Model for Evaluating Diesel Consumption in Agriculture and CO₂ Emissions, with Forest Projects to Extract Carbon from the Atmosphere

Case Study: Banana X Soybean

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Abstract The present research was developed with the objective of determining the consumption of the diesel oil in the production of cereals and fruits; assess the consequent amount of CO₂ emitted into the atmosphere; and, in addition, list forest projects that, through photosynthesis, during tree growth cycles, can contribute to the total or partial sequestration of these emissions. 41 crops were selected: 38 perennials and 03 temporary, for which were rescued production data from 13 consecutive years, from 2000 to 2012. Thus, with the resulting mathematical model, it was possible to obtain CO₂ emissions from all crops - individual or grouped -, as well as to compare the results of perennial and temporary plantations. The selected study case show, for example, a comparison the diesel consumption and the respective CO₂ emissions of the crops: BANANA (*Musa sp.*) and SOYBEAN (*Glycine max*), based on the Brazilian production. About regarding the sequestration of carbon (C) four forest mitigation alternatives were elaborated: i) FOREST PROTECTION PROJECT; ii) REFORESTATION with fast growing species; iii) AGROFLORESTAIS SYSTEMS (1st cycle); and (iv) URBAN ARBORIZATION PROJECT. For each option, there is the indication of the numbers of trees to be planted or hectares to be protected/ enriched for a purpose of the total or partial reduction of the quantity of CO₂ issued for atmosphere.

Keywords Agriculture and Forest, Diesel Consumption, CO₂ Emission, Climate Change, Carbon Sequestration with Forests Projects

1. Introduction

The modernization of the agricultural sector in Brazil and other Latin American countries began in the 1960s, with government investments in: infrastructure, implementation of communication systems; expansion of technical assistance, guarantee of minimum prices and the release of credit lines. But this modernization does not include the totality of perennial cults and the products vegetable of the extractivism.

Moreover, at the time, there was no concern about greenhouse gas emissions, but a predominant developmentalist view in all sectors of the economy. Only 1980s, climate change has awakened concern within the international community, due to scientific evidence that was correlates the increase in greenhouse gas emissions (GHG) with global warming. Only in 1990, with the first scientific report of the Intergovernmental Panel on Climate Change (IPCC) [1], a relative consensus has alncanced about this theme, however did not excluded methodologies divergences between developed and developing countries, which yet be opposing stances, principally about the agroforestry parameters.

Probably, for this reason, there has been, long the time, with rare exceptions, a delay in improving the data cataloging of agricultural production and forestry. It is observed that, in Brazil and abroad, there are, for example, difficulties inherent to the survey and inference of carbon fixation rates of tree species, which represents, among others, a high degree of uncertainty caused by considerable soil differences, climate, and vegetation of the terrestrial regions.

That way, the present agroforestry research aimed at

overcoming the following difficulties:

- The choice of crops (perennial and temporary) and of the digital processing tools;
- The decision to group in the same component of the calculation model agricultural crops with similar production processes;
- The systematization of different agroforestry data to support the technical-scientific research and the elaboration of the calculation model
- The estimated quantification of the volume of diesel used in mechanization and for the production and transportation of different crops; and
- Mathematical conversion of measurements (area and volumes) into energy parameters.

This study also shows the differences between the large harvests in agribusiness (SOYABEAN, sugar cane and cotton) [2] and the large expenditures on the production of BANANA, other tropical fruits [3-4] and products of vegetable extractivism. Consequently, the model is analyzed as peculiarities and characteristics of crops and forests, generating statistical indicators of reforestation, forestry and agroecological protection actions, to stimulate the realization of projects of rural producers and public institutions to reduce carbon dioxide emissions (CO₂). In some cases, due to an inconsistency in data and socioeconomic information, it was necessary to make inferences and complementary studies, emphasizing:

- level of mechanization of a productive process [5];
- The importance attached to one type of cultural treatments in relation others; and
- Living standard of rural producers (small, medium or large producers).

In opting in this study for a comparison between a traditional and other highly mechanized crop, the intention is to show, based on the Brazilian and Latin American agricultural experiences, the great difference that exists between the activities of small and medium farmers and of the large investors of agribusiness [6]. Therefore, the choice of BANANA and SOYBEAN was based on the fact that they occupy the extremes in the *ranking* of the

consumption of diesel oil and of the respective emissions of carbon dioxide.

2. Justification and Objectives

This mathematical model intends to raise awareness in society as a whole, and of business persons from the agricultural segment in particular, of the need for investments in recovery of forest landscapes and in related projects in order to protect the soil and the biodiversity and also mitigate the CO₂ emissions derived from agricultural activities. Neutralization of emissions tends to improve of the company's reputation and to contribute to generation new job opportunities and the increased income of the rural producer.

2.1. General Objectives

- Propose Model of data systematization on agricultural production for to calculating diesel oil consumption and of the corresponding CO₂ emissions; and
- Forest and agroforestry options to support carbon sequestration projects, indicating the number of trees and hectares to be planted or protected, using as a comparative example banana and soybean crops.

3. Methodology

3.1. Calculation Worksheets - Input Data

Were selected 41 different products (agricultural and extractive), being: 38 perennials and 03 temporary (Tables 1), from which we ransomed production data of 13 consecutive years, from 2000 to 2012.

Table 2 shows the basic data of the production, productivity and internal transport of the crops of soybean and banana, the fruit that is produced in 130 countries, making up the diet of people from all continents [7].

Table 1. Researched Crops and Major Groupings

	SPECIFICATIONS	TOTAL
perennials crops	BANANA	38
	Coffee and Cocoa	
	Coconut and Palm	
	Citrus Fruits: Orange, Lemon and Tangerine	
	Tropical Fruits: Avocado, Anonáceas (atemoia, graviola, pineapple, etc.), Cashew, Guava, Papaya, Mango	
	Subtropical Fruits: Persimmon, Fig, Apple, Pear + Quince and Peach + Plum + Nectarine	
	Grape, Passion Fruit and Pepper of the Kingdom	
	Plant Extractivism (Palm Trees): Açai, Babaçu, Buriti + Carnaúba, Palmito and Piaçava.	
	Plant Extractivism (Hardwoods): Rubber, Chestnut, Yerba Mate, Guaraná, Mangaba, Pequi and Umbu.	
Temporary crops	Cotton (Herbaceous and Arboreal)	03
	Sugar cane	
	SOYBEAN	
TOTAL		41

Table 2. Basic Data on Production and Internal Transport of the Crops of Banana and Soybean

BANANA		2000	2001	..	..	2011	2012
INPUT DATA							
Planted Area	(thousand ha) [8]	524.8	510.3			505.7	523.5
Productivity	(tons / ha) [9]	14.20	13.40			14.36	12.96
Transport Days/year - 70% according to production and harvest zones	[24]	204	204			204	204
Distance: from planting area to trade / industry	(km) [24]	125	125			125	125
Average truck capacity: truck and 'Toco'	(~ tons) [10]	14.0	14,0			14.0	14.0
Estimated consumption of diesel oil by truck	(km/l) [11]	3.0	3.0			3.0	3.0
Conversion: 1.0 ton of diesel =	0,848 tEP [12]	0.848	0.848			0.848	0.848
Diesel oil density =	0,840 ton/m ³ [12]	0.84	0.84			0.84	0.84
Average Price of Diesel Oil at Pump	[13]	0.713	0.821			2.120	2.319

SOYBEAN		2000	2001	..	..	2011	2012
INPUT DATA							
Planted Area	(thousand ha) [8]	13,693.7	13,988.4			24,052.4	27,721.5
Harvested Area	(thousand ha)	12,023.3	13,854.1			24,050.2	27,716.6
Productivity	(tons / ha) [9]	2.73	2.40			14,36	12,96
Transport Days/year - 70% according to production and harvest zones	[25]	136	136			136	136
Distance: from planting area to trade / industry	(km) [25]	85	85			85	85
Average load capacity of trucks with 02 and 03 axles	(~ tons) [10]	30.0	30.0			30.0	30.0
Estimated consumption of diesel oil by truck	(km/l) [11]	4.0	4.0			4.0	4.0
Conversion: 1.0 ton of diesel =	0,848 tEP [12]	0.848	0.848			0.848	0.848
Diesel oil density =	0,840 ton/m ³ [12]	0.84	0.84			0.84	0.84
Average Price of Diesel Oil at Pump	[13]	0.713	0.821			2.120	2.319

3.2. Technical Criteria Adopted for the Calculation of Carbon Sequestration

In order to quantify the CO₂ emissions from the consumption of diesel oil from planting, harvesting and internal transport of agricultural production were adopted the criteria suggested by the International Climate Convention: "Guidelines for National Inventory of Greenhouse Gas Inventories".

According to the IPCC *top-down* method, the first task is to convert for a common unit (TERA JOULE): the amount of greenhouse gas emissions and energy consumption. Only afterwards CO₂ emissions can be measured using the following equation:

$$CC = CA \times F_{conv} \times tEP \times F_{corr}$$

Where:

1 tOE (ton oil equivalent) = 45.2 x 10⁻³

TJ (Tera-Joule = 1012 J)

CC = energy consumption (TJ);

CA = Fuel consumption (m³, l or kg/ton)

F_{conv} = conversion factor of the physical unit of measurement of the amount of fuel for tOE, based on the higher calorific value (PCS) of the fuel¹

F_{corr} = PCS correction factor for PCI (lower calorific value)².

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

$$QC = CC \times F_{emiss} \times 10^{-3}$$

Where:

QC = carbon content expressed in GgC = tonC x 10⁻³

CC = energy consumption in TJ;

F_{emiss} = carbon emission factor (tonC/TJ)³.

To estimate the amount of dioxide of carbon and of carbon dispersed in the atmosphere a molecular weight ratio is used, which is expressed by the following equation:

$$ECO_2 = EC \times \frac{44}{12}$$

Where:

ECO₂ = CO₂ emission and EC = C emission.

3.3. Forestry Alternatives to Mitigate Carbon Dioxide (CO₂) Emissions – Technical Parameters

The 04 (four) proposals selected to promote carbon

sequestration consider the following premises:

- Annual tree growth estimates;
- Suitable tree species;
- Full forest development cycles as determined by Carbon fixation;
- Agroforestry systems cycles (AFSs); and
- Data on degraded forest regeneration with forest enrichment.

FLORAM Project [14] data indicate each hectare of native forest in climax accumulates on average between 7.0 and 10.0ton of Carbon/year. On the other hand, Eucalyptus plantations (2,5m x 2,5m, with 1600 trees), accumulate about 144tonC per hectare, in a 06 to 07 year cycle. These rates explain the preference this specie in most forestry projects. Suggestions of operational partnerships and a summary of each alternative is shown in the sequence:

1st OPTION: REFORESTATION with Fast Growing Species

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 x 2.5m spacing (1600 trees per hectare) [15-16-17], during 04 (four) cycles of 06 (six) year each.

2nd OPTION: FOREST PROTECTION AND ENRICHMENT PROJECT

For this alternative, is recommended partnerships with State and Municipal Environment Departments, companies in the power sector and NGOs. The chosen areas should surround and protect riparian forest remnants [18-19], freshwater springs and the degraded areas of reservoirs margins. The main idea is to protect water resources, soil and regional biodiversity. It is important to identify local leaders and carry out educational activities to involve other stakeholders.

3rd OPTION: DEPLOYMENT OF AN AGROFORESTRY SYSTEM (1st cycle)

This alternative suggests the adopt Agroforestry Systems (AFSs). 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 models may be modified regionally based experiments undertaken by EMBRAPA. Family farmers would be responsible for projects maintenance in

1 According to the National Energy Balance, published by the Energy Research Company - EPE / 2014). The **F_{conv}** value for diesel oil in 2014 was 0.848456 tOE / m³;

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 carbon emission factor for diesel oil is **20.2 tonC / TJ**;

the subsequent years, with the assistance of agroforestry development agencies [20-21]. Like the other options, AFSs require the completion of the cycles to expect achieve carbon sequestration.

4rd. OPTION: STREET AFFORESTATION PROJECT (STREETS AND PARKS)

It is suggested, in this case, that the Municipal Secretariats of the Environment establish partnerships with companies, NGOs and public entities in urban areas. The cycle of growth of urban species was estimated in 25 to 30 years [14, 25]. We used 01 (one) hectare of reference to facilitate the calculation. Thus, the number of trees to be planted in a conventional rectangular area is indicated according to the available space.

Option 1:	Option 2:

<p>Planting of tree seedlings from the Reference Center for Forest Recovery (CR-ad UNIVASF – Petrolina, Northeast Brazil) to REFORESTATION and RECOVER DEGRADED areas.</p>	<p>FOREST PROTECTION fences to stimulate natural regeneration in areas of permanent preservation (protection of springs, river banks, valleys, etc.).</p>
Option 3:	Option 4:

<p>AGROFLORESTAIS SYSTEMS (AFS's), where trees are intermingled with agricultural crops (beans, BANANA, coffee, etc.) in the same site, providing food and income for family farmers.</p>	<p>Example of URBAN AFFORESTATION PROJECT, in Brasília / DF, Brazil, for landscaping and climatic mitigation (<i>Cassia sp.</i>).</p>

<p>Comparative photos: 1) Traditional plantation of BANANA, from the municipality of Delfinópolis, Minas Gerais, Brazil; little mechanization. Photo: EMATER / MG.</p>	<p>2) Large agricultural equipments performing SOYBEAN harvest in the Center West of Brazil: extremely high diesel consumption Photo: Daniel Popov, Rural Channel.</p>

Table 3 presents data decomposition for each option, indicating cycles, tree planting assumptions, data on AFSs and growth of native species, as well as the requirements for urban afforestation.

Table 3. Forestry technical assumptions considered for each CO₂ emission mitigation alternative [27]

1st option: reforestation with fast growing species	
Species used	<i>Eucalyptus</i> sp.
Number of cycles for commercial use/years	4 cycles $\times$ 6 years = 24
Area (m ²)	10,000
Spacing	2.5 m $\times$ 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 $\times$ 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 $\times$ 1,600
2nd option: forestry protection project with enrichment	
(1) Surrounding degraded areas with forests at an initial stage of regeneration	
Reference area (m ²)	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) $\times$ 0.55 $\times$ 30 years]
Spacing	4.0 m $\times$ 4.5 m = 18.0 m ²
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 $\times$ 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 $\times$ 0.55) + (114.8 $\times$ 0.45)]
Total C captured during entire cycle (ton C)	2,639 = [(4.67 $\times$ 30 years $\times$ 3.67) + (67 $\times$ 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 (m ²)	10,000
% for forest management (ha)	0.5
Forest plantation area (m ²)	5,000
Proposed spacing	3.5 m $\times$ 4 m = 14 m ²
Number of arboreal species	714.3 = 10,000 /14
Estimate of annual C fixation (ton/tree/ha)	6.34 = (0.008871 $\times$ 714)
Timber extraction cycle	3 cycles $\times$ 6 years = 18.0
Total C captured during the complete forest management cycle (ton)	418.20
(2) Agronomic part	
Reference area (m ²)	10,000
% for agricultural production (ha)	0.5
Banana planting (m ²)	3,000
Number of day cycles (sprouts and replanting)	12.0
Proposed spacing	2.0 m $\times$ 2.0 m = 4 m ²

(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)	$24.4 = (48.8 \times 0.4 \text{ default IPCC})$
Estimation of C fixation per banana tree (ton/ha)	$0.026 = (19.5/750 \text{ tree})$
Amount of C fixed in AFS planting (example) (ton)	$234 = 0.026 \times 750 \times 12$
Total C capture during the complete cycle (ton)	$858.8 = 234 \times 3.67$
Planting of grains + sugarcane	
Area of various crops to produce grains (corn, beans) and others (m ²)	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)	$1.82 = 7.5 \times 0.242$
Amount of C fixed in the present planting of the agroforestry system (ton)	$32.67 = 1.82 \times 18 \text{ years}$
Total C capture during the complete cycle (ton)	$119.79 = 32.67 \times 3.67$
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)	$10,232 = 14.32 \times 714$
4th option: Urban afforestation project (streets and public parks) with native species	
Reference area (m ²)	10,000
Estimated full development cycle	1 cycle $\times$ 25 years = 25
Planting space in streets and avenues	6 m $\times$ 6 m = 36 m ²
Planting space in public parks	2.5 m $\times$ 2.5 m = 6.25 m ²
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)	$15.944 = 0.00849 \times 1,878$
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.	

4. Results and Discussions

The carbon sequestration alternatives presented in this mathematical model (**Options: 1, 2, 3 and 4**), cover the different aspects of forest science, from reforestation with fast growing species to agroforestry projects. In all of them there is an explicit desire to stimulate the planting of trees to meet the demands for wood and other products; as well as to protect: soil, biodiversity and water resources, as a way to offset the emissions caused by the consumption of diesel oil [22].

The greatest difficulty encountered in terms of carbon capture was, undoubtedly, in relation to the alternative that deals with the protection and enrichment of forest remnants (**Option 2**), since each area to be recovered, due to different levels of degradation, requires planting of species and number of varied trees [23].

In spite of this, the contribution of natural regeneration should not be overlooked, especially in tropical and subtropical regions where the high incidence of sunlight combined with other soil and climatic factors favor the rapid growth of vegetation cover. Therefore, it was

considered that certain areas, with enrichment plantations an important action to mitigate part of CO₂ emissions.

On the other hand, **options 1 and 4**, of reforestation and urban afforestation, which indicate, respectively, plantations of eucalyptus trees and of native or exotic species that should reach the climax age at 25 years, were those with the lowest degree of complexity.

The Eucalyptus, for example, has many forestry development studies carried out in Brazil, which facilitated the determination of your parameters.

In turn, due to the fact that the urban arborization of Brazilian cities uses a reduced number of forest species, the average data of tree growth could be inferred with the support of the bibliography consulted.

Option 4, which proposes the implementation of agroforestry systems (AFS), is intended to stimulate small and medium-sized rural producers to make integrated plantings of food and trees to meet their needs. In this case, the model presents an example of association of species of 1.0 hectares (0.5 ha with forest species, 0.3 ha with banana; and 0.2 ha with grain and sugar cane), through which, in a complete cycle of 18 years, 860.0 tonnes of carbon can be sequestered. However, this result applies only to this specific situation because the amount of carbon to be captured will depend directly on the composition of the agroforestry system. But, it is assumed that large-scale participation of small farmers tends to be relevant, contributing to environmental balance and food security.

In table 3 it is verified that, in detail, the basic information of each one of the alternatives suggested by this research. The growth data of the forest species were obtained from the **FLORAM Project** (USP). The CO₂ the emissions data were elaborated by the IVIG / COPPE / UFRJ team, after the bibliographic research, including: agricultural production data, EMBRAPA studies, and consultations in internet on the crops products methods that are part of the mathematical model (Table 1).

The Tables 4A/4B exemplify the results of the Brazilian productions of bananas and soybeans, which occurred between 2000 and 2012; and the table 5 presenting the suggestions for to mitigate the respective emissions. For its part, the table 6 summarizes the results of the mitigation alternatives of all the cultures agricultural: permanents and temporary, highlighting the fact that bananas and soybeans occupy the extremes of the ranking. According to this table, banana cultivation, in Brazil, launched for the atmosphere, during 13 years (2000 to 2012), only 6.90 thousand tons of CO₂; while soybean 5.60 million toneladas.

Finally, table 7 presents the ranking that shows, in descending order, the cultures that consumed more diesel oil and more emitted CO₂ for the atmosphere, with the respective conversion to consumption in ton of oil equivalent (tOE) during the 13 years. Note the fact that banana and soybean crops occupy the extremes of the ranking, probably both in Brazil and in all other Latin American countries.

Table 4a. BANANA PRODUCTION RESULTS

	2000	2001	...	...	2011	2012	Total
PRODUCTION – Cargo transported per year (thousands tons)	7,451.5	6,838.7			7,262.9	6,786.7	90,580.5
[25] Average Annual Production							6,967.7
MECHANIZATIONS DATA and CULTURAL TREATMENTS							
Nº of hectares with Mechanization (Planting, Maintenance and harvest - 1000 ha)	47,23	51.03	...	...	75.86	78.53	
Estimate Average Diesel Oil Consumption (Liters per hectare)	44,0	44,0	...	...	44,0	44,0	
Consumption Total Diesel Oil in Mechanization (Liters)	2,078,010.0	2,245,377.2			3,337,620.0	3,455,100.0	35,758,125.4
TRANSPORTATION OF THE PLANTATION AREA TO THE TRADE							
Distance Traveled - Transportation: round trip (km)	133,062	122,120	...	...	129,694	121,191	
Nº of Trips per Year	532	488	...	...	519	485	
Cargo Carried per Day (1000 ton)	36.53	33.52	...	...	35.60	33.27	
Total Consumption of Diesel Oil to the Distributor (Liters)	33,265.4	30,529.9	...	...	32,423.5	30,297.8	404,377.3
DIESEL and ENERGY CONSUMPTION ESTIMATE							
Estimate Total Consumption Diesel Oil (L/year)	2,111,275.4	2,275,907.1	...	...	3,370,043.5	3,485,397.8	36,162,502.7
Estimate Total Consumption Diesel Oil (m³/year)	2,111.28	2,275.91	...	...	3,370.04	3,485.40	36,162.5
Estimate Total Consumption Diesel Oil (ton/year)	1,773.5	1,911.0	...	...	2,830.8	2,927.7	30,376.5
Consumption of Diesel Oil (Ton Oil Equivalent - tOE/year)	1,504.7	1,621.2	...	...	2,400.5	2,482.7	25,760.1
ESTIMATE OF THE CO₂ EMISSIONS (ton)	5,215.7	5,622.4	...	...	8,325.35	8,610.32	89,335.8
GENERAL AVERAGE CO₂ EMISSIONS (13 year) (ton)							6,872.0
TOTAL CONSUMPTION ENERGY (TJ)							1,206.2

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Table 4B. SOYBEAN PRODUCTION RESULTS

	2000	2001	...	...	2011	2012	Total
PRODUCTION – Cargo transported per year (thousands tons)	38,823.61	37,905.72	...	...	74,815.46	81,486.8	718,086.6
[25] Average Annual Production							55,237.4
MECHANIZATIONS DATA and CULTURAL TREATMENTS							
N° of hectares with Mechanization (Planting, Maintenance and harvest - 1000 ha)	12,324.31	12,589.52	...	...	21,647.17	24,949.35	
Estimate Average Diesel Oil Consumption (Liters per hectare)	118	118			118	118	
Consumption Total Diesel Oil in Mechanization (Liters)	1,429,619,878.8	1,460,383,844.4	...	...	2,511,071,604.0	2,894,124,600.0	28,020,466,083.6
TRANSPORTATION OF THE PLANTATION AREA TO THE INDUSTRY							
Distance Traveled - Transportation: round trip (km)	1,094,120	1,263,524	...	...	2,493,849	2,716,227	
N° of Trips per Year	186,000,451	214,799,059	...	...	461,758,756		
Cargo Carried per Day (1000 ton)	241,350.07	278,718.50	...	...	550,113.67	599,167.68	
Total Consumption of Diesel Oil to the Industry (Liters)	66,428,732.5	76,713,949.6	...	...	151,412,237.6	164,913,770.0	1,453,270,533.5
DIESEL and ENERGY CONSUMPTION ESTIMATE							
Estimate Total Consumption Diesel Oil (L/year)	1,496,048,611.3	1,537,097,794.0	...	...	2,662,483,841.6	3,059,038,370.0	29,473,736,617.1
Estimate Total Consumption Diesel Oil (m³/year)	1,496,048.61	1,537,097.8	...	...	2,662,483.84	3,059,038.4	29,473,736.6
Estimate Total Consumption Diesel Oil (ton/year)	1,256,680.8	1,291,162.1	...	...	2,236,486.4	2,569,592.2	24,757,938.8
Consumption of Diesel Oil (Ton Oil Equivalent - tOE/year)	1,066,238.4	1,095,494.3	...	...	1,897,560.3	2,180,185.9	21,006,021.7
ESTIMATE OF THE CO ₂ EMISSIONS (ton)	3,695,836.9	3,797,244.74	...	...	6,577,397.23	7,557,045.11	72,811,887.3
GENERAL AVERAGE CO ₂ EMISSIONS (13 year) (ton)							5,600,914.4
TOTAL CONSUMPTION ENERGY (TJ)							22,074,472.9

Table 5. Suggested Options to Mitigate Carbon Dioxide (CO₂) Emissions / Comparative Table between Banana and Soybean Crops

AGRICULTURAL CROPS / ALTERNATIVES OF CARBON SEQUESTRATION		2000	2001	..	..	2011	2012	FOREST PLANTATIONS	
1ª OPTION:	REFORESTATION with <i>EUCALYPTUS SPP.</i>							GENERAL AVERAGE	
BANANA	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº de ha)	1.4	1.5	..	..	2.3	2.4	Nº of hectares	2.0
	# Nº OF TREES TO BE PLANTED	2,281	2,458	..	..	3,639	3,764	Nº of Trees	3,004.0
SOYBEAN	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº de ha)	1,010.3	1,038.0	..	..	1,798.1	2,065.9	Nº of hectares	1,531
	# Nº OF TREES TO BE PLANTED	1,616,519	1,660,873	..	..	2,876,881	3,305,369	Nº of Trees	2,449,779
2ª OPTION:	FOREST PROTECTION PROJECT + Forest Enrichment								
BANANA	# PROJECTION: Number of hectares to be isolated, with tree plantations	4.6	5.0	..	..	7.4	7.6	Nº of hectares	6.1
SOYBEAN	# PROJECTION: Number of hectares to be isolated, with tree plantation	3,283.6	3,373.7	..	..	5,843.7	6,714.1		4,976.2
3ª OPTION	IMPLANTATION OF AGROFORESTRY SISTEM (1st. Cycle)								
BANANA	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº de Ha)	1.7	1.9	..	..	2.8	2.9	Nº of hectares	59.0
	# Nº OF TREES TO BE PLANTED	1,250.0	1,347.0	..	..	1,964.0	1,962.0	Nº of trees	1,646.0
	# Nº OF BENEFICIARY FAMILY FARMERS (02 families / ha)	3,0	4.0	..	..	6.0	7.0	Nº of Producers Benefited	05
SOYBEAN	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº de ha)	1,239.8	1,273.9	..	..	2,206.5	2,535.2	Nº of hectares	3,180.8
	# Nº OF TREES TO BE PLANTED	885,606	909,905	..	..	1,576,092	1,810,838	Nº of árvores	1,342,105
	# Nº OF BENEFICIARY FAMILY FARMERS (02 families / ha)	1,240	2,548	..	..	4,413	5,070	Nº of Producers Benefited	3,663
4ª OPTION	URBAN AFFORESTATION PROJECT								
BANANA	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº hectares of reference)	1.0	1.1	..	..	1.6	1.7	Nº ha of reference	10.0
	# Nº OF TREES TO BE PLANTED	1,935.0	2,084.0	..	..	3,086	3,192.0	Nº of trees	2,548.0
SOYBEAN	# PROJECTION FOR EMISSIONS NEUTRALIZATION (Nº hectares of reference)	730	750	..	..	1,299.2	1,492.7	Nº ha de reference	7,473
	# Nº OF TREES TO BE PLANTED	1,370,853	1,408,467	..	..	2,439,677	2,803,046	Nº of trees	2,077,482

Model for Evaluating Diesel Consumption in Agriculture and CO₂ Emissions,
with Forest Projects to Extract Carbon from the Atmosphere

Table 6. ALTERNATIVES TO MITIGATE CO₂ EMISSIONS, BY TYPE OF CULTIVATION

PERMANENT CROPS								
	Average CO ₂ Emissions	Tons Oil Equivalent	OPTION 1		OPTION 2	OPTION 3	OPTION 4	
	(in 13 years)	tOE	N° of Trees	N° of Hectares	N° of Trees	N° of Hectares	N° of Trees	N° of Producers Benefited
Banana	6,872.0	1,981.5	3,004.0	2.0	2,548.0	3.90	1,646.0	5.0
Coffee and Cocoa	156,234.4	45,049.0	68,299.0	43.0	57,919.0	90.0	34,417.0	105.0
Coconut and Palm	43,703.3	11,946.8	19,105	12.0	16,202.0	25.0	10,467.0	29.0
Citrus Fruits	282,222.0	81,376.5	123,374.0	80.0	104,625.0	162.0	67,590.0	189.0
Tropical Fruits	135,658.6	39,141.7	59,343.0	37.0	50,324.0	77.8	32,511.0	91.0
Subtropical Fruits	313,171.3	90,300.5	136,904.0	85.0	116,099.0	179.0	75,003.0	210.0
Grape, Passion Fruit and Pepper of the Kingdom	34,245.6	9,874.5	14,971.0	9.0	12,696.0	19.6	8,202.0	23.0
Plant Extractivism (Palm Trees):	13,719.7	4,709.5	7,140.0	4.5	6,055.0	9.50	3,912.0	11.0
Plant Extractivism (Hardwoods):	30,180.7	10,359.9	15,707.0	10.0	13,320.0	20.6	8,605.0	24.0
SUBTOTAL (Permanentes)	1,016,007.6	294,739.8	447,847.0	280.0	379,786.0	587.4	245,351.0	687.0
CULTIVOS TEMPORÁRIOS (agribusiness)								
	Average CO ₂ Emissions	Tons Oil Equivalent	OPTION 1		OPTION 2	OPTION 3	OPTION 4	
	(in 13 Years)	tOE	N° of Trees	N° of Hectares	N° of Trees	N° of Hectares	N° of Trees	N° of Producers Benefited
Cotton (Herbaceous and Arboreal)	310,668.7	89,578.9	135,810.0	85.0	115,171.0	178.0	74,403	208.0
Sugar cane [*]	3,570,142.7	1,029,976.0	1,561,541.0	976.0	1,324,231.0	2,046.6	855,486	2,395.0
SOYBEAN [*]	5,600,914.4	1,615,847.8	2,449,779.0	1,531.0	2,077,482.0	3,210.7	1,342,105	3,582.0
SUBTOTAL (Temporários)	9,481,725.8	2,735,402.7	4,147,130	2,592.0	3,516,884.0	5,435.3	2,271,994	6,185.0
TOTAL	10,497,733.4	3,030,142.5	4,594,977	2,872.0	3,896,670.0	6,022.7	2,517,345	6,872.0

[*]In the calculation of the options to neutralize the CO₂ emissions of soybean and sugarcane crops, the compensation for the production of biodiesel and anhydrous ethanol was not deducted from the percentages of diesel consumption. These themes were not the object of this research.

Table 7. Ranking of Emissions by Type of Cultivation, in 13 Years

AGRICULTURAL CROPS		Average CO ₂ Emissions	tOE	TYPE
1*	SOYBEAN	5,600,914.4	1,615,847.8	T
2	Sugar cane	3,570,142.7	1,029,976.0	T
3	Subtropical Fruits	313,171.3	90,300.5	P
4	Cotton (Herbaceous and Arboreal)	310,668.7	89,578.9	T
5	Citrus Fruits	282,222.0	81,376.5	P
6	Coffee and Cocoa	156,234.4	45,049.0	P
7	Tropical Fruits	135,658.6	39,141.7	P
8	Coconut and Palm	43,703.3	11,946.8	P
9	Grape, Passion Fruit and Pepper of the Kingdom	34,245.6	9,874.5	P
10	Plant Extractivism (Palm Trees):	30,180.7	10,359.9	P
11	Plant Extractivism (Hardwoods):	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	

*Temporary crops

5. Conclusions

The mathematical model, in relation to the consumption of diesel oil and CO₂ emission, shows, numerically and comparatively, a great supremacy of soybean cultivation, in relation to the others researched plants, since the use of agricultural machinery is very high in all stages of production. Instead, in the banana plantations, the mechanization process is very low, both in Brazil and in the countries of the southern hemisphere, and little contribute to the emissions.

This study contribute with a policy of incentive to low carbon agriculture, elaborated by the Brazilian Agricultural Research Corporation (EMBRAPA- [24]).

A significant result obtained was the fact that research retrieved data on carbon fixation in tropical trees; and to present estimates of the growth cycles, which served as the basis for of carbon dioxide emissions mitigation options for atmosphere.

Summaries of the calculations made, both for banana and soybean cultivation; and for all the plantations analyzed - covering 13 years (2000 to 2012) -, can be found respectively in Tables 4, 4a and 6.

Finally, they conclude that if the carbon kidnapping proposals are adopted and / or transformed into public policies other additional benefits would be, directly or indirectly, achieved:

- # Generation of jobs and income in rural area;
- # Protection of soil, water and biodiversity;
- # Improvement of urban afforestation; and
- # Encouraging the implementation of agroforestry systems, contributing to the food security of small producers.

ANNEX I. LIST OF THE MAIN PRODUCTS OF THE EXTRACTIVISM IN BRAZIL

Source: Ministry of the Environment, (MMA / Brazil).

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