CARBON SEQUESTRATION OF INOCAS MACAUBA PLANTATIONS IN BRAZIL

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INOCAS

INNOVATIVE OIL AND
CARBON SOLUTIONS

INOCAS is a private corporation which aims to develop innovative solutions for the production of sustainable vegetable oils whilst contributing to the reduction of greenhouse gas emissions. INOCAS is developing the pilot Macauba Project in Brazil, in the Cerrado region of Alto Paranaíba, State of Minas Gerais, by planting 2.000 hectares of macauba (oil palm) in a silvopastoral system in partnership with smallholder farmers, in addition to operating an oil mill and a macauba seed germination laboratory. By 2030 INOCAS plans to escalate its plantation up to 30.000 hectares.

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ABSTRACT

Recovering degraded pasture areas in the Brazilian Cerrado is central to meeting both climate and production demands. Agroforestry is an option to increase carbon sequestration, offset greenhouse gas (GHG) emissions and reduce the carbon footprint of degraded pasture areas. In this context, the Macauba Project executed by the company INOCAS – Soluções em Meio Ambiente S.A. presents a valuable strategy through the establishment of Macauba (Acrocomia aculeate) - a palm native to the tropical region whose fruit is used as the primary ingredient in the production of an array of oils and bioenergy products - intercropped with livestock (silvopastoral) and grains (agrisilvicultural). The present study aims to estimate the potential of the INOCAS project to reduce GHG emissions in the Cerrado regions of Alto Paranaíba and North-West Minas Gerais state, Brazil. The project GHG emissions balance was estimate using the Verified Carbon Standards methodology (VCS-0017 and VCS-0026). Results showed that the carbon sequestration enabled by macauba agroforestry systems significantly enhances carbon sequestration and offsets the GHG emissions from the use of farm inputs *as well as the animals in silvopastoral areas. Compared to degraded pasture areas, the INOCAS project has the potential to reduce emissions at a rate of 20.75 tCO2/ha/y (tons of carbon dioxide equivalent per hectare per year) or 0.83 MtCO2e at the scale of the project target, 2,000 ha over a 20 year implementation period. This potential could be enhanced 37% by varying the macauba planting design and extent of the intercropping systems. Most of the GHG emissions offsets come from the carbon sequestration in the Macauba biomass. If scaled up on the 23 million hectares of potentially eligible degraded pasturelands in the Cerrado today, INOCAS' agroforestry production strategy would have the potential to offset the equivalent of almost 100% of the emission from the entire Brazilian agriculture sector in 2018, which represents close to 50% of the GHG emission reduction of the Brazilian pledge to the Paris Agreement in the year of 2030 while sustainably producing meat, grains, oils and biofuels. These results suggest that the INOCAS project represents an essential strategy for supporting large-scale improvements in the production of primary agricultural commodities in Brazil, providing the potential to meet future food demands while reducing the country's overall GHG emissions.*

Keywords:
Macauba (Acrocomia aculeate), mitigation of GHG emissions, agroforestry, Brazilian Cerrado

GLOSSARY

Activity Data: Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, land areas, management systems, lime and fertilizer uses are examples of activity data. (IPCC)

Reduction Potential: one of the most simplified forms of reduction potential is defined as a project or action that leads to lower levels of emissions than would have otherwise occurred under baseline emissions or business as usual.

Afforestation: Planting of new forests on lands that historically have not contained forests. (IPCC2)

Anthropogenic: Refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities. (USEPA2)

Baseline Emissions: A baseline is a measurement, calculation, or time used as a basis for comparison. Baseline emissions are the level of emissions that would occur without policy intervention or without implementation of a project. Baseline estimates are needed to determine the effectiveness of emission reduction programs (also called mitigation strategies).

Biogenic: Produced by the biological processes of living organisms. Note that the term “biogenic” refers only to recently produced (that is non-fossil) material of biological origin. IPCC guidelines recommend that peat be treated as a fossil carbon because it takes a long time to replace harvested peat.

Carbon Dioxide (CO2): A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth’s radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1. (IPCC2)

Carbon Dioxide Equivalent (CO2e): A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

Carbon Intensity: The amount of carbon by weight emitted per unit of activity data.

Carbon Sequestration: This refers to the capture of CO2 from the atmosphere and its long term storage in oceans (oceanic carbon sequestration), in biomass and soils (terrestrial carbon sequestration) or in underground reservoirs (geologic carbon sequestration).

Deforestation: Those practices or processes that result in the change of forested lands to non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present and contributing to carbon storage. (UNFCC)

Emissions: The release of a substance, usually a gas when referring to climate change, into the atmosphere. (USEPA1)

Emission Factor: A coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions. (IPCC)

Fossil Fuel: Geologic deposits of hydrocarbons from ancient biological origin, such as coal, petroleum and natural gas.

Fuel Combustion: Fuel combustion is the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus. (IPCC)

Global Warming Potential (GWP): An index, based upon radiative properties of different greenhouse gases relative to carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. (IPCC2)

Greenhouse Gas: Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapour, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrochlorofluorocarbons (HCFCs), ozone (O3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). (UNFCC)

Intergovernmental Panel on Climate Change (IPCC): Established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988, the purpose of the IPCC is to assess information in the scientific and technical literature related to the issue of climate change. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories. (USEPA1)

Land Use and Land Use Change: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on sources and sinks of greenhouse gases, or other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate, locally or globally. (IPCC2)

LULUCF: Acronym for "Land Use, Land Use Change and Forestry", a category of activities in GHG inventories.

Methane (CH_4): A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 28 times that of carbon dioxide (CO_2). Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, flooded rice fields, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion. The GWP is from the IPCC's Fourth Assessment Report (AR5).

Metric Ton: The tonne (t) or metric ton, sometimes referred to as a metric tonne (Mt), is an international unit of mass.

Nitrous Oxide (N_2O): A powerful greenhouse gas with a global warming potential of 265 times that of carbon dioxide (CO_2). Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, manure management, fossil fuel combustion, nitric acid production, and biomass burning. The GWP is from the IPCC's Fourth Assessment Report (AR5).

Reforestation: Planting of forests on lands that have previously contained forests but that have been converted to some other use. (IPCC2)

Sink: Any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere. (IPCC2)

INTRODUCTION

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the most comprehensive assessment of climate change undertaken so far, confirms that human influence on the climate system is evident and growing, with impacts observed across all continents and oceans. The IPCC is now 95 percent certain that greenhouse gas (GHG) emissions originated from human activities are the leading cause of current global warming (IPCC, 2014).

The Agriculture, Forestry and Other Land Use (AFOLU) sector is responsible for just under a quarter (~10–12 GtCO2eq/yr) of anthropogenic GHG emissions, mainly from deforestation and agricultural emissions from livestock, soil and nutrient management (IPCC, 2014), making the sector critical to meeting mitigation targets. As part of the land sector, agriculture has the potential not only to reduce emissions but also to sequester carbon. Global implementation of best agriculture and livestock interventions is estimated to provide 21- 40% of cost-effective (<20

USD/tCO2e) climate change mitigation needed in the sector through 2030 for limiting warming to 2°C (Wollenberg et al., 2016). Therefore, leveraging the mitigation potential in the sector is extremely important not only to meet emissions reduction targets but also to ensure food security (IPCC, 2014).

The Paris Agreement, adopted during the 21st session of the Conference of the Parties (COP 21), within the United Nations Framework Convention on Climate Change (UNFCCC), aims to maintain the global average temperature below 2 °C of pre-industrial levels. The signatory countries stipulate their Intended Nationally Determined Contributions (INDCs), which are the main commitments and contributions of the respective countries for the fulfilment of the agreement (UNFCCC, 2015).

The Brazilian NDC proposes to reduce greenhouse gas (GHG) emissions by 43% by 2030, compared to 2005 levels. For the agriculture sector, the primary emission source in Brazil, the Brazilian NDC pledged strength the "low-carbon agriculture plan" (ABC Plan) to promote sustainable practices in agriculture by reducing GHG emissions while maintaining profitability (Brazil, 2015; SEEG, 2019).

The ABC plan focuses on the implementation of agricultural practices which aim to restore 30 million hectares of degraded pastures by 2030, such as improved pasture management, no-tillage farming and agroforestry systems (Brazil, 2015). Agroforestry systems are land-use *management techniques that may combine trees and/or woody perennials, pasture and livestock, benefiting from ecological and economic interactions between its parts due to diversification of production (Feliciano et al., 2018).*

In this context, the Macauba Project, implemented by the company INOCAS - Soluções em Meio Ambiente S.A. (INOCAS Project), proposes a valuable option for tackling land degradation and helping to implement the Brazilian NDC in the Cerrado region, where the reality is of 23 million hectares of degraded pasture (equivalent to 60% of the area of Germany) (LAPIG, 2019). By establishing agroforestry systems with Macauba (Acrocomia aculeate), INOCAS is recovering degraded pasture areas in the Cerrado region of Alto do Paranaiba and Northwest of Minas Gerais state, Brazil.

The INOCAS Project's implementation strategy consists of partnering with local farmers over a 20-year period. Degraded pasture is recov-

ered by implementing agroforestry systems with macauba intercropped with pasture (silvopastoral) and/or grain (agrisilvicultural) production systems. Macauba is a tropical palm native to the tropical regions which produces a fruit containing a high oil content, which is the primary product in various industrial sectors, such as cosmetics, food, and bioenergy (biodiesel and biokerosene) (Cortez et al., 2014). Therefore, farmers enrolled in the INOCAS Project integrate palm trees in land-use planning in order to recover degraded pastures using agroforestry systems while diversifying and increasing farm production, resilience, and income.

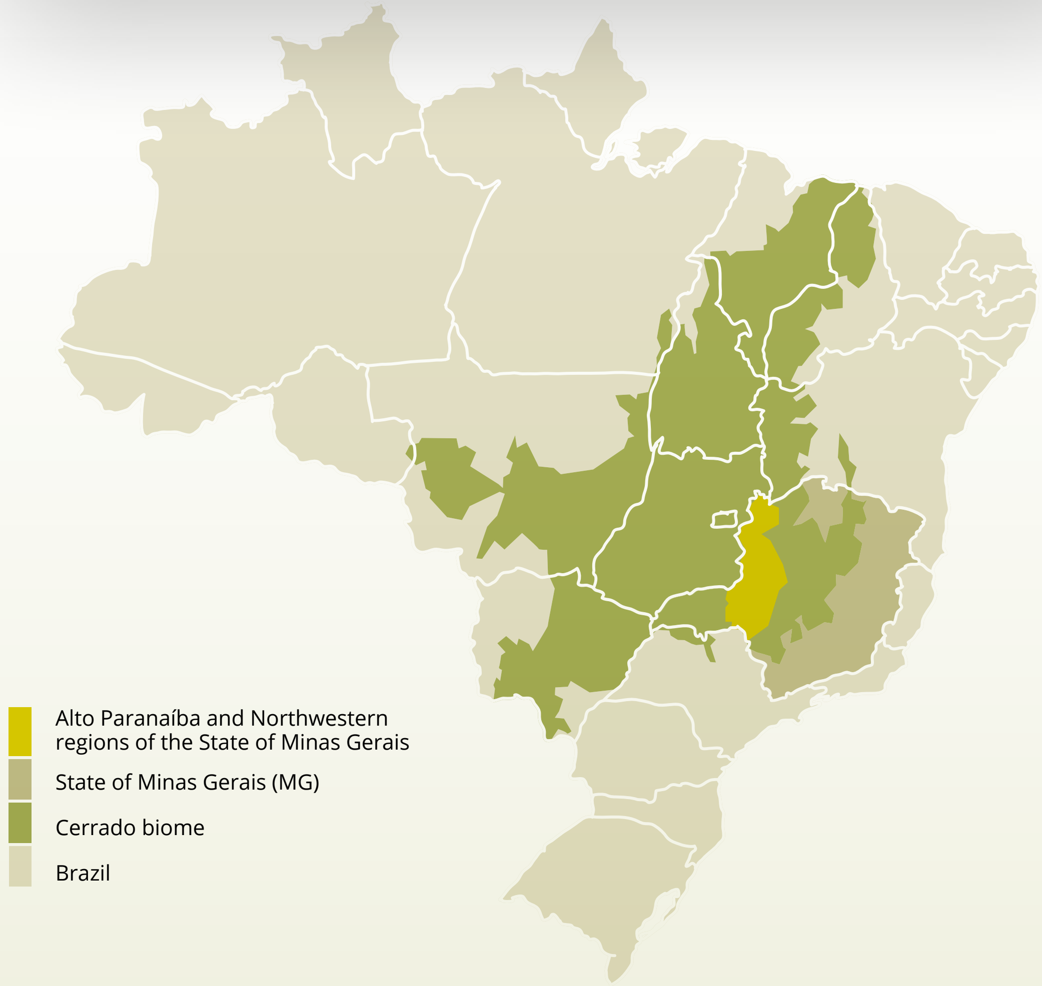
The INOCAS Project is committed to implementing 2,000 ha of agroforestry systems over the next 2 years, while also envisioning upscaling to 30,000 ha over the next decade. In this context, the objective of this assessment is to estimate the INOCAS Project's potential to reduce GHG emissions and sequester carbon in the Cerrado region of Alto Paranaíba and the surrounding Northwestern region of Minas Gerais State, Brazil.

MATERIAL AND METHODES

Systems analyzed

The present study focuses on analyzing the INOCAS Project strategy, which is to implement agroforestry systems with macauba plantations in the Cerrado region of Alto Paranaíba and the surrounding Northwestern region of Minas Gerais State, Brazil (Figure 1). The climate in the area is dry-winter humid subtropical and dry-winter subtropical highland (Cwa e Cwb – Köppen-Geiger classification). Average annual temperature and rainfall is about 22°C and 1,300 mm, respectively. The majority of soil type in the region is classified as latosols (Embrapa, 2006).

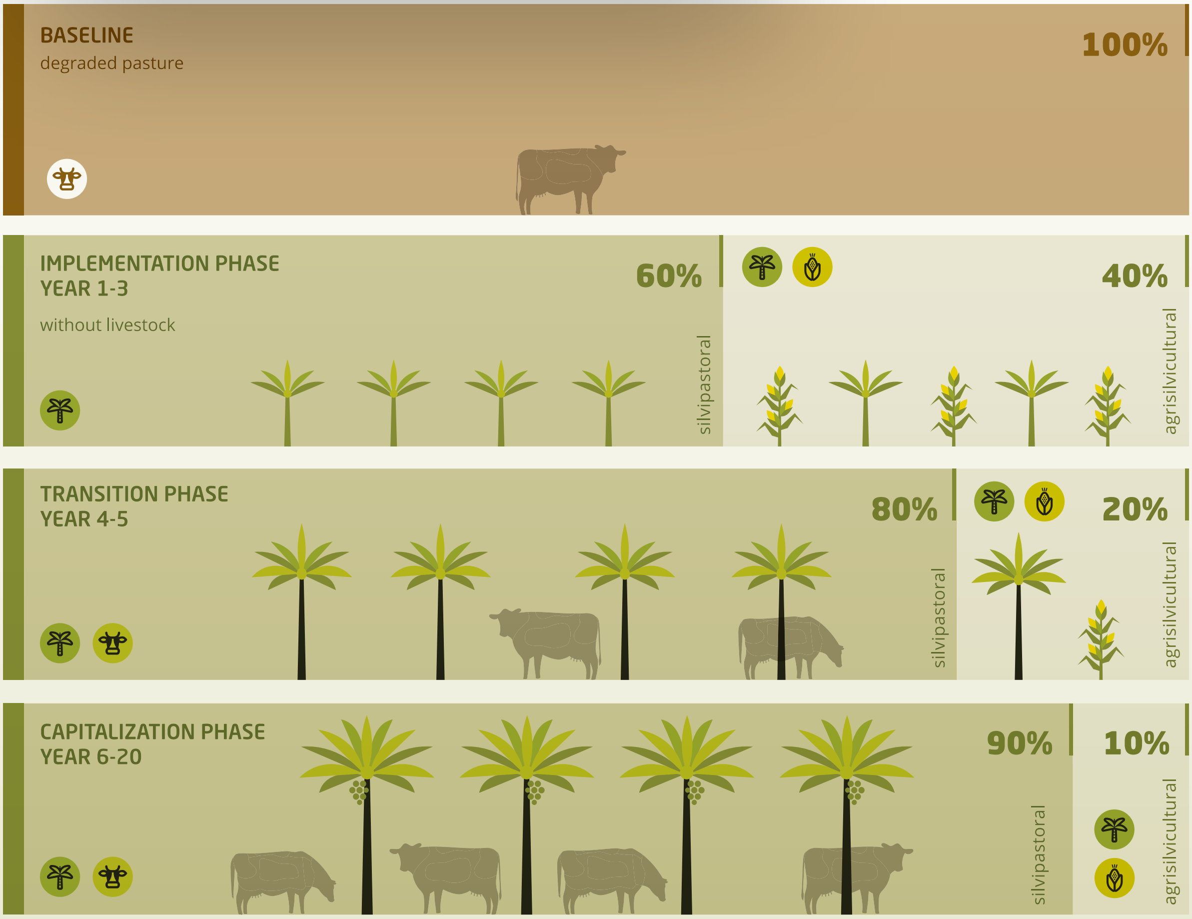
FIGURE 1. LOCATION OF THE CERRADO REGION OF ALTO PARANAIBA AND NORTHWESTERN MINAS GERAIS, BRAZIL.



This is one of Brazil's established agricultural producing regions, especially for coffee, grains, dairy and beef production. However, the INOCAS Project is implemented in areas mainly characterized by extensive cattle production systems with low investment in pasture and livestock management. Under these conditions, soils have become degraded, no significant quantity of soil inputs (i.e. fertilizers) are used, and pastures are able to hold no more than one animal per hectare. This scenario was assumed to continue in the absence of the INOCAS Project, therefore constituting the baseline scenario.

The INOCAS Project implementation strategy consists of partnering with local farmers for 20 years. Degraded pastures are recovered via implementing Macauba intercropped with pasture (silvopastoral) or agriculture (agrisilvicultural) production systems in three phases, here denominated: implementation, intermediary, and capitalization (Figure 2).

FIGURE 2. PHASES OF THE INOCAS PROJECT OVER 20-YEAR PERIOD



Implementation takes place from year 1 to year 3 of the project. It consists of soil preparation and fertility recovering, followed by the cultivation of Macauba seedlings using three plantation designs (5x5, 4x8, and 4x13; Figure 3). Pasture or crops are intercropped with macauba. Soil recovery consists of tilling (ploughing and harrowing), liming and applying fertilizers to the soil (urea and super triple phosphate) according to recommendations based on soil fertility analysis. During the implementation phase, farmers are not allowed to graze animals to avoid damages to the macauba seedlings but are allowed to keep the improved pasture or cultivating crops (Figure 2).

FIGURE 3. DIFFERENT MACAUBA PLANTING DESIGNS PROPOSED BY THE INOCAS PROJECT.

The intermediary phase comprises years 4 and 5 of the project, which is the period that farmers are allowed to keep growing crops or resume grazing animals in the improved pasture (Year 4), and start harvesting macauba fruits (Year 5). INOCAS Project estimate that during the intermediary phase 80% of the farms will carry out livestock practices and agriculture crops for the other 20% (Figure 2); corn (Z. Mays), rice (O. Sativa), beans (P. vulgaris), sorghum (S. bicolor), cassava (M. Esculenta), pineapple (A. Comosus), pumpkin (C. pepo) and watermelon (C. Lanatus) will be the significant cropping systems adopted by farmers. With the project implementation, it is expected pasture systems are improved to hold from 1 to 3.5 animals per hectare or from 0.85 to 2.98 animals per hectare averagely over 20 year of project implementation, depending on the Macauba plantation design (Table 1; Annex).

TABLE 1. DESCRIPTION OF BASELINE AND PROJECT LAND USE SCENARIOS OF INOCAS PROJECT (20 YEARS AVERAGE) IN BRAZIL*

Variable		Baseline	Project					
		Pasture	Macauba			Silvo-pastoral	Silvo-pastoral	Agrisilvi-cultural
			5 x 5 m	4 x 8 m	4 x 13 m	Pasture 1	Pasture 2**	Maize***
Soil Condition		Degraded	Improved			Improved	Improved	Improved
Use of Soil Inputs	N-Fertilizer (t N/ha/y)	0.0	0.10	0.07	0.05	0.13	0.07	0.10
	Lime (t/ha/y)	0.33	0.28	0.18	0.11	0.60	0.30	0.75
	Diesel (liter/ha/y)	5	16.30	12.65	8.65	8.50	4.25	50
Livestock	Heads/ha (age)	1 (12-24 months)	-	-	-	2.98 (12-24 months)	0.85 (12-24 months)	-
Palm trees	Number of trees	0	400	312.5	192.3	-	-	-

*each of the macauba spacing options will be combined either with pasture or cropping; see annex for detailed information;**Silvopastoral model suitable for the Macauba planting design 5x5 m ***other cropping system may apply, such as: rice (O. Sativa), beans (P. vulgaris), sorghum (S. bicolor), cassava (M. Esculenta), pineapple (A. Comosus), pumpkin (C. pepo) and watermelon (C. Lanatus).

The capitalization period comprises years 6 to 20 of the project, being the period that farmers will have fully consolidated their land use and management. During the capitalization phase the INOCAS Project estimates that 90% of the farms will carry out livestock practices and agriculture for the other 10% (Figure 2). In an attempt to be conservative in estimates, it is assumed that maize would be the main cropping systems adopted by farmers, once this cropping is one of the most GHG emissions intensive among the expected agriculture value chain within the INOCAS Project (Poore et al., 2018). The agroforestry systems with macauba will be sustained by intensified mechanization operations for regular applications of agriculture soil inputs, such as nitrogen fertilizer and lime (Table 1). It is estimate the INOCAS Project will implement the macauba planting design of 5x5, 4x8 and 4x13 at rates of 40%, 55% and 5% over the project area (Annex).

Greenhouse gas balance analyses

The analytical framework for evaluating the GHG emissions of the INOCAS Project is based on the approved Verified Carbon Standard (VCS) methodologies "Sustainable Grasslands Management" - VCS-0026 and "Adoption of Sustainable Agricultural Land Management" - VCS-0017 (VCS, 2014; 2011). The VCS-0026 and VCS-0017 were selected because of its ability to evaluate the reduction potential of GHG emissions of the scope of the INOCAS Project by considering the primary GHG sources (emissions) and sinks (removals) of the project:

1) Methane (CH_4) emissions caused by ruminant enteric fermentation;
2) CH_4 and direct and indirect nitrous oxide (N_2O) emissions by cattle manure;
3) N_2O emissions from the decomposition of crop residues;
4) N_2O and carbon dioxide (CO_2) emissions caused by the application to soils of synthetic nitrogen fertilizers (e.g. urea) and limestone (e.g. dolomite).
5) CO_2 emissions caused by the burning of fossil fuels used in machinery;
6) CO_2 removal from the atmosphere by (i) soil carbon sequestration in the recovery of degraded lands and (ii) above-and belowground trees (Macauba).

The scope of this work concentrates on on-farm emissions and removals (Figure 4). Therefore, no emissions from transport or manufacturing of soil inputs outside the farm area have been considered. Table 2 describes GHG sources (emissions) and sinks (removals) considered by the VCS-0026 and VCS-0017 methodologies, and their respective emission factors, which were gathered from a literature review and expert consultation. Calculations were restricted to 20 years, mainly because of issues related to the time-dependence of soil and tree carbon sequestration (Henry et al., 2009). Estimates were made using average values of 20 years of project implementation (Table 1; Table 2; Annex).

FIGURE 4. SCOPE OF THE GREENHOUSE GAS EMISSIONS ASSESSMENT OF THE BASELINE AND INOCAS' PROJECT SCENARIOS.

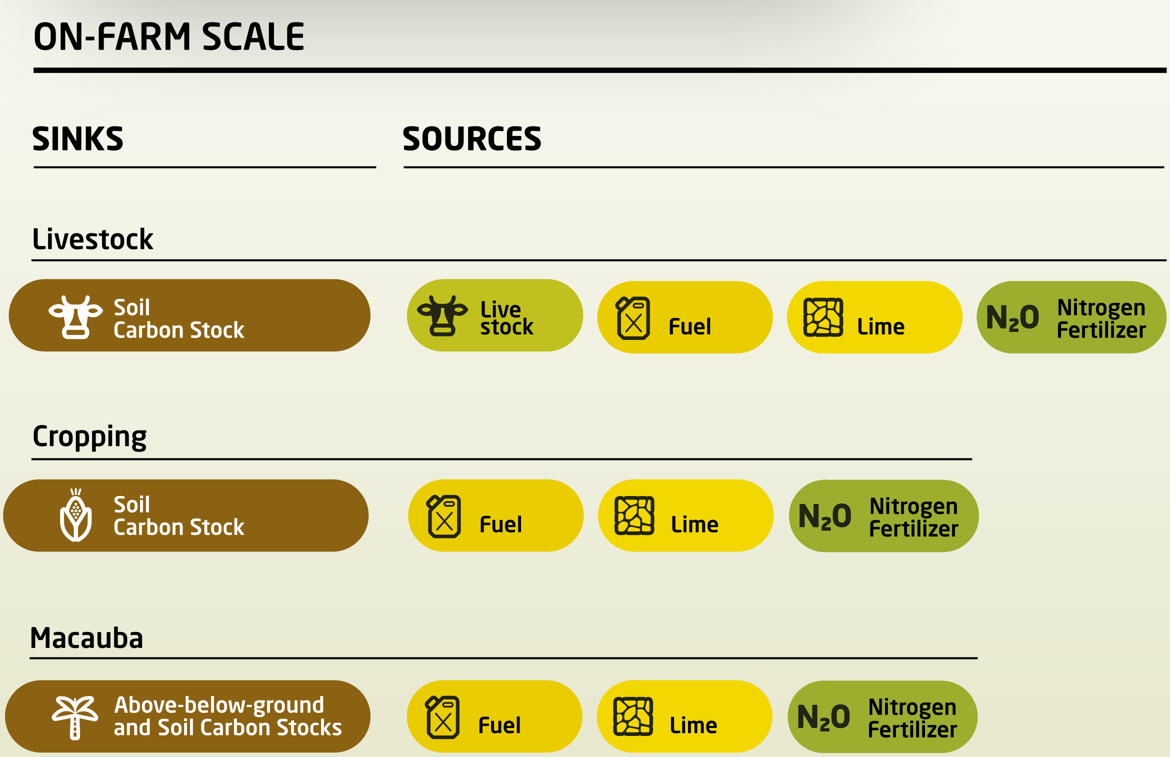


TABLE 2. GHG SOURCES INCLUDED AND EXCLUDED FROM THE PROJECT BOUNDARY AND EMISSION FACTORS USED IN THIS WORK.

Source	Gas	Included	Explanation/justification	Emission Factor	Reference
Use of fertilizer	CO2	Yes	Includes direct CO2 emissions from lime and urea (IPCC, 2006).	0.44 tCO2e / t lime applied	IPCC, 2006
	CH4	No	Not applicable	-	
	N20	Yes	Main gas for this source. This includes direct and indirect N2O emissions from synthetic nitrogen fertilizer use.	7.09 tCO2e / t N-urea applied (inc. CO2 emsisions)	IPCC, 2006
	Other	No	Not applicable	-	
Use of N-fixing species	CO2	No	Not applicable	-	
	CH4	No	Not applicable	-	
	N20	Yes	Main gas for this source. Where the area cropped with N-fixing species in the project is more than 50% larger than the area cropped with N-fixing species in the baseline, the project N2O emissions from the use of N-fixing species must be calculated.	Not applicable to INOCAS Project	
	Other	No	Not applicable.	-	
Burning of biomass	CO2	No	CO2 emissions from biomass burning in grass-land are not reported since they are largely balanced by the CO2 that is reincorporated back into biomass via photosynthetic activity.	-	
	CH4	Yes	Non-CO2 emissions from the burning of bio-mass.	Not applicable to INOCAS Project	
	N20	Yes	Non-CO2 emissions from the burning of bio-mass.	Not applicable to INOCAS Project	
	Other	No	Not applicable	-	

Source	Gas	Included	Explanation/justification	Emission Factor	Reference
Manure deposition on grassland	CO2	No	CO2 emissions from biomass decomposition are not reported since they are largely balanced by the CO2 that is reincorporated back into biomass via photosynthetic activity, within weeks to a few years after manure deposition.	-	
	CH4	Yes	Significant emission source.	(See Enteric Fermentation emissions)*	
	N20	Yes	Main gas for this source. The project emissions from manure and urine deposited on grassland soil during the grazing season include direct and indirect N2O emissions from manure and urine deposited on grassland soil during the grazing season.		
	Other	No	Not applicable.	-	
Farming machine	CO2	Yes	**CO2 emissions from fossil fuels used in farming machinery.**	**0.0027 tCO2e/liter of diesel**	
	CH4	No	Not main gas for this source. Excluded for simplification.	-	
	N20	No	Not main gas for this source. Excluded for simplification.	-	
	Other	No	Not applicable	-	
Animal respiration / Enteric fermentation	CO2	No	CO2 emissions from enteric fermentation are not reported since they are largely balanced by the CO2 that is reincorporated back into biomass via photosynthetic activity.	-	
	CH4	Yes	Main gas for this source.	1.72* tCO2e/head/y	MCTI, 2014
	N20	No	No N2O emissions from enteric fermentation.	-	
	Other	No	Not applicable.		
Wood perennials	CO2	Yes	Carbon sequestration from woody perennials – aboveground and below ground biomass.	-0.063 tCO2e/tree/y**	Moreira et al., 2020

Changes in soil organic carbon	CO2	Yes	Soil carbon is a major pool affected by changes in grassland management practices. Soils can remove carbon from the atmosphere when recovered and emit carbon to the atmosphere when degrading. VCS-0026 recommends the following options: Option 1: Estimate of project removals due to changes in SOC using a validated model. Option 2: Estimate of project removals due to changes in SOC using a measurement approach.	-2.24 tCO2e/ha/y***	Maia et al., 2009

*average for male and female beef cattle aging from 12 to >24 months for Minas Gerais state – includes emissions from manure deposited on pastures;**average values from annual macauba growth; ***data from meta-analysis for improved pastures in the Cerrado and Amazon regions; assumed here as a contribution of the agroforestry system: 50% from macauba (1.12 tCO2e/ha/y) and 50% from intercrop (pasture or annual cropping) (1.12 tCO2e/ha/y).

The balance (sum) of GHG emissions and removals from all sources were calculated at farm scale (Figure 4) and converted into CO2 equivalents (CO2e) (Table 2) using Global Warming Potential (GWP) factors provided by the IPCC (2013). For this work the GWP values of the latest IPCC assessment report (AR5; IPCC, 2013) were adopted that assumes a GWP value for CH4 and N20 of 28 and 265, respectively, and, finally, summed up as follows:

$$\text{GHG emissions Balance} = \text{GHG}_{\text{Sources (emissions)}} - \text{GHG}_{\text{Sinks (removals)}}$$

The results were further correlated with production variables described above to estimate GHG emission intensity metrics for the systems under analysis.

RESULTS

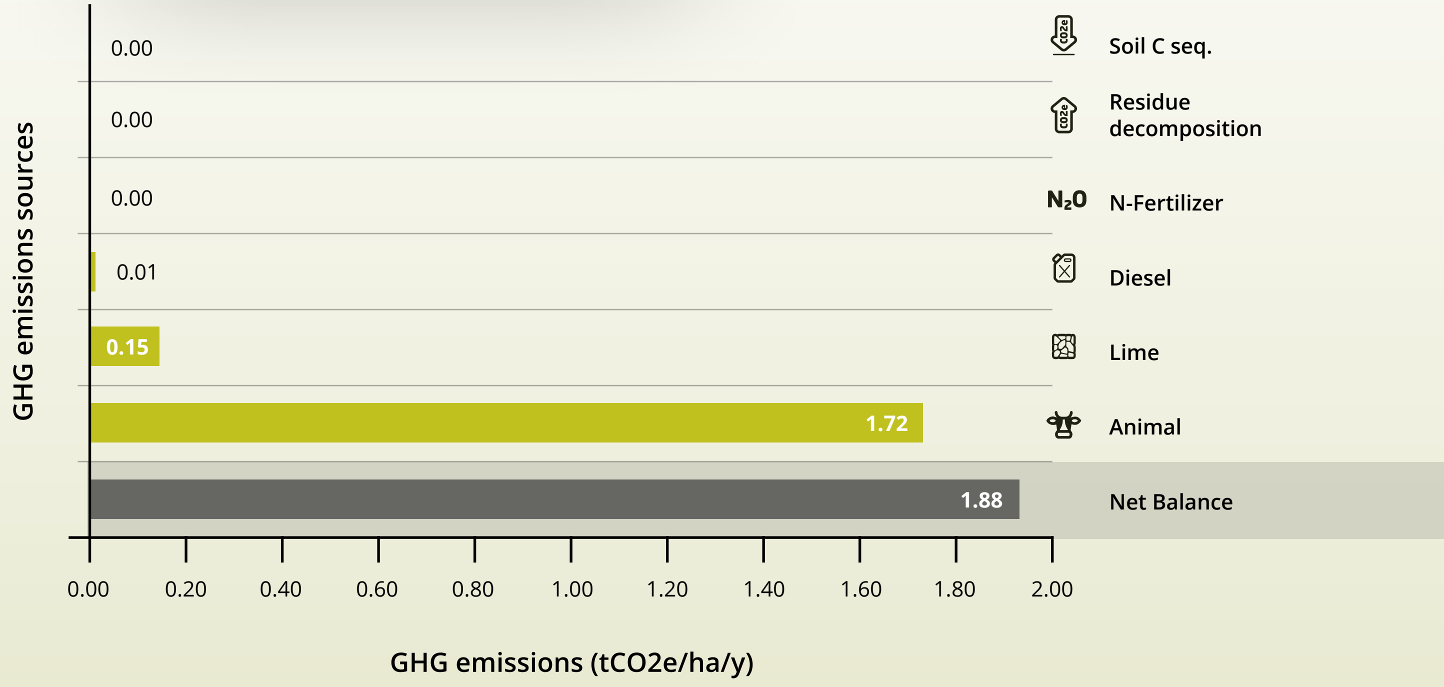
Baseline scenario - degraded pasture

Before the project implementation (baseline scenario), the GHG emissions from the degraded pasture area were estimated at 1.88 tCO2e/ha/y. Most of the GHG emissions from the baseline scenario came from the enteric fermentation and manure management (deposited on pasture) of the cattle (91%), with minor contributions from the use of lime and diesel (Figure 5).

Methane, a GHG 28 times more potent than CO2, is a by-product of enteric fermentation of ruminant livestock, and the amount emitted depends primarily on the number of animals, followed by the type and amount of feed consumed (IPCC, 2006).

Degraded soils are also a source of atmospheric GHG emissions. Degradation reduces the input of carbon from plant residues to the ground and increases soil organic matter decomposition, releasing CO2 and resulting in overall losses of soil carbon stocks. Pasture degradation in the Cerrado region has been reported to cause soil carbon losses at a rate of 1.03 tCO2e/ha/y (Maia et al., 2009). However, this emission source was not considered in the present study, in order to provide more conservative estimates (Figure 5).

FIGURE 5. GREENHOUSE GAS EMISSIONS FROM THE DEGRADED PASTURE SYSTEMS (BASELINE).



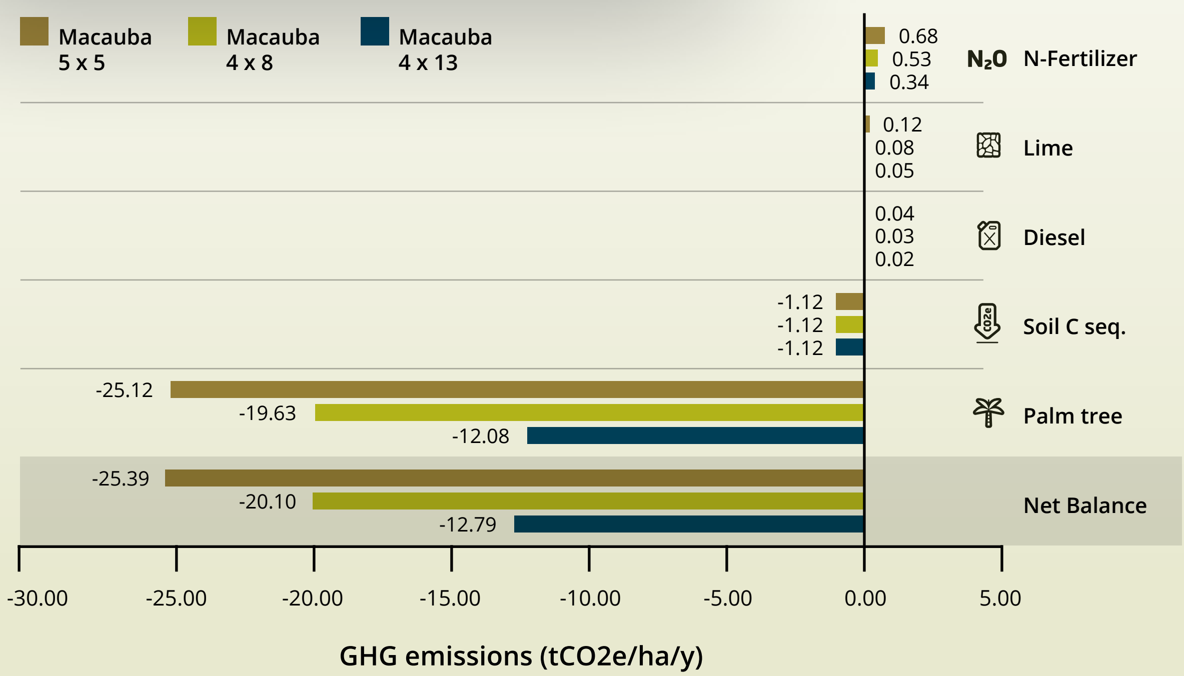
Agroforestry systems

Macauba component

The GHG emissions from macauba tree management evaluated in this work ranged from 0.41 to 0.85 tCO2e/ha/y, depending on the planting design (Table 3; Figure 6). Most emissions associated to the management of the palm tree come from the use of N-fertilizer (from 80 to 83%), diesel (from 5 to 6%) and lime (from 12 to 15%) (Table 3; Figure 6). Emissions from crop residues were considered negligible.

In general, the denser the Macauba plantations are, the more intense the use of farm inputs, especially nitrogen fertilizers and, consequently, the higher the associated GHG emissions (Figure 6; Table 3). The application of N-fertilizers to soils generally releases N2O, which is a potent greenhouse gas. This occurs primarily as a consequence of microbe-driven nitrification and denitrification processes in the soil (Butterbach-Bahl et al., 2013).

FIGURE 6. GREENHOUSE GAS EMISSIONS FROM THREE MACAUBA AGROFORESTRY PLANTING DESIGNS. NEGATIVE VALUES REFER TO CARBON SEQUESTRATION.



On the other hand, the adequate use of soil inputs supports the recovery of degraded pasture areas and more efficient growth of the macauba trees, promoting carbon sequestration able to offset the emissions of these processes accordingly (Figure 6). The establishment of macauba in degraded areas supplies organic matter to the soil (e.g. through roots exudates and senescent biomass) and, consequently, leads to soil carbon sequestration. As soil degradation reverses, the sequestration of carbon in the soil is estimated to occur at a rate assumed here as 1.12 tCO2e/ha/y (Table 2; 3).

In addition, the introduction of macauba into treeless agricultural systems promotes carbon sequestration in two further pools besides the soil: below- and above-ground biomass. According to the literature, the average rate of carbon sequestration in the below and above-ground biomass of macauba plantations comes to a total of 0.063 tCO2e/ tree/y (Moreira et al., 2020) or 25.12, 19.63 and 12.08 tCO2e/ha/y for the INOCAS plantation designs 5x5 (400 palm ha-1), 4x8 (312 palm/ha) and 4x13 (188 palm/ha), respectively (Figure 6; Table 3). This work did not touch upon possible deviations in soil carbon storage in the tree biomass as a consequence of the palm density. The values found in this work are in line with global estimates for above- and belowground carbon sequestration in agroforestry systems, which range from 12.33 to 45.25 tCO2e/ha/y (Feliciano et al., 2018).

TABLE 3. GHG EMISSIONS (SOURCES) AND CARBON SEQUESTRATION (SINKS) OF MACAUBA PLANTATIONS UNDER DIFFERENT PLANTION DESIGNES IN MINAS GERAIS STATE, BRAZIL*.

GHG emissions sources and sinks	Macauba planting design			
	5 x 5	4 x 8	4 x 13	INOCAS Project**
	tCO2e/ha/y			
N-Fert. N_2O	0.68	0.53	0.34	0.58
Lime	0.12	0.08	0.05	0.09
Diesel	0.04	0.03	0.02	0.04
Total Sources	**0.85**	**0.64**	**0.63**	**0.71**
Palm tree	-25.12	-19.63	-12.08	-21.45
Soil C	-1.12	-1.12	-1.12	-1.12
Total Sinks	**-26.24**	**-20.74**	**-13.20**	**-23.23**
Total	**-25.39**	**-20.10**	**-12.79**	**-21.85**

* The lower the total value the higher is the mitigation of GHG emissions and carbon sequestration.
**Considering that INOCAS Project will implement the macauba planting design of 5x5, 4x8 and 4x13 at rates of 40%, 55% and 5% over the project area.

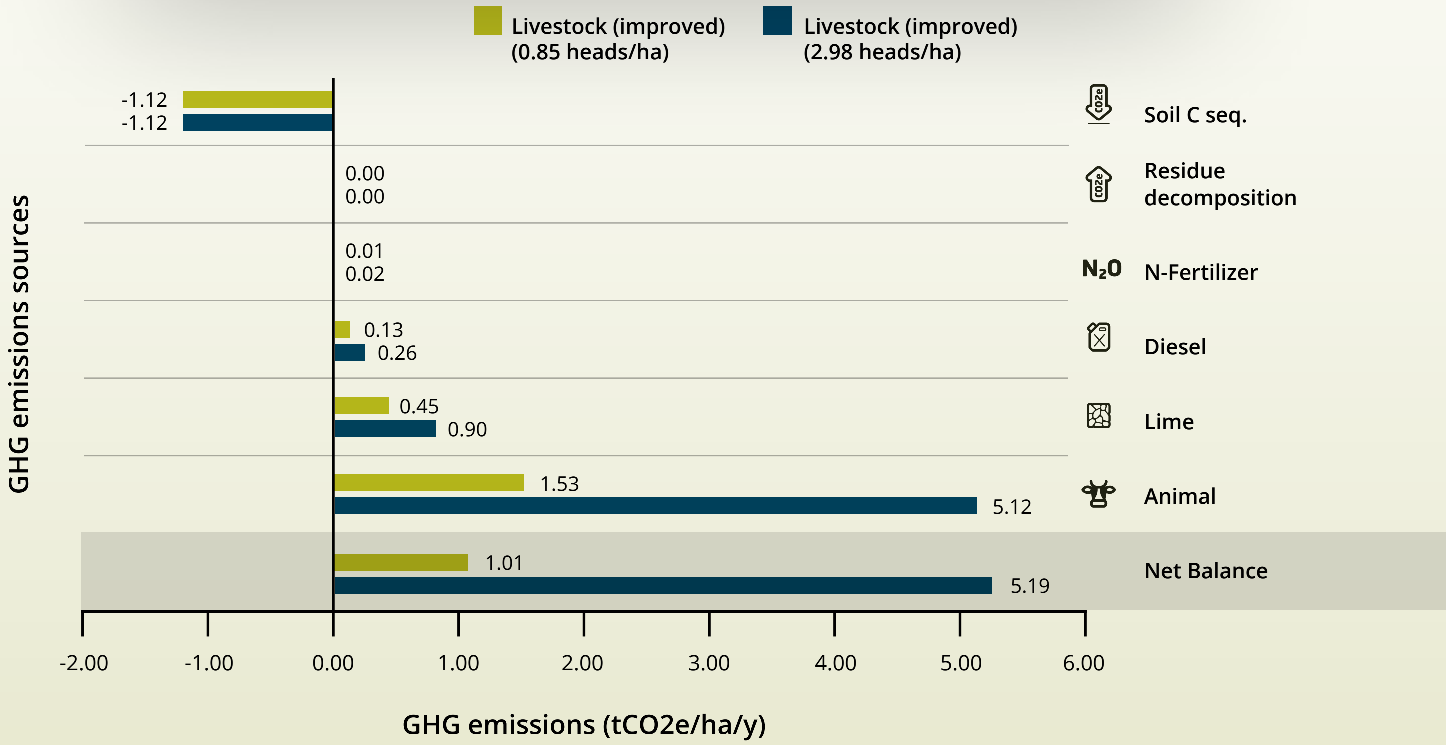
Therefore, the total carbon sequestration promoted by the implementation of the macauba (in the below and aboveground biomass and the soil) is estimate at 26.24, 20.74 and 13.20 tCO2e/ha/y for the macauba planting designs 5x5 (400 palm/ha), 4x8 (312 palm/ha) and 4x13 (188 palm/ha), respectively. The palm biomass carbon sequestration is at least 11 times higher than the soil carbon sequestration rate (1.12 tCO2e/ha/y) (Figure 6; Table 3).

As a result, the net GHG emission (emissions - removals) from the macauba plantations ranges from -12.79 to -25.39 tCO2e/ha/y; or -21.85 tCO2e/ha/y for the expected implementation of INOCAS plantations design of 5x5, 4x8 and 4x13 at rates of 40%, 55% and 5% over the project area, respectively. The 5x5 plantation design represents the highest mitigation potential, being 26% and 99% higher than the 4x8 and 4x13 designs, respectively (Table 3).

Pasture intercropped with macauba (silvopastoral system)

The implementation and management of pasture intercropped with macauba increases GHG emissions of the agroforestry system ranging from 2.13 (0.85 head/ha) to 6.31 (2.98 head/ha) tCO2e/ha/y. Most of these additional emissions from improved pastures comes from the higher cattle stocking rate but also from higher use of soil inputs for pasture maintenance, especially nitrogen fertilizer (Figure 7; Table 2).

FIGURE 7. GREENHOUSE GAS EMISSIONS FROM THE IMPROVED PASTURES UNDER TWO ANIMAL STOCKING RATES*



*Averaged for a period of 20 year; Expected animal stocking rate for macauba plantation designs 5x5 (brown) and 4x8 and 4x13 (blue).

The application of soil inputs supports pastures to improve the quantity and quality of forage and also to provide a more stable feed during the dry season, yielding substantial productivity benefits at area and animal basis (Gerber et al. 2013). As more feed is available on pastures, a more significant number of animals can graze in the same area. Hence, enhanced feed quality increases animal productivity and reduces GHG emissions of animal origin from lower enteric fermentation and manure (Herrero et al., 2016). The rate of feed energy converted to methane (CH_4) through enteric fermentation depends on the quality of the feed. Generally, low-quality forages have a higher rate of conversion than high quality feeds (IPCC, 2006).

As pasture improves, the higher biomass (forage) production also supplies organic matter to soils, leading to soil carbon sequestration, at a rate estimated here at 1.12 tCO2e/ha/y. The soil carbon sequestration under improved pastures offsets at least 17% of the total emissions and results in a net GHG emission balance (emissions - removals) from 1.01 to 5.19 tCO2e/ha/y for the improved pastures with 0.85 and 2.98 animal/ha, respectively (Figure 7) or 3.52 tCO2e/ha/y under the INOCAS project scheme (Figure 2; Table 2; 4).

As a result, the silvopastoral system, which is a target to be implemented in 90% of the total area during the capitalization phase of the INOCAS Project (Figure 2), promotes net GHG emissions (emissions - removals) of -18.34 tCO2e/ha/y. Thus, compared to the degraded pasture (baseline scenario), the implementation of the silvopastoral system reduces emissions by almost 10 times (Table 4).

TABLE 4. INOCAS' AGROFORESTRY SYSTEMS TOTAL POTENTIAL FOR REDUCING GHG EMISSIONS (SOURCES) AND SEQUESTERING CARBON (SINKS) COMPARED TO A DEGRADED PASTURE AREA (BASELINE) IN MINAS GERAIS STATE, BRAZIL (THE LOWER THE TOTAL VALUE THE HIGHER IS THE MITIGATION OF GHG EMISSIONS AND CARBON SEQUESTRATION).

Baseline — **Macauba-Livestock agroforestry**

GHG emissions and sinks (tCO2e/ha/y)	Baseline	Silvopastoral			Net GHG balance (Baseline and Sivopastoral)
	Degraded Pasture	Livestock	Macauba	Macauba + Livestok	
Animal	1.72	3.68	0.00	3.68	1.96
N-Fert. N_2O	0.00	0.72	0.58	1.30	1.30
Lime	0.15	0.21	0.09	0.31	0.16
Diesel	0.01	0.02	0.04	0.06	0.04
Sources	**1.88**	**4.63**	**0.71**	**5.35**	**3.47**
Palm tree	0.00	0.00	-21.45	-21.45	-21.45
Soil Carbon	0.00	-1.12	-1.12	-2.24	-2.24
Sinks	**0.00**	**-1.12**	**-23.23**	**-24.34**	**-24.34**
Total	**1.88**	**3.52**	**-21.85**	**-18.34**	**-20.22**

Baseline — **Macauba-Crop agroforestry**

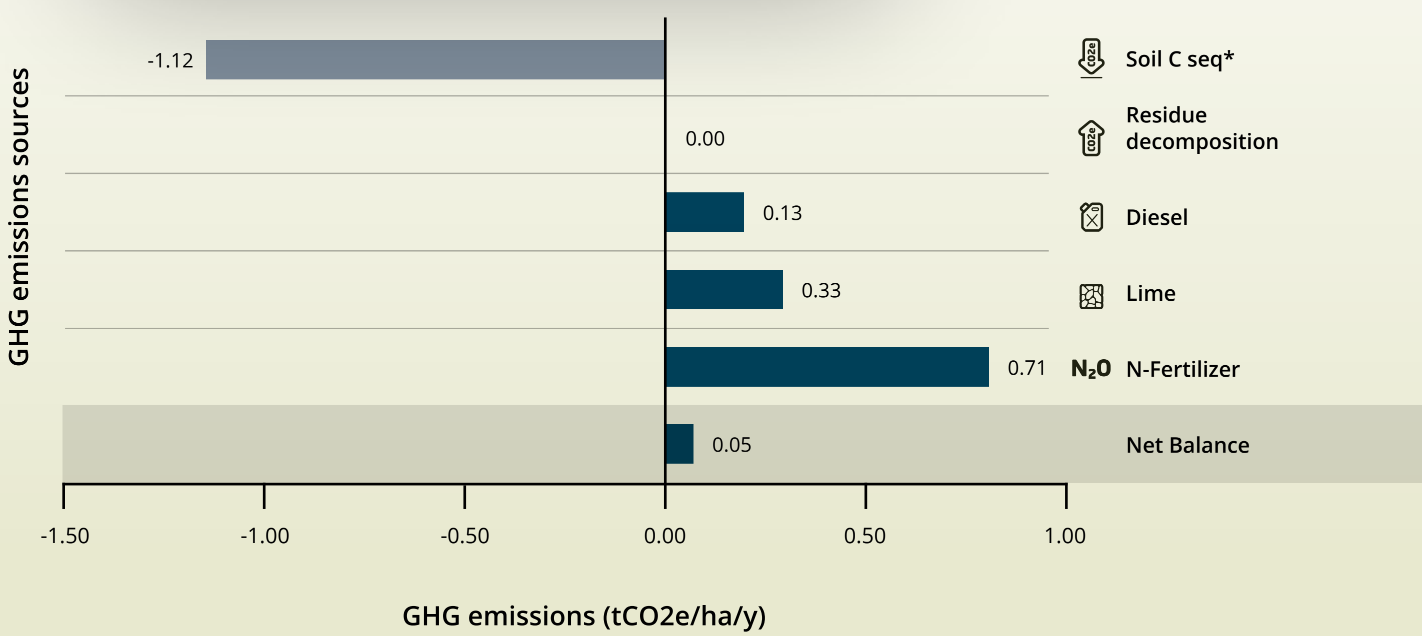
GHG emissions and sinks (tCO2e/ha/y)	Baseline	Agrisilvicultural			Net GHG balance (Baseline and Agrisilvicultural)
	Degraded Pasture	Crop	Macauba*	Macauba + Crop	
Animal	1.72	0.00	0.00	0.00	-1.72
N-Fert. N_2O	0.00	0.71	0.58	1.29	1.29
Lime	0.15	0.33	0.09	0.42	0.28
Diesel	0.01	0.13	0.04	0.17	0.16
Sources	**1.88**	**1.17**	**0.71**	**1.88**	**0.00**
Palm tree	0.00	0.00	-21.45	-21.45	-21.45
Soil Carbon	0.00	-1.12	-1.12	-2.24	-2.24
Sinks	**0.00**	**-1.12**	**-23.23**	**-24.34**	**-24.34**
Total	**1.88**	**0.05**	**-21.85**	**-21.80**	**-23.68**

*Considering that INOCAS Project will implement the macauba planting design of 5x5, 4x8 and 4x13 at rates of 40%, 55% and 5% over the project area.

Grains intercropped with macauba (agrisilvicultural system)

Implementing cropping systems (maize) intercropped with macauba palm trees increases GHG emissions of the agroforestry system by 1.17 tCO2e/ha/y. Most of the GHG emissions from cropping systems come from the use of nitrogen fertilizer/urea (61%), followed by liming (28%), the use of diesel in machinery for cropping operations (11%), and crop residue decomposition (<1%) (Table 4; Figure 8). Therefore, finding solutions for minimizing and improving the use of N-fertilizer are essential interventions for avoiding further GHG emissions from cropping systems (Figure 8; Table 4).

FIGURE 8. GREENHOUSE GAS EMISSIONS FROM MAIZE CROPPING THAT IS INTERCROPPED WITH MACAUBA IN AN AGROFORESTRY SYSTEM.



On the other hand, by enhancing the soil organic matter through reversing land degradation, the emissions from maize cropping are offset by 96% through the soil carbon sequestration (1.12 tCO2e/ha/y), resulting in net GHG emissions (emissions - removals) of 0.05 tCO2e ha/y (Table 4).

As a result, the agrisilvicultural system results in a net GHG emission of -21.80 tCO2e/ha/y, being almost 13 times lower than the baseline scenario and 23% lower than the silvopastoral system. The greater GHG emissions reduction from the silvigricultural system is primarily due to the absence of animals in the system, which is a significant source of GHGs (Table 1; 4). The agrisilvicultural systems are planned to be implemented on 40% of the area during the implementation phase, being reduced to 20% in the intermediary phase and then to 10% in the capitalization phase of the INOCAS Project (Figure 2).

INOCAS' Project potential to reduce net GHG emission

Compared to the baseline scenario, the net GHG emissions from adopting silvopastoral and agrisilvicultural systems with macauba on degraded pastures are estimated at -20.22 and -23.68 tCO2e/ha/y, respectively (Table 4). During the implementation phase, however, the INOCAS Project estimates that 40% and 60% of the degraded area will be recovered using agrisilvicultural and silvopastoral systems with Macauba, respectively. By transitioning to the capitalization phase, silvopastoral systems will take up 90% of the total area. Around 45%, 50% and 5% of the total area will adopt a Macauba plantation design with, respectively, 5x5, 4x8, and 4x13 spacing arrangements (Figure 3).

TABLE 5. THE INOCAS PROJECT'S GHG EMISSIONS REDUCTION POTENTIAL THROUGH THE IMPLEMENTATION OF AGROFORESTRY SYSTEMS ON DEGRADED PASTURE AREAS (BASELINE) IN MINAS GERAIS STATE, BRAZIL (THE LOWER THE VALUE THE HIGHER THE MITIGATION OF GHG EMISSIONS AND CARBON SEQUESTRATION).

	Agroforestry System		
INOCAS Project (over 20 years period)	**Macauba-Livestock**	**Macauba-Crop**	**Total**
Net GHG emission (tCO2e/ha/y)*	**-20,22**	**-23,68**	**-**
Phase 1 Implementation (3 years)			
Land use (% of the project area)	60%	40%	100%
Net GHG emission (tCO2e/ha)	-36,39	-28,42	-64,81
Phase 2 Intermediary (2 years)			
Land use (% of the project area)	80%	20%	100%
Net GHG emission (tCO2e/ha)	-32,35	-9,47	-41,82
Phase 3 Capitalization (15 years)			
Land use (% of the project area)	90%	10%	100%
Net GHG emission (tCO2e/ha)	-272,94	-35,52	-308,46
Total net GHG emission over 20 years (tCO2e/ha) (Phase 1 + Phase 2 + Phase 3)			**-415,09**
Total net GHG emission (tCO2e/ha/y)			**-20.75**

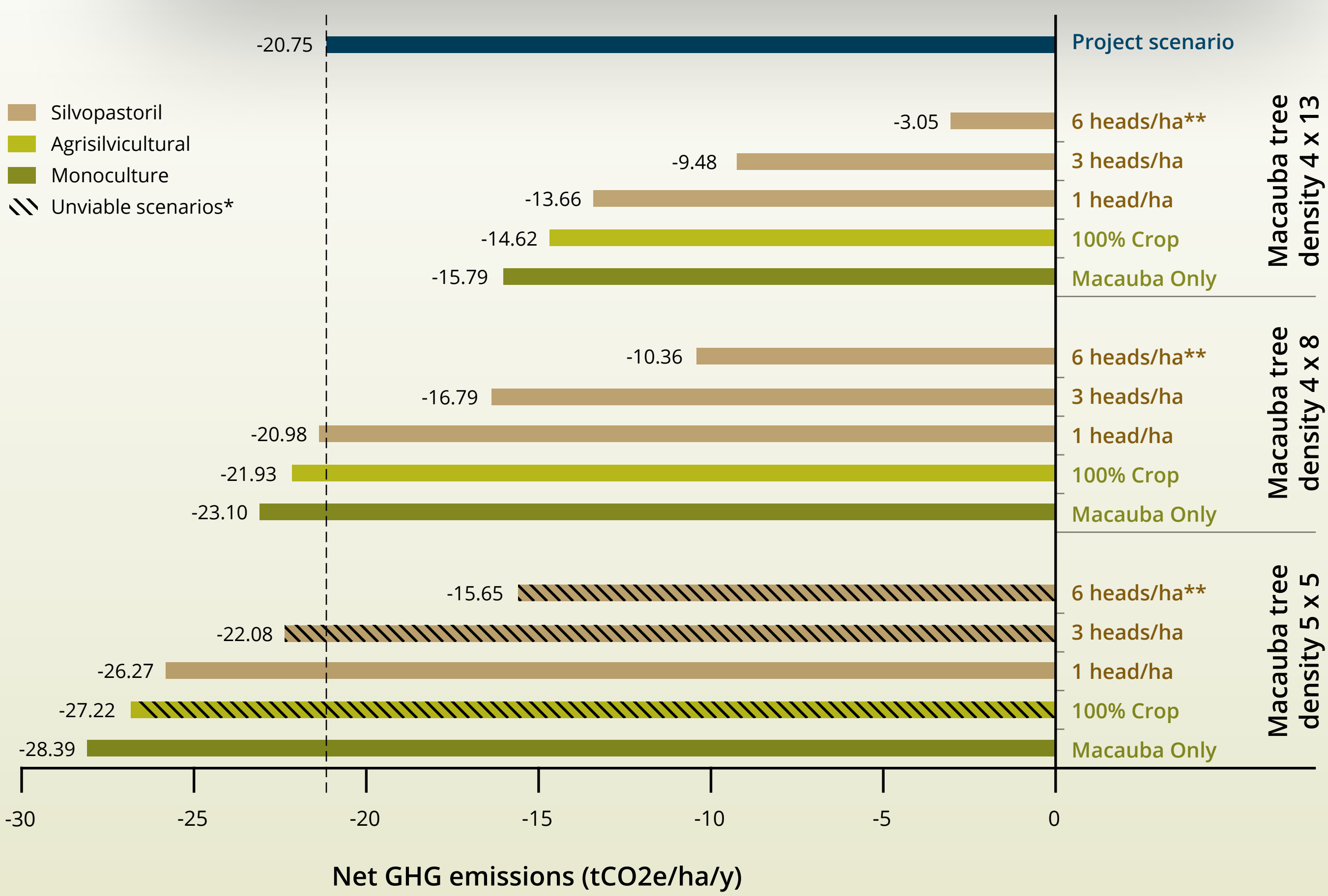
*compared to a degraded pasture areas as baseline (Table 4)

Therefore, the potential of INOCAS Project in reducing GHG emissions by recovering degraded pasture areas is estimated at 20.75 tCO2e/ha/y or 415.00 tCO2e/ha after 20 years of total project implementation (Table 4). By upscaling this model to 2,000 ha, the net GHG emission reduction is 0.83 MtCO2e (Table 5).

However, it is important to note that possible variations in the agroforestry systems arrangements proposed by INOCAS Project may significantly influence the project's potential to reduce emissions, for example, by varying the type of agroforestry, livestock stocking rate in silvopastoral systems, and macauba plantation designs

A sensitivity analysis on the INOCAS Project mitigation potential revels that out of 15 alternative scenarios, five are likely to increased mitigation potential compared to the expected Project scenario. All of them have up to six animal heads per hectare and two scenarios are no likely to occur due shading barriers promoted by the Macauba plantation within the 5x5 arrangement (Figure 9). The highest emission reductions are found only in the 5x5 macauba plantation design. This mitigation potential is reduced under silvopastoral systems and lower density of macauba plantations.

FIGURE 9. SENSIBILITY ANALYSIS OF INOCAS' PROJECT IN REDUCING GREENHOUSE GAS EMISSIONS BY VARYING MACAUBA PLANTATION DENSITY AND INTERCROPPING MANAGEMENT UNDER AGROFORESTRY SYSTEMS. (SEE TABLE 1).



*Scenarios no likely to occur due to barriers related to Macauba shading.

**Scenarios with 6 heads/ha assume doubling use of soil inputs for pasture maintenance.

Thus, if the INOCAS Project were scaled using only the 5x5 macauba plantation design, the mitigation potential of the project would be enhanced by 37% compared to the project scenario, reaching 28.39 tCO_2e/ha/y. On the other hand, a 4x13 macauba in silvopastoral system with six heads per hectare would reduce the project mitigation potential by 85% (Figure 9).

In addition, all scenarios evaluated in the present study suggest that farmers will be both more environmentally and economically resilient if they reverse land degradation, reduce GHG emissions and diversify farm activities and income. Under the INOCAS Project scenario, farmers will not only be able to improve livestock productivity in at least three times but also produce grains and raw material for biofuel production.

Macauba-endocarp biochar: a potential source of soil carbon sequestration

Biochar is a carbon-rich product resulting from the pyrolysis of organic residues. It has emerged as a potential solution to restore soils, increase agricultural performance and sequester carbon (Latawiec et al., 2019). Additional carbon sequestration by amending agricultural soils with biochar increases the agricultural soil carbon pool by converting non-recalcitrant carbon (crop residue biomass) to recalcitrant carbon (charcoal) through pyrolysis. Applied alone or combined with limestone or inoculant, biochar has also been shown to improve soil pH, nutrient content and water holding capacity (Castro et al., 2018; Majumder et al. 2019).

Macauba fruit by-product (endocarp) is a potential material to be transformed into biochar, to be applied to soils and increase carbon sequestration. It is estimated that each Macauba tree produces an average of 14 kg of endocarp annually over 20 years or 2.7, 4.4 and 5.6 t per ha in the 4x13, 4x8 and 5x5 plantation designs, respectively. Considering a 50% carbon content in endocarp and no losses during biochar manufacturing, the application of macauba endocarp biochar to soils would have the potential to sequester carbon at a rate ranging from 0.9 to 1.8 tCO_2e/ha/y.*

*Assuming no effects from biochar on increasing emissions of greenhouse gases from soil application and a carbon sequestration rate of 0.66 tCO_2e per ton of biochar applied to soils (Griscon et al., 2017).

(Foto: Leonardo Pimentel/UFV)

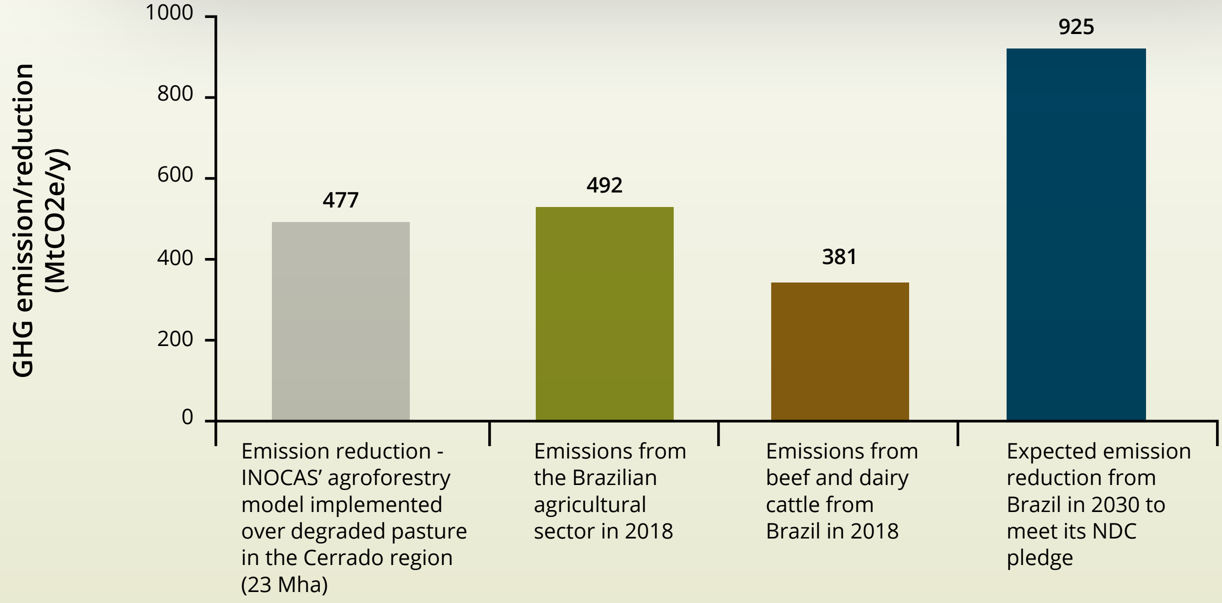
FINAL CONSIDERATIONS

Given the current, real threats of global warming and the mitigation potential of the land-use sector meeting future demand for agricultural products while lowering GHG emissions impacts seems to be the future of agricultural production (Poore & Nemecek, 2018; Griscom et al., 2017). These threats are especially real in Brazil's case: both one of the major global agricultural producers, and GHG emitters (FAOSTAT; SEEG, 2018).

Reducing GHG emissions from agricultural production can also be translated into improvements in production efficiency. So much so that recovery of degraded pastureland and implementation of integrated agricultural production systems is at the core of the Brazilian pledge to the Paris Agreement (Brazil, 2015).

The results of the present study show that impacts on GHG emissions through the implementation of agroforestry practices (silvopastoral and agrisilvicultural) in recovering degraded pastures can reduce GHG emissions by 20.75 tCO2e/ha/y. Given that close to 30% of the area of the degraded pasture area in Brazil is located in the Cerrado region (23 Mha; LAPIG, 2019), the INOCAS project may have a significant effect if scaled. Large-scale implementation of INOCAS Project agroforestry systems over the degraded pastures in the Brazilian Cerrado (23 Mha) may reduce 477 MtCO2e/year. This GHG mitigation volume could offset the equivalent of 125%

FIGURE 10. GHG EMISSIONS REDUCTION POTENTIAL OF SCALING THE INOCAS PROJECT TO THE TOTAL AREA OF DEGRADED PASTURES IN THE BRAZILIAN CERRADO (23MHA), COMPARED TO THE BRAZILIAN AGRICULTURAL SECTOR EMISSIONS AND THE BRAZILIAN NATIONALLY DETERMINED CONTRIBUTION (NDC) PLEDGED TO THE PARIS AGREEMENT.*



*BRAZIL. 2015. The Brazilian Government. Brazilian's Intended Nationally Determined Contribution (INDC); SEEG. 2018. System for Estimate GHG Emissions in Brazil.

of the Brazilian emissions from the beef and dairy cattle sectors in 2018 combined or almost 100% of the emission from the entire Brazilian agriculture sector in 2018, representing close to 50% of the GHG emission reduction of the Brazilian pledge to the Paris Agreement of 925 MtCO2e in the year of 2030 (Figure 10) (Brazil, 2015; SEEG, 2018).

Therefore, the INOCAS Project presents a critically important potential means of mitigating the environmental impacts of agriculture production. Reducing impacts means focusing on different issues for different producers and, by implication, adopting different practices. Providing producers with options to reduce their environmental impacts promotes far better decisions. It helps prevent unintended consequences, avoiding production proxies and assisting producers in navigating trade-offs and making choices that align with local and global priorities (Poore & Nemecek, 2018).

(Foto: Leonardo Pimentel/UFV)

CONCLUSION

The potential of the INOCAS Project to reduce the GHG emissions compared to the degraded pasturelands of the baseline scenario was estimated at 20.75 tCO2e/ha/y. In the full implementation phase of the INOCAS Project on 2,000 ha over 20 years, 0.83 MtCO2e in total GHG reductions will be achieved.

The sensitivity analysis revealed that out of the 15 alternative scenarios evaluated (varying extents of cropping and livestock within the three macauba plantation designs), five are likely to represent increased mitigation potential compared to the project scenario. The highest emissions reductions are displayed by the 5x5 design that does not include cropping or livestock. If the INOCAS plantations were scaled up using only the 5x5 planting design (without intercropping), the mitigation potential of the project would be enhanced by 37% compared to the project scenario, reaching 28.39 tCO_2e/ha/y. This mitigation potential is reduced as the animal stocking rate increases and the macauba plantation density decreases.

Large-scale implementation of INOCAS Project agroforestry systems on degraded pastures in the Brazilian Cerrado (23 Mha) would have the potential to reduce 477 $MtCO_2e$/year. This GHG mitigation volume could offset the equivalent of 125% of the Brazilian emissions from the beef and dairy cattle sectors in 2018 combined or almost 100% of the emission from the entire Brazilian agriculture sector in 2018, representing close to 50% of the GHG emission reduction of the Brazilian pledge to the Paris Agreement of 925 $MtCO_2e$ in the year of 2030 (Figure 10) (Brazil, 2015; SEEG, 2018).

The present study suggests that the INOCAS Project's innovations in terms of recovering degraded pastures represent a valuable strategy for supporting large-scale improvements in the production of major agricultural commodities in Brazil, while offering the potential to meet future food demands and diversifying farm activities and income, as well as reducing the country's overall GHG emissions.

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ANNEX. Activity data used for the GHG emission balance estimates

MACAUBA

		YEARS										
		Implementation of the Macauba										
		1	2	3	4	5	6	7	8	9	10-20	Mean 20
Density of palm trees	**4 x 8**											
Palm trees management		Left on the field			Left on the field							**312.5**
Inputs												
Nitrogen fertilizer - urea	t of N / ha / year	0.02	0.03	0.04	0.04	0.06	0.06	0.07	0.08	0.09	0.09	**0.07**
Liming - dolomite	t / ha / year	0.50	0	0	0.5	0	0	0.5	0	0	0.5 every 3 years	**0.18**
Fossil fuel use (machinery)	liters / ha / year	40.00	7	7	14	7	14	14	10	10	11.7	**12.65**
Soil Management		Soil plowing	No-tillage		No-tillage							
Density of palm trees	**5 x 5**											
Palm trees management		Left on the field			Left on the field							**400**
Inputs												
Nitrogen fertilizer - urea	t of N / ha / year	0.02	0.04	0.05	0.05	0.07	0.08	0.09	0.10	0.11	0.12	**0.10**
Liming - dolomite	t / ha / year	0.80	0	0	0.8	0	0	0.8	0	0	0.8 every 3 years	**0.28**
Fossil fuel use (machinery)	liters / ha / year	52.00	9	9	18	9	18	18	13	13	15	**16.30**
Soil Management		Soil plowing	No-tillage		No-tillage							
Density of palm trees	**4 x 13**											
Palm trees management		Left on the field			Left on the field							**192.3**
Inputs												
Nitrogen fertilizer - urea	t of N / ha / year	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	**0.05**
Liming - dolomite	t / ha / year	0.31	0	0	0.308	0	0	0.308	0	0	0.31 every 3 years	**0.11**
Fossil fuel use (machinery)	liters / ha / year	25.00	5	5	10	5	10	10	7	7	8	**8.65**
Soil Management		Soil plowing	No-tillage		No-tillage							

LIVESTOCK
(SILVOPASTORAL)

Implemented in silvopastoral with macauba planting design of 4x8 and 4x13m	YEAR	Before Macauba implementation	Implementation of Macauba			Livestock	Baseline	Project
		Baseline	1	2	3	4-20	Mean 20 years	Mean 20 years
HERD CATTLE								
Beef cattle Female between 12-24 months		1	**No cattle along this period**			3.5	1	**2.98**
Animal waste management								
Deposited on pasture	%	100				100	100	**100**
Soil condition	Improved (1) Degraded (2)	**2**	**1**	**1**	**1**	**1**	**2**	**1**
PASTURE								
Inputs								
Nitrogen fertilizer - urea	t N / ha / year	0	0	0	0	0.15	0	**0.13**
Liming - dolomite	t / ha / year	1	0	0	0	2 every 3 years	0.33	**0.60**
Fossil fuel use (machinery)	liters / ha / year	5	0	0	0	10	5	**8.50**
Soil Management		Soil preparation	Permanent grass			Permanent grass		

LIVESTOCK

(SILVOPASTORAL)

Implemented in silvopastoral with macauba planting design of 5x5 m

YEAR		Before Macauba implementation	Implementation of Macauba			Livestock	Baseline	Project
		Baseline	1	2	3	4-20	Mean 20 years	Mean 20 years
HERD CATTLE								
Beef cattle Female between 12-24 months		1	No cattle along this period			1	1	**0.85**
Animal waste management								
Deposited on pasture	%	100				100	100	**100**
Soil condition	Improved (1) Degraded (2)	**2**	**1**	**1**	**1**	**1**	**2**	**1**
PASTURE								
Inputs								
Nitrogen fertilizer - urea	t N / ha / year	0	0	0	0	0.15	0	**0.07**
Liming - dolomite	t / ha / year	1	0	0	0	2 every 3 years	0.33	**0.30**
Fossil fuel use (machinery)	liters / ha / year	5	0	0	0	10	5	**4.25**
Soil Management		**Soil preparation**	**Permanent grass**			**Permanent grass**		

CROPPING
(AGRISILVICULTURAL)

		YEARS				
		Implementation of the Macauba				
		1	**2**	**3**	**4-20**	**Mean 20**
Maize						
Productivity	t / ha / y	5.7	5.7	5.7	5.7	**5.7**
Crop residue management		Left on the field	Left on the field	Left on the field	Left on the field	**Left on the field**
Inputs						
Nitrogen fertilizer - urea	t of N / ha / year	0.10	0.1	0.1	0.1	**0.10**
Liming - dolomite	t / ha / year	1.50	0	1.5	1.5 every 2 years	**0.75**
Fossil fuel use (machinery)	liters / ha / year	50	50	50	50	**50**
Soil Management		**Soil plowing**	**No-till farming**		**No-till farming**	**1**

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