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EVALUATE OF CARBON FOOTPRINT IN SOYBEAN AND CORN CROPS IN MATO GROSSO

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Introdução
Mato Grosso will be the first state to use the ABNT PR 2060 technical standard to demonstrate carbon neutrality. Launched during the 27th United Nations Climate Change Conference, COP27, in Egypt, the new standard will support the Carbon Neutral MT Program, which plans measures to neutralize carbon emissions by 2035. An initiative by the state of Mato Grosso to reduce the carbon footprint was the creation of the Carbon Neutral MT program. Established by Decree 1,160/2021, the program aims to strengthen actions that contribute to sustainable development.

Problema de Pesquisa e Objetivo
In light of the initiatives proposed within the state, Mato Grosso stands out in the field of research related to the carbon market. The question arises: what is the contribution of soybean and corn crops in terms of carbon footprint in Mato Grosso?

Fundamentação Teórica
Quantifying the carbon footprint of agricultural production can help identify options for mitigating greenhouse gas emissions from agriculture. Using agricultural research data from eastern China, the carbon footprints of three major grain crops (rice, wheat, and corn) were assessed by quantifying greenhouse gas emissions from individual inputs and agricultural operations using a comprehensive life cycle assessment methodology.

Metodologia
The empirical strategy is based on the calculation model used by Cheng et al (2011). Data collection was performed by gathering information from IBGE (2023) for soybean and corn production, planted area, and average yield per hectare in the state of Mato Grosso, considering the period from 2004 to 2016. Subsequently, for the period from 2017 to 2022, information from the Mato Grosso Institute of Agricultural Economics (IMEA) was used. For the calculation of the PCA factor, the average values of active pesticide ingredients in kg/ha from 2019 to 2022 for the state of Mato on data Indea.

Análise dos Resultados
When analyzing the results of the annual CF, a reduction in carbon intensity values per quantity produced to 0.21980 in hectares is observed. When comparing the results obtained by Cheng et al. (2011), the average production intensity for the period from 1993 to 2007 was 0.110 tonC/ton while the average in the state of Mato Grosso for the soybean crop, for the period from 2004 to 2022, was 0.21980 tonC/ton

Conclusão
The work presented here can provide positive conclusions regarding the development of studies that can be applied to reduce the carbon footprint in the state of Mato Grosso. Comparing the results obtained by Cheng et al. (2011) to the present study, the carbon intensity for Mato Grosso from 2004 to 2022 averaged 0.21980 tons of carbon per ton of production, whereas Cheng et al.'s (2011) average for the period 1993 to 2007 was 0.110 tons of carbon per ton.

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Palavras Chave
Carbon footprint, Environmental indicator, Mato Grosso

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Abstract

Carbon footprint (CF) emerged with the intention of managing greenhouse gas emissions (GHG) and is one of the various ways to measure their impacts. This study aims to evaluate the CF in the agricultural sector of soybeans and corn crops in Mato Grosso, Brazil. The estimate was calculated taking into account the individual CFs of fertilizer use, electricity for irrigation, N2O emissions, and those from the use of pesticides. The estimate was made for the period from 2004 to 2022. The methodology used was based on the work of Cheng et al. (2011). When analyzing the results of the annual CF, a reduction in carbon intensity values per quantity produced to 0.21980 in hectares is observed. When comparing the results obtained by Cheng et al. (2011), the average production intensity for the period from 1993 to 2007 was 0.110 tonC/ton while the average in the state of Mato Grosso for the soybean crop, for the period from 2004 to 2022, was 0.21980 tonC/ton. When considering the corn crop, the results of carbon intensity per quantity produced were even smaller compared to soybeans, 0.08224 tonC/ton., which demonstrates that crop rotation is too important when measuring the CF in the agricultural sector.
keywords: Carbon footprint. Environmental indicator. Agricultural sector. Mato Grosso.

1. introduction

Mato Grosso will be the first state to use the ABNT PR 2060 technical standard to demonstrate carbon neutrality. Launched during the 27th United Nations Climate Change Conference, COP27, in Egypt, the new standard will support the Carbon Neutral MT Program, which plans measures to neutralize carbon emissions by 2035. An initiative by the state of Mato Grosso to reduce the carbon footprint was the creation of the Carbon Neutral MT program. Established by Decree 1,160/2021, the program aims to strengthen actions that contribute to sustainable development, generating a balance between emissions and removals of greenhouse gases (Mato Grosso, 2023). The goal is to achieve emission neutrality by 2035, 15 years ahead of the global goal, which is in 2050.

Through the PRO Carbono Commodities initiative, Bayer's global forest protection program, agribusiness is presented as a solution to climate change and biodiversity preservation. Measurement was done using the PRO Carbono Footprint tool, collaboratively developed through a partnership between Bayer and Embrapa, and based on an internationally recognized methodology, Life Cycle Assessment (LCA). The PRO Carbono Commodities program establishes as a prerequisite for participation that farmers have not converted natural vegetation areas into agricultural fields in the last 10 years, a practice aligned with international carbon certification standards. Furthermore, they commit to preserving the surplus of natural vegetation on their properties.

Approximately 4 million bags of soybeans from the 2022/2023 harvest, produced on an area of 159,000 arable hectares in Mato Grosso, were processed with a measured carbon footprint, tracked, and free from deforestation (DCF - Deforestation and Conversion FREE Soy). The program recorded primary data from the areas related to the 240,000 tons of soybeans produced and calculated an average carbon footprint of 861.55 CO_2 eq/t. (Source: Odocumento, 2023).

The agriculture sector is the largest contributor to anthropogenic greenhouse gas emissions (GHGs). Therefore, quantifying different agricultural practices is essential for identifying more sustainable ones. The carbon footprint has the potential to serve as a tool for assessing and comparing the GHG performance of different agricultural products, along with identifying points for improving environmental efficiency (Pandey & Agrawal, 2014).

Grain cultivation can be viewed as a system that incorporates the production of energy-rich materials through photosynthesis and the use of inputs highly dependent on fossil fuels, such as diesel, fertilizers, and pesticides (Pimentel & Pimentel, 2006). Due to the use of fossil fuel-dependent inputs, environmental issues such as global warming through GHG emissions have arisen (Cowell & Parkinson, 2003). Consequently, in addition to energy balance, there has been a need to determine the total GHG emissions associated with agricultural production. The carbon footprint represents this determination and is one of the metrics (impact categories) of the life cycle assessment of the agricultural production system (Rotz et al., 2010).

Managing the carbon footprint in the product chain is an important step in the effort to reduce GHG emissions and mitigate climate change (CARBON TRUST, 2006). An important criterion that has been used to assess the environmental sustainability of food production and distribution is the quantification of GHGs, such as carbon dioxide equivalent (CO_2 eq) (DREWNOWSKI et al., 2015), which are generated significantly from the field to consumption or disposal (GARNETT, 2013; ROY et al., 2009).

Climate change, such as temperature increase, is one of the highly influential factors in the agribusiness sector, given that it is one of the economic activities most sensitive to its variation, which can result in water stress and the incidence of pests and diseases, as observed in the quantity and quality of agricultural production in many producing regions (GROSSI et al., 2010).

The carbon footprint (CF) has gained significant academic visibility by providing effective results in managing GHG emissions, becoming an important tool for measuring their impacts. Its importance is mainly indicated by its estimate generated to reduce pollution levels and serve as an indicator of the sustainability of economic activities by quantifying the negative impact generated by the various stages that produce GHG emissions (CARBON TRUST, 2012; PANDEY et al., 2011; HERTWICH & PETERS, 2009).

It can be understood as a Life Cycle Analysis of various production sectors that generate impacts and GHGs, with various means of investigation (CUCEK et al., 2012). Its use also helps policymakers and decision-makers to more efficiently perceive the various socio-environmental interfaces presented by their enterprises or actions, contrasting with the usual view of "growth at the expense of the environment" (GALLI et al., 2012; MONTIBELLER et al., 2012).

In light of the initiatives proposed within the state, Mato Grosso stands out in the field of research related to the carbon market. The question arises: what is the contribution of soybean and corn crops in terms of carbon footprint in Mato Grosso?

This study aims to assess the carbon footprint in the soybean and corn agricultural sector in Mato Grosso, Brazil. This research seeks to contribute to the discussion and evaluation of the contribution of the soybean and corn sectors, two of the state's main commodity exporting crops, to the balance of emissions and global and regional climate change through the estimation of the carbon footprint in Mato Grosso..

2. Theoretical Framework

The concept of carbon footprint has evolved as an expression of greenhouse gas (GHG) intensity for activities and products. Public acceptance and the availability of GHG information have also attracted scientists and policymakers to review and refine their calculations. Standard methods for calculating the carbon footprint have been formulated, and industry-specific standards are under development. These standards guide the procedures for calculating the carbon footprint through life cycle assessment combined with GHG accounting, categorizing activities into three levels based on the order of emissions (Pandey & Agrawal, 2014).

The agricultural sector makes a significant contribution to total greenhouse gas (GHG) emissions. With high demand for food and population growth, the proportion of GHG emissions from the agricultural sector is rising. The total amount of GHGs (in terms of carbon equivalent (C-eq)) emitted by processes in the agricultural sector is considered the agriculture's carbon footprint. Various agricultural activities such as plowing, cultivation, fertilization, irrigation, crop variety, livestock farming, and related equipment emit a significant amount of GHGs, categorized into three levels of carbon footprint, separated by hypothetical limits (Jaiswal & Agrawal, 2020).

Energy input through machinery, electricity, livestock management, and fossil fuels constitutes a large proportion of carbon emissions from agriculture. The cereal cultivation system, in particular, produces higher GHGs than any other cultivation system, such as vegetables and fruits. Additionally, land-use changes, including the conversion of natural ecosystems into agricultural land, deforestation, and the burning of crop residues after harvest, contribute significantly to increased carbon emissions (Jaiswal & Agrawal, 2020).

Quantifying the carbon footprint of agricultural production can help identify options for mitigating greenhouse gas emissions from agriculture. Using agricultural research data from eastern China, the carbon footprints of three major grain crops (rice, wheat, and corn) were assessed by quantifying greenhouse gas emissions from individual inputs and agricultural operations using a comprehensive life cycle assessment methodology. The use of synthetic nitrogen fertilizers contributed 44–79%, and mechanical operations contributed 8–15% to the total carbon footprints. Irrigation and direct methane emissions significantly contributed 19% and 25%, on average, to rice production. However, irrigation was responsible for only 2-3% of the total carbon footprints in wheat and corn. The carbon footprints of wheat and corn production varied among climatic regions, largely explained by differences in nitrogen fertilizer inputs and mechanical operations to support crop management. Furthermore, a significant decrease (22-28%) in product carbon footprint, both for wheat and corn, was found on larger farms compared to smaller ones (YAN, Ming et al., 2015).

2.1 Related Research

Square 1 - Related studies

Autors	Theory	Material and methods	Results
Pandey, D., Agrawal, M. (2014).	The carbon footprint has the potential as a tool to assess and compare the greenhouse gas emissions (GHG) performance of different agricultural products, along with identifying points for improving environmental efficiency.	Case studies on the application of carbon footprint in cultivation practices.	A standard guideline addressing the carbon footprint specifically for agriculture is essential for the effective application of this tool in quantifying GHG intensity, mitigating global warming, and adapting to future climate change scenarios.
Jaiswal & Agrawal, (2020)	The review article will focus on the carbon footprint of agriculture, including inputs for energy use, fertilizers, organic fertilizers, pesticides, and processes that affect agricultural carbon emissions.	Effective mitigation practices in reducing the carbon footprint of various agricultural activities will also be reviewed.	
Zortea et al. (2018)	This study aimed to calculate emissions from changes in carbon stock due to land use change (LUC) for soybean cultivation in the state of Rio Grande do Sul.	Using the Tier 1 methodology from the IPCC (2006a), recommended in the guide for calculating carbon reserves in soils (EUROPEAN COMMISSION, 2010), and utilizing official national data on soybean expansion over 20 years, from 1992 to 2013.	For each hectare planted in the 2012/2013 crop season, only 15.4% comes from pasture areas, a lower figure than estimated in other studies that did not investigate potential soybean occupations during expansion.
Vasconcelos, Beltrão, & Pontes (2016)	The objective is, therefore, to use a carbon footprint indicator to estimate the GHG emissions generated in soybean production in the municipality of Paragominas-PA, from 1997 to 2013.	The carbon footprint was calculated using data on soybean production volume and planted area in the municipality of Paragominas. Afterward, the methodology of Cheng et al. (2011) was employed to assess its value. This methodology calculates the total Carbon Footprint by summing the individual carbon footprints from fertilizer use, electricity used for irrigation, pesticide use, and N2O emissions.	It is also inferred that the CF value is more closely related to the planted area than to soybean production itself because it is during planting that fertilizers and pesticides are used, which are reflected in the CF and CA values. The total production area directly influences the CI values and indirectly the other individual Footprints.
Campos et al. (2017)	The aim of this study was to establish the carbon footprint for the production of margarine and butter using ISO and PAS standards applied to a food company located in the southern region of	The LCA for margarine and butter was based on the Brazilian Standard (NBR) ISO 14040 (ABNT, 2009a), which defines the principles and structure, on NBR ISO 14044 (ABNT, 2009b),	The carbon footprint of butter is predominantly affected by milk production, followed by processing, packaging, and, with a relatively small impact, transportation. In the case

	Brazil, from the field stage to its packaged form.	which establishes requirements and guidelines, and on PAS 2050 (BSI, 2008), which specifies the assessment of GHG emissions in the life cycle of goods and services.	of margarine production, the predominant factor depends on the origin of the soybeans, with agricultural expansion using burning.
Cheng et al. (2011)	It reports a basic estimate of the carbon footprint of agricultural production using Chinese national statistical data for the period from 1993 to 2007.	The dataset includes the quantity of individual agricultural inputs (fertilizers, pesticides, diesel, plastic film), cultivated area, and total production of whole crops. Using estimated emission factors for China's agricultural characteristics, as well as those available from abroad.	Although there was a significant positive correlation between carbon intensity and total production, carbon efficiency showed a decreasing trend during 2003-2007. Therefore, low-carbon agriculture should be pursued, with a priority given to reducing fertilizer application in Chinese agriculture. However, for the development of better climate change mitigation management practices in Chinese agricultural production, further studies on crops, regions, and variations under different climatic conditions and agricultural management practices are necessary.
Yan et al. (2015)	Using agricultural research data from eastern China, the carbon footprints of three major grain crops (rice, wheat, and corn) were assessed by quantifying greenhouse gas emissions from individual inputs and agricultural operations using a comprehensive life cycle assessment methodology.	The carbon footprints of wheat and corn production varied among climatic regions, and this was largely explained by differences in nitrogen fertilizer inputs and mechanical operations to support crop management. Additionally, a significant decrease (22-28%) in the product carbon footprint, both for wheat and corn, was found on larger farms compared to smaller ones.	It demonstrated that the carbon footprint of agricultural production can be affected by farm size and climatic conditions, as well as crop management practices. Improving crop management practices, reducing the use of nitrogen fertilizers, and developing large-scale farms with intensive agriculture can be strategic options for mitigating climate change in Chinese agriculture.

3. Material and methods

In the first stage, a systematic review of the literature on carbon footprint-related studies was conducted. Data collection was performed by gathering information from IBGE (2023) for soybean and corn production, planted area, and average yield per hectare in the state of Mato Grosso, considering the period from 2004 to 2016. Subsequently, for the period from 2017 to 2022, information from the Mato Grosso Institute of Agricultural Economics (IMEA) was used. For the calculation of the PCA factor (Table 2), the average values of active pesticide ingredients in kg/hectares from 2019 to 2022 for the state of Mato Grosso, based on Indea (2023), were used and then calculated on a unit basis by dividing kg of pesticides by the planted area in hectares. The empirical strategy is based on the calculation model used by Cheng et al (2011) and follows the formula below:

$$CF_{(hectares)} = CFF_{(fertilizers)} + CFE_{(eletricity)} + CFN_{(emission\ N20)} + CFP_{(pesticides)}$$

CF represents the sum of the values resulting from the multiplication of the factors by the area in hectares. The CFF factor is the carbon footprint resulting from the use of fertilizers in hectares in Mato Grosso; CFE is the carbon footprint of electricity used for irrigation in hectares; CFN is the carbon footprint of N2O emissions in hectares; and CFP is the carbon footprint resulting from the use of pesticides in hectares. All individual values result from the multiplication of input data by the factors. The factors used here were also considered in the work of Cheng et al. (2011) and are presented in Table 1.

Table 1
Emission Factors by Type of Individual Footprint

Individual footprint	Emission Factor	Description
CFF	1,74	ton de C/ton de fertilizante N
CFF	0,2	ton de C/ton de fertilizante P
CFF		
CFF	0,15	ton de C/ton de fertilizante K
CFN	0,01	ton de N_2O de fertilizante N
CFP	4,93	ton de C/ton de total de agrotóxicos
CFE	0,74	ton de C/ha

Source: Cheng et al. (2011)

4. Results and discussions

The results presented here aim to demonstrate the role of maximum production efficiency, with an increase in planted area, average yield per hectare, and soybean production, while reducing the carbon footprint. Table 2 shows the unit values of each of the factors, as well as the quantity consumed per hectare in Mato Grosso, according to IBGE data. The last column shows the product of the factors per hectare, which will be subsequently used for calculating the carbon footprint when considering the planted area.

Table 2
Emission Factors, Usage in Mato Grosso, and Total per Hectare for Soybean and Corn Crops

Soybean crop			
Individual footprint	factors	Quantity consumed per hectare	total factors per hectare
CFF	2,09	300	627,00
CFN	0,01	300	3,00
CFP	4,93	4,72	23,27
CFE	0,74	200	148,00

Corn crop			
Individual footprint	factors	Quantity consumed per hectare	total factors per hectare
CFF	2,09	165	344,85
CFN	0,01	165	1,65
CFP	4,93	3,62	17,83
CFE	0,74	200	148,00

Source: IBGE (2023) e Indea (2023)

Tables 3 and 4 present the results of the product of total factors per hectare in Mato Grosso by the area in hectares for soybean and corn crops. The values are the result of calculations involving the application of fertilizer factors (627/ha), energy (148/ha), nitrous oxide (3.00/ha), and pesticides (23.27/ha) multiplied by the annual harvested area in hectares and then converted into tons. Finally, the sum of the results of these factors represents the total Carbon Footprint for Mato Grosso in tons per year. In Table 3, it can be observed that the Carbon Footprint of soybeans considering production factors has been increasing year by year due to the average yield of production. The same applies to the results of the Carbon Footprint for corn (Table 4).

Table 3
Calculation of the Carbon Footprint of soybean cultivation per ton in Mato Grosso - 2004 to 2022

Year	CFF	CFE	CFN	CFP	CF
2004	3.300.169,36	778.987,34	44.465,44	186.550,69	4.310.172,83
2005	3.828.872,06	903.784,79	56.077,40	216.436,99	5.005.171,25
2006	3.644.065,69	860.162,24	50.214,88	205.990,33	4.760.433,13
2007	3.182.074,53	751.111,69	42.935,17	179.875,07	4.155.996,47
2008	3.548.286,42	837.554,05	50.932,34	200.576,16	4.637.348,97
2009	3.656.330,44	863.057,26	52.483,21	206.683,63	4.778.554,54
2010	3.656.330,44	863.057,26	52.483,21	206.683,63	4.778.554,54
2011	4.046.865,54	955.240,99	60.412,54	228.759,64	5.291.278,71
2012	4.376.892,63	1.033.142,12	66.595,78	247.415,29	5.724.045,82
2013	4.961.881,75	1.171.225,68	72.647,65	280.483,32	6.486.238,39
2014	5.400.722,81	1.274.811,76	77.005,52	305.289,96	7.057.830,06
2015	5.622.107,73	1.327.068,49	85.542,12	317.804,32	7.352.522,66
2016	5.707.406,69	1.347.202,86	81.924,50	322.626,07	7.459.160,12
2017	5.960.681,19	1.406.986,95	97.951,28	336.943,07	7.802.562,48
2018	6.025.177,03	1.422.210,85	96.930,23	340.588,87	7.884.906,97

2019	6.260.761,22	1.477.819,24	106.210,52	353.905,88	8.198.696,85
2020	6.561.481,01	1.548.802,54	108.155,02	370.904,85	8.589.343,42
2021	7.193.003,23	1.697.869,98	122.516,36	406.603,29	9.419.992,86
2022	7.600.816,87	1.794.132,21	135.950,66	429.656,02	9.960.555,76

Source: IBGE (2023); Indea (2023) e IMEA (2023)

The calculation of Carbon Footprint and carbon intensity per quantity produced for soybean and corn in the state of Mato Grosso from 2004 to 2022 is presented in Tables 4 and 5. Carbon intensity per quantity produced in hectares represents the ratio between the Carbon Footprint (tons) and the quantity produced of soybean (tons) or corn (tons). The results show that despite the increase in the carbon footprint, the carbon intensity footprint ends up being diluted due to the quantity of planted and harvested area each year.

Table 4
Calculation of the Carbon Footprint of corn cultivation per ton in Mato Grosso - 2004 to 2022

Year	CFF	CFE	CFN	CFP	CF
2004	324.535,58	139.281,62	5.145,99	16.780,89	485.744,07
2005	359.959,60	154.484,62	5.208,22	18.612,58	538.265,02
2006	372.427,65	159.835,56	7.494,88	19.257,27	559.015,37
2007	568.544,19	244.003,31	9.004,22	29.397,95	850.949,67
2008	631.219,30	270.901,72	12.805,60	32.638,72	947.565,33
2009	573.447,62	246.107,72	13.499,34	29.651,49	862.706,17
2010	573.447,62	246.107,72	11.134,21	29.651,49	860.341,04
2011	662.491,68	284.322,95	12.809,23	34.255,73	993.879,59
2012	945.079,70	405.601,84	25.815,60	48.867,62	1.425.364,77
2013	1.178.249,34	505.671,75	33.306,68	60.924,22	1.778.152,00
2014	1.148.627,41	492.958,84	29.820,35	59.392,55	1.730.799,15
2015	1.231.323,48	528.449,69	35.231,17	63.668,55	1.858.672,89
2016	1.288.470,30	552.975,51	25.313,20	66.623,46	1.933.382,47
2017	1.631.796,12	700.321,37	46.635,38	84.375,95	2.463.128,83
2018	1.681.619,17	721.704,04	53.542,86	86.952,17	2.543.818,24
2019	1.868.888,46	802.074,79	58.493,28	96.635,38	2.826.091,92
2020	2.014.287,81	864.476,14	53.576,08	104.153,61	3.036.493,63
2021	2.464.695,49	1.057.778,55	72.333,75	127.443,02	3.722.250,82
2022	2.557.879,70	1.097.770,61	77.555,47	132.261,34	3.865.467,12

Souce: IBGE (2023); Indea (2023) e IMEA (2023)

Table 5
Carbon Footprint Intensity per hectare for soybean cultivation in Mato Grosso - 2004 to 2022

Year	area (ha)	Quantity of soybean produced (tons)	tonnes of soybeans produced per hectare	Carbon footprint (tons)	Carbon intensity per quantity produced
2004	5.263.428	14.821,81	2,816	4.310.173	0,29080
2005	6.106.654	18.692,47	3,061	5.005.171	0,26776

2006	5.811.907	16.738,29	2,880	4.760.433	0,28440
2007	5.075.079	14.311,72	2,820	4.155.996	0,29039
2008	5.659.149	16.977,45	3,000	4.637.349	0,27315
2009	5.831.468	17.494,40	3,000	4.778.555	0,27315
2010	5.831.468	17.494,40	3,000	4.778.555	0,27315
2011	6.454.331	20.137,51	3,120	5.291.279	0,26276
2012	6.980.690	22.198,59	3,180	5.724.046	0,25786
2013	7.913.687	24.215,88	3,060	6.486.238	0,26785
2014	8.613.593	25.668,51	2,980	7.057.830	0,27496
2015	8.966.679	28.514,04	3,180	7.352.523	0,25786
2016	9.102.722	27.308,17	3,000	7.459.160	0,27315
2017	9.506.669	32.650,43	3,434	7.802.562	0,23897
2018	9.609.533	32.310,08	3,362	7.884.907	0,24404
2019	9.985.265	35.403,51	3,546	8.198.697	0,23158
2020	10.464.882	36.051,67	3,445	8.589.343	0,23825
2021	11.472.094	40.838,79	3,560	9.419.993	0,23066
2022	12.122.515	45.316,89	3,738	9.960.556	0,21980

Source: IBGE (2023); Indea (2023) e IMEA (2023)

When analyzing the results regarding the annual Carbon Footprint, a reduction in the carbon footprint intensity is observed due to the increase in soybean cultivation area in Mato Grosso. It can be inferred that the CF value is more closely related to this planted area than to soybean production itself.

When comparing the results obtained by Cheng et al. (2011), the average production intensity for the period from 1993 to 2007 was 0.110 tonC/ton, while the average for the state of Mato Grosso, in the period from 2004 to 2022, was 0.21980 tonC/ton. When looking at the results for corn cultivation, a similar reduction in carbon intensity per unit of production is observed, on a larger scale compared to soybean cultivation, since a smaller amount of pesticides is used, and corn productivity increases.

Table 6
Carbon Footprint Intensity per hectare for corn cultivation in Mato Grosso - 2004 to 2022

Year	area (ha)	Quantity of corn produced (tons)	tonnes of corn produced per hectare	Carbon footprint (tons)	Carbon intensity per quantity produced
2004	941.092	3.118,78	3,314	485.744	0,15575
2005	1.043.815	3.156,50	3,024	538.265	0,17053
2006	1.079.970	4.542,35	4,206	559.015	0,12307
2007	1.648.671	5.457,10	3,310	850.950	0,15593
2008	1.830.417	7.760,97	4,240	947.565	0,12209
2009	1.662.890	8.181,42	4,920	862.706	0,10545
2010	1.662.890	6.748,01	4,058	860.341	0,12750
2011	1.921.101	7.763,17	4,041	993.880	0,12802
2012	2.740.553	15.645,82	5,709	1.425.365	0,09110
2013	3.416.701	20.185,87	5,908	1.778.152	0,08809
2014	3.330.803	18.072,94	5,426	1.730.799	0,09577
2015	3.570.606	21.352,22	5,980	1.858.673	0,08705

2016	3.736.321	15.341,33	4,106	1.933.382	0,12602
2017	4.731.901	28.263,87	5,973	2.463.129	0,08715
2018	4.876.379	32.450,22	6,655	2.543.818	0,07839
2019	5.419.424	35.450,47	6,541	2.826.092	0,07972
2020	5.841.055	32.470,35	5,559	3.036.494	0,09352
2021	7.147.152	43.838,64	6,134	3.722.251	0,08491
2022	7.417.369	47.003,32	6,337	3.865.467	0,08224

Source: IBGE (2023); Indea (2023) e IMEA (2023)

The idea of this study is to identify the efficiency and the relationship between yield per hectare, increased planted area, and a reduction in the carbon footprint (PC). Maximum efficiency was achieved in the production of 2022, with a carbon intensity of 0.21980 for soybean cultivation and 0.08224 for corn cultivation. As the analysis of the results shows, Mato Grosso has consistently increased its planted area, along with an increase in productivity and yield per hectare. It can be inferred, therefore, that the investments made by producers and advancements in technology lead to increased productivity and, consequently, contribute to greater efficiency and a solution to environmental issues.

5. Conclusions

The work presented here can provide positive conclusions regarding the development of studies that can be applied to reduce the carbon footprint in the state of Mato Grosso. Comparing the results obtained by Cheng et al. (2011) to the present study, the carbon intensity for Mato Grosso from 2004 to 2022 averaged 0.21980 tons of carbon per ton of production, whereas Cheng et al.'s (2011) average for the period 1993 to 2007 was 0.110 tons of carbon per ton. However, to draw a better conclusion about this comparison, one should analyze the average production intensity of soybeans in Brazil as a whole, as was done in Cheng et al.'s (2011) study for China as a whole.

Furthermore, as mentioned earlier, Mato Grosso will be the first state to use the new Recommended Practice for demonstrating carbon neutrality, ABNT PR 2060, launched during the 27th United Nations Climate Change Conference, COP-27, in Egypt. The new standard will support the Carbon Neutral MT Program, which aims to neutralize carbon emissions by 2035. The PRO Carbon program developed in partnership with Embrapa for measuring the carbon footprint is evidence of the state's concern for exporting commodities to the global consumer market. PRO Carbon Commodities is an extension of PRO Carbon, which started in 2021 with 1,900 Brazilian farmers and focuses on increasing field productivity and carbon sequestration in the soil through regenerative practices.

6. Authors' Contributions

Interpretation and writing of the paper: author 1. Conception of the econometric model, planning, analysis, and interpretation: author 2. Review and corrections: authors 3 and 4. Contribution to the article's discussion and translate: author 5. Both authors approved the final version submitted.

7. Conflict of Interest

There are no conflicts of interest in this work.

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