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Agroclimatic zoning of the Brazilian state of *Mato Grosso* for the production of soybean seeds of early cultivars[1]

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ABSTRACT – The objective of this work was to carry out the agroclimatic zoning of the Brazilian state of *Mato Grosso*, in order to identify the regions with the best climatic conditions for producing seeds with high quality of early soybean cultivars. For this purpose, the average monthly temperature data from 11 conventional and 34 automated meteorological stations were used. Due to the low number of stations with data temperature available, this variable was estimated using spatial regression equations, having latitude, longitude and altitude as input variables. Regions with high or low climatic risk were defined according to the average temperatures observed in January and February. The following three categories were established: favorable (≤ 24 °C); moderately favorable (24.1 to 25 °C) and slightly favorable (≥ 25.1 °C). For the material confection, map usage, and geographical data compilation, the inverse distance squared weighted interpolation method was applied. The ArcGIS system was employed to compose the thematic map, in which the best areas for producing seeds of early soybean cultivar were marked. Most of the Southeastern, and Western regions of *Mato Grosso* were considered to be favorable for producing high quality seeds of early soybean cultivars (average temperature ≤ 24 °C).

Index terms: *Glycine max*, temperature, altitude, ArcGIS.

Zoneamento agroclimático do estado de Mato Grosso para a produção de sementes de soja de cultivares precoces

RESUMO – O objetivo neste trabalho foi realizar o zoneamento agroclimático, visando identificar as regiões do estado de Mato Grosso com as melhores condições climáticas para a produção de sementes de soja com alta qualidade de cultivares precoces. Para a elaboração desse zoneamento, foram utilizados, inicialmente, dados mensais de temperatura média de 11 estações meteorológicas convencionais e 34 estações meteorológicas automáticas. Devido à baixa densidade de estações com dados de temperatura, esta variável foi estimada por meio de equações de regressão espacial, que tinham como variáveis preditoras a latitude, longitude e altitude. A definição das regiões de maior ou menor risco climático foi associada à ocorrência de temperaturas médias dos meses de janeiro e fevereiro. Foram definidas três classes: favorável (≤ 24 °C); medianamente favorável (24,1 a 25 °C) e pouco favorável (≥ 25,1 °C). Para elaboração, utilização dos mapas e compilação dos dados geográficos, procedeu-se a interpolação para espacialização, utilizando-se o método do inverso do quadrado da distância. Utilizou-se o sistema ArcGIS, por meio do qual foi confeccionado o mapa temático com as representações das melhores regiões para a produção de sementes de soja de cultivares precoces. A maior parte das regiões Sudeste e Oeste de Mato Grosso é classificada como favorável (temperatura média ≤ 24 °C) para a produção de sementes de soja com alta qualidade de cultivares precoces.

Termos para indexação: *Glycine max*, temperatura, altitude, ArcGIS.

Introduction

Among the factors inherent to agricultural production, climate emerges as the one most capable of limiting the maximum potential productivity (Farias, 2011). Its unpredictability is a major risk factor, which answers for a

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fairly significant part of the unsuccess of some cultures. Climatic stresses, such as drought, excessive rainfall, extreme temperatures, and insufficient light, not only can drastically reduce crop yields and seed quality, and restrict sites of production, sowing dates and soils where commercially important species can be grown. Thus, they are considered some of the leading causes of seed deterioration in the field (França-Neto et al., 2016).

Soybean seeds are highly sensitive to hot and humid environments during their physiological maturity phase. So, obtaining high-quality seeds can be challenging for most soybean production areas in Brazil, particularly in those located above 24º N latitude (Costa et al., 1994). In these locations, the humidity attached to climatic oscillations induces seed deterioration. The effects are magnified in hot weathers, typical of tropical and subtropical regions (Forti et al., 2010).

On account of that, the most viable alternative for producing high-quality soybean seeds under tropical conditions, such as those in the Brazilian state of *Mato Grosso*, is by cultivating it in sites above 700 m. In these regions, the climate is predominantly dry with mild temperatures during the maturation and harvest stages. It is also possible to adjust the sowing date, so that these events take place in a more favorable environmental condition (França-Neto et al., 2016).

In this sense, a very useful and important instrument is the climatic-risk agricultural zoning, which has been promoted by the Brazilian Ministry of Agriculture for over 20 years (Brasil, 2012; Rodrigues and Rodrigues, 2016). This strategy is included among the national policies for rationalizing the use of natural resources to promote more profitability, stability, and competitiveness in agriculture. In addition it provides farmers the autonomy to identify the suitable planting seasons for cultures in general, also considering the different types of soil and cultivar cycles (Brasil, 2017). Therefore, zoning studies aiming at lowering climate-related risks are of utmost importance to agricultural practices, once they allow producers to allocate their crops to sites where conditions are more favorable to seed production (Pádua et al., 2014).

The climatic-risk zoning uses data to model how climate variability over the years affects the performance of a given culture. It allows inferring, with a sizeable safety margin, the most appropriate place and time for sowing, taking into account differences in the Brazilian regions. In addition, it lists the cultivars that better suit each scenario (Mitidieri and Medeiros, 2008).

In spite of holding one of the highest yields in the country, *Mato Grosso* has not had climatic zoning directed to soybean seed production performed yet. The climate in the state is often not favorable, which results in high indices of field deterioration. This fact, jointly with injuries caused by stink bugs and mechanical damages, compromises the quality of the seeds in some regions.

For these reasons, the objective of this study was to carry out the agroclimatic zoning of the state, and to identify the regions in *Mato Grosso* with the best conditions to produce high-quality soybean seeds from early cultivars.

Material and Methods

The elaboration of the agroclimatic zoning maps initially used the average monthly temperature data (T_{med}) from 11 conventional and 34 automated meteorological stations located in *Mato Grosso* (Table 1). The selection of these units was based on their spatial distribution over the state. Also, given the scarcity of long-observation series, only stations with at least eight years of monitoring were chosen. All meteorological data used were provided by the *Instituto Nacional de Meteorologia* [National Institute of Meteorology] (INMET, 2015).

Since there are few meteorological stations with available temperature data in *Mato Grosso*, it is difficult to elaborate highly accurate maps, containing local variations. Thus, the estimation and spatialization of this variable were performed in order to overcome this setback. Additionally, these procedures allow the obtainment of thermic values in any location, as a function of geographical-dependent parameters – altitude, latitude, and longitude (Cargnelutti Filho et al., 2006; 2008).

The average temperature was estimated and spatialized from latitude, longitude, and altitude inputs, by using spatial regression equations. In this study, multiple regression equations for average monthly temperature entries were used, as proposed by Tarifa (2011). Equations 1 and 2 were applied to January and February, respectively, as these months were deemed to be the period when the final stages of maturation and harvest seeds of early soybean cultivars occur in the state.

$$Y = (-0.0062223 * alt) - (0.0168041 * long) + (0.1488236 * lat) + 26.10685 \quad (1)$$

$$Y = (-0.0057064 * alt) + (0.0343606 * long) + (0.148176 * lat) + 22.893694 \quad (2)$$

Where: *Y* is the air average monthly temperature (°C), *alt* stands for altitude, *long* for longitude, and *lat* for latitude.

Prior to the spatial variability and zoning studies, the average temperature in both January and February were estimated by using the databank obtained from selected stations (Table 1). In this assessment, the following parameters were considered: root mean square error (equation 3); Wilmott's index of agreement (equation 4), Nash-Sutcliffe coefficient (equation 5), correlation coefficient and confidence index (equation 6).

Table 1. Meteorological stations that provided data to build the equations for estimating the average air temperature, with the respective geographical coordinates of the cities in the state of *Mato Grosso* (INMET, 2015).

Type	Meteorological stations	Latitude	Longitude	Altitude (m)
Auto	*Água Boa*	14°00’	52°12’	432.0
Auto	*Alta Floresta*	09°50’	56°06’	289.0
Auto	*Alto Araguaia*	17°33’	53°22’	753.0
Auto	*Alto Taquari*	17°48’	53°17’	875.0
Auto	*Apiacás*	09°33’	57°23’	220.0
Auto	*Brasnorte*	12°31’	58°13’	431.0
Auto	*Cáceres*	16°02’	57°41’	116.0
Conv	*Cáceres*	16°02’	57°41’	116.0
Auto	*Campo Novo*	13°47’	57°50’	570.0
Auto	*Campo Verde*	15°31’	55°08’	749.0
Conv	*Canarana*	13°47’	52°27’	430.0
Auto	*Carlinda*	10°00’	55°47’	290.0
Auto	*Comodoro*	13°42’	59°45’	591.0
Auto	*Cotriguaçú*	09°54’	58°34’	261.0
Conv	*Cuiabá*	15°37’	56°06’	151.3
Auto	*Cuiabá*	15°37’	56°06’	151.3
Conv	*Diamantino*	14°40’	56°45’	286.3
Auto	*Gaúcha do Norte*	13°11’	53°15’	379.0
Auto	*Guaratã do Norte*	09°57’	54°53’	320.0
Conv	*Gleba Celeste*	12°28’	55°29’	415.0
Auto	*Guiratinga*	16°20’	53°45’	526.0
Auto	*Itiquira*	17°10’	54°30’	585.0
Auto	*Juara*	11°16’	57°31’	260.0
Auto	*Juína*	11°22’	58°43’	200.0
Conv	*Matupá*	10°25’	54°91’	285.0
Auto	*Nova Ubiratã*	13°24’	54°45’	518.0
Auto	*Novo Mundo*	12°31’	58°13’	431.0
Conv	*Nova Xavantina*	14°70’	52°35’	316.0
Auto	*Paranatinga*	14°25’	54°02’	474.0
Auto	*Pontes Lacerda*	15°15’	59°20’	256.0
Auto	*Porto Estrela*	15°21’	57°13’	145.0
Conv	*Poxoréo*	15°83’	54°38’	450.0
Auto	*Querência*	12°37’	52°13’	382.0
Conv	*Rondonópolis*	16°27’	54°34’	284.0
Auto	*Rondonópolis*	16°27’	54°34’	284.0
Auto	*Salto do Céu*	15°08’	58°06’	303.0
Auto	*Santo Antônio do Leste*	14°55’	53°53’	648.0

Tabela 1. Continuation.

Type	Meteorological stations	Latitude	Longitude	Altitude (m)
Conv	*Santo Antônio do Leverger*	15°78’	56°06’	140.0
Auto	*São Félix do Araguaia*	11°37’	50°43’	218.0
Conv	*São José do Rio Claro*	13°27’	56°39’	350.0
Auto	*São José do Rio Claro*	13°27’	56°39’	350.0
Auto	*Sinop*	11°58’	55°33’	371.0
Auto	*Sorriso*	12°33’	55°43’	380.0
Auto	*Tangará da Serra*	14°39’	57°25’	321.5
Auto	*Vila Bela*	15°03’	59°52’	222.0

Auto–Automated station.
Conv–Conventional station.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{Yobs} - \mathrm{Yest})^{2}}{n}} \quad (3)$$

Where: *RMSE* is the root mean square error, *Yobs* the observed value, *Yest* the estimated value, and *n* the total number of pairs of observed and estimated values.

The agreement refers to how accurate, or close to the real data, the estimated values are. To mathematically quantify such approximation, Willmott (1982) proposed a coefficient (*D*), which ranges from zero to 1, representing none to full agreement, respectively. This index is given by equation 4.

$$D = 1 - \frac{\sum_{1=1}^{n}(\mathrm{Yest} - \mathrm{Yobs})^{2}}{\sum_{i=1}^{n}(|\mathrm{Yest} - \overline{\mathrm{Y}}| + |\mathrm{Yobs} - \overline{\mathrm{Y}}|)^{2}} \quad (4)$$

$$NS = 1 - \frac{\sum_{i=1}^{n}(\mathrm{Yobs} - \mathrm{Yest})^{2}}{\sum_{i=1}^{n}(\mathrm{Yobs} - \overline{\mathrm{Y}})^{2}} \quad (5)$$

Where: *D* is the agreement index, $\bar{Y}$ is the mean of the observed values, and *NS* corresponds to the Nash-Sutcliffe coefficient.

The accuracy was assessed by the correlation coefficient (*r*). It indicates the degree to which data scatter from a linear regression model. In this case, measured and estimated temperature values were considered (Biudes et al., 2008).

The confidence index (equation 6) uses both coefficients (*r* and *D*). If its value equals zero, the confidence is null; if it equals 1, there is a total match (Camargo and Camargo, 2000).

$$C = r \times D \quad (6)$$

Where C is the confidence index, r is the correlation coefficient, and D is the agreement index.

The criterion adopted to interpret the confidence index (C), specifically for the average monthly temperature values, was that of Camargo and Sentelhas (1997), displayed in Table 2.

The definition of regions of either high or low climatic risk was associated with the incidence of the average temperatures during the soybean maturation (from January to February). During this phase, the physiological potential is considered to be at its highest. Both the altitude of the site and the sowing moment of the early cultivars were also taken into account. The following three categories were sorted according to temperature intervals: favorable (≤ 24 °C), moderately favorable (24.1 to 25 °C), and slightly favorable (≥ 25.1 °C).

After evaluating the efficiency of the models, the thematic maps were elaborated. In the creation process, map usage and geographical data compilation, interpolations were done through the inverse square distance method, in order to obtain the spatialization (Mello et al., 2003). The geographical information system ArcGIS was used to draw the map representing the best regions in *Mato Grosso* for producing seeds of early soybean cultivars.

Results and Discussion

In January and February, the minimum average temperatures were 22.5 °C and 22.6 °C, respectively; whereas the maximum average temperatures were 27 °C and 26.8 °C (Table 3). All these observed values were close to the corresponding average temperature estimated for these months.

Overall, the estimates obtained by the model were very close to the observed data (Table 3). Both the Nash-Sutcliffe efficiency coefficient (*NS*) and the agreement index (*D*) neared 1, implying that the estimated temperature numbers

Table 2. Interpretation criterion for the performance of temperature, assessed by the confidence index (C), as suggested by Camargo and Sentelhas (1997).

C value	Performance
> 0.85	Excellent
0.76–0.85	Very good
0.66–0.75	Good
0.61–0.65	Average
0.51–0.60	Passable
0.41–0.50	Bad
≤ 0.40	Very bad

Table 3. Average observed (Tobs) and estimated (Test) temperatures (ºC) at the meteorological stations located in the state of *Mato Grosso*, from 2007 to 2014.

Meteorologial station	January		February	
	Tobs	Test	Tobs	Test
Alta Floresta	24.92	24.83	24.80	24.63
Alto Araguaia	22.93	23.14	23.13	23.03
Alto Taquari	22.47	22.42	22.59	22.37
Apiacás	25.91	25.19	26.28	25.03
Brasnorte	23.80	24.31	24.00	24.29
Cáceres	26.90	26.80	26.10	26.59
Cáceres (Conv.)	27.09	26.80	26.96	26.59
Campo Novo	24.28	23.64	24.03	23.67
Campo Verde	22.89	22.83	23.03	22.81
Canarana	25.28	24.60	24.90	24.28
Carlinda	24.78	24.85	24.93	24.64
Comodoro	23.11	23.46	22.94	23.60
Cotriguaçú	24.88	24.97	24.67	24.88
Cuiabá (Conv.)	26.93	26.55	26.98	26.27
Cuiabá	26.74	26.55	26.70	26.27
Diamantino	25.87	25.47	25.80	25.29
Gaúcha do Norte	25.05	24.82	25.63	24.51
Guaratã do Norte	25.33	24.67	25.08	24.43
Gleba Celeste	25.62	24.45	25.75	24.28
Guiratinga	25.12	24.36	25.11	24.16
Itiquira	24.08	24.11	24.20	23.97
Juara	25.29	25.20	25.17	25.06
Juína	24.56	25.57	24.46	25.45
Matupá	25.04	24.95	24.94	24.72
Nova Ubiratã	23.90	23.96	24.40	23.80
Novo Mundo	24.12	24.31	24.18	24.29
Paranatinga	24.24	24.40	24.24	24.18
Pontes Lacerda	25.65	25.79	25.24	25.73
Porto Estrela	26.40	26.53	26.20	26.31
Poxoréo	25.55	24.83	25.48	24.63
Querência	24.50	24.73	24.70	24.38
Rondonópolis (Conv.)	25.77	25.87	25.77	25.59
Rondonópolis	25.57	25.87	25.59	25.59
Salto do Céu	25.40	25.50	25.03	25.40
Santo Antônio do Leste	23.45	23.39	23.68	23.26
Santo Antônio do Leverger	26.84	26.72	26.74	26.44

Table 3. Continuation.

Meteorologial station	January		February	
	Tobs	Test	Tobs	Test
São Félix do Araguaia	25.82	25.63	25.98	25.11
São José do Rio Claro (Conv.)	24.84	24.98	25.04	24.84
São José do Rio Claro	25.77	24.98	24.97	24.84
Sinop	24.43	24.65	24.69	24.46
Sorriso	24.73	24.67	25.10	24.50
Tangará da Serra	24.65	25.32	24.40	25.20
Vila Bela	25.77	25.96	25.0	25.91
RMSE	0.42		0.57	
NS	0.86		0.70	
D	0.93		0.84	
r	0.99		0.83	
C	0.92		0.83	

RMSE– root mean square error; *NS*–Nash-Sutcliffe efficiency coefficient; *D*–agreement index; *r*–correlation coefficient; *C*–confidence index.

were good enough, and that the model is therefore efficient. The correlation coefficient (*r*) found for both observed and expected values were also close to 1, indicating that there was a significantly strong positive correlation between the variables in January, and a strong positive one in February.

Table 3 also lists the confidence indices (*C*) obtained for January (0.92) and February (0.83), which respectively represented a great and very good confidence levels. Hence, the estimated data have reliable applicability, according to the criteria proposed by Camargo and Sentelhas (1997) (Table 2).

It is worth noticing that the methods currently employed in Brazil for temperature modeling have been developed and used for quite some time. They have already proved to be efficient when it comes to specific localities, such as the state of *Mato Grosso*, where not enough data are available (Buriol et al., 1973; Sandanielo, 1987; Lima and Ribeiro, 1998; Abreu et al., 2011).

Since the coefficients satisfactorily endorsed the estimates of average temperature data, it became possible to elaborate the thematic maps of *Mato Grosso*, considering January (Figure 1A) and February (Figure 1B).

The zones deemed favorable (areas in green, Figure 1A) for the production of seeds of early soybean cultivars, considering maturation and harvest phases to taking place in January, are concentrated in both the Southeast and West of the state. Another favorable area was identified in the Central-South zone, including the proximities of the cities of *Tangará da Serra* and *Diamantino*, as well as some small locations bordering the Southeastern region. In a less extent, other favorable sites were found in the Middle-North (*Santa Rita do Trivelato*, *Nobres* and *Nova Ubiratã*), Northwest (small areas in *Aripuanã*, *Juara* and *Juína*), Northeast (*Santa Teresinha* and *Vila Rica*), and North (*Guarantã do Norte*, *Novo Mundo*, *Matupá*, *Terra Nova do Norte*, *Santa Helena* and *Marcelândia*) (Figure 1A).

Similar profiles of favorable areas with temperatures below 24 ºC were noticed in both months assessed. Nonetheless, in February, there was an enlargement of the zones considered favorable and moderately favorable in the Southeast, Middle-North, North, and Northeast of the state (Figure 1B). In the Southeastern region particular case, over 50% of the territory was sorted as favorable for producing seeds of early soybean cultivars. The exceptions were the town of *Araguaiana*, in the vicinities of *Barra do Garças*, and locations near *Rondonópolis*, *Juscimeira*, and *Pedra Preta*.

The areas in the Middle-North and North of *Mato Grosso* were almost entirely regarded as moderately favorable for the production of soybean seeds, with temperatures between 24.1 and 25 °C (Figures 1A and 1B). The Northeast and Northwest of the state also presented zones with the same classification. Likewise, moderately favorable sites were found in the Southeast, namely in the cities of *Paranatinga*, *Itiquira*, and *Barra do Garças*, and also in the West, in *Comodoro* and North of *Sapezal*.

The Central-South regions (Figures 1A and 1B) showed the largest area considered slightly favorable for producing seed of early soybean cultivars. Within this region are the municipalities of *Nobre*, *Tangará da Serra*, *Diamantino* and *Nortelândia*.

Studies carried out in the states of *Minas Gerais*, *Paraná*, and *Goiás* pointed to different temperature classes. In the former, the agroclimatic zoning for production of high-quality soybean seeds defined regions with high and low climatic risk, by associating it with the average temperatures during the phases of maturation (when the physiological potential is at its maximum) and the altitude of the sites (Pádua et al., 2014). Considering the regular sowing season and having the maturation final stages and harvest happening in March, the authors established the following three classes of regions: favorable (average temperature equal to or below 23.5 ºC); moderately favorable (average temperature ranging from 23.6 to 24.9 °C); and slightly favorable (average temperature above 25 ºC).

In the state of *Paraná*, the areas were classified in T1 (average temperature above 24 ºC), T2 (average temperature between 22 and 24 ºC), and T3 (average temperature below 22 ºC). In this zoning study, the authors verified that the best areas to produce soybean seeds coincided with mild temperatures (below 22 ºC) during the maturation phase. This ambient condition benefits the production of seeds with superior physiological and sanitary qualities (Costa et al., 1994).

In the state of *Goiás*, the zoning was altimetric (França-Neto et al., 2016). In this case, areas between 850 and 1189 m high were deemed the most favorable; whereas those from 700 to 849 m were considered favorable for soybean seed production.

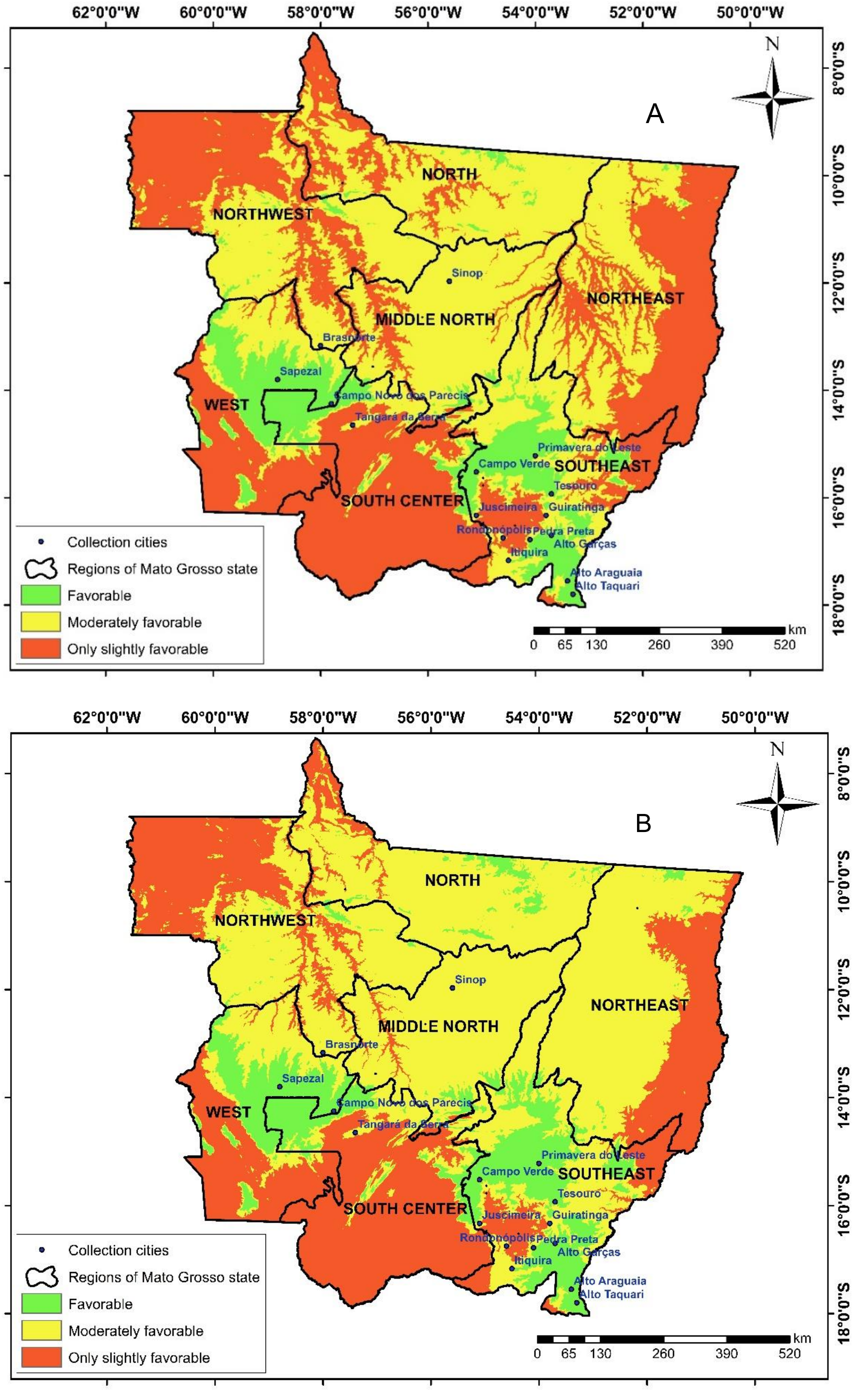

Figure 1. Agroclimatic zoning of the state of Mato Grosso for the production of seeds of early soybean cultivars [*Glycine max* L. Merrill] in January (A) and February (B). Favorable (≤ 24 ºC), moderately favorable (24.1–25 °C), and slightly favorable (≥ 25.1 °C).

Conclusions

The majority of Southeast and West regions of *Mato Grosso* state are classified as favorable (average temperature ≤ 24 ºC) for producing seeds of early soybean cultivars.

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