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REQUIREMENT OF SUPPLEMENTAL IRRIGATION FOR DRY SEASON COMMON BEAN IN GOIÁS

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1 ABSTRACT

Common bean crop is grown in Goiás state in three crop seasons, "wet", “dry”, and autumn/winter. In "dry" crop season, common bean yield is lower and it can be attributed in large part to the water deficit during its cycle. The use of supplemental irrigation can be an alternative to overcome this stress and increase grain yield. The objective of this study was to quantify the impact of water stress in "dry" season common bean and the irrigation depth required to mitigate this stress, using the CSM-CROPGRO-Dry bean simulation model. The model was calibrated and evaluated against observed data set for Pérola cultivar. Grain yield for six sowing dates (10/1, 20/01, 30/1, 10/2, 20/2, and 28/2) and three soil classes (Oxisol, Ultisol, and Inceptisol) were simulated considering growth under rainfall and growth with supplemental irrigation, using daily climatic data of 26 weather stations in Goiás for the period of 33 years. The relative impact of water deficit, estimated by the grain yield gap in both cases, was 48%. Soil classes had low impact on average values of irrigation depth required as well as on irrigated grain yield. The irrigation depth required increased from 70 to 157 mm and the grain yield decreased from 3,813 to 3,510 kg ha^{-1} with the advance of sowing date.

Keywords: *Phaseolus vulgaris*, water deficiency, simulation model.

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2 RESUMO

O feijoeiro é cultivado em Goiás em três safras, “águas”, “seca” e outono/inverno. Na safra da “seca”, com semeadura de 01/01 a 28/02, a produtividade do feijoeiro é menor e pode ser atribuída, em grande parte, a ocorrência de deficiência hídrica durante o seu ciclo. O uso de irrigação suplementar pode ser uma alternativa para superar esse estresse e incrementar a produtividade. O objetivo deste trabalho foi quantificar o impacto da deficiência hídrica no feijão da “seca” e a lâmina de irrigação requerida para mitigar essa deficiência, utilizando o modelo de simulação CSM-CROPGRO-Dry bean. O modelo foi calibrado e validado por meio da comparação de dados observados e simulados para a cultivar Pérola. Foram simuladas a produtividade para seis datas de semeadura (10/1, 20/01, 30/1, 10/2, 20/2 e 28/2) e três classes de solo (Latossolo, Cambissolo e Argissolo), considerando o crescimento sob precipitação pluvial ou com o uso da irrigação suplementar, utilizando dados climáticos diários de 26 estações meteorológicas de Goiás para o período de 33 anos. O impacto relativo da deficiência

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hídrica, estimado pela diferença de produtividade nas duas situações, foi de 48%. As classes de solo tiveram pouco impacto na lâmina media requerida como também na produtividade irrigada. A lâmina média de irrigação requerida aumenta com o avanço da data de semeadura, variando de 70 a 157 mm, e a produtividade decresce de 3.813 a 3.510 kg ha^{-1}.

Palavras-chave: *Phaseolus vulgaris*, deficiência hídrica, modelo de simulação.

3 INTRODUCTION

Common bean is grown in Goiás state in three crop seasons denominated "wet", sowing date from 01/11 to 31/12, "dry", sowing date from 01/01 to 28/02, and autumn/winter, sowing date from 01/05 to 30/6. In the first two crop seasons, common bean is cropped as rainfed and, for the last one, it is fully irrigated by central pivot. These crop seasons responded in the period 2001-2010 by 35%, 12%, and 53% of the total state production and had average yields of 1,756; 1,576 and 2,720 kg ha^{-1}, respectively (EMBRAPA, 2015). The lower yield of the "dry" crop season can be attributed in large part to water deficit during the common bean cycle.

Indeed, Meireles et al. (2003) found that for the Carioca cultivar the risk of water deficit in "dry" crop season, in Santo Antônio de Goiás, GO, is greater than 50% and gradually increases from the first ten days of January (50%) for the last ten days of February (71%).

The supplemental irrigation can be an alternative to overcome this stress and increase grain yield. According to De Fraiture e Wichelns (2010), irrigated agriculture contributes with 40% of world food production. However, facing the challenge of preserving the quality and quantity of water used in the production system, since it is essential for the preservation of ecosystems and agricultural production (PEREIRA et al., 2012), effective water management is needed in order to promote their economy front the growing demand in the production system.

Effective management for water use is the only way to save water for the increasing irrigated agriculture. Different approaches have been adopted aiming to reduce the damage caused by drought; among these approaches there is the water productivity or water use efficiency, WUE (BOUTRAA, 2010). In this context, one viable alternative and of easy adoption by common bean producers to address the need to increase WUE and productivity levels of the "dry" crop season is the choice of suitable sowing date, covering the period in which still there is good water availability provided by the rainfall in Goiás state.

The effects of sowing date in common bean yield and WUE can be estimated with the use of a growth simulation model. Some simulation models use genetic coefficients as inputs, which permit simulating crop performance in different soils, climate and environmental conditions. Using simulation, the most suitable strategies can be assessed in each specific condition, such as irrigation management strategies, which can be simulated to predict effects on crop yield and hydrologic components, such as evapotranspiration and crop water requirements (DALLACORT et al., 2010). Oliveira e Carvalho (2003), using the DEMAND software, found that the average supplemental irrigation depth required for "dry" crop season common bean in Goiás state ranged from 34 to 207.9 mm, with an average of 116.5 mm.

Among the crop models, the CSM-CROPGRO-Dry bean model has been widely used for various applications across a wide range of regions in Brazil (HEINEMANN et al., 2002; MEIRELES et al. 2003; DALLACORT et al., 2010). It is a process oriented computer model that simulates growth, development and yield of common beans as a function of environmental conditions and crop management scenarios.

The objective of this study was to quantify the impact of water stress in "dry" crop season common bean and the irrigation depth required to mitigate this deficiency, using the CSM-CROPGRO-Dry bean simulation model.

4 MATERIAL AND METHODS

4.1 Crop model description

The CSM-CROPGRO-Dry bean uses one day as main time step for integration, corresponding to the daily recording of weather information. The soil water balance computes (on a daily basis) all processes that directly affect the water content in the soil profile throughout the seasonal simulation. Evapotranspiration is calculated based on soil evaporation and plant transpiration. Potential evapotranspiration is based on the Priestley-Taylor evapotranspiration method. Soil evaporation is a function of the amount of energy that reaches the soil surface, which is proportional to the leaf area index (LAI), soil albedo, and the soil water content of the boundary surface layer. The rate of root water uptake from soil layer is calculated using a “law of the limiting” approach in which the larger of the soil profile or the root resistance determines the flow rate of water into roots (WEBBER et al., 2010).

4.2 Model calibration

The CSM-CROPGRO-Dry bean crop model was calibrated and evaluated for one standard check cultivar, Pérola. This cultivar is classified as indeterminate growth habit (type II and III) and has a long cycle, with 90 days after emergence. According to Teixeira et al. (2015), LAI and radiation use efficiency for this cultivar is 3.7 and 1.04 g MJ^{-1}, respectively.

For calibration process, crop model parameters for development and growth were calculated using the observed crop data from five experiments sowing in 15/06/2011; 22/05; 08/06; 20/06 and 04/07/2012. These experiments were fully irrigated and conducted to minimize all biotic and abiotic stress. Based on our field knowledge, Pérola cultivar is not photoperiod sensitive, then PPSEN (slope of the relative response of development to photoperiod with time) and CSDL (critical short day length below which reproductive development progresses with no daylength effect) parameters were set as 0 and 12.7. The SDPRO and SDLIP parameters, related to the protein and oil fractions in seeds, were set as default of “Carioca” cultivar due to the lack of observed data set. After that, the SLAVR (specific leaf area of cultivar under standard growth conditions) parameter was optimized. After the automatic procedure, the calibration has been refined by using a manual and iterative approach according to Hoogenboom et al. (2010). The genetic parameters have been refined to fit time series observation data (LAI, total, leaf, stem and pod biomass). Calibration and evaluation have been done with water and nitrogen balance module turned on.

4.3 Model evaluation

Model evaluation efforts focused on assessing the differences between variables measured in seven experiments with sowing dates at 29/06; 13/07; 28/07/11; 24/01; 28/02; 30/03 and 23/04/2012. For the data evaluation the observed data set was composed by flowering, first pod, first seed and physiological maturity dates, maximum LAI, shoot weight at flowering and maturity and grain yield.

4.4 Simulated scenarios

Simulations were performed for six sowing dates from 10/01 to 28/2, that encompassing the "dry" crop season, for three soil classes (Oxisol, Ultisol, and Inceptisol) which represent 64%, 19%, and 6% of the agricultural area in the Goiás state. Climatic data were obtained from 26 weather stations (Figure 1) in the production area with daily data for rainfall, maximum and minimum temperature and solar radiation from 1980-2013. Almost the entire state of Goiás has tropical climate, classified as Aw according to the Köppen's classification. There are two well defined seasons, normally dried from May to September (autumn/ winter) and raining from October to April (spring/ summer). Annual mean rainfall is 1,500 mm and annual mean temperature is 23.4°C (CARDOSO et al., 2014).

Simulations were performed for yield potential for irrigated systems (Y_{ns}), assumed that an irrigated crop can be provided with adequate water supply throughout growth, and water-limited yield potential (Y_{wl}), defined as yield of an adapted crop variety when grown under rainfed, favorable conditions without growth limitations from nutrients and pests (LOBELL et al., 2009). For Y_{ns} simulation, we used automatic irrigation to apply 20 mm of water when the first 30 cm of soil layer get 50% of the field capacity. The same management practice used by farmers in the region for irrigation. For Y_{wl}, the simulation was set for rainfed conditions. Biotic constraints and nitrogen limitations were not taking into account for both simulations as already described above.

4.5 Drought quantification

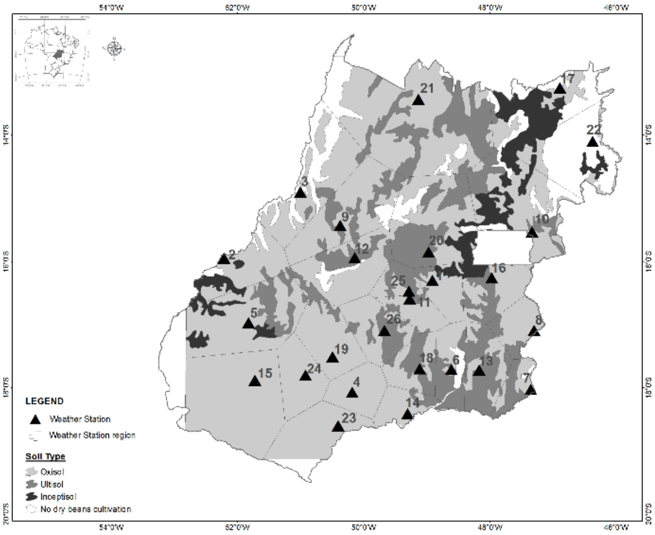
The relative water stress impact (RWSI) was evaluated by expressing simulated attainable yield (Y_{wl}) as a fraction of simulated yield with no water limitation (Y_{ns}), irrigated, nevertheless considering the three soil classes. Water stress impact (WSI) was evaluated expressing the difference between Y_{ns} and Y_{wl}.

$$\mathrm{RWSI} = \frac{(\mathrm{Y_{ns}} - \mathrm{Y_{wl}})}{\mathrm{Y_{ns}}} \quad (1)$$

$$\mathrm{WSI} = (\mathrm{Y_{ns}} - \mathrm{Y_{wl}}) \quad (2)$$

Where by:
RWSI - relative water stress impact (%);
WSI - water stress impact (kg ha^{-1});
Y_{wl} - simulated yield with water restriction (kg ha^{-1}) and
Y_{ns} - attainable yield with no water limitation (kg ha^{-1}).

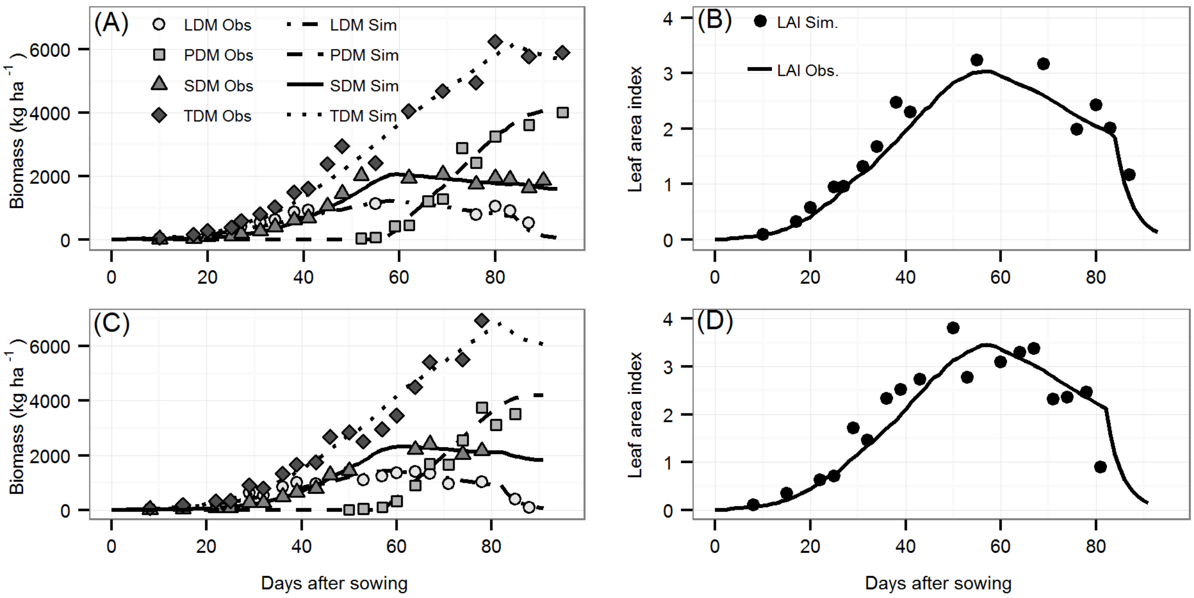
Figure 1. Common bean target population of environment in Goiás State and the geographic distribution of weather station locations (triangles), weather station coverage area (polygons) and soil classes.



5 RESULTS AND DISCUSSION

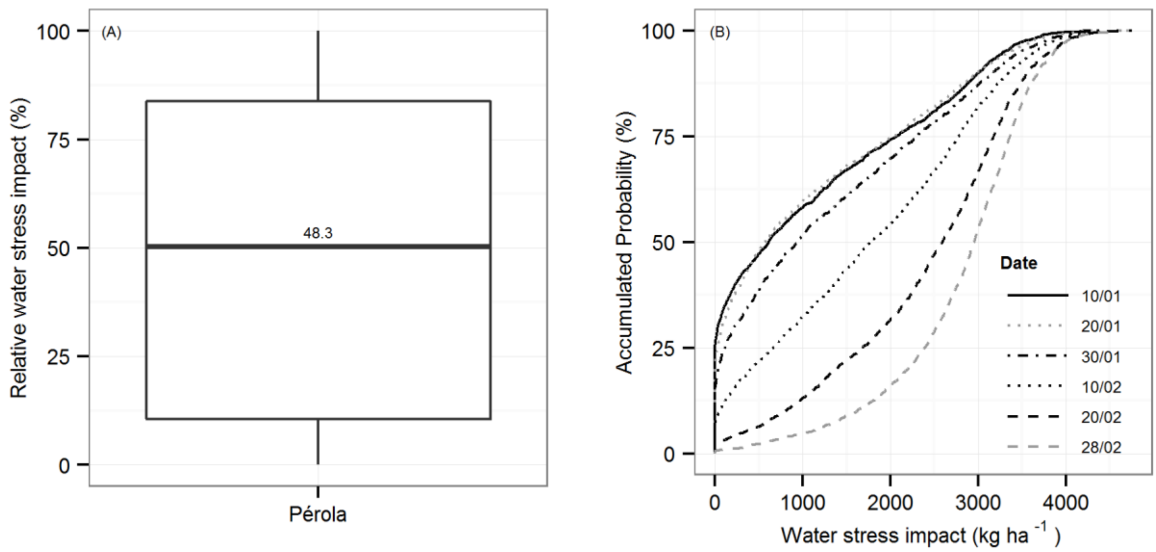
The CSM-CROPGRO-Dry bean crop model showed a good performance for predicting common bean phenology for Pérola cultivar. The model showed a good performance for predicting flowering, first pod, first seed and maturity dates - phenology calibration (data set not showed). The crop model also captured well the seasonal variation in total dry matter dynamic under moderate drought (Figure 2A and C). Leaf area index was also well simulated for moderated drought (Figure 2B and D). These results show that the model successfully simulates the growth and development of the common bean cultivar under study and may be used to determine the most appropriate date for sowing this *Fabaceae* in the “dry” crop season.

Figure 2. Simulated (lines) and measured (point) for total dry matter (TDM), leaves (LDM), stems (SDM), and pods (PDM), and leaf area index (LAI) for sowing dates 22/05/2012 (A) and (B), and 20/06/2012 (C) and (D) for Pérola cultivar.



Considering all sowing dates and soil classes in "dry" crop season, the median and mean of relative water stress impact were 50% and 48% (Figure 3A). The sowing date towards the beginning of the sowing window (till 30/01) (Figure 3B) minimize the water stress impact on yield, agreeing with the results obtained by Meireles et al. (2003) and indicating that management practices have a significant impact to decrease the drought effects on yield.

Figure 3. Box plot showing the relative water stress impact (RWSI, %) on yield (box indicates 25th, 50th, and 75th percentiles) (A), Risk (%) of water stress impact (lines) for each sowing date considering all soils classes for Pérola cultivar (B). Number in (A) represents the average value and the horizontal black line the median.



The supplemental irrigation depth for common bean increases with the advance of sowing date, ranging from 70 to 157 mm (Figure 4), showing few differences among the soil classes. This increase is due to the decrease in rainfall (Figure 5). In spite of average supplemental irrigation values are similar for all soil classes (Fig. 4A, B and C), Inceptsol showed the highest variability, followed by Ultisol. The irrigation depths are in the range found by Oliveira e Carvalho (2003). Independently of the sowing dates and soil classes, the irrigation depth increases from south to northeast of Goiás state (Figure 6).

Figure 4. Supplemental irrigation depth (A), (B) and (C) and simulated yield (D), (E) e (F) according to sowing dates and soil classes (box indicates 25th, 50th, and 75th percentiles). Black full circle means average values.

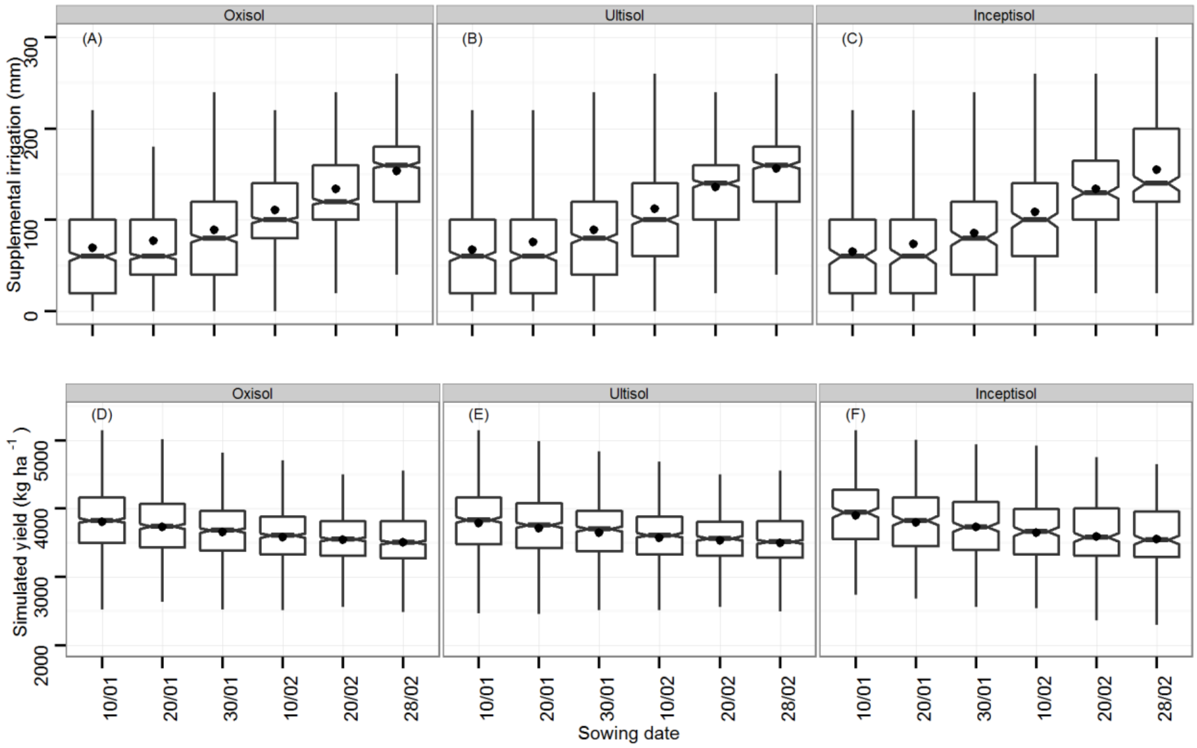


Figure 5. Climate variable accumulated by crop cycle according to sowing dates. Rain – rainfall, Tmin and Tmax –minimum and maximum temperatures, and SRAD – global solar radiation.

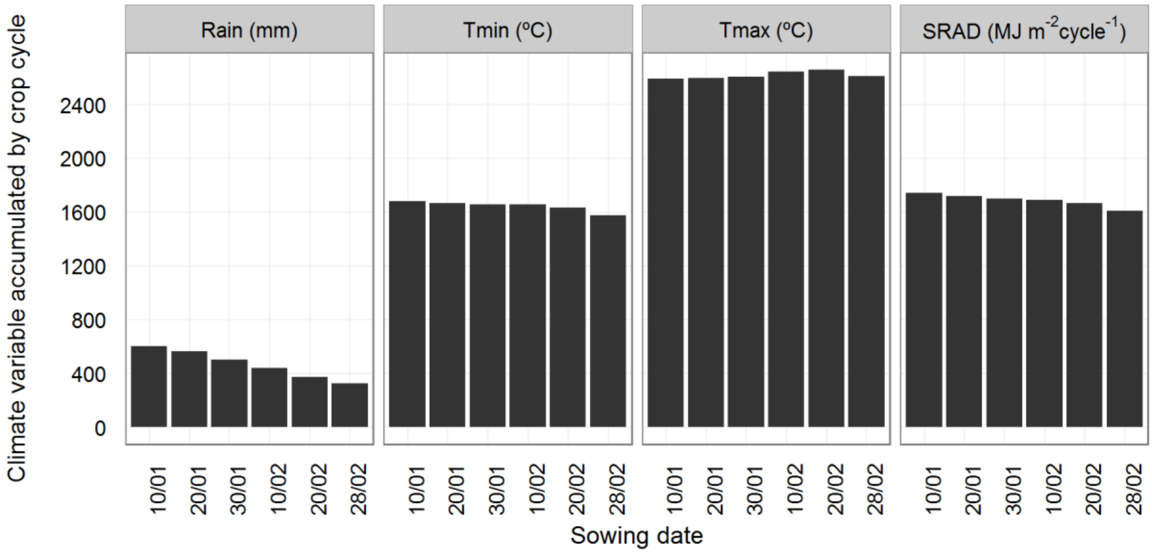
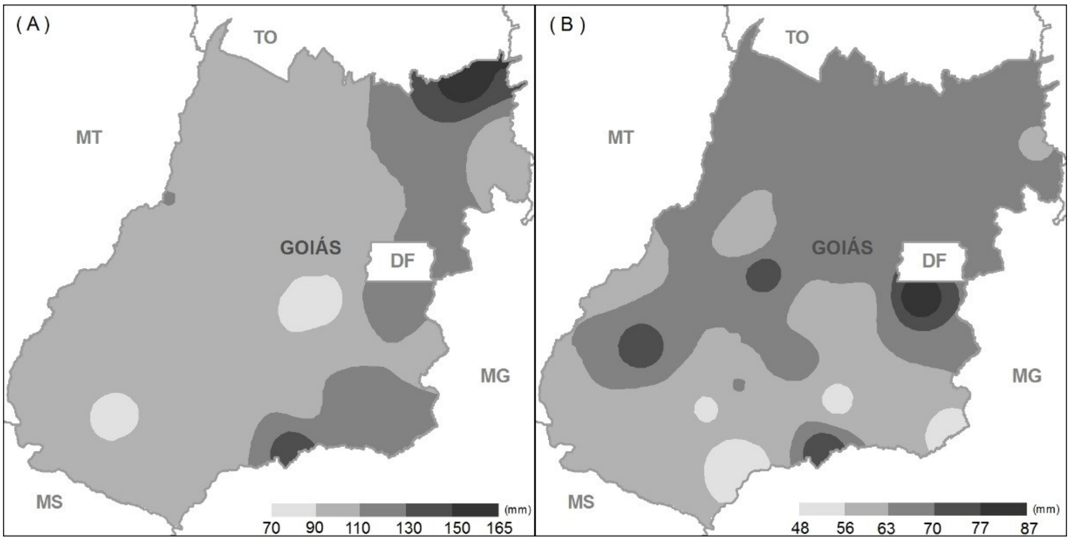


Figure 6. Spacialization of mean (A) and standart deviation (B) of the supplemental irrigation depth (mm) for "dry" season common bean in Goias state.



The grain yield decreased from 3,813 to 3,510 kg ha^{-1} with the advance of sowing date (Figure 4), probably due to the decrease in solar radiation (Figure 5). These values are close but higher than those simulated by Meireles et al. (2003), who found for the Carioca cultivar values between 3,232 and 3,348 kg ha^{-1} for the same sowing dates, in Santo Antônio de Goiás, GO. Silva et al. (2012) reported for Pérola cultivar grown under irrigation in Cristalina, GO, grain yields around 3,400 kg ha^{-1} in farmers' area.

6 CONCLUSIONS

The relative impact of water deficit on grain yield was 48%, considering the three soil classes and all sowing dates.

Soil classes had low impact on both irrigation depth required as grain yield under irrigation.

The irrigation depth required increased from 70 to 157 mm and the grain yield decreased from 3,813 to 3,510 kg ha^{-1} with the advance of sowing date.

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