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INTERANNUAL RAINFALL VARIABILITY AND SOYBEAN YIELDS IN MATA ROMA MUNICIPALITY, MARANHÃO

Eduardo Silva dos Santos[1], Plinio Antonio Guerra Filho[1], Sheyla Sales de Oliveira[1], Breno dos Santos Silva[1], Antonio Emanuel Souta Veras[1] & Daniela Abreu de Souza[1]

1 - Maranhão Federal University, Agricultural Engineering Department, Chapadinha Sciences Center, Chapadinha, MA, Brazil

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ABSTRACT

Among the activities affected by rainfall variability, agriculture is one of the most vulnerable. In this sense, this work aimed to relate the interannual rainfall variability with the soybean yields variability in Mata Roma municipality, Maranhão, considering dry and rainy events. For this, for the period from 2003 to 2019, data on average soybean yield and rainfall in this producing region, which is one of the main ones in the State, were analyzed. Monthly rainfall data for the period 1985-2019 were also analyzed and the dry and rainy events were identified in these two meteorological data series. The results showed that rainfall from January to May explains about 99%, on average, of the interannual variation of yields and that occurrence of dry and very humid periods disfavor the soybean crop, causing, in most cases, yields and productions far below the average for the study region. Based on the regression analysis, it was found that maximum average yield of 2942.52 kg×ha^{-1} was reached with an average rainfall of 1709 mm.

Palavras-chave:
Rendimento da soja
Precipitação
Agroclimatologia

VARIABILIDADE INTERANUAL DA PRECIPITAÇÃO PLUVIAL E RENDIMENTO DA SOJA NO MUNICÍPIO DE MATA ROMA, MARANHÃO

RESUMO

Dentre as atividades afetadas pela variabilidade dos índices pluviométricos, a agricultura é uma das mais vulneráveis. Nesse sentido, este trabalho objetivou relacionar a variabilidade interanual da precipitação pluvial com a variabilidade das produtividades da cultura da soja no município de Mata Roma, Maranhão, considerando os eventos secos e úmidos. Para isso foram analisados, para o período de 2003 a 2019, dados da produtividade média da soja e de precipitação pluvial dessa região produtora que é uma das principais do Estado. Foram também analisados dados de precipitação mensal do período 1985-2019 e identificados os eventos secos e úmidos nessas duas séries de dados meteorológicos. Os resultados mostraram que a precipitação do período de janeiro a maio explica cerca de 99%, em média, da variação interanual das produtividades e que a ocorrência de períodos secos e muito úmidos desfavorecem a cultura da soja, ocasionando, na maioria das vezes, produtividades e produções muito abaixo da média para região de estudo. Com base na análise de regressão, constatou-se que a produtividade máxima média de 2942,52 kg×ha^{-1} foi alcançado com uma precipitação média de 1709 mm.

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Email (corresponding author)*: santos.eduardo@ufma.br

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INTRODUCTION

Soybean (Glycine max (L) Merrill) is a worldwide cultivated oilseed, being the main culture in Brazil, and due to its productive potential and nutritional value, it offers several applications in human and animal nutrition and, above all, socioeconomic relevance (Maud *et al*., 2010).

Mata Roma municipality is located in the Eastearn Region of Maranhão state, inserted in the Chapadinha microregion and formed by nine municipalities. With regard to soybean production under dryland water regime in the microregion, the following stand out: Anapurus, Brejo, Buriti, Chapadinha and Mata Roma, together they were responsible for 87.27% of the planted area with an average yield of 3105.8 kg×ha^{-1}, being Mata Roma the third largest producer in 2019/2020 season (IBGE 2022).

According to Presoti (2008), the soybean farming expansion is mainly due to the following factors: rainfall regime — which occurs from January to June (Passos *et al*., 2016) — suitable soil type, occurrence of large flat areas — favoring the mechanization use during the entire production process — ease of production flow through ports and the possibility of exportation due to the flow infrastructure.

Research carried out in Brazil has shown that soybean yield is influenced by climatic factors such as water deficit (Alberto *et al*., 2006), water excess (Schoffel *et al*., 2001) and temperature (Schoffel & Volpe, 2002). Among these factors, the rainfall regime is the main responsible for the soybean yield variability in several Brazilian producing regions (Farias *et al*., 2001).

The rainfall behavior analysis has great relevance due to the great space-time variability, not exclusively from a water and climate approach, but also due to the resulting economic, social and cultural instances (Lucena *et al*., 2011). Among the activities affected by the rainfall variability, agriculture is one of the most vulnerable (Lopes *et al*., 2016).

In Brazil, most of soybean yield is dependent on rainfall. In soybean, water is important throughout the crop cycle, except after the grains physiological maturity, being relatively tolerant to water deficit in its vegetative phase, but it is very sensitive to stress during the yield components formation, that is, flowering and grain filling (Sentelhas *et al*., 2015). The soybean crop needs a water total volume that varies between 450 mm and 800 mm/ harvest (Farias *et al*., 2007). The water need is greater as the plant develops, reaching a maximum during flowering-grain filling, decreasing after this period (Bergamaschi *et al*., 1999).

Among the various meteorological systems that cause high rainfall variability in Maranhão state, the South Atlantic Convergence Zone (SACZ), the Intertropical Convergence Zone (ITCZ), the Frontal Systems and the Upper Level Cyclonic Vortices (ULCV), the Instability Lines (IL) and the East Wave Disturbances (EWD) stand out, making the rainfall distribution, both in space and time, irregular from North to South of the State (Nascimento *et al*., 2015).

El Niño Southern Oscillation (ENSO) is a phenomenon of ocean-atmosphere interaction, linked to anomalies in average ocean temperature (Marengo *et al*., 2016). According to Molion (2017), El Niño (EN) is the warming of the Tropical Pacific waters near the South America coast. Hiera *et al*., (2019) considers that the ITCZ is located further north of its normal position during the years with the occurrence of EN, in such a way that the trade winds from the southeast and northeast are weaker, causing a decrease in the humidity that penetrates the northeast region of Brazil. On the other hand, La Niña (LN) events are distinguished by the surface waters cooling and the trade winds intensity increase, reaching above-average speeds (Molion, 2017).

In recent decades, the rainfall studies have gained notable attention, and among the most important studies, the rainfall regime classification in the agricultural regions of Taperoá - PB, Areia e Sumé - PB and Mossoró - RN stands out (Araújo *et al*., (2007), Almeida *et al*., (2013), Santos *et al*., (2014)). Through these studies, we can highlight several methodologies that are used statistically to adjust and classify the rainfall behavior, such as the Standardized Precipitation Index (SPI) (Mckee *et al*., 1993), the Quantile Technique (Pinkayan, 1966) and the Rainfall Anomaly Index (RAI) (Rooy, 1965). The RAI obtains great prominence, in addition to establishing dry and rainy months or years, it allows establishing the climate regime of a given region or location using only rainfall data.

Maniçoba *et al*., (2017), when evaluating the RAI of a 54 years rainfall series in the microregions of Mossoró, Ceará-Mirim, Santa Cruz, Cruzeta, Natal and Apodi (Rio Grande do Norte state), showed a high number of years with negative RAI, being 30, 30, 33, 29, 29 and 34 years, respectively. Due to these occurrences, the practice of rainfed agriculture in these localities becomes unstable, with risks of yield losses due to water deficit (Alberto *et al*., 2006). In the southern region, Berlato *et al*., (2005) demonstrate that high corn yield rates are achieved with rainfall above the climatological normal, which are caused by the El Niño phenomenon, and La Niña determines a drop in yield.

Given the above, the objective of this research was to relate the interannual rainfall variability with the soybean grain yield interannual variability in Mata Roma municipality, through the characterization of the Rainfall Anomaly Index (RAI).

MATERIAL AND METHODS

Agricultural and climate data

Average yield data (kg×ha^{-1}), which is the ratio between production and harvested area, for the soybean crop referring to the municipality of Mata Roma were obtained from the SIDRA/IBGE database, with records covering the period from 2003 to 2019.

The daily rainfall data for the period from 1985 to 2019 were obtained from the rainfall network belonging to the National Water and Basic Sanitation Agency (ANA) located in the municipality, with code 343009 at coordinates 43°6’43” W and 3°37’33” S (Figure 1). Initially, a consistency analysis of the rainfall data was carried out to verify the existence of flaws in the data, where years with dates without records were found. Once such occurrences were identified, they were removed (1992; 1995; 1997 and 1998) from the analysis of the rainfall historical series, resulting in 31 years of rainfall data.

Rainfall Anomaly Index Analysis

The analysis of the monthly and annual Rainfall Anomaly Index (RAI) for the entire rainfall series was based on the classification elaborated by Araújo *et al*., (2009) for both dry and wet years (Table 1). In determining the RAI, the methodology suggested by Rooy (1965) and adapted and tested by Freitas (1998), Marcuzzo *et al*., (2011), Gross

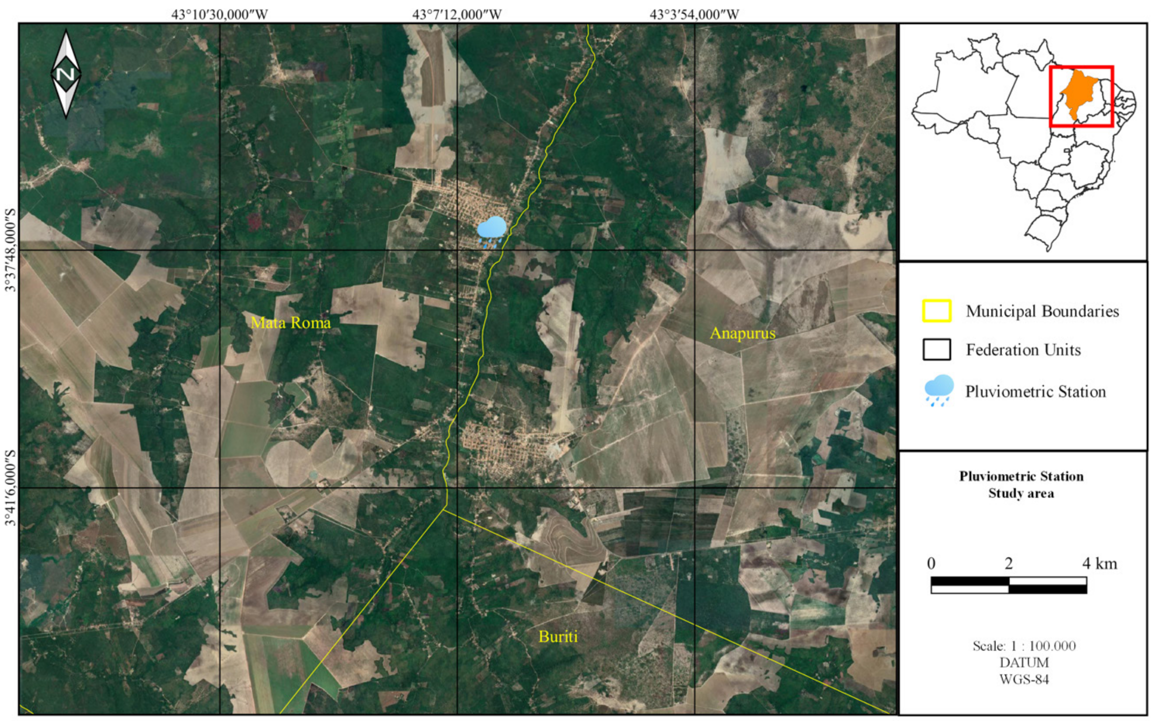

Figure 1. Study area and pluviometric station locations

and Cassol (2015), Noronha *et al*., (2016) and Cury *et al*., (2018), which aims to obtain the positive and negative anomalies of the historical rainfall series, and the equations are expressed below:

$$RAI_{POSITIVE} = 3 \times \left(\frac{N-\bar{N}}{X-\bar{M}}\right) \quad (1)$$

$$RAI_{NEGATIVE} = -3 \times \left(\frac{N-\bar{N}}{X-\bar{M}}\right) \quad (2)$$

where,

N = represents the monthly precipitation of the period, in mm;

$\bar{N}$ = represents the average monthly precipitation of the historical series, in mm;

$\bar{M}$ = represents the average of the ten highest monthly rainfalls of the historical series, in mm, and;

X = represents the average of the ten smallest monthly rainfalls of the historical series, in mm.

Table 1. Rainfall Anomaly Index (RAI) intensity classes

(RAI)	**Intensity classes**
≥ 4	Extremely Rainy
2 > 4	Very Rainy
0 > 2	Rainy
0 < −2	Dry
−2 < −4	Very Dry
≤ −4	Extremely Dry

Initially, the Pearson correlation analysis (r) was performed between the quarterly rainfall centered in the months of January, February, March, April and May (DJF, JFM, FMA, MAM, AMJ). Subsequently, the relationship between grain yield in Mata Roma municipality and the integrated rainfall of the periods with significant correlation coefficients was determined by Equation 3 (Gomes *et al*., 2019). After identifying the periods (months) in which rainfall exerts the greatest influence on soybean yields, the quadratic regression model was adjusted. The interannual variability of yields and precipitation for the period 2003-2019 was also represented. For the analysis of the rainfall distribution in the soybean producing region associated with the RAI, historical series from the period 1985-2019 were used and the data represented in the form of a boxplot.

$$r = \frac{\Sigma(X-\bar{X})\times(Y-\bar{Y})}{\sqrt{\Sigma(X-\bar{X})^2\times\Sigma(Y-\bar{Y})^2}} \quad (3)$$

where,

X = represents rainfall, in mm;

Y = represents grain yield, in kg×ha^{-1};

$\bar{X}$ = represents the average rainfall, in mm, and;

$\bar{Y}$ = represents the average grain yield, in kg×ha^{-1}.

RESULTS AND DISCUSSION

Descriptive statistics of rainfall data and soybean grain yield

In Figure 2, we can analyze the total annual precipitation data for the historical series from 1985-2019, the monthly total in the period from 2003 to 2019 for the months of January to May and the soybean yield (2003-2019) in Mata Roma producing region.

The average rainfall was 1565.1 and 1455.4 mm for the periods 1985-2019 and 2003-2019, respectively. Most of the annual precipitation (1985-2019) occurred in the range between 1220.3 to 1790.5 mm, with an atypical value of 3007.5 mm and high variability with an amplitude of 2485.6 mm in the series. Analyzing only the rainfall data from the period 2003-2019, which concentrates the months from January to May, there was an occurrence in the range of 1083.6 to 1509.1 mm, high amplitude (1535.5 mm) and an extreme value of 405.8 mm. Regarding soybean yield data, the average for the period (2003-2019) was 2622.2 kg×ha^{-1}, with occurrence in the range between 2408 to 2820 kg×ha^{-1}.

Rainfall and soybean yield correlation

Table 2 shows the correlation between rainfall and yield for Mata Roma municipality. It is verified that the rainfalls of all evaluated quarters correlated positively with the soybean yield, with emphasis on the AMJ period (r = 0.607). When calculating the rainfall correlation coefficient for the period from January to May, it was verified that it increased (r = 0.653), demonstrating that the associated rainfall in this period is responsible for most of the interannual variability of the soybean yield in Mata Roma municipality. This positive correlation from January to May is explained by the soybean sowing

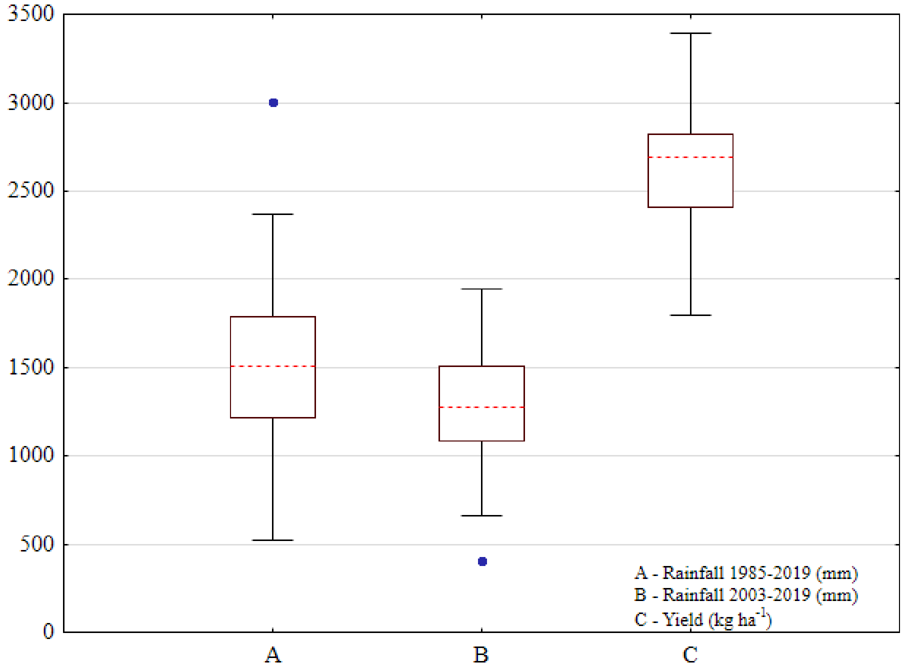

Figure 2. Rainfall events boxplot for the entire 1985-2019 historical series (A), for the 2003-2019 period (B) and for the 2003-2019 soybean yield data (C)

season in the region, which runs from January to February, associated with the use of cultivars with cycles ranging from 110 to 140 days.

Table 2. Correlation between rainfall and soybean yield in Mata Roma municipality, Maranhão

Period	Correlation Coefficient (r)
Dec-Jan-Feb	0,523 (p = 0,031)
Jan-Feb-Mar	0,484 (p = 0,048)
Feb-Mar-Apr	0,517 (p = 0,033)
Mar-Apr-May	0,513 (p = 0,035)
Apr-May-Jun	0,607 (p = 0,009)
Jan-Feb-Mar-Apr-May	0,653 (p = 0,004)

p – value considering 5% probability

RAI on an annual scale (1985-2019)

The dry and rainy years in the 31-year series (1985-2019) can be visualized through the annual RAI analysis, making it possible to identify periods where these events were more intense or lasting. It is possible to see that for the entire analyzed period, there were 14 years with positive deviations and 17 years with negative deviations, with a variation from 8.16 to 0.48 and −0.20 to −5.90, respectively (Figure 3).

Maniçoba *et al.*, (2017), using the same methodology to identify dry and rainy years in the Rio Grande do Norte mesoregion, found that among the analyzed municipalities, Apodi was the one that presented the most severe result, with 34 dry years and 20 rainy years.

Analyzing the period from 2003 to 2019, which coincides with soybean yield records in the study region, two consecutive periods of negative RAI (−RAI) stand out, the first period from 2004 to 2007 and the second from 2012 to 2016 with more negative RAI values than the period from 2004 to 2007, and a period of more than two consecutive years of positive RAI (+RAI) from 2017 to 2019. Among the aforementioned −RAI years, 2012 was the year with the most negative RAI (−5.90), being classified as extremely dry. The total annual rainfall in this period was 1177.4 mm, below the average of the historical series (1985-2019 and 2003-2019), and of this total, only 405.8 mm occurred from January to May, the period with the highest correlation with soybean yield. Corroborating this research results, Nascimento *et al.*, (2017), evaluating the main dry and rainy events for a rainfall series from 1987 to 2015 also in Maranhão state, found the occurrence of 70 dry months with maximum peaks occurring in the 1990s and 2010s, with extreme drought values equal to −2.98 and −3.61, respectively, and 107 rainy months, with the longest rainy sequence occurring from January 1988 to May 1990, with an average RAI value equal to 1.57.

As the Mata Roma microregion is located in the northern of Maranhão state and in the north of Northeast Brazil (NNEB), the most important systems that act on rainfall in this location are the ULCV, in the months of January and February, and the ITCZ , in March and April (Nascimento *et al*., 2015). However, large-scale events such as El Niño and La Niña can positively or negatively influence rainfall in a given region (Brito *et al*., 2022; Rodrigues *et al*., 2021). Studies carried out by Reboita and Santos (2015) identified that drought conditions intensify in the NNEB when under the influence of El Niño and the Atlantic Ocean, with warmer anomalies in the northern than in the southern areas, as observed for periods of –RAI (2003-2019).

RAI on a monthly scale (January to May/2003-2019)

The RAI analysis for the period 2003-2019, on a monthly scale, for the entire period on an annual scale and the obtained classifications are shown in Table 3. Analyzing the average of the monthly RAI (January, February, March, April and May) with the respective annual RAI, it is observed that there were few changes in the classification, these changes being observed for the years 2007, 2012, 2013, 2015, 2016 and 2018. The fact that there are not so many classification changes can be explained by the rainfall behavior in the study region, which is concentrated in the months of January to July due to the action of the ULCV and the ITCZ, with a maximum value occurring in the month of March (Nascimento *et al*., 2015). Thus, for the period from January to May (2003-2019), the total rainfall represents on average 85.96% of the total annual rainfall. And based on the analysis of the monthly RAI, four climate classes are grouped for the period 2003-2019, being very dry (VD), dry (D), rainy (R) and very rainy (VR), with average values of rainfall and soybean yield ranging from 665.75 to 1941.3 mm and 2160 to 2815.57 kg×ha^{-1}, respectively.

Rainfall variability and soybean yield

The interannual variability of the average soybean yield and rainfall in the period of greatest correlation (January to May) is shown in Figure 4, where it is verified that the yields interannual variability is associated with the rainfall interannual

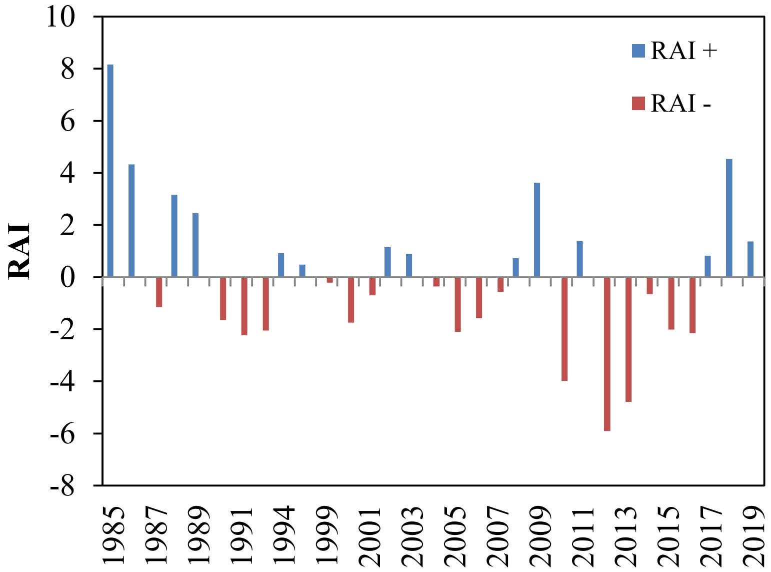

Figure 3. Rainfall anomaly index on an annual scale for the period from 1985 to 2019 for Mata Roma municipality

Table 3. Comparison between the Rainfall Anomaly Index for the period 2003-2019 on a monthly scale and the full period (1985-2019) on an annual scale

Year	Mensal RAI						Classification	
	Jan	Feb	Mar	Apr	May	Average	Monthly	Yearly
2003	−2.85	5.18	−0.81	0.03	0.53	0.41	R	R
2004	1.63	0.30	−0.12	−0.89	−1.83	−0.18	D	D
2005	−2.86	−1.07	−2.49	−2.44	−1.90	−2.15	VD	VD
2006	−2.98	1.57	−4.38	−1.29	2.21	−0.98	D	D
2007	−5.02	2.70	4.07	1.48	−2.85	0.08	**R**	D
2008	0.80	−2.83	1.78	2.56	1.27	0.72	R	R
2009	3.73	−1.75	2.03	4.64	4.49	2.63	VR	VR
2010	−1.74	−3.86	−1.71	−3.46	−2.65	−2.69	VD	VD
2011	−2.85	2.20	−2.70	6.88	4.41	0.71	R	R
2012	−2.32	−3.13	−4.21	−6.22	-3.70	−3.92	**VD**	ED
2013	−0.58	−2.44	−5.21	−4.35	−1.61	−2.84	**VD**	ED
2014	0.47	−1.96	−4.55	−0.94	4.77	−0.44	D	D
2015	−3.70	−2.31	2.69	−1.17	−1.18	−1.13	**D**	VD
2016	1.08	−2.68	3.32	−2.31	−3.70	−0.86	**D**	VD
2017	1.47	1.32	−0.46	0.65	−0.52	0.49	R	R
2018	4.42	5.29	−2.08	2.61	−0.39	1.97	**R**	ER
2019	1.85	0.92	1.02	1.38	2.41	1.51	R	R

R – Rainy; VR – Very rainy; ER – Extremely rainy; D – Dry; VD – Very dry; ED – Extremely Dry

variability for the period of January to May. Two years (2010 and 2012) are observed with yields well below the average, which coincide with very dry years (Table 3), with rainfall of 731.3 and 405.8 mm and yield of 1800 kg×ha^{-1}, respectively. Comparing with the average yield (2622.2 kg×ha^{-1}) from the period 2003-2019, there was a soybean yield loss of 68.64% on average. The severe drought that occurred in 2012 was reported from the north (Rodrigues *et al*., 2021) to the south (Gross & Cassol, 2015, Chechi & Sanches, 2013) of Brazil, bringing social, environmental and agricultural yield losses (Martins *et al*., 2017). Regarding the NNEB region, the main atmospheric system that induces rainfall is the ITCZ. However, according to Reboitas & Santos (2015), when there is a system of large proportions characterized as strong, such as El Niño (EN) for example, which inhibits the vertical formation of clouds over the Brazilian Northeast region, combined with greater warming of the Tropical Atlantic North surface, these systems favor the formation of the ITCZ further north of their climatological position, causing severe droughts like those observed in 2010 and 2012 in the study region.

On the other hand, high average yields generally coincide with annual rainfall above 1000 mm. However, when there is excess rainfall in the first months (Jan and Feb), as observed in 2018 (an accumulated amount of 871.1 mm), a decrease in soybean yield is observed, indicating that above an optimal value there is a reduction in soybean yield (Santos *et al*., 2018). Soybean has two well-defined periods negatively related to lack of water: from sowing to emergence, both excess and lack of water are harmful to the crop establishment (Farias *et al*., 2001).

Based on the climatic risk zoning for soybeans in Maranhão state prepared by the Ministry of Agriculture (crop year 2020/2021), the sowing period for Mata Roma occurs from January to February. Considering a sowing carried out on January 1, 2018 using a cultivar with an early cycle of 110 days (Fehr & Caviness, 1977), this cultivar will have completed its cycle at the end of April of that year. Considering that May presented a monthly precipitation of 484.2 mm, mechanized harvesting is impaired, with significant losses occurring due to torrential rains (Holtz & Reis, 2013).

In Figure 5, it can be seen that the quadratic function fits well to the average data, showing that rainfall from January to May explains 99% of the interannual variation in soybean yields in Mata Roma municipality, considering a more suitable sowing period between January and February, cultivars adapted to the edaphoclimatic conditions of the region and with an average cultivation cycle of 110 to 140 days (Kaster & Farias, 2012).

According to the function, the average maximum soybean yield of 2942.52 kg×ha^{-1} is achieved with a rainfall of 1709 mm, equivalent to 341.75 mm, on average, per month. This rainfall is higher than the monthly average for the period from January to May (2003-2019). According to Farias *et al.*, (2007), the water requirements for

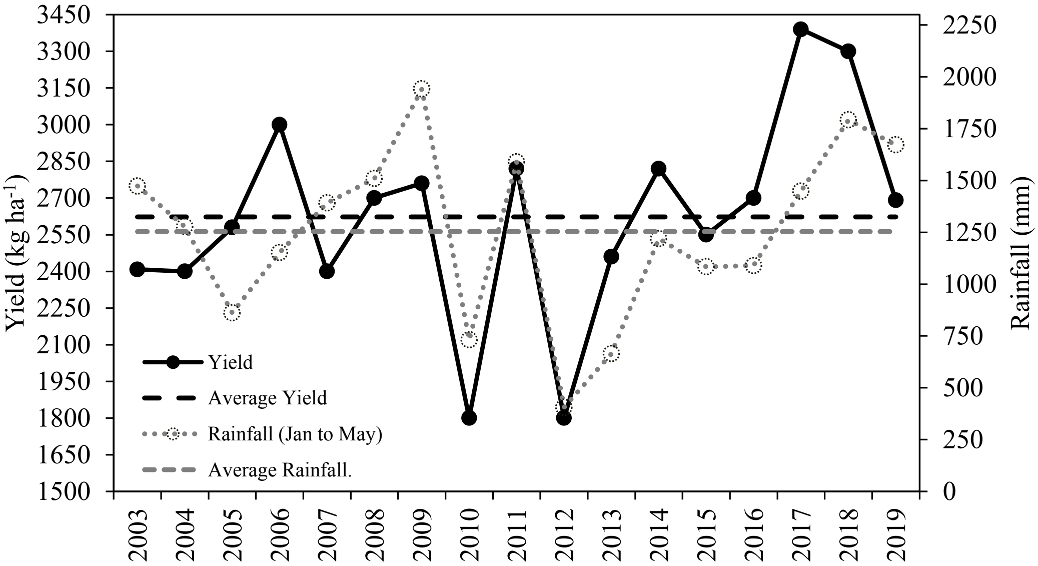

Figure 4. Soybean yield and rainfall from January to May (2003-2019) for Mata Roma municipality

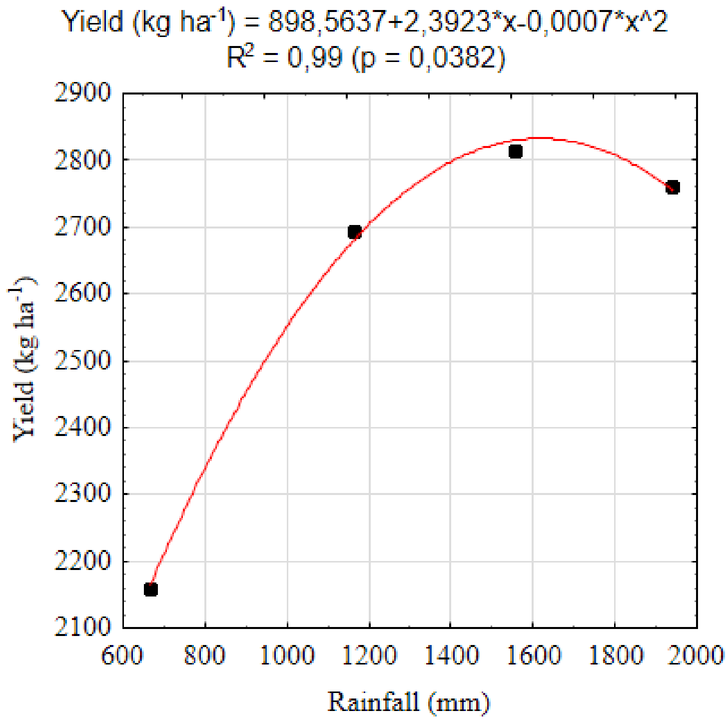

Figure 5. Relationship between rainfall and soybean yield (from January to May) for Mata Roma municipality (2003 to 2019)

maximum soybean yield vary between 450 and 800 mm. Although it was observed, on average, rainfall above the water requirements for the soybean crop, Figures 2 and 4 indicate that there was high variability in rainfall, adding the occurrence of years with negative anomalies — as was observed for the year 2012, for example, with accumulated precipitation for the months of January to May of 405.8 mm — resulting in a drop in soybean yield, as it has two periods that are very critical to the water deficit, flowering and grain filling. Suyker and Verma (2009) found in an experiment under natural field conditions a total water consumption by soybeans from sowing to harvest equivalent to 420 mm. In edaphoclimatic conditions of Paragominas-PA, Souza *et al*., (2016) verified that the total water consumption by soybean (cultivar BRS Tracajá) was 335 mm. Berlato *et al*., (1986) found that soybean needs, on average, about 827 mm for the entire cycle for the climatological conditions of Rio Grande do Sul state. Depending on the Brazilian region and the used cultivar, the water requirement of the entire soybean cycle to obtain good yield levels varies (Farias *et al*., 2007).

CONCLUSION

- The rainfall interannual variation in the period from January to May was a determining factor that resulted in the variability of soybean crop yields under rainfed regime for Mata Roma municipality.
- It was found that soybean yield followed the rainfall behavior in the analyzed period (2003-2019), emphasizing that there may be discrepancies in specific years, as occurred in 2005, for example, very dry and with yield of 2580 kg×ha^{-1}, value close to average. Periods with high rainfall at sowing can also cause yield declines, as seen in 2018 with rainfall of 871.1 mm in the sowing window (January to February).
- Years with very dry periods can lead to an average soybean yield loss of 68%. However, there is strong evidence that in years considered dry, soybean yield reaches values close to the average (2622.2 kg×ha^{-1}) for the period 2003-2013. The average maximum soybean yield in the Mata Roma region occurs with an average rainfall of 1709 mm, equivalent to 341.8 mm per month from January to May.
- The employed methodology has potential for use and adaptation to other locations and cultures.

AUTHORSHIP CONTRIBUTION STATEMENT

SANTOS, E.S.: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft; **GUERRA FILHO, P.A.:** Supervision, Visualization, Writing – review & editing; **OLIVEIRA, S.S.:** Data curation, Investigation; **SILVA, B.S.:** Data curation; **VERAS, A.E.S.:** Data curation; **SOUZA, D.A.:** Data curation.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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