrial levels). Any increase in temperature above 2°C can cause dangerous and unpredictable impacts to mankind, ecosystems and agricultural systems (Mora et al., 2018; Easterling et al., 2007).

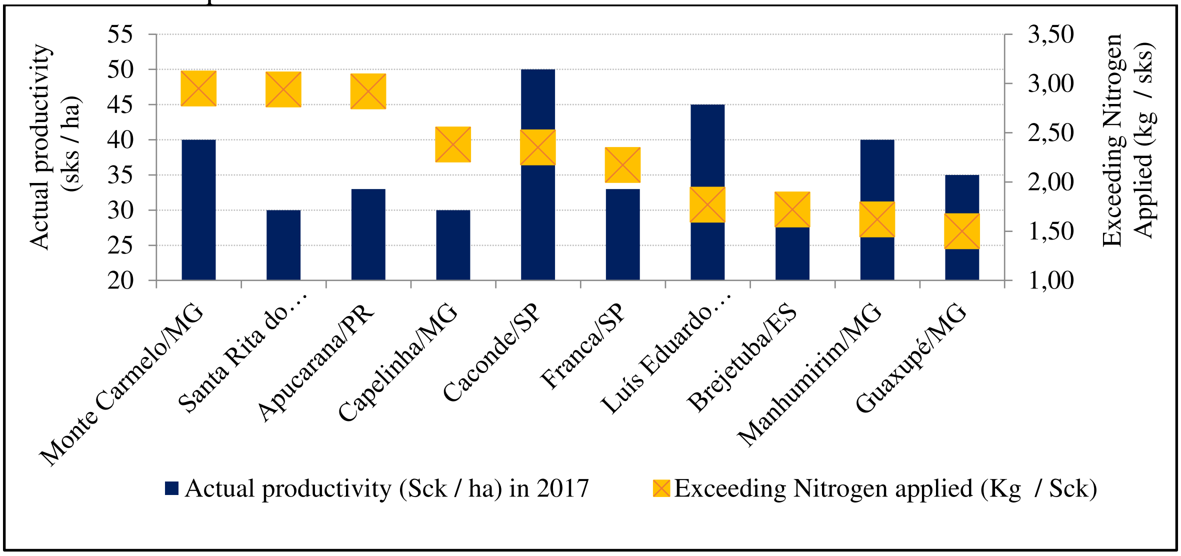
In this sense, coffee cultivation can become a neutral-carbon or even negative-carbon activity throughout its productive cycle, contributing to the mitigation of GHG emissions (Noponen et al.; 2013). In addition, the supply of environmentally friendly coffee is attractive to the industry as it can provide increased sales and greater profitability at key supply chain links (Giovannucci and Koekoek, 2003).

Therefore, sustainable coffee production and biodiversity conservation can support each other in providing ecosystem services to farmers and society (Souza et al., 2012). For this to occur, other variables should be considered, such as temperature, precipitation, altitude, soil properties, tree species, shade density, and input management (Noponen et al.; 2013).

The results showed that nitrogen fertilizers were the main responsible for GHG emissions in coffee production. Therefore, proper management and application of adequate nitrogen fertilizers are key practices for sustainable development, which can help reduce emissions and their impacts on climate change (Noponen et al.; 2013).

The excess of N applied may be related to the low nutrient utilization by plants because of volatilization losses (Favarin et al.; 2013). The excess of N in agriculture has direct impacts on GHG emissions, since it raises the level of emissions and potentiates Global Warming. Effects of changing nitrogen management were verified in Figure 5.

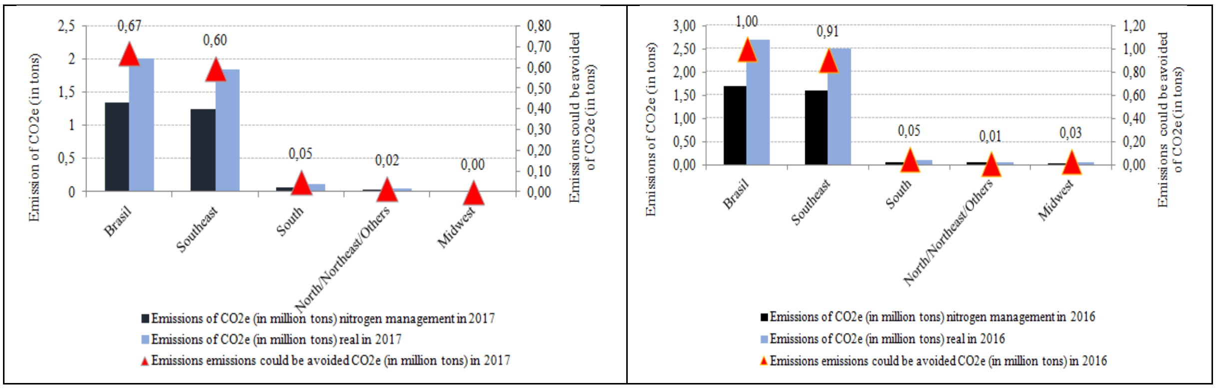
Figure 5 - Nitrogen (N) excess applied (Kg/sacks) in relation to productivity identified in Brazilian coffee production in 2017/2016.

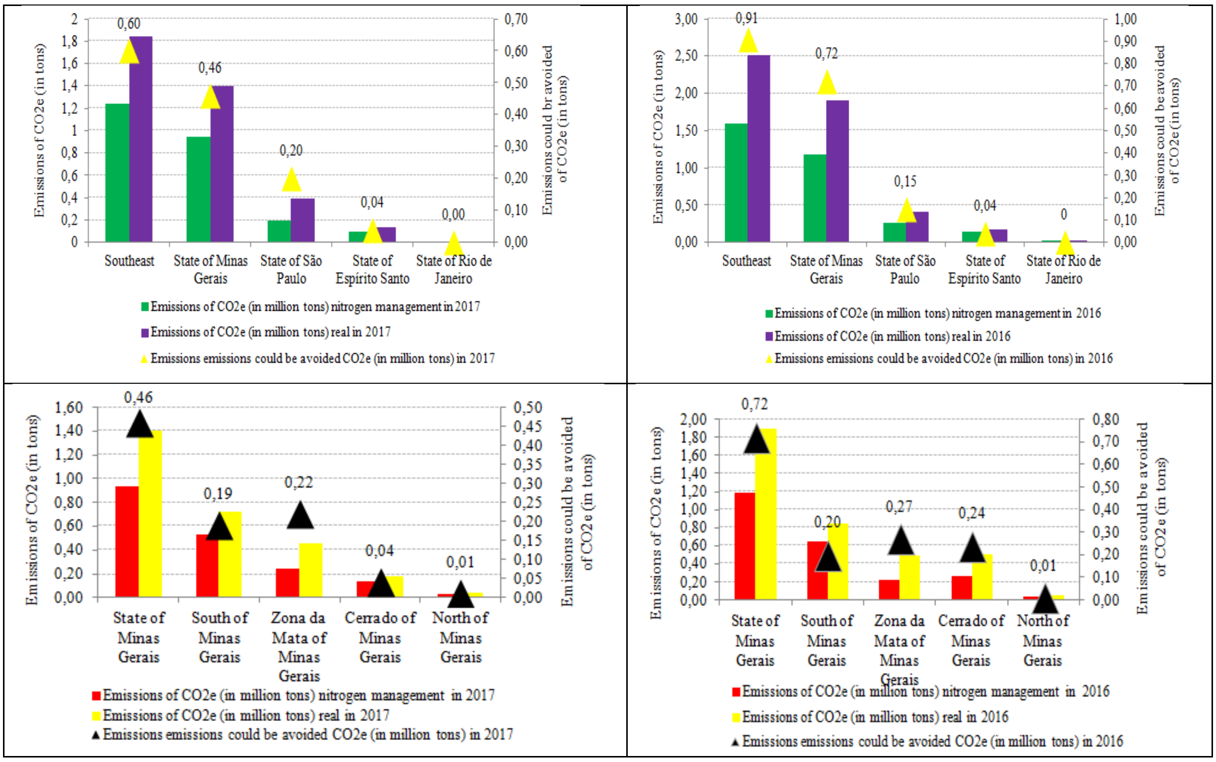


Source: Prepared by the authors based on data from Future Field (2017).

By 2017 (negative biennial cycle), 0.67 million tons of GHG emissions could be avoided only with the change in nitrogen management. In the Southeast of Brazil (region with the largest coffee production and GHG emission), about 0.60 million tons of GHG emissions could be avoided by adopting adequate nitrogen management. In 2016 (positive biennial cycle), 1 million tons of avoidable GHG emissions were verified. GHG emissions in coffee production and impacts on global climate change would be even smaller if nitrogen management were changed and the recommended doses of nitrogen fertilizers were adopted (Figure 6).

Figure 6 - Simulations of GHG emissions (millions of tons) that could be avoided in *Coffea Arabica* production due to changes in nitrogen fertilizer application management. Brazil, Brazilian regions, states and major producing regions. 2016-2017 harvest.





Source: Prepared by the authors based on data from Campo Futuro (2017) and CONAB (2017).

Southeastern Brazil, the region with the largest coffee production, could have avoided the emission of 0.60 million tons of GHG in 2017 and 0.91 million tons of GHG in 2016. Southeastern Brazil corresponds to 90% of the levels of GHG emissions verified in Brazilian coffee production. Two years of analysis demonstrate a possible 32% reduction in emissions.

In southeastern Brazil, the state of Minas Gerais is the largest producer of coffee and therefore contributes to the highest levels of GHG emissions. In coffee production in Minas Gerais, emissions of 0.72 and 0.46 million tons of GHG could be avoided in 2016 and 2017, respectively. Only Minas Gerais could reduce almost 70% of total emissions. It can be observed that the south of Minas Gerais and Zona da Mata can contribute significantly to the reduction of GHG emissions.

Brazilian coffee cultivation presents the worst rates of efficiency in the use of nitrogen (Cunha et al.; 2016). In addition to the immobilization of nitrogen by soil microorganisms, 30-70% of the amount of nitrogen applied in coffee plantations is lost. Improving nitrogen management to minimize volatility and losses in periods of rain is essential. The use of densification in coffee plantation can help the recovery of volatilized nitrogen through foliar absorption, reducing emissions significantly (Favarin et al.; 2013).

6 CONCLUSION AND CONTRIBUTION

This study aimed to estimate GHG emissions in the production of arabica coffee and to verify how changes in management can reduce GHG emissions in coffee plantations.

Based on GHG emission values for the various coffee producing regions in Brazil, it was possible to calculate total GHG emissions in Brazilian coffee production. In 2017, a negative biennial cycle of arabica coffee, the production emitted 2.01 million tons of CO_2e, representing 2.81% of total GHG emissions in Brazilian agriculture. In 2016, a positive biennial cycle of Arabica coffee, the production emitted 2.70 million tons of CO_2e, representing 3.93% of total GHG emissions in Brazilian agriculture. It is observed that the negative biennial cycle implied a 25.5% reduction in total GHG emissions in the coffee plantations of the studied regions.

The largest production of Brazilian coffee is in the state of Minas Gerais, where the largest volume of GHG in coffee cultivation is emitted. In 2017, the production of Arabica emitted about 1.40 million tons of CO_2e. This represented 70% of total GHG emissions in the Brazilian coffee production.

Most GHG emissions in coffee cultivation come from the application of synthetic nitrogen fertilizers. They accounted for 46% of total emissions in coffee cultivation.

In this way, it is possible to elaborate emission mitigation strategies through the adequate management of nitrogen fertilization. The ideal amount of N required to maintain the productive and vegetative states of coffee plants is 6.2 kg per sack per hectare. However, in 2016 and 2017, the amount of nitrogen applied to coffee plantations exceeded the nutritional needs of plants. If nitrogen fertilization followed the recommended doses, 0.67 million tons of GHG emissions would be avoided in 2017 (negative biennial Arabica coffee cycle). Likewise, 1 million tons of GHG emissions would be avoided in 2016 (positive biennial cycle of Arabica coffee). This result suggests a possibility of reducing the impact of emissions from coffee cultivation on global climate change.

Possible approaches for future research would be to investigate how temperature, rainfall, altitude, soil characteristics, tree species and shade density could impact GHG emissions. Alternative measures could then be proposed to improve coffee production and minimize GHG emissions.

NOTES

[1] Nitrification occurs in aerobic conditions and is directly related to the supply of $N\text{-}NH_4^+$, originating from the biological oxidation of nitrogen by autotrophic bacteria (nitrosomonas and nitrobacter). The main product of this reaction is $N\text{-}NO_3^-$ (Baggs and Philippot, 2010).

[2] When the proportion of pores filled by water is 35 to 60%, there is the formation of N_2O as a by-product of nitrification. Above 70%, the higher anaerobic conditions favor denitrification and consequently increase N_2O emission.

[3] The coffee has high productivity in one crop and low in the next, alternating biannually. In the year of greatest production, the plant sends energy to fruiting and there is not enough energy left to form leaves and branches. In the next harvest, the plant enters the vegetative phase, sending energy to the formation of leaves and branches. At this stage the productivity of the plant decreases.

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