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Diesel Consumption and CO_2 Emissions in Agricultural Crops: An Estimation Model and a Forestry-Based Neutralization Proposal

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Abstract: This research presented a mathematical model to calculate the consumption of diesel oil and the respective emissions of CO_2 from 41 agricultural crops (38 permanent and 3 temporary) in Brazil. It contains data obtained between 2000 and 2012, from accredited bibliographic sources. In addition to spreadsheets containing diesel consumption, resulting from the analysis of the productive processes, this research presents data on energy conversion and forest development used to subsidize CO_2 emissions and mitigation options. Specifically for C sequestration of the atmosphere, four options of forest projects were systematized: (1) reforestation with fast growing species; (2) forest protection projects, with enrichment plantations; (3) implementation of agroforestry systems (1st cycle); and (4) urban afforestation projects (streets and parks). Such alternatives are in line with the proposals of the "sectorial plan for mitigation and adaptation to climate change for the consolidation of a low C emission in agriculture", of the Brazilian Agricultural Research Corporation (EMBRAPA). The results show that three temporary products (soybean, sugarcane and cotton) are responsible, for at least, 85% of all CO_2 emissions, comparatively the low consumption of diesel oil verified in the management of the 38 permanent products studied in this research. Therefore, in order to contribute to the reduction of the release of CO_2 into the atmosphere, perennial crops and ecologically rational extractivism should be more encouraged and more supported by the public authorities.

Key words: Agricultural crops, diesel consumption, CO_2 emissions and C sequestration.

1. Introduction

Historically, in Brazil and other countries of South America, the process of modernization of agriculture, in its initial phase, is linked to governmental initiatives to stimulate the market of certain industrial sector [1]. It is incumbent on the state to pay for investments in infrastructure, implementation of communication systems to facilitate the marketing of "elected" agricultural products, as well as expansion of technical assistance with guaranteed minimum prices and the release of special credit lines.

However, this modernization, which began in the 1960s, does not cover all perennial crops and the products of vegetable extractivism [2]. After the first oil crisis in the early 1970s, the agricultural sector becomes more important, because it starts to contribute to alternative energy production programs. In this context, Proálcool is born, the energetic use of residues from agricultural production begins and the production of biodiesel has gradually increased [3]. These facts help to explain, for example, the expansion and the great technological and operational progress verified in the planted areas of soybean and sugarcane (temporary crops) [4].

However, even discounting the contribution of the agricultural sector to the production of alternative energy, the consumption of diesel oil in agriculture (derived from petroleum) is still high, mainly in mechanized agribusiness plantations [5]. The

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modernization in the field promoted by the Brazilian government maintained, through subsidies, the cost of capital artificially low in relation to the cost of other factors of production [1]. This favors the wealthier companies and producers who are able to use modern and more efficient inputs and agricultural machinery [6].

Meanwhile, there is a decrease in production and productivity of small and medium-sized properties, unable to afford the capital investments required to enter the role of modernized agricultural enterprises. This situation explains, in part, the existence of information gaps, mainly in relation to the products of extractivism and those of agricultural origin of less economic expression [7].

On one hand, the expansion of agricultural monocultures and super-crops generates an increase in exports and incorporates new technologies; on the other hand, contributes to the increase in deforestation and forest fires and brings the dilemma caused by the intensive use of agricultural mechanization. That is, it reduces jobs, stimulates rural exodus and emits large amounts of CO_2 into the atmosphere [8].

In summary, this study was designed to show the correlations and differences between the significant investments of temporary agribusiness crops (soybean, sugarcane and cotton) and the low expenditures of family farmers, who plant bananas, other tropical fruits (perennial crops) [9-11] or are dedicated to vegetable extractivism.

This paradox is demonstrated in this mathematical modeling, which indicates, by forestry projects, the number of trees to be planted to mitigate CO_2 emissions [12, 13]. The inconsistencies of the technical data were overcome by inferences and complementary analyzes, which emphasized:

- The level of mechanization of production processes;
- The importance of one agricultural product in relation to the others;
- The economic conditions of rural producers (small, medium or large producers).

This concern was made considering that the governments of South American and Caribbean countries could give small and medium-sized farmers incentives and better financing conditions for the relevant services that provide food security, as well as consume less fossil fuels. In addition, the neutralization of emissions through the recovery of forest landscapes and/or related projects, albeit partial, tends to improve the image of companies and contribute to the generation of new employment and income opportunities in the countryside [14, 15].

The first report of Intergovernmental Panel on Climate Change (IPCC) [16] indicates that CO_2 emissions correspond to about 95% of total greenhouse gas (GHG) emissions from mobile sources.

In the present research, in addition to normal inconsistencies verified by the use of different forms of data collection and analysis, five other difficulties had to be overcome:

- The choice of crops (perennial and temporary);
- The decision to group some of them into a single component of the model;
- The collection and systematization of data in the spreadsheet;
- The survey of the amount of diesel used in the mechanization of agricultural production;
- Mathematical conversions of measurements (areas and volumes) for energy parameters.

Regarding the forest parameters adopted, it is important to highlight the difficulties encountered in inferring the carbon capture and fixation rates in tree species, according to IPCC experts, a high degree of uncertainty.

Therefore, the general objective of this study was to present a mathematical model to allow calculation of the diesel consumption of agricultural production and the corresponding CO_2 emissions, with the additional purpose of:

(1) To rescue data on the growth of forest species and agricultural production to support the development of forestry and agroforestry projects to partially mitigate the amount of CO_2 released into the atmosphere;

(2) Encourage rural producers and public institutions to carry out reforestation projects, urban afforestation, protection and recovery of degraded areas, and agroforestry in order to mitigate CO_2 emissions from its own agricultural crops (the mathematical model indicates how many trees need to be planted or the number of hectares protected by the amount of CO_2 emitted).

2. Methodology

Bibliographical research was the underpinning of this study. Data from the agricultural, livestock and energy sectors from the most prominent Brazilian institutions were collected for 13 consecutive years between 2000 and 2012 (Tables 1 and 2).

2.1 Calculation Worksheets

A sample worksheet stating all studied items and respective bibliographic sources is shown in Table 1. This is the input data from the spreadsheet. Coffee and cocoa crops, which are very important for the continent's agricultural economy, were taken here as example of permanent crop.

2.2 Technical Forestry Development and C Sequestration Parameters

The criteria stated in the International Climate Convention and published in the "Guidelines for National Greenhouse Gas Inventories" [16] were adopted to calculate CO_2 emissions.

According to the IPCC top-down method [17], an estimate of greenhouse gas total emission uses to convert oil consumption units, firstly, to terajoule (TJ) as a common unit. After that, the carbon content calculation is recommended to be done with the energy consumption already converted to this unit. Only then will the CO_2 emissions be measured.

The following is an equation for calculating unit conversion in accordance with IPCC rules, as Eq. (1):

$$CC = CA \times Fconv \times tOE \times Fcorr \quad (1)$$

where, CC = energy consumption (TJ);

CA = fuel consumption (m^3, L or kg/ton);

Fconv = conversion factor of the physical unit of measurement of the amount of fuel for tOE, based on the higher calorific value (PCS) of the fuel[1];

Fcorr = PCS correction factor for lower calorific value (PCI)[2];

1 tOE (ton oil equivalent) = 45.2×10^{-3} TJ, and 1 TJ = 1,012 J.

In this research, according to the IPCC [18], for the conversion of the common unit was used the lower calorific value, which considers the energy of the fuel effectively usable. Therefore, the following formula Eq. (2) was adopted:

$$QC = CC \times Femiss \times 10^{-3} \quad (2)$$

where, QC = carbon content expressed as GgC = ton C $\times 10^3$;

CC = energy consumption (TJ);

Femiss = carbon emission factor (ton C/TJ)[3].

Through the amount of fossil fuel burned in agricultural activities, the amount CO_2 and the molecular weight ratio, as Eq. (3), how much C would have been dispersed in the atmosphere was obtained:

$$ECO_2 = EC \times \frac{44}{12} \quad (1)$$

where, ECO_2 = CO_2 emission and EC = C emission.

In other words, 44 ton of CO_2 correspond to 12 ton of C. The Floram project[4] [17] from the Institute of Advanced Studies at the University of São Paulo (IEA/USP) established the average C absorption rate. According to this study, the absorption rate for native species is about 7.5 ton C/ha[5].

According to this project, productivity levels range, on average, between 2.60 ton of dry matter/ha/year (1.30 ton C/ha/year) for small plants and 26.2 ton of

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[1] According to the National Energy Balance, published by the Energy Research Company (EPE) 2014, the Fconv value for diesel oil in 2014 was 0.848456 tOE/m^3.

[2] In the present study, the correction factor used, which corresponds to the ratio of PCS to PCI, was 0.939534884.

[3] According to the IPCC (1996), the value of the C emission factor for diesel oil is 20.2 ton C/TJ.

[4] The Floram project was a pioneering afforestation project proposal from 1990 by the IEA/USP, focusing on C sequestration in the atmosphere.

[5] Average annual accumulation rate based on the total accumulation capacity of a planted forest at the end of its growth period.

dry matter/ha/year (13.1 ton C/ha/year) for some forest species.

The C fixation index variation is due to the irregular behavior of plant species, which depends on physiological and edapho-climatic aspects. For tropical countries, the difficulty of estimating the amount of C sequestered by trees is very large, due to an immense diversity in flora.

Considering the slow growth of native species, average annual C fixation values per tree per hectare ranged from 0.0070 to 0.0098 ton C.

Overall, the suggested IPCC index (default) was

Table 1 Crops researched in this study.

Classification	Crop specifications	Total
Permanent [19]	Banana	
	Coffee and cocoa	
	Coconut and palm oil	
	Citrus: orange, lemon and tangerine	
	Tropical fruits: avocado, Annonaceae (atemoya, sweetsop, soursop, etc.), cashew, guava, papaya, mango	38
	Subtropical fruits: Khaki, fig, apple, (pear + quince)* and (peach + plum + nectarine)*	
	Grape, passion fruit and black pepper	
	Extractivism (palm trees): Açaí, Babaçu, (Buriti + Carnauba)**, palm heart and Piaçava	
	Extractivism (hardwood): rubber, chestnuts, mate herb, Guaraná, Mangaba, Pequi and Umbu	
Temporary	Cotton (herbaceous and arboreal)	
	Sugarcane	3
	Soybean	
Total		41

*Fruits whose crops are similar and thus calculations are integrated; **palm trees occur in nature, whose exploitation of their products is relatively small, so that their data have been integrated.

Table 2 Basic data on agricultural production and internal transport[6] of coffee and cocoa.

Permanent crops: coffee and cocoa	Year				Sources
	2000	2001	2011	2012	
Coffee					
Planted area for coffee (thousand ha)	2,395.00	2,402.30	2,149.01	2,335.32	[7, 18-21]
Average productivity (kg/ha)	845.00	829.00	1,256.60	1,311.70	[7, 20, 21]
Average weight of coffee bag (kg)	60.0	60.0	60.0	60.0	[7, 20, 21]
Average price of coffee bag paid to the producer (R$)	136.13	100.49	317.76	288.70	[19]
Cocoa					
Planted area for cocoa (thousand ha)	723.7	691.9	682.48	742.87	[7, 21, 22]
Average productivity (kg/ha)	227.00	221.00	364.15	346.52	[7, 21, 22]
Average weight of cocoa (kg)	14.7	14.7	14.7	14.7	[7, 21, 22]
Average price of cocoa paid to producer (R$)	51.00	65.61	83.00	93.20	[23]
Transport days/year[7] (d)	136	136	136	136	[19, 23]
Distance from crop planting area to trade/industry area (km)	106.0	106.0	106.0	106.0	[19, 23]
Average truck load capacity (ton)	12.0	12.0	12.0	12.0	[19]
Estimated consumption of diesel oil by truck (L/km)	4.30	4.30	4.30	4.30	[19]
Diesel oil density = 0.84 ton/m^3	0.84	0.84	0.84	0.84	[24]
Conversion: 1.0 ton of diesel = 0.848 ton of oil equivalent (tOE)	0.848	0.848	0.848	0.848	[25]
Average price of diesel oil in the gas station (R$)	0.713	0.821	2.120	2.319	[26]

[6] Technical inferences made by the author based on various searches.
[7] Estimation of diesel consumption (L/ha) in cultural tract and internal transport, as well as inferences on the consumption of mechanical harvesters (two passes). Harvest period: five months or 136 working days.

adopted for typologies, which established 0.5 ton C/ton dry matter as a conversion factor for above ground tree biomass[8]. As for agroforestry systems agricultural crops (AFS option No. 03), the conversion index ranged from 0.2 to 0.3 ton C of total dry matter.

2.3 Forestry Alternatives to Mitigate CO_2 Emissions

Four alternatives (Fig. 1) chosen to contribute to C sequestration typically included the following requirements: (1) suitable tree species; (2) annual tree growth estimates; (3) full forest development cycles as expressed by C fixation; (4) agroforestry system cycles (AFSs); (5) data on degraded forest regeneration with forest enrichment.

According to Floram project data, 1 ha native forest in climax accumulates on average between 7.0 ton and 10.0 ton C per year. *Eucalyptus* crops (2.5 m × 2.5 m, with 1,600 trees), conversely, accumulate about 144 ton C/ha in a 6-7 years cycle [27, 28]. These rates explain the preference for *Eucalyptus* in most forestry projects.

Option 1

Forest nurseries of the reference center on forest recovery (UFLA/MMA-Brazil) for projects of: reforestation and recovery of degraded areas.

Option 2

Planting in fenced grounds for forest protection in areas of permanent preservation (protection of springs and riverbanks and on slopes with high slope).

Option 3

Agroforestry systems (AFS) where in one place there are tree species interspersed with agricultural crops, which provide food and income for family farmers.

Option 4

Example of urban afforestation, in Brasília/DF, Brazil: landscaping and climatic mitigation (*Caesalpinea ferrea*)

Fig. 1 Photographic examples of the alternatives for mitigating CO_2 emissions.

[8] According to the IPCC manual, estimates of underground phytomass are yet to be presented.

Now in the following, each option and its operational partnership suggestions will be discussed:

(1) 1st option—reforestation with fast growing species [29, 30]. This neutralization alternative should be done with *Eucalyptus* crops by establishing partnerships with companies that carry out reforestation with economic purposes. According to this model, crop stands should respect a 2.5 m × 2.5 m spacing (1,600 trees/ha) in four cycles of six years each;

(2) 2nd option—forest protection with enrichment project. For this alternative, it is recommended to establish partnerships with State and Municipal Departments of Agriculture and the Environment, companies in the power sector and NGOs. The chosen areas should surround and protect freshwater springs, riparian forest remnants and the degraded boundaries of reservoirs [31, 32]. The main idea is to protect soil, water resources and regional biodiversity. It is important to identify local leaders and carry out educational activities to involve other stakeholders;

(3) 3rd option—deployment of an agroforestry system (AFS-1st cycle). This option suggests employing agroforestry systems. It is essential to seek partnerships with State and Municipal Departments of Agriculture and the Environment that in partnership with Rural Workers' Unions and specialized technical assistance and rural extension agencies, may help choose which rural and/or family producer settlements ought to be aided.

In Brazil, such AFS's models may be modified or regionally adapted based on preexisting experiments that were undertaken by EMBRAPA [33]. Family farmers would be responsible for project maintenance in the subsequent years, with the assistance of agroforestry development agencies. Like the other options, AFSs require compliance to management cycles to fully achieve C sequestration according to the recommended agroforestry project;

(4) 4th option—street afforestation project (streets and parks): In this case, it is suggested that the Municipal Environment Departments establish partnerships with companies, NGOs and other public institutions in urban areas.

The growth cycle of these urban species was estimated in 25-30 years. A reference hectare was used to expedite calculation. This indicates the number of trees, if planted in a conventional rectangular area, according to the recommended spacing. Table 3 presents a calculation breakdown for each option, stating cycles, reforestation premises and data on AFSs and native species growth, as well as the suggested criteria for urban afforestation.

3. Results and Discussion

In all the forest projects (options 1, 2, 3 and 4) suggested in this mathematical model, it is the explicit desire to encourage the forest management in different ways: through reforestation to supply the demands for wood and other forestry products; and/or for the protection of soil, biodiversity and water resources.

The most difficult to conceive and evaluate over time in terms of C capture from the atmosphere, is, undoubtedly, which deals of the protection and enrichment of forest remnants (option 2: fenced grounds), since each area presents the need of varied tree planting due to the different levels of degradation. But, the natural regeneration must also be considered as an important inducer of forest recovery of legal reserves and the permanent preservation areas that exist in the properties, according to Brazilian environmental legislation.

In addition, with the accession of large numbers of producers and entrepreneurs, this research provides indicators that natural regeneration and planting of enrichment will contribute, effectively, to capturing C from the atmosphere, mitigating part of CO_2 emissions.

Option 4, which proposes the implementation of agroforestry systems, is intended to stimulate small and medium-sized rural producers to make integrated plantings of food and trees to meet their needs.

Table 3 Forestry technical assumptions considered for each CO_2 emission mitigation alternative [27].

1st option: reforestation with fast growing species	
Species used	*Eucalyptus* sp.
Number of cycles for commercial use/years	4 cycles × 6 years = 24
Area (m²)	10,000
Spacing	2.5 m × 2.5 m = 6.25 m^2
Number of trees/ha	1,600 = 10,000/6.25
Annual C fixation by tree (ton C/tree)	0.0450
Total amount of fixed C (ton C/ha)	287.8
Conversion factor for CO_2/ha	44/12 = 3.67
Total C captured in the complete cycle (ton C/ha)	1,055.3 = 287.8 × 3.67
Technical projection for emissions neutralization (number of ha)	19.0 = 20,000 (ton C/ha)/1,055 (ton C)
Total number of trees to be planted	30,400 = 19 × 1,600
2nd option: forestry protection project with enrichment	
(1) Surrounding degraded areas with forests at an initial stage of regeneration	
Reference area (m²)	10,000
Percentage of forests in 1 ha	0.55
Amount of C accumulated after four years (ton)	27.83
Estimate of total natural regeneration until the forest reaches climax stage (ton C)	114.8 = [(27.83/4) × 0.55 × 30 years]
Spacing	4.0 m × 4.5 m = 18.0 m²
Enrichment with forest species and fruit trees (number of trees)	555.6 = 10,000/18
Total yearly estimated carbon (ton C/tree/ha)	4.70 = (0.00840 ton/tree/ha × 556)
Number of native trees or planted fruit species	4,214
(2) Enclosure to protect native forest remnants and/or secondary forests	
Percentage of forests in 1 ha	0.45
Amount of C accumulated/year (ton C)	114.8
Estimated cycle until climax (years)	30
Estimated C asset per year (ton)	1.30
Estimation of the amount of accumulated carbon at climax (ton C)	64.0
Estimation of annual C fixation (ton/ha)	67.0 = [(27.83 × 0.55) + (114.8 × 0.45)]
Total C captured during entire cycle (ton C)	2,639 = [(4.67 × 30 years × 3.67) + (67 × 30 years) + 114.8]
Projected area to neutralize CO_2 emission (ha)	7.6 = 20,000 (ton CO_2)/2,639 (ton CO_2/ha)
3rd option (family farmers financing): implantation of agroforestry system (1st cycle)	
(1) Forest part	
Reference area (m²)	10,000
% for forest management (ha)	0.5
Forest plantation area (m²)	5,000
Proposed spacing	3.5 m × 4 m = 14 m²
Number of arboreal species	714.3 = 10,000 /14
Estimate of annual C fixation (ton/tree/ha)	6.34 = (0.008871 × 714)
Timber extraction cycle	3 cycles × 6 years = 18.0
Total C captured during the complete forest management cycle (ton)	418.20
(2) Agronomic part	
Reference area (m²)	10.000
% for agricultural production (ha)	0.5
Banana planting (m²)	3,000
Number of day cycles (sprouts and replanting)	12.0
Proposed spacing	2.0 m × 2.0 m = 4 m²

(Table 3 continued)

Number of banana trees	750 = 3000/4
Estimation of the amount of dry matter/ha in the 1st cycle (> 500 to < 600 d) (ton)	48.79
Estimated amount of C/ha (ton)	24.4 = (48.8 × 0.4 default IPCC)
Estimation of C fixation per banana tree (ton/ha)	0.026 = (19.5/750 tree)
Amount of C fixed in AFS planting (example) (ton)	234 = 0.026 × 750 × 12
Total C capture during the complete cycle (ton)	858.8 = 234 × 3.67
Planting of grains + sugarcane	
Area of various crops to produce grains (corn, beans) and others (m²)	2,000
Number of cycles (years)	18.0
Estimation of dry matter/ha/cycle (ton)	7.5
Estimation of the fixation of C/ha by temporary crops (ton)	1.82 = 7.5 × 0.242
Amount of C fixed in the present planting of the agroforestry system (ton)	32.67 = 1.82 × 18 years
Total C capture during the complete cycle (ton)	119.79 = 32.67 × 3.67
Total C captured by the agroforestry system (ton C)	1,396.8 = 418.2 + 858.8 + 119.8
Technical project for emission neutralization (ha)	14.32 = 20,000/1,396.8
Number of trees for forest management/enrichment (considering suggested cycles)	10,232 = 14.32 × 714
4th option: Urban afforestation project (streets and public parks) with native species	
Reference area (m²)	10,000
Estimated full development cycle	1 cycle × 25 years = 25
Planting space in streets and avenues	6 m × 6 m = 36 m²
Planting space in public parks	2.5 m × 2.5 m = 6.25 m²
Amount of trees per referential ha (planting in the streets)	10,000/36 = 278
Amount of trees per referential ha (planting in squares)	10,000/6.25 =1,600
Total trees/reference ha	278 + 1,600 = 1,878
Estimation of annual C fixation per tree (ton C)	0.00849
Estimate of the annual fixation of C/reference ha (ton C)	15.944 = 0.00849 × 1,878
Estimation of total carbon fixation (ton C)	398.32
Conversion factor for CO_2	44/12 = 3.67
Total C capture in the complete cycle (ton C)	1,460.5
Technical project for emission neutralization (number of reference ha)	13.7
Total number of trees to be planted	25,714

Sources of options 1, 2, 3 and 4: templates developed by the author, using data from Floram project and information's studies done by EMBRAPA and Brazilian universities.

In this case, the model shows an association of species of 1.0 ha (0.5 ha with forest species, 0.3 ha with banana and 0.2 ha with sugarcane), through which, in a complete cycle of 18 years 860 ton of C can be sequestered. However, this result applies only to this specific field situation, since the greater or lesser intensity of C sequestration will depend directly on the composition of the agroforestry system.

It is known that large-scale participation of small and medium-sized farmers tend to be relevant, contributing to environmental balance and food security.

The reforestation and urban afforestation options (options 3 and 4), what propose, respectively, the realization of eucalyptus plantations and native or exotic species, with a climax age of approximately 25 years, were those with the lowest degree of complexity.

The *Eucalyptus*, for example, has many studies of forest development [28, 29], a fact that greatly facilitated the definition of the technical criteria of these homogeneous plantations.

In turn, urban afforestation projects in Brazil are carried out with a reduced number of species. Both options are suitable, especially, to stimulate the formation of partnerships between large polluting companies and public power.

In Table 3, it can be verified, in detail, how the information on C capture of each proposed alternative gave subsidies for this research. The growth data of the forest species and the composition of the mathematical model were obtained from the Floram project (USP/Brazil). Meanwhile, the definition of CO_2 mitigation alternatives was elaborated by team of forestry engineers of IVIG/COPPE/UFRJ-Brazil, after a long literature search, which included several studies carried out by EMBRAPA, CEPLAC and IBGE surveys, many others.

Tables 4 and 5 show a summary of the results of calculating cocoa and coffee production and the respective CO_2 mitigation proposals. These two perennial crops emitted, during 13 years (2000 to 2012), 156.0 thousand ton of CO_2. In the same period, only soybean cultivation in Brazil released into the atmosphere 5.6 million ton.

Table 6 summarizes all the results determined by the mitigation model with forestry and agroforestry projects, considering all agricultural crops: permanent and temporary crops. It also shows the number of trees and/or hectares to be recovered or protected, and also shows the total carbon CO_2 of all crops surveyed.

In turn, Table 7 presents the ranking, in descending order, of the cultures that consumed more diesel oil and emitted CO_2 in the atmosphere during the 13 years. It has been found that the amount of trees needed to mitigate emissions from temporary crops is enormous. Together the culture of soybean, sugarcane and cotton issued, in the period, was 9.5 million ton. All other temporary crops totaled 1.02 million ton.

Table 4 Standard spreadsheet template used to exemplify the Brazilian coffee and cocoa agricultural production.

Results of agricultural production	2000	2001	2011	2012	Total	References
Coffee						
Mechanization data and/or cultural treatment						[34, 35]
Number of ha with planting maintenance and harvest (1,000 ha)	407.15	432.41	902.58	1,050.89		[7, 21]
Estimate average of diesel oil consumption (L/ha)*	76	76	76	76		[5, 20, 34-36]
Consumption of diesel oil in mechanized process (L)	30,943,400.0	32,863,464.0	68,596,271.5	79,867.773.0	680,733,612.7	
Estimate to average fuel spending in mechanized process (R$/ha)*	54.19	62.40	161.12	176.24		[24]
Transportation of plant benefit						
Total freight carried (coffee + cocoa) (1,000 ton)*	2,188.05	2,144.42	2,948.97	3,320.65		
Number of trip for year*	182,338	178,701	245,747	276,721		
Distance traveled (transportation round trip) (km)	38,655,636.6	37,884,693.3	52,098,412.8	58,664,876.5		[23]
Estimate total consumption of diesel oil of transport to the factory (L)*	8,989,682.9	8,810,393.8	12,115,909.9	13,642,994.5	141,420,096.0	
Estimate of average diesel oil of transportation to the factory (R$)*	6,409,643.9	7,233,333.3	25,685,729.1	31,638,104.3		
Production of coffee freight carried per year (thousand ton)*	2,023.78	1,991.51	2,700.44	3,063.23	31,813.70	[20]
Average product in the period					2,447.21	
Numbers of coffee bags produced (thousand)	33,729.6	33,191.8	45,007.3	51,053.9		[7, 20]
Physical production variables in relation to the previous year	1.000	0.984	0.929	1.134		

(Table 4 continued)

Results of agricultural production	2000	2001	2011	2012	Total	References
Production of cocoa freight carried per year (thousand ton.)*	164.28	152.91	248.53	257.42	2,607.42	[23]
Average product in the period					200.57	
Quantity of cocoa almonds produced (thousand)*	11,175.5	10,409.1	16,918.0	17,523.5		[7, 19, 21, 22]
Physical production variables in relation to the previous year	0.750	0.31	1.056	1.036		[23]
Total coffee + cocoa (ton)	2,188,054.90	2,144,416.60	2,948,966.76	3,320,653.38	34,421,117.71	[7, 20-22]
Factory price of coffee production ($\times 10^3$ R$)	4,591,608.2	3,335,441.8	14,301,535.2	14,739,254.6		[19, 20]
Factory price of cocoa production ($\times 10^3$ R$)	569,950.67	682,926.42	1,404,196.26	1,633,193.27		[22]
Energy consmption estimate (tOE)						
Estimate of total consumption of diesel oil (L/year)*	39,933,082.9	41,673,857.8	80,712,181.5	93,510,767.5	822,153,708.7	[24]
Estimate of total consumption of diesel oil (m^3/year)*	39,933.1	41,673.9	80,712.2	93,510,8	822,153.7	[24]
Estimate of total consumption of diesel oil (ton/year)*	33,543.8	35,006.0	67,798.2	78,549.0	690,609.1	[24]
Diesel oil consumption (tOE/year)	28,445.1	29,685.1	57,492.9	66,609.6	585,636.5	[24, 25]
Total energy consumption (TJ)					27,421.9	[25]
Estimation of consumption (ton)*	98,650.60	102,951.05	199,391.29	231,008.90	2,031,047.6	[24]
General CO_2 emission average (ton)					156,234.4	
Average (tOE/year)					45,049.0	[25]

*Data inferred by the author for the composition of the mathematical model.

Table 5 Recommended options to mitigate CO_2 emissions by agricultural products.

Farm crops coffee + cocoa	Years				Crops and forestry protection		Sources
	2000	2001	2011	2012	Average ha	Average amount of trees	
1st option: reforestation with fast growing species—*Eucalyptus*							[28]
Technical projection for emission neutralization (ha)*	27.0	28.1	54.5	63.1	43		[12, 29, 30]
Total amount of trees to be planted	43,126	45,005	87,165	100,986		68,299	
2nd option: forest protection project + enrichment planting							[8, 27]
Quantity of ha that should be sequestered, with forest enrichment (ha)*	56.5	59.0	114.2	132.4	90		[13, 31, 32]
3rd option: implantation of agroforestry system (1st cycle)							[27]
Technical projection for emission neutralization (ha)*	33.1	34.5	66.9	77.5	52.5		[6, 29, 33]
Total amount of trees to be planted	23,626	24,656	47,753	55,325		37,417.2	
No. of benefited family farmers (two families/ha)	66	69	134	155			
Average producers or beneficiaries/year	105						
4th option: urban afforestation project (streets and public parks)							[27]
Projection for emission neutralization (ha)*	19.5	20.3	39.4	45.6			[14, 15]
Total amount of trees to be planted	36,572	38,166	73,918	85,639		57,919	

*Data inferred by the author for the composition of the mathematical model.

Table 6 Emission mitigation alternatives by type of crop.

Crops	CO_2 emission in 13 years (ton)	Ton of oil equivalent (tOE)	Option 1		Option 2	Option 3	Option 4	
			Amount of trees	Quantity of ha	Amount of trees	Quantity of ha	Amount of trees	Amount of producers
Permanent								
Banana	6,872.0	1,981.5	3,004	2.0	2,548	3.90	1,646	5
Coffee-cocoa	156,234.4	45,049.0	68,299	43.0	57,919	90.0	34,417	105
Coconut-palm tree	43,703.3	11,946.8	19,105	12.0	16,202	25.0	10,467	29
Citrus	282,222.0	81,376.5	123,374	80.0	104,625	162.0	67,590	189
Tropical fruits	135,658.6	39,141.7	59,343	37.0	50,324	77.8	32,511	91
Subtropical fruits	313,171.3	90,300.5	136,904	85.0	116,099	179.0	75,003	210
Grapefruit, passionfruit and black pepper	34,245.6	9,874.5	14,971	9.0	12,696	1.6	8,202	23
Extrativism (palm)	13,719,7	4,709.5	7,140	4.5	6,055	9.50	3,912	11
Extrativism (hardwood)	30,180.7	10,359.9	15,707	10.0	13,320	20.6	8,605	24
Subtotal	1,016,007.6	294,739.8	447,847.0	280	379,786	587.4	245,351	687
Temporary (agrobusiness) [5, 37-39]								
Cotton	310,668.7	89,578.9	135,810	85	115,171	178.0	74,403	208
Sugarcane*	3,570,142.7	1,029,976.0	1,561,541	976	1,324,231	2,046.6	855,486	2,395
Soybean*	5,600,914.4	1,615,847.8	2,449,779	1,531	2,077,482	3,210.7	1,342,105	3,582
Subtotal	9,481,725.8	2,735,402.7	4,147,130	2,592.0	3,516,884	5,435.3	2,271,994	6,185
Total of permanent and temporary	10,497,733.4	3,030,142.5	4,594,977	2,872.0	3,896,670	6,022.7	2,517,345	6,872

*When estimating options for neutralizing CO_2 emissions from sugarcane and soybean crops, the decrease in diesel consumption percentages resulting from the national power generation policy, respectively, for ethanol (anhydrous ethyl alcohol) and for biodiesel were not included. These issues were not considered in this paper.

Table 7 Ranking of the emissions of the agricultural crops chosen for this research.

Ranking	Crops	CO_2 Emissions (ton)	tOE	Type
1	Soybean	5,600,914.4	1,615,847.8	T
2	Sugarcane	3,570,142.7	1,029,976.0	T
3	Subtropical fruits	313,171.3	90,300.5	P
4	Cotton	310,668.7	89,578.9	T
5	Citrus fruits	282,222.0	81,376.5	P
6	Coffee-cocoa	156,234.4	45,049.0	P
7	Tropical fruits	135,658.6	39,141.7	P
8	Coconut-palm tree	43,703.3	11,946.8	P
9	Grape, passionfruit and black pepper	34,245.6	9,874.5	P
10	Extra activism (hardwood)	30,180.7	10,359.9	P
11	Extra activism (palm trees)	13,719.7	4,709.5	P
12	Banana	6,872.0	1,981.5	P
Total		10,497,733.4	3,030,142.5	

P = Permanent T = Temporary.

4. Conclusions

Among the several conclusions that can be drawn from the elaboration of this mathematical model is the great difference between the consumption of diesel oil verified in the management of the crops that are part of the agribusiness (temporary crops) and the permanent plantations. The results showed that in the samples of 41 Brazilian agricultural products, only soybean, sugarcane and cotton (temporary products on the list) accounted for at least 85% of all CO_2. These three monocultures, besides having annual harvests, mechanized cultural treatments and integrating the export agenda, receive great governmental and business support, having occupied in 2016, respectively, about 28, 10.0 and 1.5 million hectares of Brazilian territory.

On the other hand, the perennial products and the ones extracted directly from the nature, because they have, in general, low mechanization index, presented, as expected, a low consumption of this fossil fuel and, consequently, much lower emission levels of Carbon Dioxide (CO_2) to the atmosphere. Therefore, for this contribution perennial crops and products derived from extractivism should be more encouraged and have more support from the public power. Moreover, comparatively, they protect soils from erosive processes; Help to maintain and enhance biological diversity; Contribute to the reduction of rural exodus; and have a relevant role in protecting water resources and food security of the poorest populations.

Another conclusion of the study shows that the options presented for the C sequestration are fully in line with the proposals of the "Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture" (ABC-EMBRAPA) and the commitments made by Brazil to the international community for CO_2 reduction.

In view of the above, it is attributed to this sample survey of Brazilian agriculture, which correlates fuel consumption in crop management, carbon dioxide emission and the number of trees to be planted and/or protected hectares, of great socio environmental importance. As such, it is expected that it will have the capacity to mobilize government agencies to implement forest (urban and rural) and agroforestry public policies; as well as to encourage NGOs to support small and medium-sized rural producers; researchers and entrepreneurs of the agricultural sector to also contribute with associated projects of: Recovery of degraded areas; Technical support for the enrichment of legal reserves of rural properties; and Formation of public-private partnerships for the development of integrated projects of economic and ecological reforestation.

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Attachment I

Fig. 1 List of the main products of plant extra activeness

Attachment II

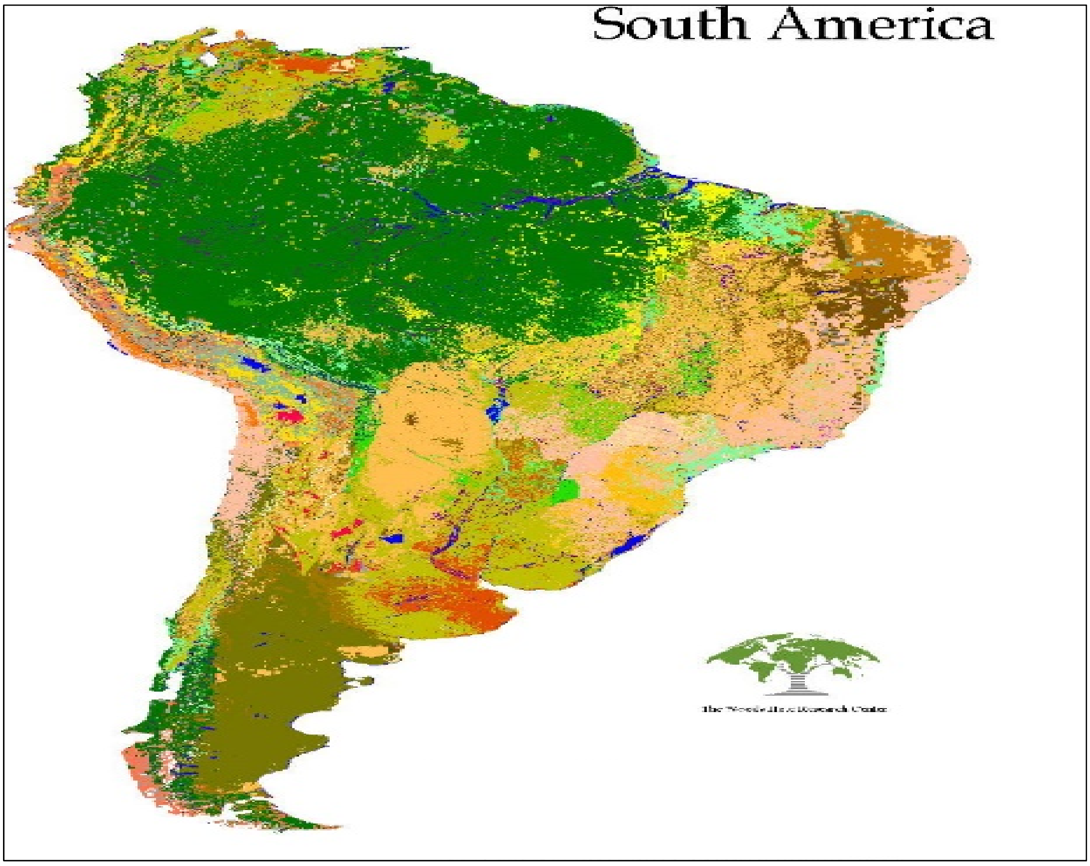

Fig. 2 A map of the current land cover based on NOAA AVHRR satellite data.