Original Research Article

Zoning of water deficiency risk for conventional cotton, in Mato Grosso

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ABSTRACT

The agroclimatic zoning of cotton is a very important tool because it allows to establish the most favorable periods for its cultivation, when the environmental conditions are more propitious, in order to reduce agricultural activity risks. The objective of this work was to elaborate the zoning of the risk estimation of cotton productivity reduction in Mato Grosso, using the FAO method. Cultivars of precocious, medium and late cycles were considered, with four sowing dates (12/11, 12/21, 1/01 and 1/11) and three available water capacities (60, 140 and 200 mm). Results were specialized by ordinary kriging. The state southern most regions are the ones with the highest reduction risk, due the lower precipitation in these places, and the sowing season 1 was the one with the lowest productivity reduction risk, and the late-cycle cultivar season 4 was the one that presented the highest reduction risk. Trough the validation of the obtained results, it can be considered that the methodology adopted in this work to verify the risk of a productivity decrease was efficient.

Keywords: Yield reduction, water deficit, Gossypium hirsutum.

1. INTRODUCTION

Mato Grosso state is currently the largest cotton producer in the country, according to data from CONAB (National Supply Company), with production of 880.5 thousand tons in 2015/16 cotton crop [1].

In the state, precipitations occur in the spring-summer season, when agricultural activities are intensified, and precipitation anomalies can occur, resulting in dry day sequences during the rainy season, which interferes negatively in crop productivity [2].

Rainfall is one of the most significant and influential meteorological elements in environmental conditions, specific to the agricultural sector, playing a fundamental role in the development of agricultural crops and in final production [3]. Considered one of the factors that most influence cotton development, considering that, through the water deficit, there are significant reductions in growth, development, production per plant and consequently in final productivity, and that such severity depends on the stress duration and the stage of plants development when it occurs [4].

Climate risk zoning is an alternative used to establish more favorable periods for different crops, where environmental conditions are conducive to crop development. When sowing is carried out in periods in which climatic conditions are adequate to the crop needs, there is a reduction in losses risks due to deficit or water surplus at the critical stages of crop development [5].

Simulation models are used to study and define the most favorable sowing times for cotton cultivation in which there is no water restriction. A world-wide methodology to verify the effect of water deficiency on cotton productivity was advocated by FAO [6], where the relative productivity decrease is estimated considering the relative evapotranspiration reduction and a response coefficient.

Once sowing times are defined, with a lower risk of reduced productivity, it is possible to define the favorable regions for conventional cotton cultivation, and zoning through data interpolation and map generation. Considering the above, the objective was to elaborate the zoning of the risk estimation of conventional cotton productivity considering different cycles, sowing times and soil water storage capacity in Mato Grosso, as well as the validation of the model used.

2. MATERIAL AND METHODS

The study area corresponds to Mato Grosso state, located in Center-West region of Brazil, whose territory is 903,198,091 km^2 [7]. The success of agriculture and cotton in the cerrado region has been driven by favorable climate conditions, flat reliefs, favoring agriculture mechanization, programs to encourage the culture implemented by region states and, specially, intensive use of modern technologies [8].

The daily temperature data (maximum, average and minimum), relative humidity, wind speed and precipitation were obtained from National Institute of Meteorology (INMET). Regarding precipitation data, these were obtained from National Water Agency (ANA). In this study, stations that had a minimum of 10 years of observation were used, totaling 15 conventional INMET stations and 169 ANA rain stations.

Data were organized in tens and analyzed to verify their homogeneity, data organization in tenties consists of dividing the daily values into 36 groups with ten days each, disregarding the periods in which observations failed, so that the occurrence or not of interruptions (failures) in the climatological series was what determined which tests would be applied.

For time series that did not present interruption, Wald-Wolfowitz test was applied for randomisation. This test application consisted of determining the series median, then comparing the values sequence number above or below the median, in the observations chronological order, at the 5% significance level. When series presented an interruption, Wald-Wolfowitz test was used for two samples, whose application consisted in arranging the data in ascending order, identifying the sequences number in which data appeared before or after the interruption [9, 10, 11].

The nonparametric Kruskal-Wallis test was applied for series with two or more interruptions, which was used to test if a samples set comes from the same distribution, at a significance level of 5%. Trough this test, it is possible to test the null hypothesis that all populations have equal distribution functions against the alternative hypothesis that at least two of the populations have different distribution functions [12].

The interruptions that occur in the climatological series do not make them unfeasible, failing to fill in, since it is not possible to estimate missing data without changing the frequency distribution dispersion scale [13].

After verification of the data homogeneity, the potential evapotranspiration (ETo) (mm d^{-1}) for the 15 INMET stations was calculated, using the equation proposed by [14], which considers the variables: radiation at the top of the atmosphere, maximum, average and minimum daily temperature. This equation is an alternative for estimating potential evapotranspiration in sites with limited data availability, according to [15], and is expressed by the following equation:

$$ETo = 0{,}0023\,(T_{med} + 17{,}8) \times (T_{max} - T_{min})^{1/2} \times Ra \times 0{,}408$$

Where:

ETo: evapotranspiration reference potential, in mm day^{-1};

Tmed: average daily temperature in ºC;

Tmax: maximum daily temperature in ºC;

Tmin: minimum daily temperature in ºC;

Ra: radiation at the top of the atmosphere, in MJ m^{-2} $day\text{-}^{1}$.

As the number of stations with only precipitation data (169) was often higher than that of stations with data to calculate potential evapotranspiration (15), the ANA rainfall series were grouped by INMET meteorological station. For this grouping, Thiessen polygon method was used, in order to obtain estimates of actual and maximum evapotranspiration for the 184 stations. This method consists of connecting the stations by straight sections, drawing lines perpendicular to these stretches, passing through the middle a line connecting the two stations. The perpendicular lines are then extended until they find the others [16].

Climatological water balance was performed on a decendial scale, and only precipitation data with 75% probability were used, that is, precipitation values were used with 75% confidence that an event corresponding to that or higher occurred. For an empirical determination of rainfall probability, it is enough that rainfall values are organized in a decreasing manner, together with the probability in ascending order and the following equation was used, where: *P* = probability; *M* = order number of appearance of the value in the ordered series; *N* = number of data in the series.

$$P = \frac{M}{N + 1}$$

The use of rain probability values is important due the variation in distribution over the years, so for the purposes of agricultural activities planning, it is recommended to use the rainfall frequency distribution, which is the case of this work, [17]. In addition, it is important to note that the probability of precipitation is higher than precipitation.

The maximum evapotranspiration (ETm) was estimated by the following equation, according to [6]:

$$ETm = ETo \; x \; Kc$$

Where:

ETo: potential evapotranspiration (mm day^{-1});

Kc: coefficient of culture.

The values of Kc used, varied according to the cotton crop cycle phases, being equal to 0.5 in initial development, 0.8 in growth, 1.05 in the reproductive period, and 0.8 at the end of the cycle, as proposed by [6].

For water balance preparation, an early-cycle cultivar (150 days), one medium-cycle (160 days), and one late-cycle cultivar (170 days) was considered. Four sowing seasons were simulated for each cultivar (11/12, 21/12, 01/01 and 11/01). The sowing dates were selected according to Embrapa recommendations, following the sowing window of the cotton crop for Mato Grosso state [8].

In water balance calculation, the estimation of soil water storage and the "accumulated negative" was done using the First Order Potential equation [18], which considers the fraction p, that is, a water fraction, as a function of the AWC, that is readily available in the soil for extraction by plants without impairing growth, and for this the following conditions are taken into account [19]:

□□When *AWC* □□*(1 – p)* < *ARM* ≤ *AWC*, that is, in the humid zone.

$$ARM = AWC - L$$

□□When *0* < *ARM* ≤ *AWC* □□*(1 – p)*, that is, in the dry zone.

$$ARM = AWC * (1-p) \; e^{\left[\left(p - \frac{L}{AWC}\right) * \left(\frac{1}{(1-p)}\right)\right]}$$

Where:

AWC: available water capacity (mm);

p: fraction of available water (mm);

ARM: soil water storage (mm);

L: accumulated negative (mm).

Available water fraction values available can be seen in Table 1, according to [6]. From these values, a regression was generated so that it was possible to determine the values of the fraction p at each site as a function of potential evapotranspiration.

Table 1: P fraction of soil water for cotton and maximum evapotranspiration

ETm mm/day	2	3	4	5	6	7	8	9	10
Fraction *p*	0,875	0,8	0,7	0,6	0,55	0,5	0,45	0,425	0,4

Source: [6].

General values for the available water capacity (AWC), as a function of soil texture, were 60, 140 and 200 mm [6]. Trough the climatic water balance, it is determined the water accounting of a determined soil layer, defining the dry periods (water deficit) and wet (water surplus) of a given location [20].

Productivity reduction estimates were made according to a methodology proposed by [6], considering that productivity decreases proportionally to the reduction of relative water consumption, in a certain proportion that depends on the crop under study.

The productivity reduction was estimated by the following equation:

$$R = Ky_d \cdot \left(1 - \frac{ETR}{ETm}\right) + Ky_f \cdot \left(1 - \frac{ETR}{ETm}\right) + Ky_m \cdot \left(1 - \frac{ETR}{ETm}\right)$$

Where:

R: productivity reduction fraction, decimal;

Ky_d: crop response factor to the hydric deficiency in vegetative phase, decimal;

Ky_f: crop response factor to water deficit in flowering, decimal;

Ky_m: crop response factor to the water deficit in the maturation, decimal;

ETR: actual evapotranspiration or water consumption, decendial in mm; and

ETm: crop maximum evapotranspiration or water demand, decendial in mm.

The values of Ky used, varied according to crop cycle phases, being: 0.20 for vegetative development; 0.50 for flowering; and 0.25 for maturation [6].

The model aims to determining the potential productivity penalty due to water deficiency, which is due to the sum of the products Ky * (1-ETR / ETm) that quantify the productivity reduction caused by water deficiency.

To characterize the spatial variability of risk values of productivity reduction, data were analyzed, using geostatistical methods by means of semivariograms calculation.

As the semivariograms showed a tendency, that is, they did not stabilize in a plateau with the distance growing uninterruptedly, a polynomial surface was adjusted, calculated according to [21], being realized then a new adjustment with the residues obtained by the difference between the original data and the surface adjusted.

$$Z*(x,y) = A_0 + A_1X + A_2Y + A_3X^2 + A_4XY + A_5Y^2$$

Where:

Z: attribute value at point X, Y;

X, Y: point coordinates;

An: coefficients to be calculated.

The semivariograms were adjusted for each sowing season, AWC and cultivar cycle, selecting the models that presented the best adjustments, adopting as one of the parameters the spatial dependence degree (SSD). According to [22], the SDDrepresents the portion of spatial variability that is due to chance and has the following proportions: (a) strong spatial dependence, <25%, (b) moderate spatial dependence, 25-75%; and (c) weak spatial dependence,> 75%.

$$SDD = \left(\frac{Co}{Co + C}\right) \times 100$$

Where:

SDD: spatial dependence degree;

Co: nugget effect;

Co+C: sill.

After analyzing the semivariograms and establishing spatial dependence among the analyzed variables, the spatial variability of the productivity reduction for Mato Grosso state was mapped using the ordinary kriging technique.

In order to validate the estimates, yield, precipitation, soil and cultivar characteristics were collected in six commercial cotton production plots, located in Tangará da Serra, Campo Novo do Parecis and Deciolândia counties in Mato Grosso.

With the information collected, calculations of decendial climatological water balance were performed, in the same way as it was done to estimate the zoning of productivity decrease risk, this procedure was carried out with the objective to verifying that the precipitation that occurred during the crop cycle would be a limiting factor for the productivity obtained in the commercial plots where the surveys were made. For this, the commercial plots productivities were compared with the cultivars average productivity values in the regions and crop analyzed.

3. RESULTS AND DISCUSSION

Table 2 shows the semivariograms parameters of productivity risk reduction percentage as a function of water deficit, used to analyze the spatial dependence and reliability of the generated maps.

Table 2: Parameters of spherical model semivariograms used for spatialization of productivity risk reduction values (%) in Mato Grosso state.

VARIABLES	PARAMETERS				
	Nugget effect	Sill	Range (km)	r^2	SDD (%)
AWC 60 SP1 EARLY	50.49	7.50	78.90	0.624	12.93
AWC 60 SP1 MEDIUM	39.85	24.40	312.28	0.710	37.97
AWC 60 SP1 LATE	30.62	17.42	305.61	0.769	36.26
AWC 60 SP2 EARLY	50.03	7.10	68.90	0.633	12.42
AWC 60 SP2 MEDIUM	34.46	23.70	324.50	0.706	40.74
AWC 60 SP2 LATE	39.45	6.70	71.12	0.587	14.51
AWC 60 SP3 EARLY	24.67	15.42	302.27	0.707	38.46
AWC 60 SP3 MEDIUM	25.04	12.98	303.39	0.615	34.13
AWC 60 SP3 LATE	18.55	9.30	301.16	0.724	33.39
AWC 60 SP4 EARLY	21.41	2.76	65.56	0.501	11.41
AWC 60 SP4 MEDIUM	22.43	3.85	71.12	0.521	14.64
AWC 60 SP4 LATE	13.38	8.95	321.17	0.594	40.08
VARIABLES	PARAMETERS				

	Nugget effect	Sill	Range (km)	r^2	SDD (%)
AWC140 SP1 EARLY	58.00	34.30	298.94	0.676	37.16
AWC140 SP1 MEDIUM	45.39	26.60	316.72	0.781	36.94
AWC140 SP1 LATE	58.26	10.10	84.46	0.600	14.77
AWC140 SP2 EARLY	74.83	12.20	67.79	0.612	14.01
AWC140 SP2 MEDIUM	56.80	9.80	75.56	0.657	14.71
AWC140 SP2 LATE	48.51	8.10	71.12	0.641	14.30
AWC140 SP3 EARLY	38.86	6.40	76.68	0.629	14.14
AWC140 SP3 MEDIUM	31.64	2.40	78.90	0.658	7.05
AWC140 SP3 LATE	25.84	1.02	71.12	0.606	3.79
AWC140 SP4 EARLY	33.33	4.70	71.12	0.546	12.35
AWC140 SP4 MEDIUM	28.78	4.29	71.12	0.649	12.97
AWC140 SP4 LATE	20.84	2.80	75.56	0.595	11.84

VARIABLES	PARAMETERS				
	Nugget effect	Sill	Range (km)	r^2	SDD (%)
AWC 200 SP1 EARLY	67.64	9.00	75.56	0.534	11.74
AWC 200 SP1 MEDIUM	69.43	0.80	70.01	0.491	11.39
AWC 200 SP1 LATE	56.36	21.80	323.39	0.759	29.00
AWC 200 SP2 EARLY	49.52	31.00	322.39	0.700	38.49
AWC 200 SP2 MEDIUM	64.90	9.10	67.79	0.551	12.29
AWC 200 SP2 LATE	59.23	10.70	65.56	0.530	15.30
AWC 200 SP3 EARLY	55.71	8.00	70.01	0.635	12.55
AWC 200 SP3 MEDIUM	37.64	5.40	62.23	0.477	12.54
AWC 200 SP3 LATE	31.53	5.72	86.68	0.528	15.35
AWC 200 SP4 EARLY	35.15	5.30	68.90	0.532	13.10
AWC 200 SP4 MEDIUM	34.13	5.30	60.01	0.416	13.44
AWC 200 SP4 LATE	26.10	4.70	78.90	0.467	15.25

AWC: available water capacity (mm); SP: seeding period; EARLY, MEDIUM, LATE: crop cycle (days); r^2: coefficient of determination of semivariogram; SDD: spatial dependence degree

The SDD values indicated strong and moderate spatial dependence for regionalized variables (Table 2) according to Cambardella et al. (1994) classification, considering that all semivariograms presented values between 3.79% and 40.74% for this parameter. This result indicates that the semivariogram has the capacity to represent the data spatial variability in Mato Grosso state.

Figures 1, 2 and 3 shows the cotton productivity reduction risk maps for Mato Grosso state, using three AWC's (60, 140 and 200 mm). The risk of reduced productivity increases in the north to south direction of the state, following the precipitation distribution direction, due the fact that rainfall is associated with the air rise and can occur due to factors such as thermal convection and frontal action of masses, as highlighted by [23].

In a study by [24], it was possible to identify that there is an irregular rainfall variability in Mato Grosso, and the average annual precipitation of a rainier core to the north of Mato Grosso can reach values higher than 2750 mm. These values decrease in the east, west and south directions of the state, resulting in precipitation with maximum values in summer and minimum in winter, and 70% of the accumulated rainfall during the year precipitate between November and March, corresponding to summer, whose rainier months are concentrated in January to March interval.

There are two air masses that operate in Mato Grosso (continental equatorial mass and Atlantic polar air mass), which affect the distribution and amount of rainfall in Mato Grosso territory: equatorial air mass, present between spring and summer, due to the thermal effect and the high humidity, contained in Amazon, moves towards the country interior in northwest direction to the southeast, causing rains. The Atlantic polar mass is characterized by polar air accumulation, which acts more frequently in the winter, in south-north direction, favoring temperature and drought decrease [25, 26]. However, it is worth mentioning that, due the period in which cotton is cultivated, the continental equatorial air mass is the one that exerts most influence in its development, since it is responsible for the rains in this period.

Considering the occurrence of three large biomes in Mato Grosso: Amazonia, Cerrado and Pantanal, it is possible to verify the variation in rainfall distribution in the state. The highest rainfall averages are found in Amazon biome, located in the extreme northwest and north, and the lowest indices located in the extreme southwest and south, corresponding to Pantanal biome [25]. This rainfall variation in these biomes corroborates the results obtained, considering that, in the region corresponding to Pantanal biome, greatest productivity reduction risk was found, and in Amazon biome the lowest risk.

Thus, through the results obtained, the relationship between water availability and cotton productivity is evident, mainly due the oscillation of precipitation in time and space.

By adopting AWC values corresponding to 60 mm (Figure 1), it is possible to observe a variation in reduction risk between 0 and 75.71% for AWC 140 mm (Figure 2), variation was between 0 and 67.3 %, and for 200 mm AWC (Figure 3) the observed interval was 0 and 60.31%. The variation of these values is basically due to the different available water capacities, sowing times and cultivars cycle length. However, it is observed that reduction risk is lower in soils whose available water is 200 mm, due the lower water restriction to the plants.

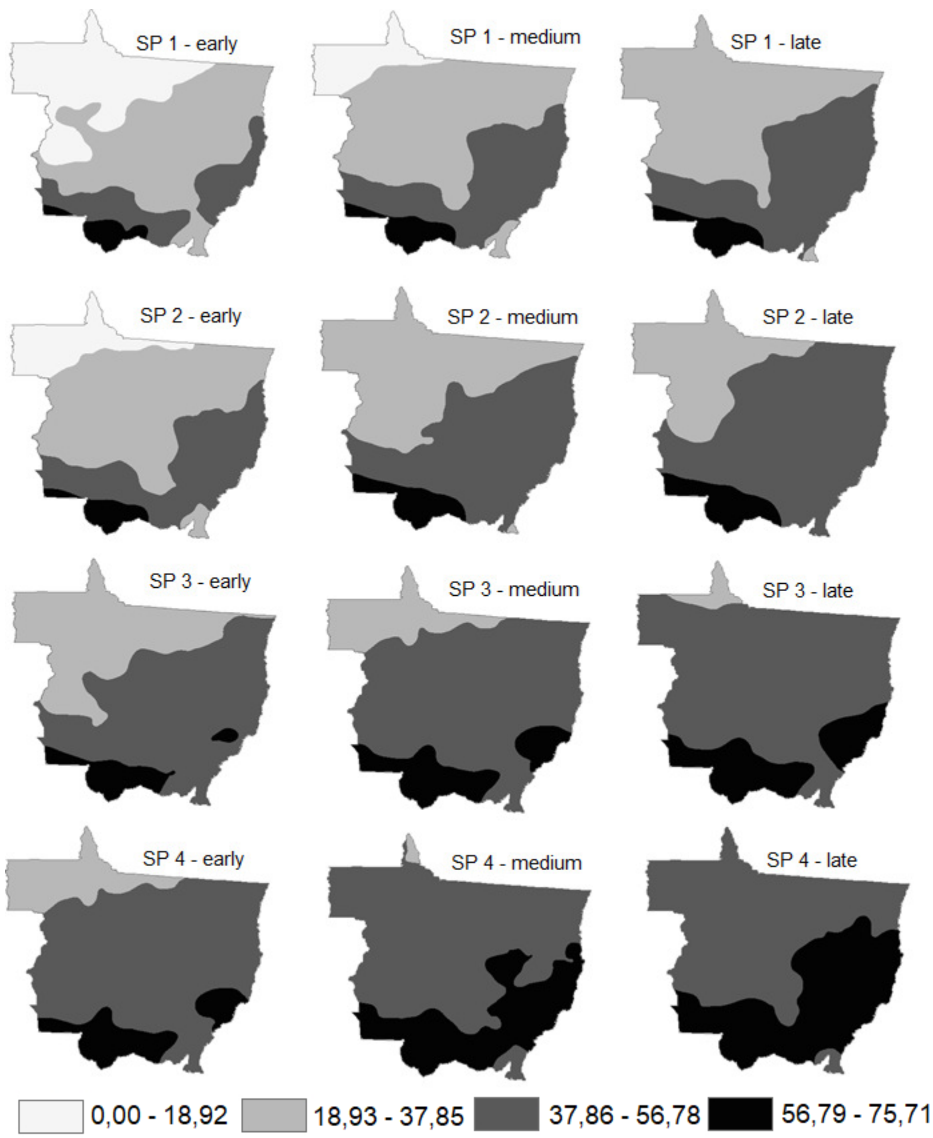

Figure 1. Map of conventional cotton productivity reduction risk (%) for Mato Grosso state, under AWC 60 mm. AWC: available water capacity (mm), SP: seeding period, early, medium, late: crop cycle (days).

In a study by [27], whose objective was to determine the peanut crop agroclimatic zoning to the Upper Paraguay Basin region, in Mato Grosso, a smaller restriction was observed for peanut cultivation in soils with AWC, which is similar to those obtained in this work. The lower restriction risk in soils whose AWC's are higher ~~are~~ due the greater soil water storage in these soils, allowing late cultivation.

The sowing season 1 presented a satisfactory performance, being the season with lower productivity reduction risk, mainly for early cycle cultivars. According to [17], it is possible to verify that rainfall in Mato Grosso reaches maximum values in late December and early January, gradually decreasing until dry season beginning, which favored season 1, which corresponds to 12/11. In this sense, the sowing season choice is determinant for the success in the seek for high yields, which are possible when juxtaposing the development of crop phenological stages with the climatic environment favorable to the productivity expression of the cultivar in use [28].

In addition, the sowing season 1 obtains a lower risk in the regions located to north and northwest, compared to other state's regions, since according to [25] the month of December shows a rainfall pattern with rainfall maximums located at extreme north and northwest, in Amazonian biome and lowest in south, in Pantanal biome.

Seeding period 4 (1/11) was the one that presented the highest productivity reduction risk, mainly the late cycle cultivar, this occurred due the water availability decrease in this period. [17] states that with the delay of sowing, in relation to water deficit, the possibility of the cotton critical phase occurring in the dry season increases. Thus, when sowing in times when climatic conditions are adequate to the needs of any crop, it is possible to reduce losses risks due to water deficit at the critical stages, which occur in reproductive phase, when the crop water requirement is bigger.

Thus, one of the determining factors for success in cotton cultivation is the sowing season, which, when carried out until the end of December, causes a lower productivity losses risk due the water deficit occurrence.

Generally, zoning is a fundamental tool to prevent losses and to increase profits, increasing the competitive potential of agricultural enterprises that grow cotton, as observed by [5], in which yield losses were higher than 100%, it being evident that the cotton is sensitive to environment variables behavior, be they climatic, edaphic or biotic, having productivity directly related to the time and place of sowing, corroborating with the results obtained in this work, in which it was verified that the time and place of sowing can reduce in up to 75% of the productivity.

With the zoning adoption it is possible to minimize the climate elements oscillations effects, since such unforeseen climatic variabilities have always been the main sources of risk to agricultural activity [29]. It was verified that the success of agriculture is related to the anticipated knowledge of the local conditions of soil, solar radiation and rainfall, and their variation along a crop cycle are significant to obtain satisfactory yields, since these factors are determinants for crop success [30].

Comment [AMA1]: variability's

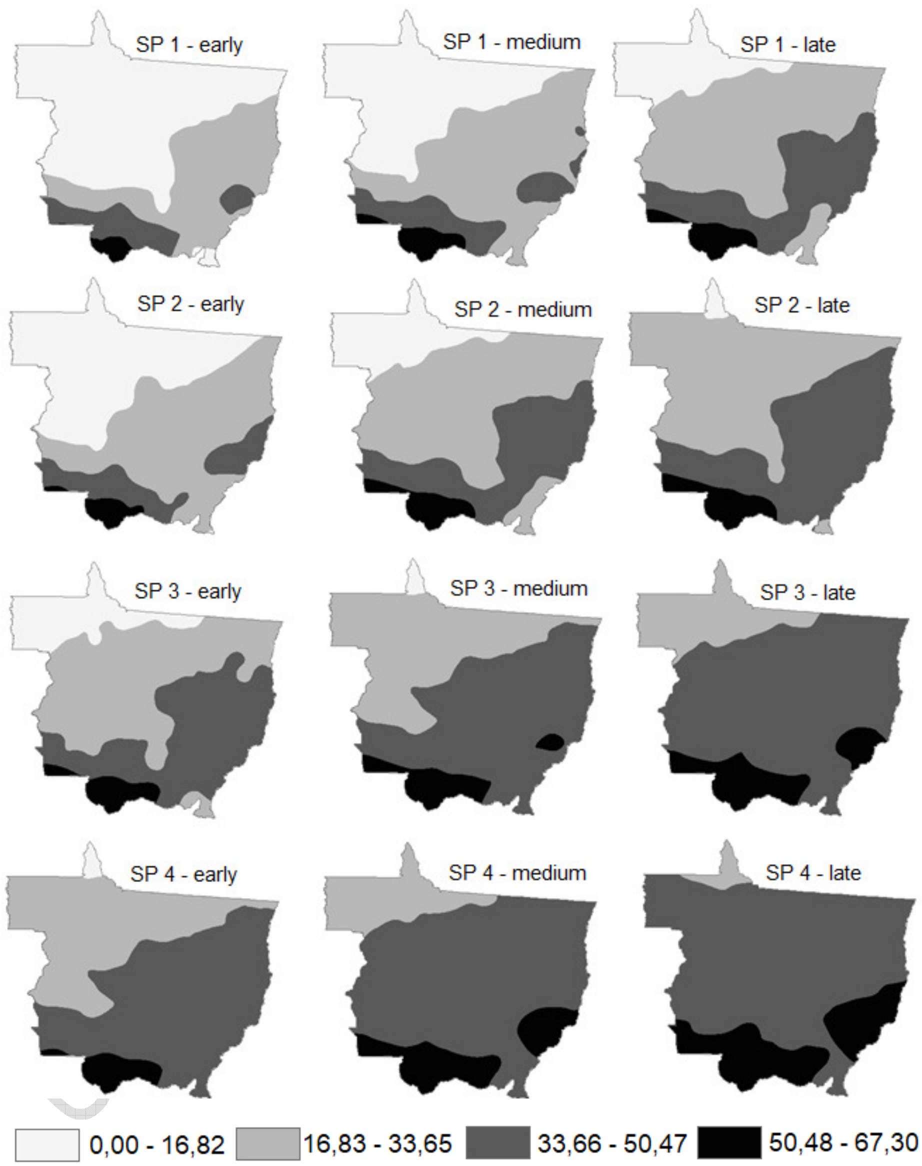

Figure 2. Map of conventional cotton productivity reduction risk (%) for Mato Grosso state, under AWC 140 mm. AWC: available water capacity (mm), SP: seeding period, early, medium, late: crop cycle (days).

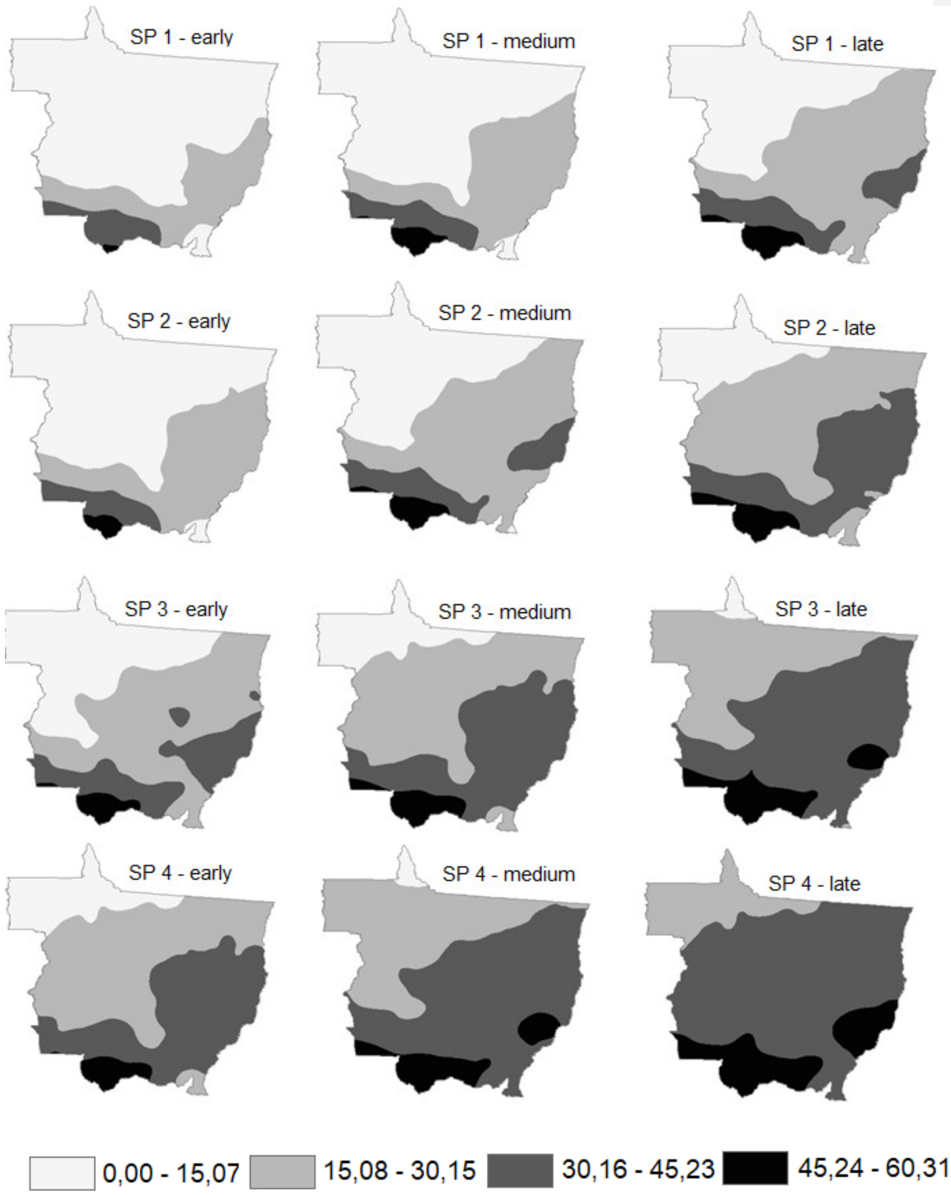

Figure 3. Map of conventional cotton productivity reduction risk (%) for Mato Grosso state, under AWC 200 mm. AWC: available water capacity (mm), SP: seeding period, early, medium, late: crop cycle (days).

Analyzing the cultivar cycle effect, it was observed that the late cultivar presented a higher productivity reduction risk in relation to the others, this occurred because with the longer cycle of the late cultivar, the chances of critical phase increase, in relation to the water deficit occurs in a period of low water availability, considering that rain plays a fundamental role for agricultural crops and exerts influence in several processes, such as nutrient absorption, transpiration and photosynthesis. It is also necessary to consider that, in the same place, in different years and even at different times of year, the adequate water amount depends on factors such as total rainfall over the days, sunshine, wind, temperature, plant size or the spacing used in its cultivation, and the soil's ability to retain rainwater [9].

Table 3 shows the results of FAO method validation described by [6]. In Tangará da Serra there was no risk of a reduction in productivity during the growing season, however, the three cultivars did not reach the region productivity for the crop analyzed, presenting a variation between 36 and 8 @ ha^{-1}. The occurrence of such differences indicates the interference of other factors that are not related to the occurrence of water deficit, such as the possible incidence of pests and diseases in crop.

Table 3: Results and validation information of FAO method (Doorenbos and Kassam, 1979) for cotton crop in Mato Grosso.

Local	Cultivar	Sowing date	Average cultivar productivity @ ha^{-1}	Real productivity @ ha^{-1}	Risk Red. (%)
Tangará da Serra	TMG 81 WS	17/1/02	316.00	280.00	0.00
Tangará da Serra	FM 954 GLT	17/1/15	321.00	300.00	0.00
Tangará da Serra	FM 944 GLT	17/1/25	308.00	300.00	0.00
Campo Novo do Parecis	FM 975 WS	17/1/20	343.00	225.20	34.00
Campo Novo do Parecis	TMG 47 B2 RF	17/1/20	272.00	184.10	33.00
Deciolândia	FM 975 WS	17/1/08	328.00	280.00	18.00

For Campo Novo do Parecis there was a reduction risk of 34 and 33%, and for Deciolândia the risk was 18%, being in agreement with the average productivity values. Thus, the methodology proposed by FAO [6] guaranteed satisfactory results to analyze cotton productivity reduction risk in Mato Grosso.

Comment [AMA2]: Paresis

Thus, the regions and times with the lowest productivity reduction risk are defined, information is extremely important for cotton farmers in Mato Grosso, making possible a more reliable agricultural planning in relation to water availability.

4. CONCLUSION

The sowing season 1 was the one with the lowest cotton productivity reduction risk, and season 4 was the inverse, presenting a higher risk. The month of December is considered the most favorable for conventional cotton cultivation in Mato Grosso.

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