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Soybeans in Mato Grosso: Production Analysis and Crop Estimation Model

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Abstract
The UN signals a global population of 9.5 billion people by 2050, which will impact the need for an increased food supply. In this sense, this article aims to clarify the transformations that have occurred since the 1970s in soybean production, having as spatial clipping the state of Mato Grosso, collating in a model of crop and area planted. This is a quantitative, exploratory research, using secondary data provided by different institutions, which were analyzed by linear regression. It was found that productivity grew continuously during the period studied (1977 to 2021), that the 20 largest producing municipalities in the state of Mato Grosso were hegemonic in production but were noticed a reduction in participation from 73% to 59%, and that the area expected for 2019 is close to 10 M ha^{-1} (10 million hectares).
Keywords: Mato Grosso. Productivity. Soy.

Resumo
A Organização das Nações Unidas (ONU) sinaliza para uma população global de 9,5 bilhões de pessoas em 2050, o que vai impactar na necessidade de aumento de oferta de alimentos. Nesse sentido, o presente artigo objetiva esclarecer as transformações ocorridas desde a década de 1970 na produção de soja, tendo como recorte espacial o estado de Mato Grosso, coligindo em um modelo de previsão de safra e área plantada. Trata-se de uma pesquisa quantitativa, exploratória, utilizando dados secundários, os quais foram analisados por meio de regressão linear. Verificou-se que a produtividade cresceu continuamente durante o período estudado (1977 a 2021), e que os 20 municípios maiores produtores do estado eram hegemônicos na produção, mas perceberam redução na participação de 73% para 59%, e que a área esperada para 2019 é próxima de 10 M ha^{-1} (10 milhões de hectares).
Palavras-chave: Mato Grosso. Produtividade. Soja.

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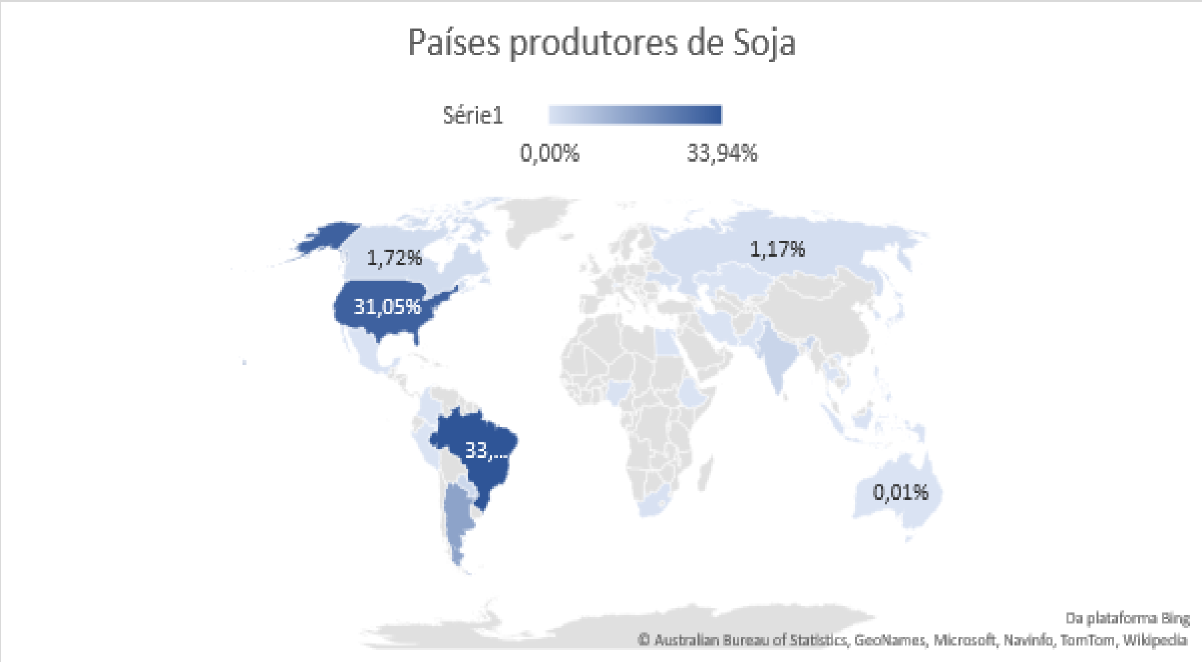
1 Introduction

Agribusiness is one of the fastest growing sectors in the Brazilian economy, accounting for half of the trade balance in recent decades (IPEA, 2022). The agricultural productions that stand out are grains: soy, corn, rice, wheat, cotton, coffee, fruit farming, sugar cane, tobacco, in addition to livestock (BRASIL, 2017).

One of the most structured and developed sectors of agriculture, the agro-industrial system of the oilseed *Glycine max* (soybean), the main commodity of Brazilian agribusiness, over the last decades, was driven by management techniques that allowed increased productivity, as well as the expansion of planted areas (CONAB, 2018).

The world soy production forecast in 2021 was 367 million tons (Mt), harvested from a planted area of 126.2 million hectares (Mha^{-1}). Brazil was responsible for approximately 34%; followed by the United States with 31%; Argentina 15%; China 5% and India with 3%. Brazil was able to produce 124,566.3 Mt in an area of 37.31 M ha-1, with a production of 3,338 kg ha^{-1}, in 2020/2021, this year, less than 30 countries produced the oilseed (ORGANIZATION FOR INTERNATIONAL COOPERATION AND ECONOMIC DEVELOPMENT - OECD, 2021), as shown in Figure 1.

Figure 1 - Soybean planted area by country in 2021



Source: Elaborated by the authors, based on OECD (2021).

The process of expansion of the soybean agricultural frontier, which was originated in southern Brazil, spread to the Cerrado biome, making the state of Mato Grosso (in transition zones that are centered in northern and northeastern mesoregions), the largest Brazilian producer of soybeans, considering that in 2018/2019 it produced 32.3 Mt in a planted area of 9.6 Mha^{-1}, reaching an average production of 3,367 kg ha^{-1} (IMEA, 2019, 2021; EMBRAPA, 2019; OECD, 2019 , 2021) and, as a global player, produces approximately 10% of the world's soybeans in 8.2% of the national production area.

Given the importance of this crop in the State, the following research question is proposed: What are the qualities and potentialities to be used by soybean crops in the State of

Mato Grosso, in relation to the planted area, production and productivity of their municipalities? This article aims to clarify the changes that have taken place since the 1970s in soybean production, taking the state of Mato Grosso as a spatial cut.

We chose to deepen this analysis, as the agricultural sector is relevant to the performance of the Brazilian economy (AIUBE; FERREIRA; LEVY, 2020; LAS CASAS; BACHA; CARVALHO, 2016; SCHNEIDER; FERREIRA; ALVES, 2013). Soybean is a product of recognized international competitiveness for Brazil (FREITAS; MENDONÇA, 2016; ZHANG et al., 2018). The country stands out as a major producer and exporter of the commodity (AIUBE; FERREIRA; LEVY, 2020; ZHANG *et al.*, 2020), in addition, Mato Grosso has a productivity 25% (2018/19) higher than the world average.

2 Background

Mato Grosso is one of the federative units of Brazil located in the Midwest region, situated between three basins: Amazonas (615,020,1 km²) containing the Juruena, Teles Pires and Xingu rivers, to the North; the Tocantins Basin (116,486,5 km²) with the Araguaia, Guaporé, Piquerí, São Lourenço and das Mortes rivers to the east; and the Paraguay Basin (48,765,3 km²) to the Center-South and Southwest of the State, containing the Sepotuba, Cuiabá and Paraguai rivers, which is important for the State as it is a river that can reach the sea directly, providing an opportunity for commercial use and being fundamental in the Pantanal biome, as well as being widely used for tourism.

Mato Grosso occupies an area of 903,357 km², equivalent to the area of Venezuela. It is organized into five mesoregions and 22 microregions, divided into 141 municipalities, the most populous and important of which are also the largest soybean producers: Rondonópolis, Sinop, Tangará da Serra, Barra do Garças, together with the capital Cuiabá and the metropolitan region Varzea Grande. Its population is 3,441,998 inhabitants (IBGE, 2018), being the seventeenth most populous in Brazil with 1.6% of the total population, having a population density of 3.36 inhabitants per square kilometer and an HDI of 0.725 (IBGE, 2010). In recent decades, the state of Mato Grosso has stood out on the national scene for presenting high growth rates in agricultural production.

Soybean, official botanical nomenclature *Glycine max* (L.) Merrill, from the *Fabaceae* family, is a legume that was originated in northeast China (between 45º and 50º N), a latitude that, in the Americas, corresponds in the south to Patagonia and, in the Northern Hemisphere, north of the United States of America and south of Canada (GAZZONI, 2018). Consumed for over 5000 years in the East, it is still considered today as one of the sacred cultures. In the Americas, the oilseed gained commercial crop status in the early 20th century, initially planted in the southeastern United States. In less than a century, research on variations adapted to the different climates and soils of the Americas allowed soybeans to expand across the continent (DALL’AGNOL *et al.*, 2007; WESZ JUNIOR *et al.*, 2021).

Soybean cultivation in the state of Mato Grosso was introduced at the end of the 1950s in the fields and cerrado areas, until then occupied by livestock. In the mid-1970s, the soybean area began to expand rapidly, largely due to investments made in agriculture in the south of Mato Grosso by large business groups (BONATO; BONATO, 1987). In 1970, less than 2% of the national production was harvested in this region and was concentrated in the state that is now Mato Grosso do Sul (DALL'AGNOL *et al.*, 2007; WESZ JUNIOR *et al.*, 2021).

Soybean cultivation in the state of Mato Grosso was introduced at the end of the 1950s in the fields and cerrado areas, until then occupied by livestock. In the mid-1970s, the soybean area began to expand rapidly, largely due to investments made in agriculture in, what was called at the the time, the south of Mato Grosso by large business groups (BONATO; BONATO, 1987). In 1970, less than 2% of the national production was harvested in this region and was concentrated in the state that is today Mato Grosso do Sul (DALL'AGNOL *et al.*, 2007).

The 1977/78 agricultural year, marked by the division of the state of Mato Grosso (where Mato Grosso do Sul was originated), was cultivated on 5,566 hectares and produced 7,269 t, concentrated in the district of Taquari, Alto Araguaia (border with Goiás and Mato Grosso do Sul) (BONATO; BONATO, 1987).

With the acquisition of varieties more adapted to the Cerrado biome, it moved to the north, expanding its cultivated area at the speed allowed by the competitiveness of the product, limited by the distance from the consumer center (PASIN, 2007). With these investments, the State conquered the third position in the national production, with participation of 14% in 1985. The recent development of production techniques, adapted to the conditions of the State, determined a significant improvement in the productivity, being today among the highest of the country (GUBERT, 2018; DOMINGUES *et al*., 2017; BARCELLOS, 2014).

3 Methodology

This is a quantitative, exploratory research, based on a review of specific literature of the area. The methodology included documental research and analysis of secondary data from information obtained from historical series of the National Supply Company (Companhia Nacional de Abastecimento - CONAB); Agribusiness Geographic Information System (Sistema de Informação Geográfica do Agronegócio - SIGAMS); information from the Mato Grosso Soy Producers Association (Associação dos Produtores de Soja de Mato Grosso - APROSOJA); database of the Mato-grossense Institute of Applied Economics (Instituto Mato-grossense de Economia Aplicada - IMEA) and; United States Department of Agriculture (USDA) COMTRADE database. With time cut from 1977 to 2021.

To study the possible correlations between production, area, productivity and harvest, tests were applied with ARIMA and ARMAX models. Verification statistics of model hypothesis violations were performed. The aim was to obtain a simplified model that mathematically described the area and soybean production in the state. To perform the statistical analyzes of the corresponding models and graphs, the *Gretl* statistical software, version 2019d, was used. All other graphs were generated by the *Excel* program. The maps were generated with the statistical *software* R.

4 Results

4.1 Planted area

Soybean, in 1940, becomes economically important in the State of Rio Grande do Sul and, later, in the States of Santa Catarina and Paraná. In 1949, Brazil appears as a world player, producing 25,000 tons (CONAB, 2014). After expanding to the acid soil states of the Midwest of Brazil, it moved towards the North of the country, but the characteristics of the Center-North contributed to the expansion and incorporation of the Cerrado into national and international markets (ESPINDOLA; CUNHA, 2015).

The agricultural year 1977/78 was chosen as the starting point for this study, as it was the year in which the division of the state of Mato Grosso took place. At the time, the then President Ernesto Geisel, signed on October 11, 1977, the Complementary Law nº 31, which decreed the dismemberment of Mato Grosso, creating the state of Mato Grosso do Sul, where the cultivation of soybeans had been introduced in the 1950 by farmers from the south of Brazil, who started in the fields and cerrado areas, until then occupied by livestock.

The book by authors Bonato and Bonato (1987), edited by EMBRAPA, presents a table entitled 'Soybean in Mato Grosso do Sul', because production was concentrated in the southern lands of Mato Grosso, before the division, the authors showed that with the implementation of the consolidation of states, in 1979, it became the starting point for the soybean crop. The aforementioned authors included data before the state's dismemberment, in 1977/1978, since until that time soybean was cultivated in the regions that today belong to Mato Grosso do Sul.

Therefore, for the present study, it was considered as a starting point, the analysis of the 1977/78 agricultural year, as it considered a separate state from what was hypothetically one of the leaders in production. That year, 5,566 hectares were cultivated and a production of 7,269t was obtained, concentrated in the districts of Taquari and Alto Araguaia (border with Goiás and Mato Grosso do Sul) (BONATO; BONATO, 1987).

From the 1990s onwards, it was noticed that the state of Mato Grosso expanded the area incorporated into soybean production, using technological resources, which provided growth in average income and allowed it to surpass Rio Grande do Sul and Paraná in production volume and, in the early 2000s, also in production area, as this set favored high profits, with average yields ranging between 2,600 and 3,300 kg/ha^{-1} (BASSO *et al.*, 2021).

The production showed significant growth, once the planted area in Mato Grosso jumped from 5,609,703 ha in 2007/08 to 9,579,538 ha in 2018/19 (Table 1), indicating an increase of 70.8% in this period. It is important to note that from 1977/78, when the State planted 5,566 ha^{-1} (BONATO; BONATO, 1987), to 2018/19, when it planted 9,579,538 ha^{-1} (IMEA, 2019), there was an increase of 172,108%.

The soils of the Cerrado biome, an area where crops have expanded, are naturally poor compared to the southern regions of the country in terms of retention of nutrients and organic matter. Even so, they have considerable production and lead us to understand that it is possible to obtain an increase in their productivity even in soils with poor standards" for what was known (CONAB, 2018).

In Mato Grosso, the soil is predominantly poor in mineral nutrients (QUEIROZ, 2004). For the aforementioned author, the typical vegetation of the Cerrado is adapted to adverse situations such as drought and fire, has a high degree of acidity and toxic amounts of aluminum. Other characteristics, such as "altitude, periodicity of fires and slope influence the physiognomic formation of the biome, which present variations" (QUEIROZ, 2004, p. 2). This view led misleadingly to the idea that it was a biologically poor biome and not conducive to the development of this activity. The absence of studies of environmental impacts in the region as well as mitigating and/or preventive measures led to the erroneous interpretation that the cerrado soil is a minor biome, biologically poor and, therefore, destined only for the occupation of grain crops (PIAIA, 1999; QUEIROZ, 2004; SANTOS *et al.*, 2010).

The tax incentives for the opening of new areas for agricultural production, as well as the establishment of producing and processing companies of grains, where financing occurs primarily via own resources, in almost 50%, and financing via Barter [1] in 30%, and the institutions banks in only 20% (CONAB, 2019). Meat producers (beef) in the Center-West and Northeast regions took advantage of this condition, added to the low land values, in addition to

[1] Barter is a comercial strategy that aims to exchange inputs for production with price locking of negotiated commodities. It currently translates into a mechanism that is much demanded by agricultural producers due to negotiation security and protection against exchange rate or price fluctuations of agricultural commodities produced and previously traded.

a flat and mechanized topography combined with climatic conditions with a highly favorable pluviometric regime for summer cultivation in which the rains occurred in a comprehensive and constant way, with the pluviometric precipitation having registered rates within the historical average (CONAB, 2019), these factors added together, resulted in the geographic expansion (ESPINDOLA; CUNHA, 2015).

Soybeans should expand due to factors such as: frontier expansion in regions where land is still available and in abundance; by the occupation of natural pasture lands and for the exchange of crops where there is land available for this exchange. The state of Mato Grosso should be the biggest beneficiary, being able to reach 12.2 million hectares (ESPINDOLA; CUNHA, 2015). However, it should lose strength in this expansion process, mainly due to land prices that are more than double the prices of farmland in the states of Matopiba (encompasses the states of Maranhão, Tocantins, Piaui and Bahia) (CONAB, 2019), also understanding that in the 20/21 harvest it was already above 10.4 million hectares.

Mato Grosso is a highlight in soybean production in Brazil and its municipalities are exponents in this sector, and of the twenty leading soybean municipalities in Brazil, thirteen are from Mato Grosso (BRASIL, 2017, PORCIONATO *et al.*, 2018). The production has contributed to the quality of life of producing municipalities, which can be seen in indicators such as the Firjan Municipal Development Index (IFDM - Índice Firjan de Desenvolvimento Municipal), in which Lucas do Rio Verde (MT) and Luís Eduardo Magalhães (BA). Municipalities with an economic base focused on soybean production, didn't achieve the highest IFDM in their states. In Mato Grosso, nine of the ten municipalities with the highest IFDM are soybean producers and some of these have processing industries (PELICANO; CAPDEVILLE, 2021).

This is because it is associated with a recent advance, which is the completion of paving of the BR-163, which allows the flow of grain production from the main producing regions of the country, from the Midwest, especially Mato Grosso, via Miritituba (district of municipality of Itaituba, PA) and Santarém, with lower costs, time, and risks. However, there are logistical advances projected for the upcoming years that could impact agribusiness logistics, such as the navigability of the Araguaia-Tocantins Waterway called the Bioceânica Route (PELICANO; CAPDEVILLE, 2021).

CONAB, in its compendium of studies on soybean productivity in 2017, concluded that the agricultural development of states such as Mato Grosso, Goiás, Tocantins, Maranhão, Piauí and Bahia are good examples of the insertion of new cultivars that can be planted in different times and under different conditions, whether soil, climate or another reason, however, there is a need for research that can work together with producers, identifying collaborative reasons to express soybean productivity in all its potential. They explain that soybean productivity, in the future, depends on breaking and leveraging the current productive balance that has been established and that there is potential for soybean productivity, but it is still far from being achieved in large producing centers (OLIVEIRA NETO, 2017).

Table 1 - Production and productivity from 1977/78 to 2020/21

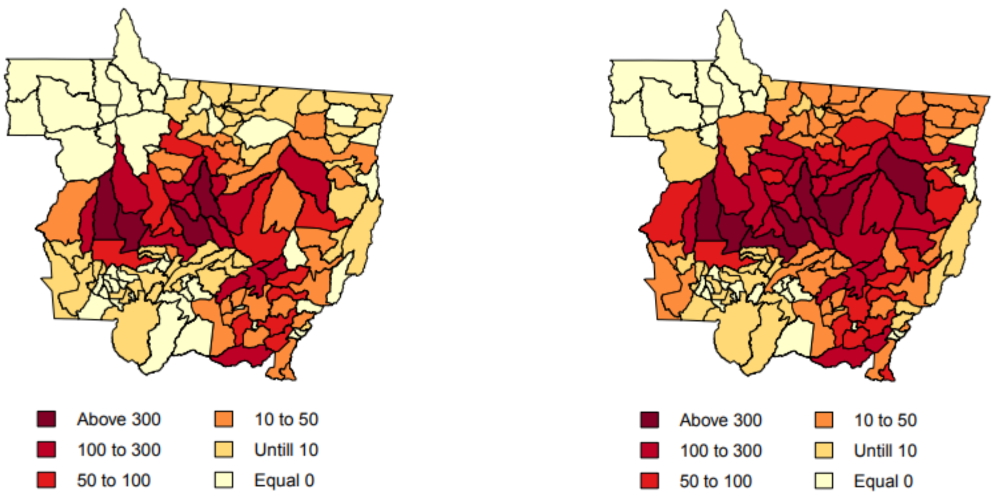
arvest	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88
Production (t)	7,269	26,503	117,173	224,901	365,501	611,258	1,050,095	1,656,039	1,910,000	2,387,000	2,750,000
Area (ha)	5,566	19,13	70,431	120,089	194,331	301,839	538,169	795,438	909,5	1,100,000	1,375,000
Average Outturn (kg ha $^{-1}$)	1,306	1,385	1,664	1,873	1,881	2,025	1,951	2,082	2,1000	2,1700	2,000
Harvest	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99
Production (t)	3,689,700	3,064,700	2,738,400	3,642,700	4,118,700	5,319,700	5,491,400	5,032,900	6,060,800	7,228,000	7,473,000
Area (ha)	1,708,200	1,503,000	1,100,000	1,452,000	1,713,400	1,996,000	2,295,400	1,905,200	2,095,700	2,600,000	2,548,000
Average Outturn (kg ha $^{-1}$)	2,16	2,039	2,489	2,509	2,404	2,665	2,392	2,642	2,892	2,78	2,933
Harvest	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Production (t)	8,774,400	9,533,200	11,684,800	12,965,900	14,517,900	17,761,400	15,594,200	15,400,000	17,650,737	17,406,835	18,814,693
Area (ha)	2,904,700	3,120,000	3,853,200	4,419,600	5,2405	6,105,200	6,196,800	5,125,000	5,609,703	5,727,160	6,217,450
Average Outturn (kg ha $^{-1}$)	3,021	3,056	3,032	2,934	2,77	2,909	2,516	3,005	3,146	3,039	3,026
Harvest	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Production (t)	20,566,781	21,367,054	23,660,496	26,291,262	28,619,362	27,811,761	31,271,827	32,524,966	32,317,718	35,403,507	36,051,673
Area (ha)	6,402,940	7,072,268	7,914,088	8,438,533	9,017,860	9,311,522	9,408,526	9,464,343	9,579,538	9,609,533	10,464,882
Average Outturn (kg ha $^{-1}$)	3,212	3,021	2,989	3,116	3,174	2,987	3,324	3,436	3,373	3,545	3,445

Source: Prepared by the authors, based on: IMEA (2020), Bonato and Bonato (1987) and Cunha (2008).

The 20 largest municipalities in Mato Grosso, in soy production areas, increased their planting from 4,099,247 ha^{-1} in 2007/08 to 5,242,673 ha^{-1} in 2012/13 (28% growth). They expanded to 5,690,784 ha^{-1} in 2017/18 (8.5% from 2012/13 to 2017/18) and the global increase between 2007/08 and 2017/18 was 38.8%, totaling 1,591,537 ha^{-1}.

It is noticeable that the 20 municipalities that planted soybeans intensively in 2007/08 represented 73.1% of the entire soybean harvested area in Mato Grosso. Over time, although the total area of these 20 largest municipalities have increased, they have had this relative concentration reduced, as more municipalities began to produce and increase participation, indicating the expansion of the crop across the state (Figure 2). It is also important to highlight that in the 2012/13 crop year, the participation dropped to 66.2% and in the 2017/18 crop year it dropped to 59.4%.

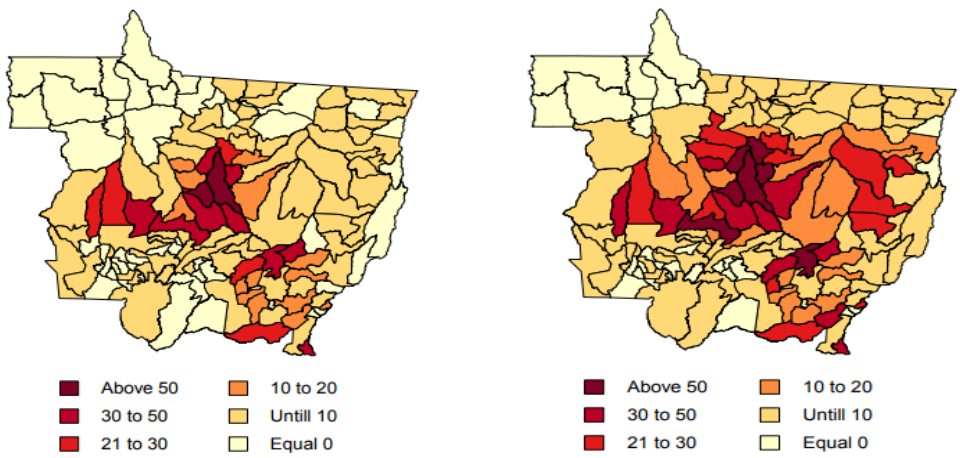
Figure 2 - Soybean planted area by municipality in 2007 and 2018 (per 1000 hectares)



2.a: Soy area in 2007 2.b: Soy area in 2018

Source: Prepared by the authors (2020), based on the IMEA database (2020).

The area planted with soybeans in Mato Grosso had a significant impact over the years studied, and it was possible to verify this percentage in each municipality (Figure 3).



3a: Percentage area in 2007 3b: Percentage area in 2018

Figure 3 - Percentage of soybean planted area in 2007 and 2018 by municipality
Source: Prepared by the authors, based on the IMEA database (2020).

For expansion planning, it is essential to study the available area that can be used in each municipality in the state that is investigating the crop. Figure 4 illustrates the evolution from 2007/08 to 2018/19 of non-producers and the 20 smallest municipalities in percentage of planted area. Note the increase in the maximum level that delimits the 20 municipalities, indicating that, even in these, the planted area increased in the period. There was also a reduction in non-producing municipalities.

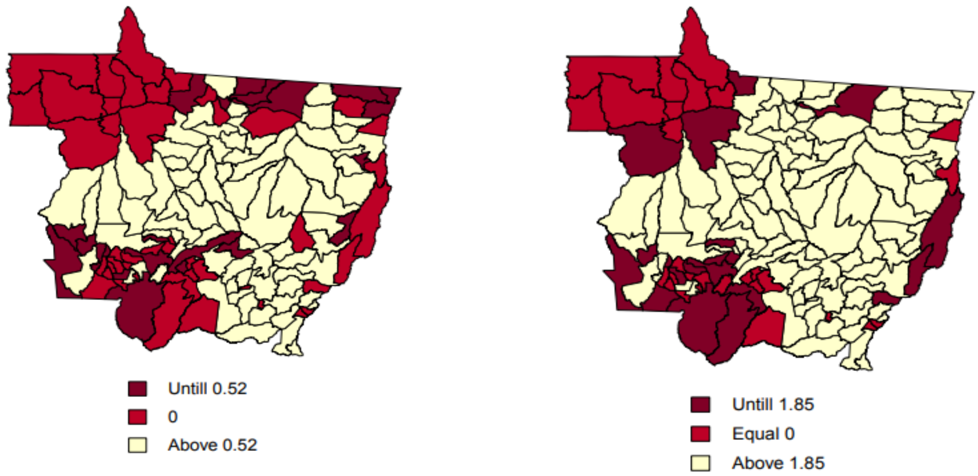


Figure 4a: 2007 Figure 4b: 2018

Figures 4 - Non-producers and the 20 smallest municipalities in percentage of soy planted.
Source: Prepared by the authors, based on the IMEA database (2020).

In total, 94 municipalities in Mato Grosso have less than 10% of their area planted with soybeans, 48 municipalities have an area between 10% (Feliz Natal with 358.5 km²) and 63.6% (Lucas do Rio Verde with 2,258.3 km²). In 2018/19, the smallest municipalities in terms of cultivated area were: Porto Esperidião, Juína, Barra do Bugres and Araputanga.

The regression models were limited only to the crop, area, production and productivity variables, since the study presents an overview of the research object. An attempt was made to obtain an estimate for the 2019/2020 cultivation area. Some regressions between area and culture were tested. The models were obtained using the ARIMA and ARMAX processes. There was no evidence of annual seasonality.

Despite the preliminary analysis of the root of the unit, indicating that the best model is ARIMA with drift, it was the ARMAX model (0.3) that best met the criteria of normality, heteroscedasticity and autocorrelation (Table 2) and that also presented the best values for the AIC, BIC and HQC criteria (Table 3), being the harvesting (time trend) the exogenous variable, and with the introduction of *dummy* variables for fifteen-year intervals, this interval being chosen only for data division, without apparent correlation with any weather or market seasonality. Neither the ARIMA nor ARMA models, with the extraction of the deterministic trend by linear regression, were more efficient among the analyzed cases.

Table 2 - Model validation statistics p value ARMAX (0.3)

validity	normality	arc	LM (min)
P- Value	p = 0,205636	p = 0,355968	p = 0,387

Source: Prepared by the authors, based on the IMEA database (2020).

Table 3 - ARMAX model (0.3).

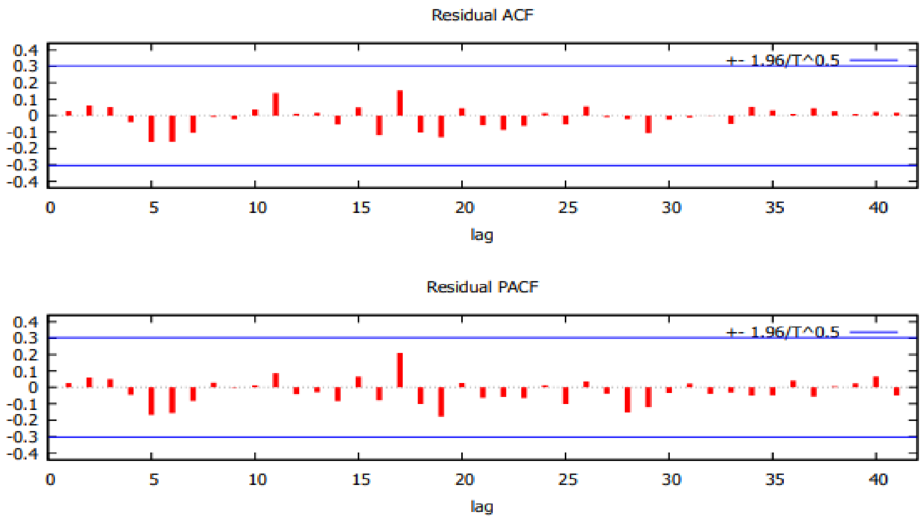
Modelo: ARMAX, utilizando observações 1977-2018 (T = 42)
Estimated using AS 197 (ML exato)
Dependent Variable: Area 1000 ha^{-1}

	Coefficient	**Error Pattern**	**Z.**	**p-values**	**Meaning**
theta_1	1.46655	0.149664	9.799	1.14e-022	***
theta_2	1.10008	0.217387	5.060	4.18e-07	***
theta_3	0.480865	0.151107	3.182	0.0015	***
colheita	217.102	7.95956	27.28	8.26e-164	***
dum1	−1010.23	243.761	−4.144	3.41e-05	***
dum2	−1395.68	236.762	−5.895	3.75e-09	***
Criteria	Akaike	Black	Hannan-Quinn	R^2	Adjusted R^2
	612.4402	624.6039	616.8987	0.991292	0.990082

Source: Prepared by the authors (2020).

The residuals correlogram shows the absence of autocorrelation, confirmed by the LM test.

Figure 5 - ARMAX MODEL WASTE Correlogram (0.3)



Source: Prepared by the authors (2020).

The expected area for the 2019 harvest was 9791.6 x 10^3 ha^{-1}, representing an increase of 1.3% compared to the 2018 harvest. For the 2020 harvest, the estimated area was 9815.7 x 10^3 ha^{-1}, with an increase of 1.0% in relation to the estimated area in 2019. The perspectives found for the remaining 5 years are shown in Table 4 and (Figure 6).

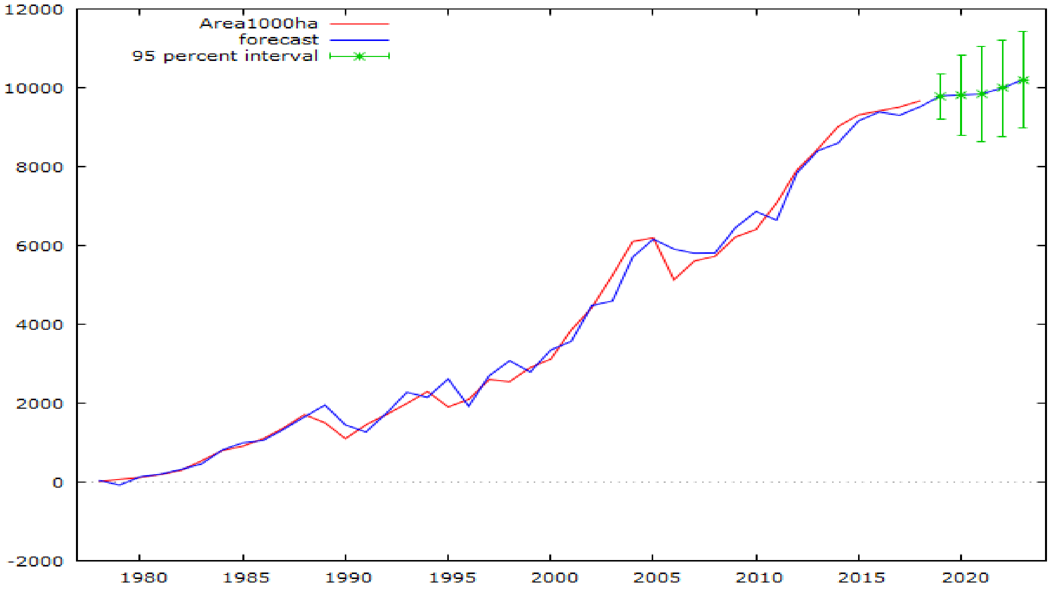
Table 4 - Area Perspective for the next 5 harvests.

Harvest	**Forecast**	**Standard Error**	**Interval (95%)**	
2019	9791.6	291.84	9219.6	10363.5
2020	9815.7	518.02	8800.4	10831.0
2021	9841.8	609.44	8647.3	11036.2

2022	9986.7	625.39	8761.0	11212.4
2023	10203.8	625.39	8978.1	11429.5

Source: Prepared by the authors (2020).

Figura 6 - Area Perspective for the next 5 harvests.



Source: Prepared by the authors (2020).

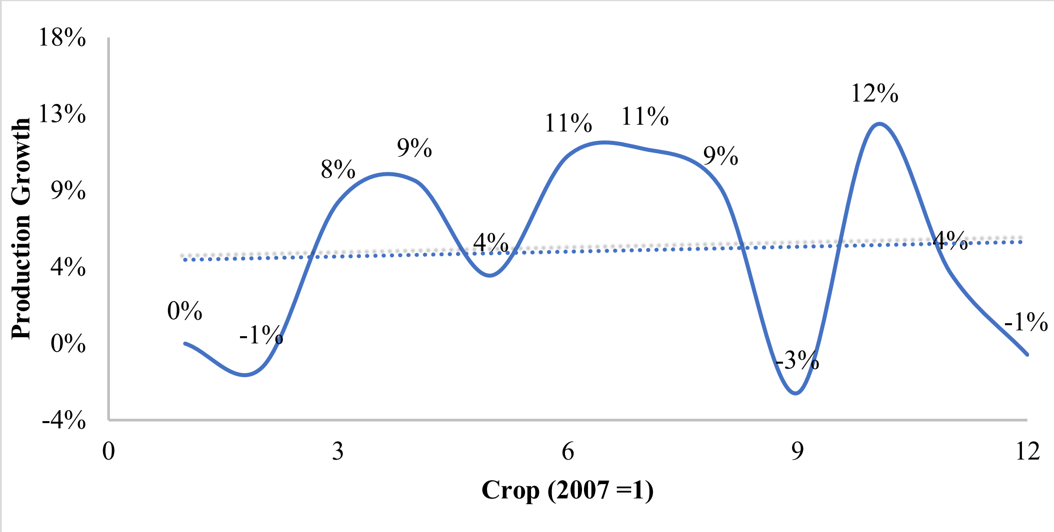
When this study was completed, data for 2019 and 2020 were not available. According to CONAB, these areas were 9.609 and 10.464 million hectares, in that order. Both values were within the 95% confidence interval, with variations of -1.9% and 1.1% in relation to the estimated value, respectively, denoting a satisfactory accuracy of the model. Also, according to the IMEA, the forecast for the planted area for 2021, at the time of completion of this study, was 10.84 million hectares, 3.6% greater than the previous actual area and 10.1% greater than value estimated by the model, however, still within the 95% confidence interval. It was also noted, in the years 2014 to 2019, a decreasing trend in the growth of the planted area, as seen in Figure 6.

4.2 Soy Production

Soybean production in the state of Mato Grosso demonstrates the expansion dynamics at the beginning of this new millennium, which was 1.7 million tons in 800 thousand ha in the period 1984-1985, increasing to 13 Mt cultivated in 4.5 Mha^{-1} in the 2003-2004 harvest, with average yields greater than 3,000 kg ha^{-1}, higher than Brazilian and American averages. However, production at the time was already characterized by the existence of a small number of large producers (> 10,000 ha^{-1}) and medium (500 to 3,000 ha^{-1}) modern and mechanized producers, multinational companies and national groups that operate both in upstream and downstream of production (BERTRAND *et al.*, 2005; EMBRAPA, 2018 MELO, 2020).

Soybean production in Mato Grosso, in 2007/08, was 17,650,737 t, as shown in Table 1. Looking at 2007, there was a decrease of 1.4% in the first year studied, however, there was also an average increase, in the following twelve years, by 5.2% per year until 2018/19, with a total growth of 83.1% (Figure 7). As in the first year studied, in the ninth year (2015/16 harvest) there was a decrease of 2.8%.

Figure 7 - Production Growth by year



Source: Prepared by the authors (2020).

The municipality of Sorriso stands out as the main soybean producer in Mato Grosso, with 7.7% of Market-Share, considering twelve years surveyed. Together, the 15 largest producing municipalities accounted for more than half of soybean production (55%), equivalent to 164,116,939 t. Mato Grosso presented a significant growth of 83.1% in state production, as well as in individual municipalities, 19 municipalities had growth above 1,000% in the period, led by Vale de São Domingos, with growth of 4,406%.

The most detailed production in 2017/18 is shown in Figure 8, making it possible to verify the annual production of soybeans in the state. Areas without production are characterized by a lighter color, but it is still possible to see that there were cultivars in the Pantanal (upper and lower) and in the extreme north of the state, although the municipalities located in the upper left corner are in a protected region, with specific legislation for the Amazon.

Figures 8 - Soybean production in 2007 and 2018 (10^3 t)

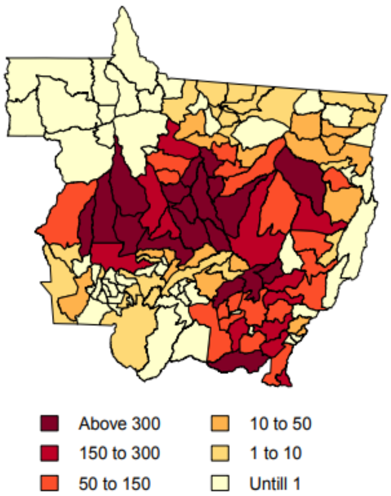


Figure 8a: Soybean production 2007

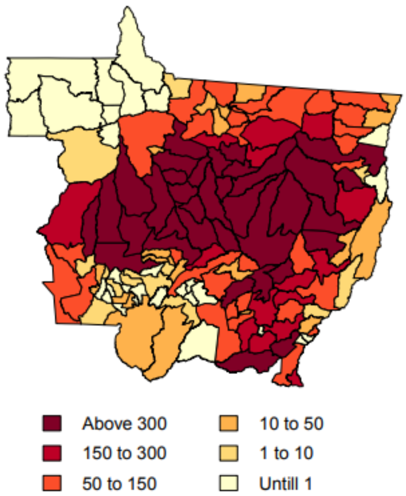


Figure 8b:Soybean production 2018

Source: Prepared by the authors (2020).

As with the area, regression models for production were tested. From the CLRM, ARIMA and ARMAX models obtained, the one which presented the best values for the criteria selection method was ARMAX (2,1,1), with Area as the exogenous variable and obtaining the regressors by Conditioned Maximum Likelihood (Table 5).

Tabela 5 - ARMAX Model (2,1,3).

Model: ARMAX, using observations 1980-2018 (T = 39)
Estimated using the method BHHH (ML condicional)
Dependent Variable: (1-L) Production 1000t

	Coeficiente	Standart Error	Z.	P-values	Meaning
phi_1	−1.01114	0.235216	−4.299	1.72e-05	***
non_2	−0,573814	0.133047	−4.313	1.61e-05	***
theta_1	0.712732	0.276159	2.581	0.0099	***
Area 1000ha	0.486134	0.0651965	7.456	8.89e-014	***
Criteria	Akaike	Black	Hannan-Quinn	R^2	Adjusted R^2
	650.0145	658.3324	652.9989	0.992709	0.992084

Source: Prepared by the authors (2020).

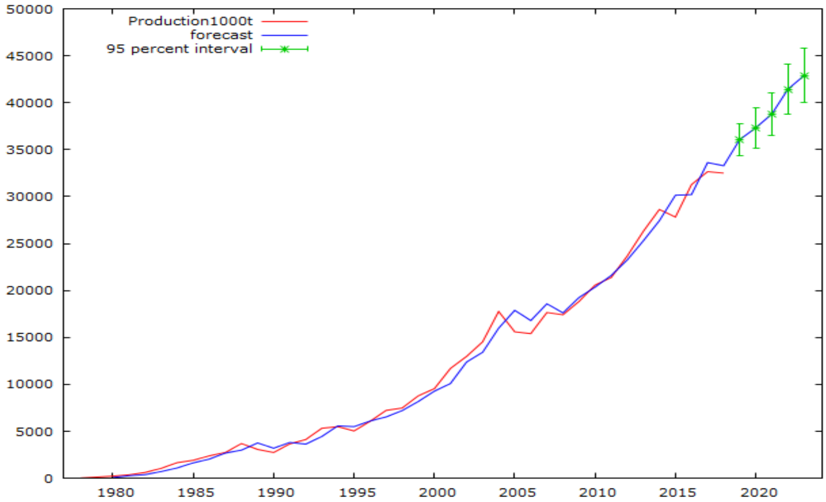
The production forecast for the 2019 harvest was 36064.7 x 10^3 t, an increase of 11.0% compared to the 2018 harvest. The forecasts for the next five years are shown in Table 6 and Figure 9.

Table 6 - Production forecast for the next five harvest.

Harvest	Forecast	Standard Error	Interval (95%)	
2019	36064.7	885.70	34328.8	37800.7
2020	37318.5	1081.94	35198.0	39439.1
2021	38790.3	1146.87	36542.4	41038.1
2022	41437.6	1384.59	38723.8	44151.3
2023	42876.7	1477.02	39981.8	45771.6

Source: Prepared by the authors (2020).

Figure 9 - Production forecast for the next five harvest.



Source: Prepared by the authors (2020).

Data obtained a posteriori, for the 2019 and 2020 harvests, were 35403.5 and 36051.7 thousand tons, in that order, with variations of -1.8% and -3.4% in relation to the estimated values. Nevertheless, the variations in relation to the real values were 9.5% and 1.8%.

Analyzing these last three results, together with those observed for the area, it was evident that the area presented an upward trend in relation to the estimates, while the production denoted a decrease. A possible explanation may be associated with the fact of increased demand, which may have led soybean producers to expand planting areas to regions that were not yet prepared to obtain good productivity. It is emphasized, however, that such an analysis must be carried out with caution, since all the quoted values are within the statistical confidence interval. New studies may confront this evidence.

4.3 Productivity Analysis

In the 2018/19 national harvest, the national average productivity was 3,206 kg/ha^{-1}, and the productivity range was between 2,927 and 3,393 kg/ha^{-1} in the last ten years. In Mato Grosso, the average in 2018/19 was 3,374 kg/ha^{-1}, with an interval from 2,987 to 3,437 kg/ha^{-1} in the last decade. The evolution of productivity in the state's municipalities is illustrated in Figure 10.

Figure 10 - Productivity per kg ha^{-1} for the 2007 and 2018 crops

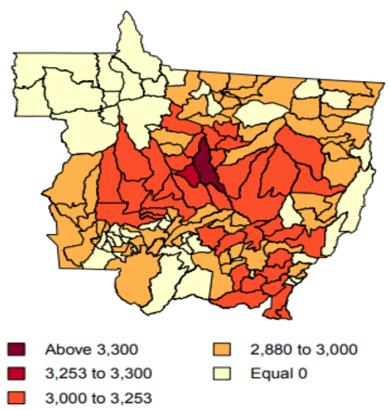


Figure 10a – Productivity in 2007

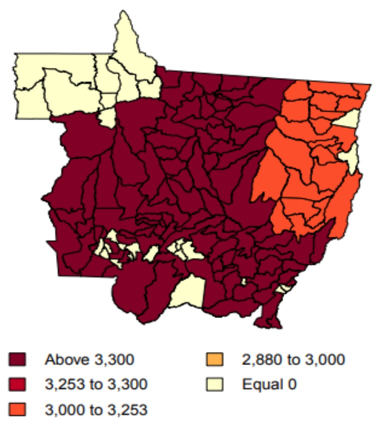
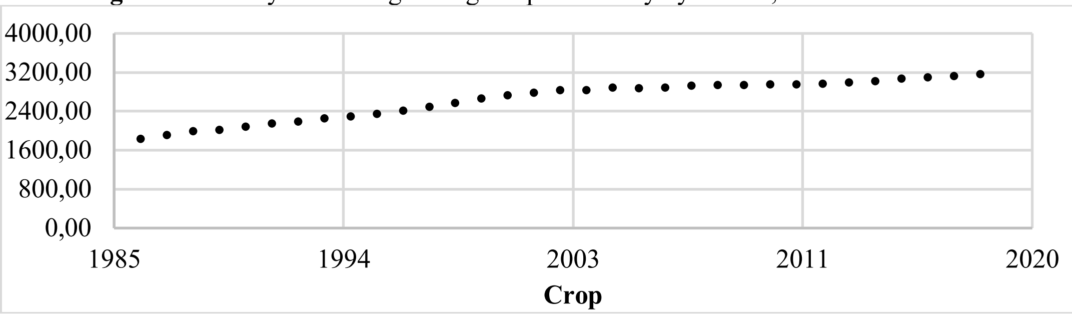


Figure 10b – Productivity in 2018

Source: Prepared by the authors (2020).

The average productivity per decade, in Mato Grosso, showed a slow but steady growth trend (Figure 11).

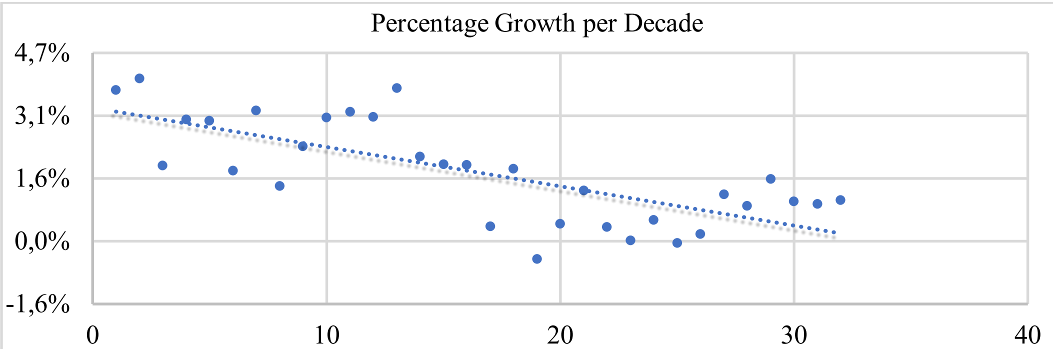
Figure 11 - Ten-year moving average of productivity by decade, from 1986 to 2018.



Source: Prepared by the authors (2019).

The percentage growth rate per decade has not exceeded 2.1% in the last 19 years (Figure 12) and has been around 1% in the years 2016 to 2018.

Figure 12 - Ten-year moving average of percent productivity growth, from 1986 to 2018.



Source:Prepared by the authors (2019).

This fact allows us to assume a technological barrier, indicating that new advances in techniques also in matrixes of seed varieties adapted to climate, soil and biome different from those currently adopted, are necessary for a more consistent, perennial and substantial increase to occur. However, research results and more aware producers in favorable production environments indicated that the soybean potential was greater than 8,000 kg/ha^{-1}(CONAB, 2018).

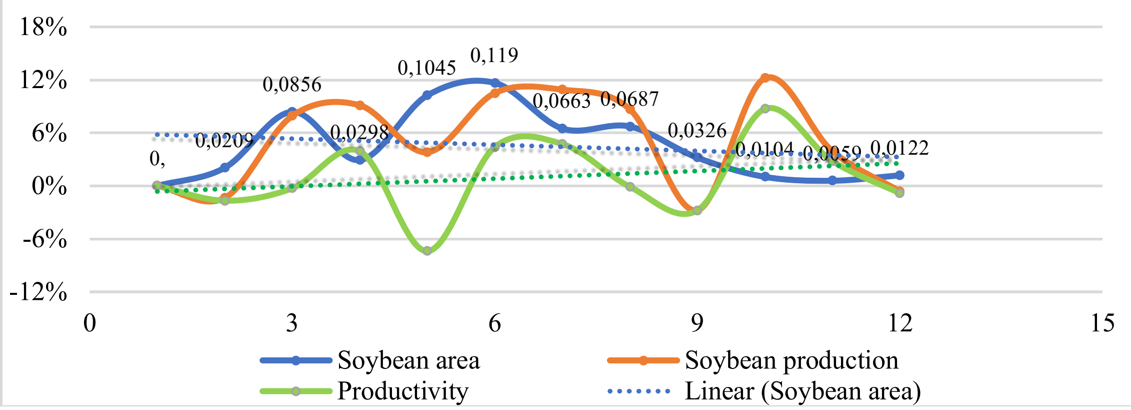
5 Discussion of Results

It is necessary to question whether productivity is increasing and whether geographic space is relevant for soybean production, with the aim of verifying whether Mato Grosso as a whole can increase its production or divided by the municipalities that cultivate soybeans.

Soybean production in Mato Grosso has increased, as well as the planted area. The soy harvest improved year after year, going from 17,650,737 t to 32,317,718 t, with growth of 83% in the period, while the expansion of the area planted with soy grew by 71%. It was noted that the state of Mato Grosso also grew in productivity, which in this case was 12%, going from 3,025 kg ha^{-1} to 3,396 kg ha^{-1} (Table 1).

However, when delimiting the linear trend lines of the variation in relation to the previous year (t1-t0), it is noticed that the soybean area is inclined downwards (slightly). That is, there is a downward trend in area growth from year to year, as opposed to slightly sloping production as well as productivity, as shown in Figure 13.

Figure 13 - Area, production e productivity.



Source: Prepared by the authors (2020).

So that this study could have more details, it was necessary to use data from IMEA (2021), available in its database, from 2008, which includes planting and harvesting dates, broken down by municipality of Mato Grosso, so it was possible analyze in twelve years (2008 – 2020), a production ranking:

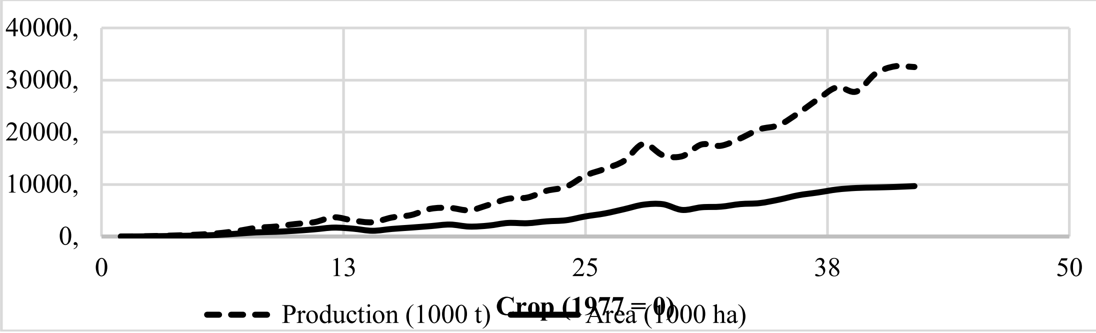
The most productive region in the state of Mato Grosso was the Mid-north region, which had the best maximum average of the entire period in 2017/18, of 3,468 kg ha^{-1}. This region has the largest and best producers in the state and Nova Ubiratã was by far the best average in the state with 3,573 kg ha^{-1}, bringing together the best producers in the state for seven years.

The West region was the second best in this ranking, three years with the best average productivity per region, in 2011/12, 2015/16 and 2018/19, in 2018/19 all municipalities had the same average of 3,449 kilograms per hectare. The Southeast Region peaked in 2012/13, when it produced 3,048 kg ha^{-1} and this region also had an interesting year, in which all 29 municipalities had the same average per hectare. The Center-South Region, in the 2013/14 harvest, had its best average of 3,149 kg ha^{-1}, where the municipality of Chapada dos Guimarães produced 3,180 kg ha^{-1}. The standard deviation in this case was only 16kg ha^{-1}, indicating that the municipalities produced close to the average.

The least productive region was the North, where the municipality of Guarantã do Norte, in 2011/12, produced only 2,018 kg ha^{-1}, with a standard deviation of 360 kg ha^{-1}. However, most are from areas that produce less than the average minimum yield of 2,308 kg ha^{-1}. The capital of Mato Grosso, Cuiabá, in 2013/14, had 80 hectares of soybean planting, with an average of 3,150 kg ha-1, while in this period, the state average was 3,122 kg ha^{-1}. In 2016/17, 165 ha^{-1} were planted and 3,308 kg ha^{-1} were produced compared to the average for that year (3,296 kg ha^{-1}). That is, Cuiabá produced the state average in the two tests carried out.

From 2014 to 2020, there was a trend towards stagnation in the planted area. Even so, production does not seem to have its growth affected (Figure 14).

Figure 14 - Production and Area versus Culture



Source: Prepared by the authors (2020).

The state of Mato Grosso, between 1978/79 and 2017/18, saw its area grow by 49,474%, that is, an average annual growth of 17%. At the same time, production went from 26,503 t to 32,524,966 t, an accumulated growth of 122,722%, that is, an increase of 19.5% per year.

It can be inferred that the soybean producer in Mato Grosso is still looking for new areas to test the productivity of each potential space for the cultivation of the oilseed, however, what has been found are areas with lower productivity, perhaps for lower initial acquisition costs or lease of such lands. These areas must be located close to established units, where there are machines and equipment necessary for production. However, it should be noted that this was not the case for Cuiabá, with an area of 80 ha^{-1} and 165 ha^{-1}.

Figures 3 and 4 illustrate the evolution of the lowest percentages of planted areas between 2007 and 2018, where the maximum level that delimited the 20 municipalities was observed, indicating that, even in these, the planted area increased in the period, so that the evolution of this area in smaller producing municipalities, showed that there is a possibility of an increase in planting areas. It should also be noted that the municipalities with the highest growth in planted area are strong indications that these regions are the most conducive to soybean cultivation.

It was also observed that the production, estimated in 2019 by the average area, was approximately 4% lower than 2018, meaning a reduction in production for the second consecutive year. Throughout the historical series, this reduction only occurred once for two consecutive years, in 1989 and 1990. The maximum production estimated in this analysis (which took into account the area predicted by the model that considered the last twelve years) was around 3.6% higher than 2018. Finally, understanding that the subject has not been exhausted, it is proposed to draw up a map of municipalities and their percentage of occupancy with soy production. The proposition is that this map serves as a basis for future decision-making by stakeholders about the challenges and potential of the crop for the coming years, in view of the future need for proteins, however, it remains for the soy community to verify, i*n site*, which of these points it is feasible to offer places for plantations, however, if there are new, more productive varieties, we can have the real production potential in that same space.

6 Conclusion

The biggest problem that the state of Mato Grosso faces today is the lack of new varieties of soybean seeds with the potential for greater productivity per hectare, thus surpassing the expectations of this article, because with the varieties that we have, the state is reaching the production limit.

Production is linear and grows in each region, and each of these regions has its limitations imposed by temperature, relative humidity, rainfall, altitude and sedimentary region.

Thus, the main objectives worked on during the exploratory study were to provide an overview with data from soybean panels in the state, from its division to the year 2020, as well as the analysis of temporal data in the described period, in order to allow estimates on planting areas in future harvests. With these results, the intention is to stimulate the deepening of new studies of regionality, to which they can dedicate themselves in the verification of data such as: planted variety; altitude, temperature and its variations; rainfall characteristics; or even issues related to watersheds, such as in the Pantanal region, the Amazon forest, the cerrado or the surroundings of the Araguaia.

The limitations of the study are related to the scarce database, as well as the lack of interest of some government agencies in supporting a study like this one, in such a way as to delimit data precisely, and this is what is expected for the next studies, which should detail each producing region, differentiating the soil patches, and their particular characteristics, as well as knowing new varieties that emerge towards the new productive matrix.

The present sheds light on the transformations that have taken place since the 1970s, when tax incentives for the opening of new areas for agricultural production existed and land was acquired more easily, especially due to low costs. Over the years, with a flat and mechanized topography, combined with climatic and rainfall conditions, conducive to summer cultivars, Mato Grosso gained prominence in the national production of soy, where thirteen of its municipalities are among the twenty leaders in oilseed production in Brazil.

For CONAB (2017), for the agricultural development of states such as Mato Grosso to be complete, there is a need for joint research with producers and others involved in the production chain, identifying collaborative reasons to express soybean productivity in all its potential

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