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Yield gap in cowpea plants as function of water deficits during reproductive stage

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ABSTRACT: The cowpea bean presents low productivity in the Pará state, Brazil, due to low soil fertility and climatic adversity, mainly water deficiency. The aim of this study was to evaluate the yield gap of cowpea bean in northeast of Para state in response to water deficit during its reproductive phase. The experiment was carried out in Castanhal, PA, Brazil, during 2015 and 2016. A randomized block design with six repetitions and four treatments was used; where T1 consisted of 100% replacement of the crop evapotranspiration (ETc), T2 to 50% , T3 to 25% and T4 without irrigation, in the reproductive phase. The yield was determined at R9 stage. The simulations with the SARRAZON model were carried out with different sowing dates. The total deficiencies in the reproductive phase were spatialized considering the 30 locations in order to assess the temporal and spatial seasonality of water availability and the sowing period in the study region. The cowpea bean was sensitive to soil water availability with considerable reductions in productivity due to the increase in water deficit compared to the treatment T1 (100% ETc). When water deficits reached more than 47 mm, there were yield gaps over 20%. According to the spatial variability of simulated water deficiency, the sowing of cowpea bean in regions located above 2° latitude may extend until June 20 without showing high yield gaps.

Key words: *Vigna unguiculata* (L.) Walp, sowing period, irrigation

Quebra de produtividade do feijão-caupi em função de deficiências hídricas na fase reprodutiva

RESUMO: O feijão-caupi tem baixa produtividade no Estado do Pará em função da baixa fertilidade dos solos e da adversidade climática, principalmente a deficiência hídrica. Objetivou-se com o presente estudo avaliar a quebra de produtividade do feijão-caupi no Nordeste Paraense em resposta à deficiência hídrica na sua fase reprodutiva. O experimento foi conduzido em Castanhal, PA, nos anos de 2015 e 2016. Utilizou-se delineamento experimental em blocos ao acaso, com seis repetições e quatro tratamentos; T1 consistiu na reposição de 100% da evapotranspiração da cultura (ETc), T2 em 50%, T3 em 25% e T4 sem irrigação, na fase reprodutiva. A produtividade do feijão-caupi foi determinada na fase R9. As simulações com o modelo SARRAZON foram realizadas com diferentes datas de semeadura. As deficiências totais na fase reprodutiva foram espacializadas considerando as 30 localizações a fim de se avaliar a sazonalidade temporal e espacial da disponibilidade hídrica e do período de semeadura na região de estudo. O feijão-caupi mostrou-se sensível à disponibilidade de água no solo, com reduções consideráveis na produtividade em função do aumento da deficiência hídrica. Ao se atingir deficiências hídricas superiores a 47 mm na fase reprodutiva, ocorreram quebras de produtividade da cultura superiores a 20%. De acordo com a variabilidade espacial da deficiência hídrica simulada, a semeadura do feijão caupi em regiões localizadas acima de 2º de latitude pode se estender até 20 de junho sem que apresente elevadas quebras de produtividade.

Palavras-chave: *Vigna unguiculata* (L.) Walp, períodos de semeadura, irrigação

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Introduction

The production of cowpea is concentrated in the North and Northeast regions of Brazil (Nunes et al., 2014) and has been expanding to the Midwest region (Silva Junior et al., 2018). This crop was introduced in the State of Pará by immigrants from the Northeast region of Brazil, and the genus Vigna is responsible for 85% of the beans produced in the State (Coutinho et al., 2014), generating more than 70,000 direct jobs.

Of all production in Pará, Brazil, 45% is located in the mesoregion of Northeast Pará (SEDAP, 2018), presenting productivity of only 821 kg ha^{-1} (Moreira et al., 2017), the result of several factors such as incorrect seed management, low soil fertility (Coutinho et al., 2014) and climatic adversity such as water deficiency (Souza et al., 2017b; 2019).

Water deficit causes reductions in the production components of cowpea (Costa Junior, et al., 2017), especially if it occurs in the flowering and fruiting phases (Ramos et al., 2014), but depending on the species and environmental factors (Silva et al., 2016) and the management adopted, such as inoculation with bacteria of the genus Rhizobium (Silva Júnior et al., 2018) its effect may be less severe. Therefore, it is important to understand how cowpea responds to water availability in the microregion of the Northeast of the State in order to generate low-cost technology (Locatelli et al., 2016) and assist in the indication of sowing dates with the lowest yield gap (Lima Filho et al., 2013).

Although there are numerous studies already carried out with cowpea beans in other regions with this focus (Lima Filho et al., 2013; Matoso et al., 2018), for the Northern region of Brazil, studies addressing the agroclimatic and productive aspects of cowpea are rare (Silva et al., 2016; Souza et al., 2017b, Souza et al., 2019). In view of this, the objective of this study was to evaluate the breakdown of cowpea productivity in response to water deficiency imposed in its reproductive phase and to analyze the periods appropriate for its production in the northeastern region of Pará, Brazil.

Materials and Methods

The field experiment was conducted in the municipality of Castanhal, located in the Northeast region of the State of Pará, Brazil, in the years 2015 and 2016 in an area of 0.5 ha located at the Experimental Farm of the Federal Rural University of the Amazon (UFRA)(1°19'24" S, 47°57'38" W, 41 m). The climate at the experiment site is defined as Am according to the Köppen climate classification, with the driest period of the year between June and November.

The physical and chemical characteristics of the soil determined at the Soil Laboratory of Embrapa Amazônia Oriental, from two collections carried out at a depth of 0 to 20 cm are shown in Table 1.

To evaluate the cowpea response to water deficiency, a randomized block design was used, with six replications and four treatments, which consisted of different replenishment of the water evapotranspirated by the crop (ETc) in the reproductive phase of the cowpea bean.

The treatments were constituted according to the following description: treatment T1 - replacement of 100% of the water evapotranspirated by the crop (ETc); T2 - 50% replacement of ETc; T3 - 25% replacement of ETc; and in T4 treatment there was no replacement of ETc through irrigation in the reproductive phase.

In the vegetative phase, all experimental units were kept close to field capacity, with 100% replacement of ETc. The differentiation of water depths for treatments T2 and T3 and the elimination of irrigation in T4, occurred as soon as the crop started the reproductive phase, at 36 days after sowing (DAS) for both years of evaluation. Near the end of the reproductive phase, when the plants were in the maturation phase of the grains (R9), irrigation was suspended, corresponding to 58 and 61 DAS, respectively in 2015 and 2016. According to field observation, there was a reduction in the duration of the reproductive phase due to water limitation with differences of up to one week between treatments T1 and T4.

The experimental units consisted of plots measuring 22 x 24 m, separated by a border of 1 m, with spacing of 0.5 m between planting lines and 0.1 m between plants, making up a density of 200,000 plants per hectare.

The sowing of the cultivar BR3-Tracateua was performed on September 23 and 17, 2015 and 2016, respectively. This cultivar was adopted in this study because it is the most used by rural producers in the region (Freire Filho et al., 2009).

The fertilizations were carried out according to the results of the chemical analysis of the soil, using 350 kg ha^{-1} of chemical fertilizer of the formulation NPK (10-20-20) for the 2015 experiment, and 195 kg ha^{-1} of chemical fertilizer of the formulation NPK (6-18-15) in 2016, according to Embrapa's technical recommendations.

A drip irrigation system was used, with 1.03 L h^{-1} flow emitters under service pressure of 50 kPa and spaced 20 cm from each other. Hydraulic assessments were carried out to determine its performance using the Christiansen's

Table 1. Physical and chemical characteristics of the soil in the experimental area. Permanent wilting point (PWP), field capacity (FC) and Available Water Capacity (AWC)

Chemical characteristics of the soil (0-0.20 m)								
Year	pH (H_2O)	P (mg dm^{-3})	K^+ (mg dm^{-3})	Na^{2+} ($cmol_c$ dm^{-3})	Ca^{2+} ($cmol_c$ dm^{-3})	$Ca^{2+} + Mg^{2+}$ ($cmol_c$ dm^{-3})	Al^{3+} ($cmol_c$ dm^{-3})	N (mg kg^{-1})
2015	4.9	2	26	9	1.43	0.8	0.8	0.05
2016	3.7	20	30	2	1	1.2	0.6	0

Physical characteristics of the soil (0-0.20 m)							
Year	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})	Bulk density (kg dm^{-3})	AWC(1) (mm)	FC (%)	PWP (%)
2015-2016	40	125	835	1.56	40	20	11

(1) Calculated for a root depth between 25 and 30 cm

Uniformity Coefficient (CUC), Distribution Uniformity Coefficient (CUD) and water application efficiency (Ea), according to Bernardo et al. (2006) and Cunha et al. (2014). The distribution uniformity analysis was carried out in all four treatments and in six blocks, using 1000 mL collection containers below three emitters located at the beginning, middle and end of the irrigation lines, collecting water for a period of 20 min, with two repetitions totaling 196 samples. The system presented CUC of 88, CUD of 89 and Ea of 80% in both years, a performance that is considered acceptable (Merriam& Keller, 1978).

For the determination of the liquid water depth, reference evapotranspiration (ETo) was calculated using the Penman-Monteith FAO 56 equation (Allen et al., 2011) with data obtained from the automatic meteorological station of the National Institute of Meteorology (INMET), installed 2 km from the experiment. Maximum evapotranspiration of the crop was obtained according to the crop coefficient (Kc) of each phase of the cowpea according to Farias et al. (2017).

For the collection of meteorological data, an automatic micrometeorological station programmed to collect data on air temperature, relative humidity, volumetric content of water in the soil and rainfall was installed in the center of the experimental area. All sensors were connected to a CR10X datalogger (Campbell Scientific, Inc.), with programmed reading performed every ten seconds, with averages and totals obtained every 10 min.

The average air temperature during the 2015 and 2016 experimental period was 28.03 and 27.20 °C, respectively. The reference evapotranspiration reached an average value of 5.03 mm d^{-1} in 2015 and 4.95 mm d^{-1} in 2016. Global solar radiation averaged 20.56 and 19.50 MJ m^{-2} d^{-1} for the cowpea cycle in 2015 and 2016, respectively, and the vapor pressure deficit for 2015 averaged 0.96 kPa and 0.93 kPa in 2016.

Productivity was determined at 65 and 68 DAS in 2015 and 2016, respectively, when 90% of the plants reached the phenological stage R9 that corresponds to grain maturation, adopting as a criterion the change in the color of pods. In the two years of experiment, two central planting lines of 20 m in length were previously separated in each treatment to determine productivity. Three replicates represented by plants contained in lines of two meters in length (1 m^2 of area) were collected, whose grains were placed to dry for 72 h, and subsequently weighed to estimate grain yields in each treatment.

The yield gap (YG), used to define the best sowing period, was obtained according to Eq. 1 similar to the work by Lima Filho et al. (2013).

$$YG = \left(\frac{1 - Rp}{Ap}\right)100 \tag{1}$$

where:

YG - yield gap, (%);

Rp - real productivity (kg ha^{-1}) in the presence of water deficiency and without nutritional limitation; and,

Ap - attainable productivity (kg ha^{-1}) considered as the maximum productivity obtained in the absence of water deficiency and nutritional limitation.

To quantify the deficiencies imposed by the treatments submitted to the water deficit, a sequential water balance was performed, considering the physical characteristics of the soil (Table 1) and the effective depth of the root system visually observed in the field through a trench (Souza et al., 2019). Accumulated water deficiency (AWD) was obtained by the difference between maximum crop evapotranspiration and real evapotranspiration found after sequential water balance analysis, on a daily scale and accumulated throughout the cycle. The phenological stages of cowpea were monitored after daily assessment following the development scale described by Farias et al. (2017) and by Souza et al. (2019).

The SARRAZON model was used, calibrated and validated for the crop and study region (Pinto, 2018) for the simulation of total water deficiency in the reproductive phase of cowpea according to the climatic conditions of the Northeast microregion of Pará and for an available water capacity (AWC) similar to that adopted in the field experiment (Table 1). For this, data from 30 meteorological stations located in the study region belonging to the National Institute of Meteorology (Souza et al., 2017a) corresponding to a series of 30 years were used (1986 and 2016).

Simulations with the SARRAZON model (Pinto, 2018) were performed with different sowing dates at intervals of 10-10 days between April and July for each year, a period commonly used by producers in the region (Freire Filho et al., 2009). The total deficiencies in the reproductive phase were spatialized using the ArcGis software considering the 30 locations, in order to assess the temporal and spatial seasonality of water availability and the sowing period in the study region.

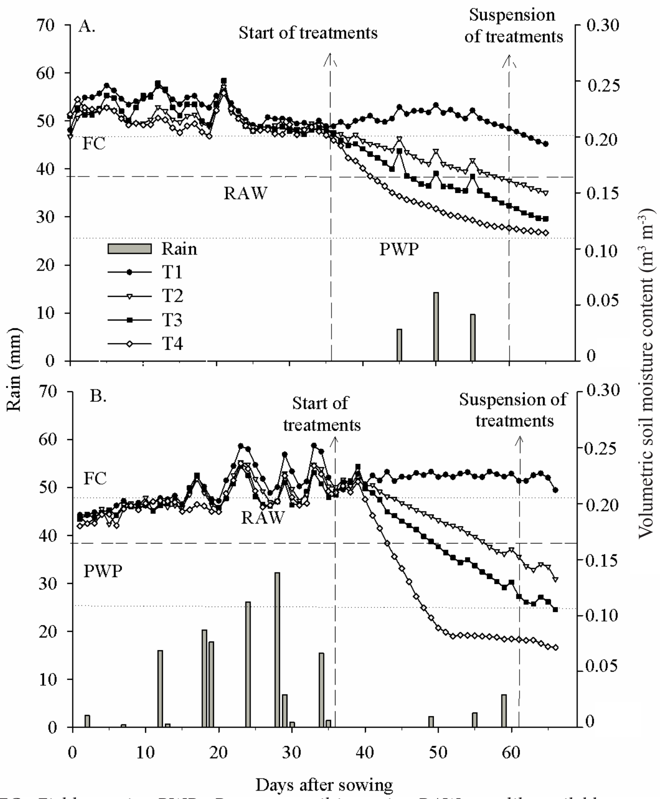
The results were submitted to variance and regression analysis, using the ORIGIN PRO 8.0v program.

Results and Discussion

The data of volumetric water content in the soil, as well as the precipitation in the cowpea cycle in the two years of evaluation, are presented in Figure 1. All treatments presented the same water availability during the vegetative period. From the reproductive phase, the soil water content varied in response to treatments, in which the T1 treatment presented the highest volumetric content of water in the soil, followed by treatments T2, T3 and T4 in both experiments (Figure 1). After the interruption of irrigation at the grain maturation stage (R9) it was found that the water content available in 2015 was 108, 54, 33 and 3% and in 2016 it was 122, 47, 8 and 0% for the T1, T2, T3 and T4 treatments, respectively.

The decrease in soil water content reduces the water potential of the plants by lowering the conductance and leaf transpiration with a consequent increase in leaf temperature and reduced production of photoassimilates (Silva et al., 2010a). Locatelli et al. (2016) observed a significant reduction in growth and productivity of three different cowpea cultivars in the Cerrado of Roraima in response to the decrease in water availability.

In the study with cowpea cultivar IPA 206 under different soil water regimes, Nascimento et al. (2004) found that plants markedly decreased their production when the available water



FC - Field capacity; PWP - Permanent wilting point; RAW - readily available water; T1 - Replacement of 100% of the water evapotranspirated by the crop (ETc); T2 - replacement of 50% of ETc; T3 - replacement of 25% of ETc; T4 - no water was supplied through irrigation

Figure 1. Precipitation (Rain) and soil moisture during the period of the experiment, in the years of 2015 (A) and 2016 (B)

was 40 to 60%, causing considerable changes in production components, in response to water availability for each treatment.

For both years, the total water depth applied in T1, treatment with 100% replacement of ETc, was sufficient to supply the water demand of cowpea (317.75 and 354.82 mm, respectively, for 2015 and 2016) (Table 2), since the water requirement of the cultivar used in the study region was approximately 267.73 ± 10.21 mm (Farias et al., 2017).

The different treatments provided a water deficiency accumulated during the reproductive phase of 30.2 and 33.1 mm in T2; 57.7 and 59.0 mm in T3 and 94.5 and 112.5 mm in T4, for 2015 and 2016, respectively, which were responsible for the observed gap in final productivity in each year (Figure 2B).

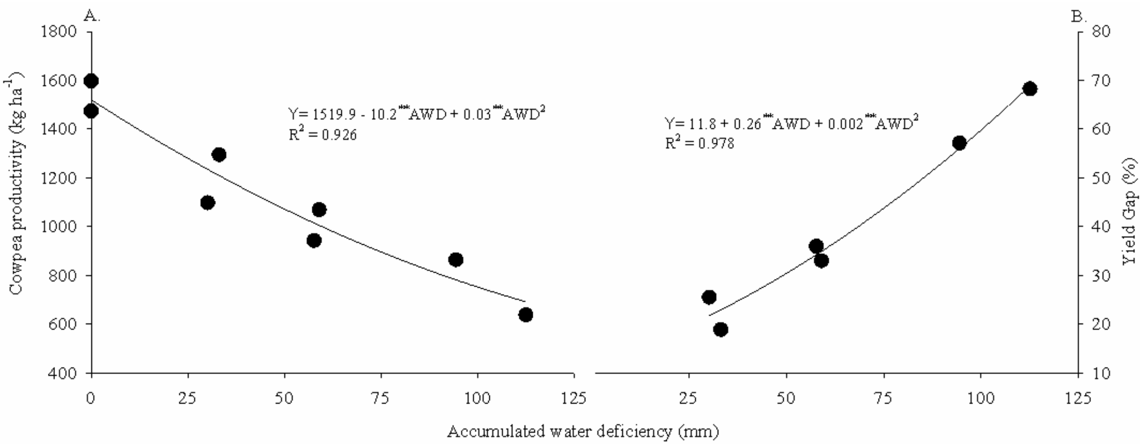
During periods of drought, plants that suffer water deficiency show inhibition of growth and photosynthesis, and sensitivity to water deficiency is a reflection of the plant's strategy to deal with the range of variation in water availability (Jones, 2007). Silva et al. (2010a) observed reductions in the stomatal conductance of cowpea due to water deficiency causing an increase in the diffusive resistance to water vapor, through the closure of stomata and consequent reduction in the supply of CO_2 for photosynthesis.

There was no significant difference in the effect of water availability between the experimental years for productivity, but there was significance for the individual effect of water deficiencies. The grain yield of cowpea observed in both years, proved that the water deficiency in the reproductive phase

Table 2. Water supplied during the vegetative and reproductive stages of cowpea and accumulated water deficiency (AWD) (mm) in 2015 and 2016, respectively

Year	Treatment	Water depth (mm)					
		Vegetative stage		Reproductive stage		Water depth	AWD
		Irrigation	Prec.	Irrigation	Prec.	Total	Total
2015	T1	173.83	0	113.45	30.5	317.75	0
	T2			56.73		261.06	30.2
	T3			28.36		232.89	57.7
	T4			0		173.83	112.5
2016	T1	87.64	141.18	113.81	12.2	354.82	0
	T2			56.09		297.10	33.1
	T3			28.45		269.46	59.0
	T4			0		228.82	94.5

T1 - Replacement of 100% of the water evapotranspirated by the crop (ET_c); T2 - replacement of 50% of ET_c; T3 - replacement of 25% of ET_c; T4 - no water was supplied through irrigation



** - Significant at p < 0.01 by the test F

Figure 2. Polynomial fitting of functions for cowpea productivity (A) and yield gap (B) in response to accumulated water deficiency (AWD) during the reproductive stage of cowpea

directly influences the production, because the greater the water deficiency imposed by the treatments, the lower the final grain weight values were (Figure 2A). The mean productivity of treatments in both years was 1,535.5 kg ha^{-1} (T1), 1,196.6 kg ha^{-1} (T2), 1069.8 kg ha^{-1} (T3) and 576.3 kg ha^{-1} (T4).

The results found by Nascimento et al. (2011) for the soil and climate conditions of Teresina, PI, Brazil, with studies on the tolerance of cowpea to water deficit, demonstrated that by reducing the supply of water in the reproductive phase (from 300 to 190 mm), there was, in general, a 72% reduction in stomatal conductance (gs) and a 60% reduction in grain yield, although there was great variation and dependence on the evaluated genotypes.

Reductions in production components and final productivity, such as those observed in the work of Costa Junior et al. (2017) and also in this study, have a direct relationship with reductions in plant gas exchange in the presence of water deficit, especially in gs regulating these gas exchange so as to have great affinity with the photosynthetic process, directly participating in the growth and development of plants (Paiva et al., 2005).

The lower productivity was due to the water deficit imposed by treatments with smaller irrigation depths. On average, a yield gap of 22.2, 33.6 and 60.5% was observed in response to accumulated average water deficiencies of 32, 58 and 104 mm, respectively (Figure 2B). Nascimento et al. (2011) and Bastos et al. (2012) obtained a reduction of 83% in the productivity of the Tracuateua-192 cultivar in a study with water deficiency imposed in the reproductive phase demonstrating its high sensitivity to lack of water.

Souza et al. (2017b) found considerable reductions in the productivity of this cultivar when it was submitted only to dry conditions, corresponding to a 41% reduction in its productivity in the presence of 26 mm water deficiency, and 72% when it experienced a 76 mm deficiency. Similar results were found by Ramos et al. (2014) who observed a reduction between 63 and 71% for two different cultivars when contrasting treatments with adequate irrigations (125% of ETo) with treatments submitted to restriction (25% of ETo).

According to Silva et al. (2010a) water deficiency makes several physiological and metabolic processes unfeasible in plants, causing decreased productivity, given that water is one of the main factors responsible for stomata regulation. Such behavior can be explained as one of the drought tolerance mechanisms used by this plant in order to seek better conditions to overcome the lack of water, produce less pods per plant, fewer grains per pod and less weight of grains (Ramos et al., 2014; Costa Junior et al., 2017).

Figure 3 shows the seasonality of total water deficiency in the reproductive phase of cowpea in Northeast Pará, obtained by the SARRAZON model (Pinto, 2018). Considering that the cultivar used presented a yield gap (loss of more than 30%) when subjected to water deficiencies greater than 50 mm (Figure 2B), it appears that sowing carried out up to April 20 would provide satisfactory yields (gap below 20%) in the entire northeastern region of the state, where accumulated deficiencies of up to 50 mm are estimated.

For regions located above the 2° S latitude range, sowing is recommended, which may extend until June 20, when deficiencies close to 75 mm are noted, which may cause yield gap of more than 30%. However, for cities located below 4° S latitude the sowing period for cowpea is limited to May 1 when deficiencies above 100 mm are already noted, which could cause considerable losses in productivity with reductions of more than 50% in crop productivity.

In Botucatu, SP, Brazil, in the southeast of the country, classified climatically according to Köppen as Cfa, large sowing period for cowpea varies from January to April, with yields greater than 800 kg ha^{-1} when cultivated until mid-March, reaching up to 2,746 kg ha^{-1} if sown in early February (Matoso et al., 2018). In the Uberaba region of MG, Brazil, also in the southeast of the country, where the climate is Cwa type according to Köppen, it was found that cowpea bean sowings performed in December, provide lower productivity compared to when performed in January and February, the latter period

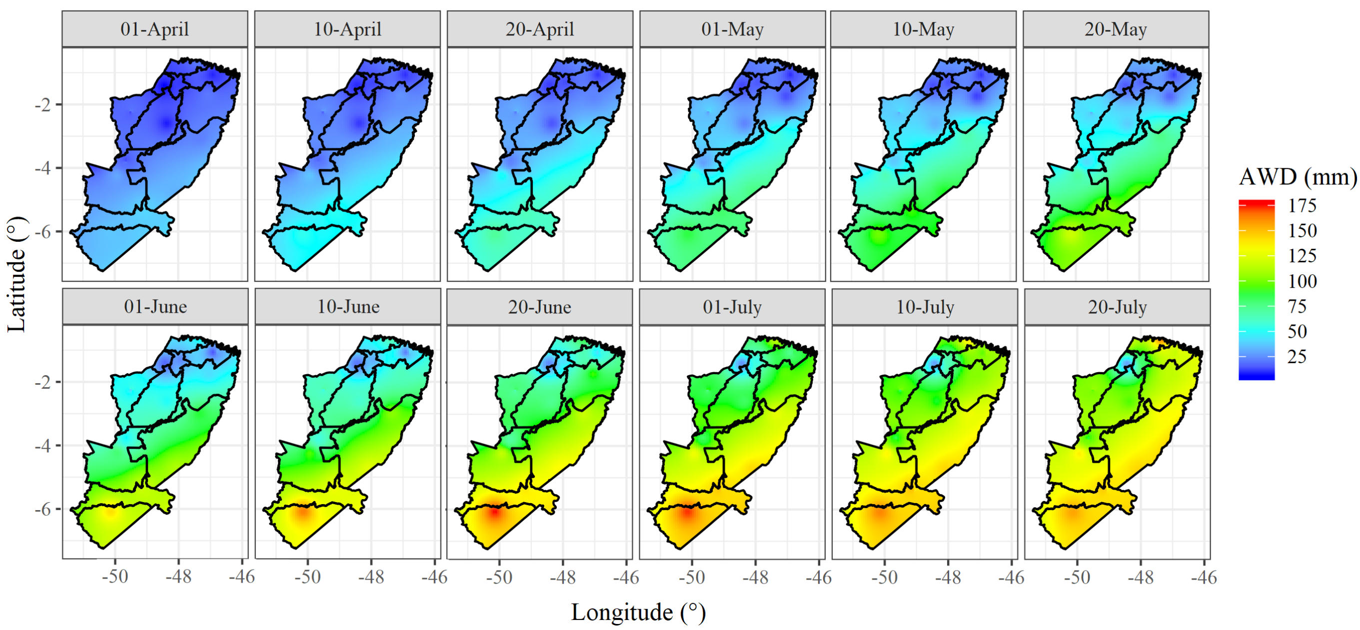


Figure 3. Accumulated water deficiency (AWD) during the reproductive stage of cowpea as a function of geographic location in Northeastern Pará - Brazil, throughout different sowing dates

is considered as ideal because it generates higher yields, which reach 2,489 kg ha^{-1} for the cultivar BRS-Potengi and 2,859 kg ha^{-1} for the cultivar BRS-Tumucumaque (Almeida et al., 2017).

In the Bahian hinterland, where the climate is of the Am type, the ideal sowing period is concentrated between June 15 and July 15, considering that previous periods, although with less yield gap, are at risk of excessive rain at harvest time (Lima Filho et al., 2013). For the State of Ceará, Brazil, where there are different climatic types (Aw, Bsh, Bwh), the cultivation of cowpea in response to climate risk is recommended for the period from 21 to 31 January, regardless of the type of soil adopted (Andrade Junior et al., 2007).

It appears that the definition of the period of sowing of cowpea for the microregion of Northeastern Pará, Brazil, is directly influenced by the natural variability of the climate, despite being located in the Amazon region where the rainfall regime is considerably higher than that observed in the regions mentioned (Souza et al., 2017a).

The cultivar BRS Tracuateua has higher productivity than the average of the State of Pará, Brazil, when it experiences water deficiencies below 60 mm in the reproductive phase. On the other hand, the greatest yield gap observed in response to water deficiencies greater than 50 mm justify the choice of municipalities located in the northern sector of the microregion of Northeastern Pará, Brazil, as the largest cowpea producers in the State (SEDAP, 2018), which can even extend their harvests to mid-June without any gap in productivity above 20%.

Future studies are needed to identify which changes occur in the sowing period of the crop in years considered atypical (El Niño and La Niña) and even under conditions of future climate scenarios in the region, since under these conditions there are changes in the region's water regime (Souza et al., 2000, 2016) and as in other places, there is a change in the sowing period (Silva et al., 2010b).

Conclusions

1. Water deficits accumulated in the reproductive phase of more than 50 mm provide a gap in cowpea productivity of more than 30%.

2. Regions located above the 2° S latitude, have a longer sowing period, with recommended sowing until around June 20.

3. Yield gap (losses) above 50% are expected for sowing carried out after May 1 in regions below 4° south latitude.

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Literature Cited

Allen, R. G.; Pereira, L. S.; Howell, T. A.; Jenses, M. E. Evapotranspiration information reporting: I. Factors governing measurement accuracy. Agricultural Water Management, v.98, p.899-920, 2011. https://doi.org/10.1016/j.agwat.2010.12.015

Almeida, F. da S.; Mingotte, F. L. C.; Lemos, L. B.; Santana, M. J. de. Agronomic performance of cowpea cultivars depending on sowing seasons in the cerrado biome. Revista Caatinga, v.30, p.361-369, 2017. https://doi.org/10.1590/1983-21252017v30n211rc

Andrade Junior, A. S. de; Barros, A. H. C.; Silva, C. O. da; Freire Filho, F. R. Zoneamento de risco climático para a cultura do feijão-caupi no Estado do Ceará. Revista Ciência Agronômica, v.38, p.109-117, 2007.

Bastos, E. A.; Ramos, H. H.; Andrade Junior, A. S. de; Nascimento, F. N. do; Cardoso, M. J. Parâmetros fisiológicos e produtividade de grãos verdes do feijão-caupi sob déficit hídrico. Water Resources and Irrigation Management, v.1, p.31-37, 2012.

Bernardo, S.; Soares, A. A.; Mantovani, E. C. Manual de irrigação. Viçosa: Universidade Federal de Viçosa - UFV, 2006. 625 p

Costa Junior, M. de J. N. da; Bastos, E. A.; Cardoso, M. J.; Andrade Junior, A. S. de. Agronomic performance of cowpea under different irrigation depths and row spacing. Revista Ciência Agronômica, v.48, p.774-782, 2017. https://doi.org/10.5935/1806-6690.20170090

Coutinho, P. W. R.; Silva, D. M. S. da; Saldanha, E. C. M.; Okumura, R. S.; Silva Junior, M. L. da. Doses de fósforo na cultura do feijão-caupi na região nordeste do Estado do Pará. Revista Agro@mbiente On-line, v.8, p.66-73, 2014. https://doi.org/10.18227/1982-8470ragro.v8i1.1310

Cunha, F. N.; Silva, N. F.; Teixeira, M. B.; Carvalho, J. J.; Freitas, L. M.; Santos, C. C. Coeficientes de uniformidade em sistema de irrigação por gotejamento. Revista Brasileira de Agricultura Irrigada, v.8, p.444-454, 2014. https://doi.org/10.7127/rbai.v8n600254

Farias, V. D. da S.; Lima, M. J. A.; Nunes, H. G. G. C.; Sousa, D. P.; Souza, P. J. O. P. Water demand, crop coefficient and uncoupling factor of cowpea in the Eastern Amazon. Revista Caatinga, v.30, p.90-200, 2017. https://doi.org/10.1590/1983-21252017v30n121rc

Freire Filho, F. R.; Cravo, M. da S.; Ribeiro, V. Q.; Rocha, M. de M.; Castelo, E. de O.; Brandão, E. S.; Belmino, C. S.; Melo, M. I. S. de. BRS Milênio e BRS Urubuquara: Cultivares de feijão-caupi para a região Bragantina do Pará. Revista Ceres, v.56, p.749-752, 2009.

Jones, H. G. Monitoring plant and soil water status: Established and novel methods revisited and their relevance to studies of drought tolerance. Journal of Experimental Botany, v.58, p.119-130, 2007. https://doi.org/10.1093/jxb/erl118

Lima Filho, A. F.; Coelho Filho, M. A.; Heinemann, A. B. Determinação de épocas de semeadura do feijão caupi no Recôncavo Baiano através do modelo CROPGRO. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.1294-1300, 2013. https://doi.org/10.1590/S1415-43662013001200007

Locatelli, V. da E. R.; Medeiros, R. D. de; Smiderle, P. J.; Albuquerque, J. de A. A.; Araujo, W. F. Desenvolvimento vegetativo de cultivares de feijão-caupi sob lâminas de irrigação no cerrado roraimense. Irriga, v.1, p.28-39, 2016. https://doi.org/10.15809/irriga.2016v1n1p28-39

Matoso, A. O.; Soratto, R. P.; Guarnieri, F.; Costa, N. R.; Abrahão, R. C.; Tirabassi, L. H. Sowing date effects on cowpea cultivars as a second crop in Southeastern Brazil. Agronomy Journal, v.110, p.1799-1812, 2018. https://doi.org/10.2134/agronj2018.01.0051

Merriam, J. L.; Keller, J. Farm irrigation system evaluation. Utah: Engineering Department - Utah State University, 1978. 42p.

Moreira, W. K. O.; Oliveira, S. S.; Alves, J. D. N.; Ribeiro, R. A. dos R.; Oliveira, I. A.; Sousa, L. A. S. de. Evolução da produtividade do feijão-caupi para os principais produtores do nordeste Pará no período de 2000 à 2014. Nucleus, v.14, p.341-351, 2017. https://doi.org/10.3738/1982.2278.1692

Nascimento, J. T.; Pedrosa, M. B.; Tavares Sobrinho, J. Efeito da variação de níveis de água disponível no solo sobre o crescimento e produção de feijão caupi, vagens e grãos verdes. Horticultura Brasileira, v.22, p.174-177, 2004. https://doi.org/10.1590/S0102-05362004000200002

Nascimento, S. P. do; Bastos, E. A.; Araujo, E. C. E.; Freire Filho, F. R.; Silva, E. M. da.Tolerância ao déficit hídrico em genótipos de feijão-caupi. Revista Brasileira de Engenharia Agrícola e Ambiental, v.15, p.853-860, 2011. https://doi.org/10.1590/S1415-43662011000800013

Nunes, H. F.; Freire Filho, F. R.; Ribeiro, V. Q.; Gomes, R. L. F. Grain yield adaptability and stability of blackeyed cowpea genotypes under rainfed agriculture in Brazil. African Journal of Agricultural Research, v.9, p.255-261, 2014. https://doi.org/10.5897/AJAR212.2204

Paiva, A. S.; Fernanades, E. J.; Rodrgigues, T. J. D.; Turco, J. E. P. Condutância estomática em folhas de feijoeiro submetido a diferentes regimes de irrigação. Engenharia Agrícola, v.25, p.161-169, 2005. https://doi.org/10.1590/S0100-69162005000100018

Pinto, J. V. N. Zoneamento de risco climático da cultura do feijão-caupi (*Vigna unguiculata* [L.] Walp.) no Nordeste Pará. Belém: UFRA, 2018. 64p. Dissertação Mestrado

Ramos, H. M. M.; Bastos, E. A.; Cardoso, M. J.; Ribeiro, V. Q.; Nascimento, F. N. do. Produtividade de grãos verdes do feijão-caupi sob diferentes regimes hídricos. Engenharia Agrícola, v.34, p.683-694, 2014. https://doi.org/10.1590/S0100-69162014000400008

SEDAP -Secretaria de Estado de Desenvolvimento Agrário e da Pesca. Banco de dados - 2018. Available on:<http://www.sedap.pa.gov.br/agricultura>. Accessed on: Nov. 2018

Silva, C. D. S. e; Santos, P. A. A.; Lira, J. M. S.; Santana, M. C. de; Silva Júnior, C. D. da. Curso diário das trocas gasosas em plantas de feijão-caupi submetidas a deficiência hídrica, Revista Caatinga, v.23, p.7-13, 2010a.

Silva, G. C.; Magalhães, R. C.; Sobreira, A. C.; Schmitz, R.; Silva, L. C. da. Rendimento de grãos secos e componentes de produção de genótipos de feijão-caupi em cultivo irrigado e de sequeiro. Revista Agro@mbiente On-line, v.10, p.342-350, 2016. https://doi.org/10.18227/1982-8470ragro.v10i4.3385

Silva, V. de P. R. da; Campos, J. H. B. C.; Silva, M. T.; Azevedo, P. V. de. Impact of global warming on cowpea bean cultivation in Northeastern Brazil. Agricultural Water Management, v.97, p.1760-1768, 2010b. https://doi.org/10.1016/j.agwat.2010.06.006

Silva Júnior, E. B. da; Favero, V. O.; Xavier, G. R.; Boddey, R. M.; Zilli, J. Rhizobium inoculation of cowpea in Brazilian cerrado increases yields and nitrogen fixation. Agronomy Journal, v.110, p.722-727, 2018. https://doi.org/10.2134/agronj2017.04.0231

Souza, E. B. de; Carmo, A. M. C.; Moraes, B. C.; Nacif, A.; Ferreira, D. B. da S.; Rocha, E. J. P.; Souza, P. J. de O. P. Sazonalidade da precipitação sobre a Amazônia legal Brasileira: Clima atual e projeções futuras usando o modelo regcm4. Revista Brasileira de Climatologia, v.18, p.293-306, 2016. https://doi.org/10.5380/abclima.v18i0.43711

Souza, E. B. de; Ferreira, D. B. da S.; Guimarães, J. T. F.; Franco, V. dos S.; Azevedo, F. T. M. de; Souza, P. J. de O. P. de. Padrões climatológicos e tendências da precipitação nos regimes chuvoso e seco da Amazônia oriental. Revista Brasileira de Climatologia, v.21, p.81-93, 2017a. https://doi.org/10.5380/abclima.v21i0.41232

Souza, E. B. de; Kayano, M. T.; Tota, J.; Pezzi, L.; Fisch, G.; Nobre, C. A. On the influences of the El Niño, La Niña and Atlantic dipole pattern on the Amazonian rainfall during 1960-1998. Acta Amazônica, v.30, p.305-318, 2000. https://doi.org/10.1590/1809-43922000302318

Souza, P. J. de O. P. de; Farias, V. D. da S.; Lima, M. J. A. de; Ramos, T. F.; Sousa, A. M. L. de. Cowpea leaf area, biomass production and productivity under diferente water regimes in Castanhal, Pará, Brazil. Revista Caatinga, v.30, p.748-759, 2017b. https://doi.org/10.1590/1983-21252017v30n323rc

Souza, P. J. de O. P.; Ramos, T. F.; Fiel, L. de C. S.; Farias, V. D. da S.; Sousa, D. de P.; Nunes, H. G. G. C. Yield and water use efficiency of cowpea under water deficit. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.119-125, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n2p119-125