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Maize sowing dates in the hinterland region of Northeast Brazil

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ABSTRACT

Maize in Alagoas State, Northeast of Brazil, is mostly cultivated under rainfed conditions, however there are few studies evaluating the best sowing dates. The aim of this work was to assess sowing dates for the maize crop in the municipality of Arapiraca, located in a typical hinterland (Agreste) region of Alagoas State, based on the Water Requirement Satisfaction Index (WRSI). The WRSI was computed by means of a simple soil water balance model and the reference evapotranspiration was determined by the standard Penman-Monteith-FAO56 method. Daily values of air temperature, relative humidity, wind speed, sunshine duration and precipitation were measured in a conventional weather station, in the period from 1973 to 2008. The sowing dates for maize in Arapiraca with the lowest risks of water deficit lies between June 3 and June 23. Sowing maize in the beginning of April appears to be a very strategic alternative since it offers very low water deficit risk at the flowering crop stage. However, this might require water supplement at first stages of the crop due to the high-water deficit risks.

Introduction

Maize yield is severely reduced due to soil water deficit (Otegui et al., 1995; Kresovíc et al., 2016), mainly when it occurs at the tasseling-silking period (Otegui et al., 1995). Thus, defining proper sowing dates for maize cropping under rainfed conditions is paramount for decision support applications, especially in arid and semi-arid regions where precipitation is scarcer (Sivakumar, et al., 2005). In the simplest way this can be assessed by determining an overall growing season or rainy season, which considers only precipitation records (Raes et al., 2004; Cardim, 2003). However, studies that include climatic, crop and soil parameters have the potential to provide more accurate analyses of the best sowing dates.

A simple approach considering these factors is the computation of the Water Requirement Satisfaction Index (WRSI), which can be defined as the ratio between actual crop evapotranspiration (ET_a) and potential crop evapotranspiration (ET_c) (Nullet & Giambelluca, 1988; Raes et al., 2006). Usually, simple empirical soil water balance models are employed to estimate ET_a, then computing WRSI. A critical WRSI value is usually set up for a crop below which crop yield is reduced. This simple approach has been used by many authors as it requires less soil and crop input data when compared to detailed crop system and crop growth models (Jones et al., 2003; van Diepen et al., 1989).

Although the cultivation of maize in the state of Alagoas is very traditional, there are still few studies relating maize growth and yield to soil water and climate variability. As examples, Cardim (2003) attempted to define the growing season for the whole Alagoas state, and Lyra et al. (2010) found that maize cultivated under the traditional tillage system (without straw mulching) had higher yield by promoting higher soil water content due to the low precipitation rates occurring at the grain fill crop stage.

The aim of this paper was to determine the best sowing dates for the maize crop in Arapiraca, a region located in a typical hinterland region of Alagoas - Brazil, based on the Water Requirement Satisfaction Index. We also analyzed the WRSI at the corresponding flowering date, in order to define the end of the maize growing season.

Material and methods

Climate, soil and crop data

The study was carried in the municipality of Arapiraca (09° 38’ S and 36°40’ W; 260 m amsl), located in the hinterland (Agreste) region of Alagoas State in the Northeastern Brazil. The climate of the region is classified as Dry subhumid Megathermal, according to the Thornthwaite climate classification (Mather,1974; Barros et al., 2012). The precipitation data were obtained from the climatological station of the Research Company of Alagoas (Agricultural Research Corporation of Alagoas – EPEAL), located in Arapiraca. The other climate data (air temperature, relative humidity, sunshine hours durations, wind speed) required to compute the reference evapotranspiration (ET_o) were obtained from the INMET (Instituto Nacional de Meteorologia–Brasil) weather station, located in the municipality of Palmeira dos Índios, with climatological similarities to Arapiraca (Barros et al., 2012). The daily meteorological data series was for the period 1973 to 2008. More details are in Brito (2009) and António et al. (2017).

The procedure to assess sowing dates for maize for Arapiraca was based on the determination of the WRSI. The WRSI is a relative measure of water stress, varying from 0 (when a crop is fully water-stressed) to 1 (no water stressed). We set up WRSI = 0.5 as the critical value above which maize can grow with no yield reduction due to water deficit (Doorenbos and Kassam, 1979). This value is generally used for maize genotype with some tolerance to water stress.

The reference evapotranspiration (ET_o, mm) was estimated by the standard method Penman-Monteith (FAO-56) presented in details in Allen et al. (1998). The crop evapotranspiration was determined from the relation $ET_c = K_c \times ET_o$, were K_c is crop coefficient, considered an average value of 1.0. The ET_a was estimated by an empirical equation derived from a simple empirical soil water balance model proposed by Nullet & Giambelluca (1988), given by:

$$ET_a = ET_c;\ if\ AW \geq AW_c \tag{1}$$

$$ET_a = AW\left[1 - exp\left(-\frac{ET_c}{AW_c}\right)\right];\ if\ AW < AW_c, \tag{2}$$

where, AW (mm) is the actual available water in the soil, given by:

$$AW = (\theta - \theta_w)Z_r, \tag{3}$$

where, θ ($m^3\ m^{-3}$) is the volumetric soil water content and θ_w ($m^3\ m^{-3}$) is the θ at the permanent wilting point and Z_r is the rooting depth, equal to 60 cm according to field measurements. AW_c (mm) is a threshold value of AW from which ET_a becomes slower than ET_c. The AW_c depends on several factors such as atmospheric demand, soil type and crop type and it is a measure of how long a soil-plant system can endure soil drying without reducing its ET_c. The AW_c was assumed as a fraction of the total available soil water (TAW) in the root zone (AW_c = 0.5 TAW), defined as:

$$TAW = (\theta_c - \theta_w)Z_r \tag{4}$$

where θ_c ($m^3\ m^{-3}$) is the θ at the field capacity.

The appropriate sowing dates for maize were determined by evaluating WRSI at both sowing and flowering dates.

Water Requirement Satisfaction Index (WRSI)

The soil water balance, computed on a daily basis, started in 1973 (the first year of the data series) in the month with the highest precipitation in order to guarantee AW ≥ TAW. Any value of AW > TAW was assumed as water excess.

The daily values of ET_c and ET_a were used to compute WRSI. The WRSI values were grouped in pentads for all years. The probability of WRSI > 0.5 ($pWRSI_{0.5}$), i.e., the assumed critical WRSI value for soil water stress with negligible effect on maize growth, for each pentad was obtained by frequency distribution analysis of these values for different sowing dates starting on March 1 until the second pentad of September. This corresponds to a period between the start and the end of the region rainy season, as determined by Cardim (2003). We also evaluated $pWRSI_{0.5}$ at 10 days before and after the flowering date. Appropriate sowing dates for maize were assumed when pWRSI0.5 > 0.8 for both sowing and flowering crop stage.

The prediction of the flowering date was based on the growing degree days (GDD) method, given by:

$$GDD = \sum_{i=1}^{n} [(T_{max} + T_{min})/2 - T_b]) , \quad (5)$$

where T_{max} and T_{min} are maximum and minimum daily (i) temperature of the air, Tb is the basal temperature, and n is the number of days from sowing until the experimentally observed flowering day. The Tb value for maize was set to 10 °C (Gilmore Jr and Rogers, 1958; Neild and Seeley, 1977).

The GDD required to flower was experimentally determined for the BR 106-Embrapa cultivar at Vila São José, located in Arapiraca, Alagoas, in an area of 6000 m^2 with sowing on 04 June 2005, spaced at 0.8 m between rows and 0.2 m between plants (62500 seeds ha^{-1}). The soil was fertilized in the seed bed with 30 kg N ha^{-1}, 66 kg P_2O_5 ha^{-1} and 36 kg K_2O ha^{-1}, followed by an application of 100 kg of urea and 30kg ha^{-1} of K_2O in topdressing. The experimental design was randomly blocks with four replications. Each plot consisted of four lines of 5 m length at 0.8 m apart and a sowing distance of 0.2 m. The soil physical properties, including θ_c and θ_w, parameters required to compute TAW (eq.3), were based on physical-hydric analysis of on-site soil (Table1).

Results and discussion

Precipitation variability

Figure 1 shows the variation of the total annual precipitation for the period between 1973 and 2008. Precipitation shows a high interannual variability with minimum of 473 mm in 1993 and maximum of 1259 mm in 1988. The average of the total annual precipitation of the evaluated period was 890 mm. During this evaluated period (36 years), almost half of the years (14 years) had precipitation well below the average, nine years above, and only seven years with values around the average.

Besides the high precipitation interannual variability with large deviations from the average, seasonal variability is also observed, which is more effective on evaluating sowing dates and crop yield. Figure 2 compares the total May–August precipitation (humid period, Figure 3) to the total precipitation of years with extremes values. In the year 1992, for instance, although the total annual precipitation was well above the average, only 315 mm occurred within the May–August period. Conversely, in 1993 the total precipitation was only 475 mm, but most of the precipitation (325 mm) concentrated in the May–August period. The year 1981 had a total precipitation of 953 mm (above the annual average), but only 196 mm within the May–August period. This amount of precipitation is insufficient, as mentioned by Doorenbos & Kassam (1979) even if the precipitation were well distributed along the crop cycle, since the minimum water requirement for maize to reach

Figure 1. Total annual precipitation in Arapiraca, Alagoas state, Brazil, for the period 1973 to 2008. Data source: EPEAL.

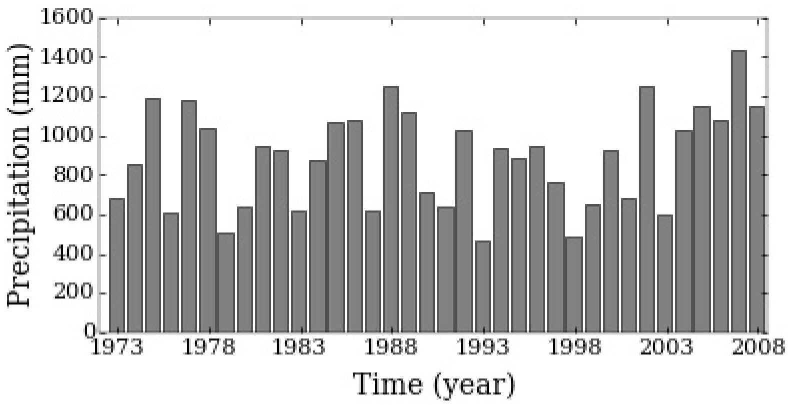


Table 1. Soil physical properties of the evaluated region, located in Arapiraca.

Field water capacity (θc, m3 m-3)	0.23			
Permanent wilting point (θw, m3 m-3)	0.14			
	Soil layer (cm)			
	0-15	15-30	30-45	45-60
Total Sand (%)	69	63	55	52
Silt (%)	9	7	14	13
Clay (%)	22	30	31	35

potential yield is 500 mm.

The highly variable pattern of precipitation in this region highlights the difficulties for precisely providing information about the start of the growing season. Such an attempt was made by Cardim (2003), which analyzed three methods to determine the growing season for the state of Alagoas. As the evaluated methods provided different results, the one recommended was the so-called precipitation at 75% probability exceeding half average evapotranspiration in a decade, a sequential period of ten days (thus a month is comprised of three decades and a year contains 36 decades). This method offers less risk of false precipitation start. For our evaluated region, the growing season found by Cardim (2003) lies between 21–30 of April and 01–10 of September. In section 3.3 we provide an analysis of adequate sowing dates for a maize crop based on the probability of the WRSI as predicted by a simple water balance model. Differently from other approaches, we also assessed the WRSI at the flowering date, when water deficit can significantly reduce maize yield (Otegui et al., 1995; Kresovíc et al., 2016). In section 3.2, we show the parameterization of the flowering date start based on growing degree days.

The variation of the mean reference evapotranspiration (ET_o) in relation to the mean precipitation (P) throughout the year in the region (Figure 3) shows a definition of the growing season, according to Frère and Popov – FAO (1979). The characteristics of the growing season are: (a) The beginning of rains and growth period – 8th decade, 11 to 20th of the March; (b1 and b2) Beginning and end of the humid period; (c) End of the rainy season – 27th decade, 21 to 30th September; and (d) End of the growth period – 29th decade, 11 to 20th of October. During the humid period, which starts in the 11th decade (from 11th to 20th of April) and ends in the 24th decade (from 21st to 31st of August), the highest ET_o values are approximately 3.2 mm d^{-1} and 2.5 mm d^{-1} for the beginning and the end of the humid period. The lowest values (approximately 1.8 mm d^{-1}) occur at the end of June. By considering the beginning of the rainy season, when rainfall exceeds half of the ET_o, it starts in the 8th decade (from 11th to 20th of March), a week before 100 % of the ET_o is exceeded.

From the 11th decade there is soil water excess as the precipitation volumes exceed the ET_o values. The highest precipitation occurs in the 18th decade (from 21th to 30th of June), coinciding with the period with the lowest ET_o values. This results in water excess, which is lost by surface runoff or deep drainage, when the soil reaches its maximum soil water capacity (TAW). This is a function of physical characteristics such as quantity and type of clay and level of structuring of soil aggregates, as well as the depth of the effective root system, which for maize is 0.6 m (Sans & Santana, 2007). In the humid period precipitation is 65 % of the total annual (890 mm).

Length of the flowering date

The maize cultivar BR 106 grown in Arapiraca needed 758 ºC to meet the flowering date. This value is within the GDD range (590-866 ºC) found for hybrids in USA (Lindquist et al., 2005). Based on the parameterized GDD for the flowering date and on the average air temperature of the evaluated period, we determined the time length (days) of the flowering date for several sowing dates from March 1 to the second pentad of September (Figure 4). The flowering time length increases considerably with time after the start of the growing season. For instance, when maize is planted on the third pentad of April, the flowering time length is 52 d, whereas sowing on the first pentad of June it takes 61 d to flower. The time to flowering reaches a maximum of 62 d in the month of June and beginning of July; then starts to steadily decrease. This pattern follows the inverse pattern of the air temperature, which starts to de-

Figure 2. Annual total (AT) and May-August (MA) precipitation for selected years in Arapiraca, state of Alagoas, Brazil. Data source: EPEAL.

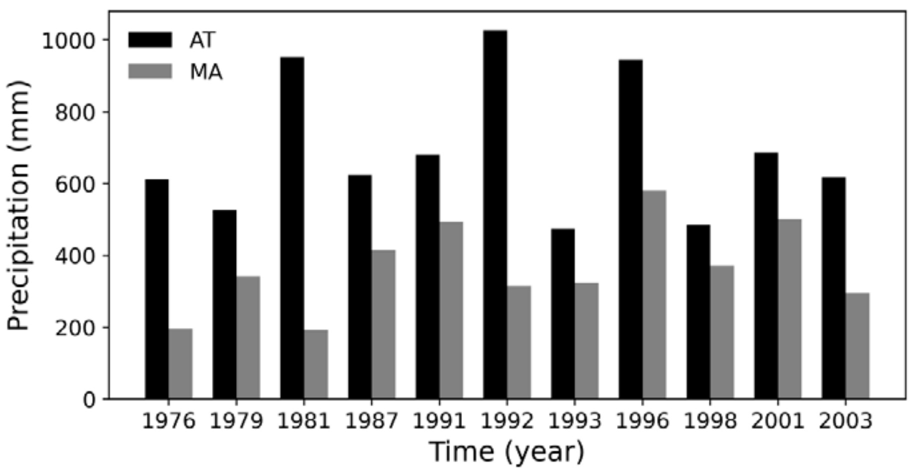
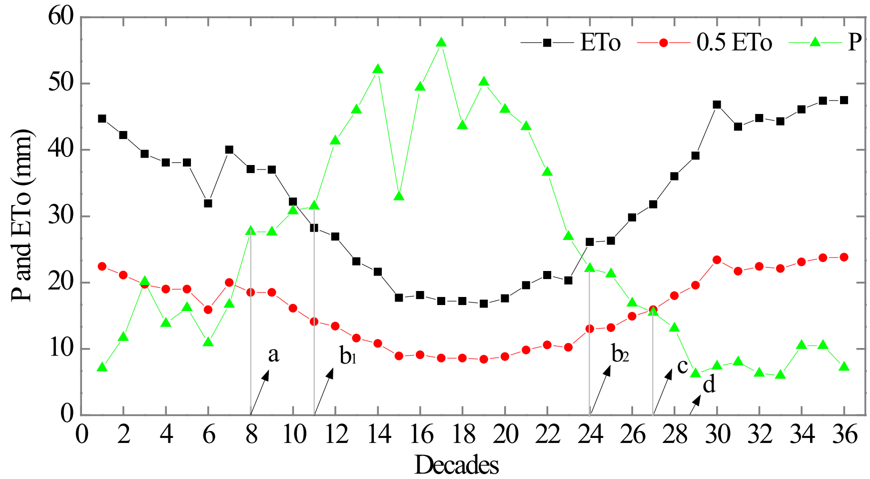


Figure 3. Average reference evapotranspiration (ET_o) and precipitation (P) of the region by decades. (a) The beginning of rains and growth period; (b1 and b2) Beginning and end of the humid period; (c) End of the rainy season; and (d) End of the growth period. Data source: EPEAL and INMET.



crease from the beginning of the growing season because the rainy season coincides with the period of lower solar radiation availability (Souza et al., 2005; Lyra et al., 2016).

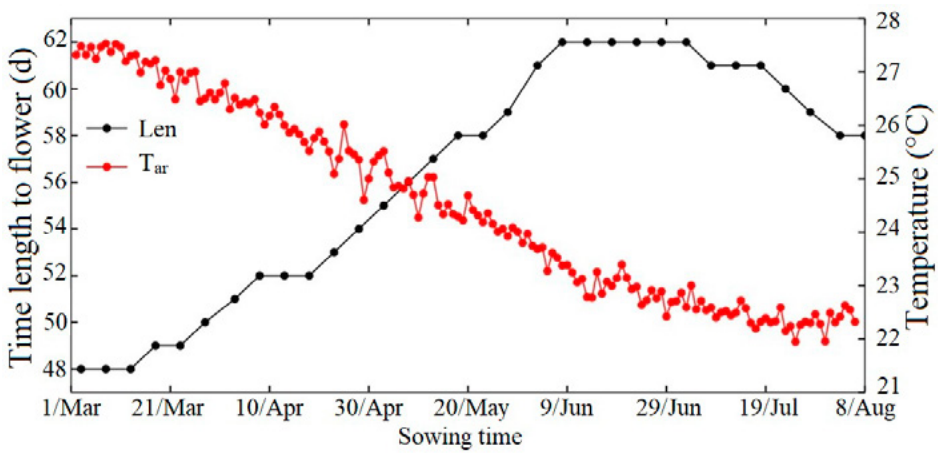
Water Requirement Satisfaction Index (WRSI)

Figure 5 shows the probability for WRSI > 0.5 at the sowing date ($pWRSI_p$) and at 10 d before ($pWRSI_{bf}$) and 10 d after ($pWRSI_{af}$) the flowering date for every pentad throughout the growing season. The $pWRSI_p$ considerably increases with time, reaching a near constant value as sowing dates approach the end of the growing season. Expectedly, $pWRSI_{bf}$ and $pWRSI_{af}$ are greater than $pWRSI_p$ for sowing dates before the start of the growing season and decrease by the end of the growing season.

The values of $pWRSI_p$ are considerably low (≈ 20 %) before the start of the growing season. However, even right after its beginning, $pWRSI_p$ is still considerably low. Thus, the sowing of maize around this period can still be subjected to severe risks of water deficit (50 % probability). Besides, it is worth pointing out that we are assuming WRSI > 0.5 as a parameter to endure water stress. However, one can assume higher WRSI values for the first crop stages since plant roots are shallower and more vulnerable to water deficit. Furthermore, as in this case there is a transition from a drier to a wetter period, there is few remaining water in the soil and most infiltrated water is stored at the soil upper layers and soon evaporated.

Suitable $pWRSI_p$ values (> 80%) only occur by the end of May, at about 30 d after the suggested beginning of the growing season by Cardim (2003). From there on $pWRSI_p$ keeps increasing, reaching near 100 % after July and starts to decrease from 80 % only by the end of the growing season. On the other hand, suitable $pWRSI_{bf}$ and $pWRSI_{af}$ values occur before the start of the growing season, meaning that sowing of maize before it has great chance of no water

Figure 4. Length of the flowering date (Len) for several sowing dates and average air temperature (T_{ar}) of Arapiraca, Alagoas state, Brazil. Data source: INMET.



stress as the crop growths. Thereby, sowing maize in the beginning of April seems to be a strategic date for farmers intending to harvest maize for green corn during the highest local maize demand, coinciding with the traditional festivals of June. However, on one hand there is a rather low pWRSIp (≈ 0.40) in this period, which may require an irrigation system in order to supply a possible water deficit, on the other hand the higher average air temperature shortens the crop cycle and $pWRSI_{bf}$ and $pWRSI_{af}$ are considerably high, reducing the risks for water deficit.

The correct procedures to determine proper sowing dates for a crop must consider water stress around the flowering date, as analyzed in this work. Taking into consideration only the sowing date can lead to misleading results by indicating sowing dates with high risks of water deficit at the flowering stage, as observed in Figure 5. By the end of June, $pWRSI_p$ is high enough to guarantee seedling and maize establishment, but $pWRSI_{bf}$ and $pWRSI_{af}$ start to decrease since then, offering high water stress risks which can potentially harm maize crop yield. Through this approach, the appropriate sowing date window of maize for Arapiraca is very short and lies between June 3 and June 23. This length is much shorter than the general growing season suggested by Cardim (2003) based on the precipitation at 75% probability exceeding half decade-average evapotranspiration. The two other methods based on accumulated precipitation provided an even wider growing season length. As compared to our method, the approach used herein is essentially more reliable, since it is based on a soil water balance model parameterized for the local soil and a local maize cultivar. Our study also parameterized the flowering date for a maize local cultivar based on growing degree days, and set the end of maize growing season when water stress occurred at 10 d before or after the flowering event.

A similar approach to defining sowing dates using simulations from a soil water balance model was used by Raes et al. (2004). They used the relative transpiration outcomes to define the proper growing season for some regions of Zimbabwe and compared to simpler methods based only on accumulated precipitation that can be easily used by farmers. However, they did not take the water stress at the flowering date into consideration in setting the end of the growing season. Other alternatives for defining sowing dates are crop system models (Soler et al., 2007) or by coupling numerical soil water flow models, e.g. SWAP model (van Dam et al., 2008) with crop growth models, e.g. WOFOST model (Supit et al., 1994). In such modeling approaches, the effect of water deficit on crop development and the reduction in crop yield can be more comprehensively assessed.

Conclusion

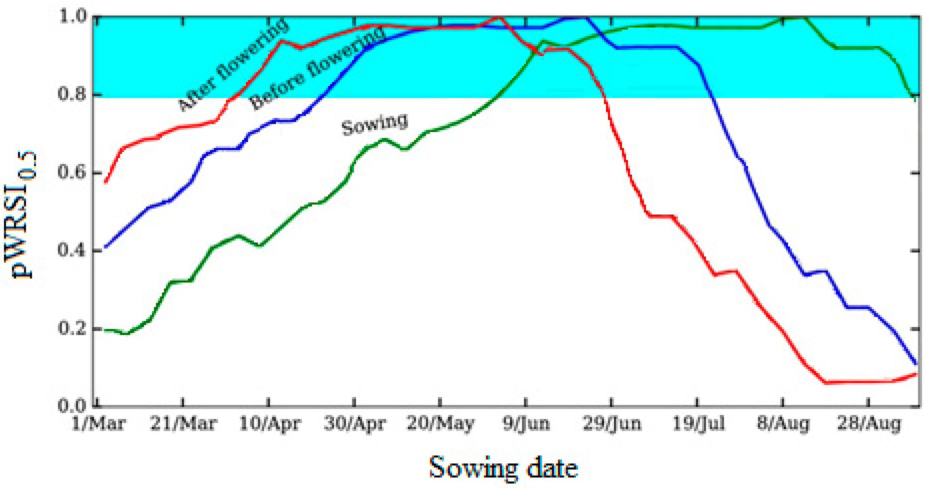
The proper sowing dates for maize in Arapiraca, a typical hinterland region of Alagoas State, Northeast of Brazil, with the lowest risks of water deficit lies between June 3 and June 23.

Sowing maize in the beginning of April has high water deficit risks only at the first stages of the crop, but it offers very low water deficit risks at the flowering crop stage.

Authors' Contribution

J. L SOUZA AND J. E. D. BRITO: conceptualization. J. E. D. BRITO, M. A. SANTOS, R. A. FERREIRA JÚNIOR, J. L. SOUZA and G. B. LYRA: data processing. J. E. D. BRITO, J. L. SOUZA and M. A. SANTOS: writing – original Draft. M. A. SANTOS,

Figure 5. Probability of Water Requirement Satisfaction Index (WRSI) greater than 0.5 ($pWRSI_{0,5}$) at sowing date ($pWRSI_p$) and 10 days before ($pWRSI_{bf}$) and after ($pWRSI_{af}$) the flowering date, as a function of the sowing date during the rainy season of the region; the blue area highlights the suitable dates for sowing maize inArapiraca, state of Alagoas, Brazil. Data source: EPEAL and INMET.



J. L. SOUZA., G. B. LYRA and R. A. FERREIRA JÚNIOR: writing – review and eEditing.

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Datas de semeadura do milho no agreste do Nordeste do Brasil

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RESUMO

O milho no estado de Alagoas, Nordeste do Brasil, é cultivado principalmente sobre condições de sequeiro (sem irrigação). Entretanto são poucos os estudos que avaliam os melhores períodos de semeadura. O objetivo deste trabalho foi avaliar as datas de semeadura da cultura do milho em Arapiraca, localizada em uma região típica do Agreste do estado de Alagoas, com base no Índice de Satisfação das Necessidades Hídricas (ISNH). O ISNH foi calculado por meio de um modelo simples de balanço hídrico do solo e a evapotranspiração de referência foi determinada pelo método padrão de Penman-Monteith-FAO56. Os valores diários da temperatura do ar, umidade relativa do ar, velocidade do vento, duração do brilho solar e precipitação foram medidos em estação meteorológica convencional, no período de 1973 a 2008. As datas de semeadura do milho em Arapiraca, com os menores riscos de déficit hídrico, estão entre 3 de junho e 23 de junho. A semeadura de milho no início de abril é uma alternativa muito estratégica, uma vez que oferece um risco muito baixo de déficit hídrico na fase da floração. No entanto, isso pode exigir suplemento de água nos primeiros estádios de desenvolvimento da cultura, devido aos altos riscos de déficit hídrico.

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