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Dry bean crop productivity simulation for soil and climatic conditions of Tangará da Serra, MT - Brazil

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The Brazilian national growing of dry bean (*Phaseolus vulgaris*) currently comes in three annual harvests, which are the wet season, sowing between October and December, the Dry Season, sowing between February and May, and finally the Winter Season, sowing in June to August. The objective of this study was to determine the optimal sowing date for each of the three different sowing seasons wet, dry and winter of dry bean to the Tangará da Serra region using a crop simulation software called Decision Support System for Agrotechnology Transfer (DSSAT). The DSSAT is comprised of crop simulation models, in which the CROPGRO-Drybean model was used to simulate the dry bean growth, development, and yield. The model was calibrated using the dry bean cultivar 'BRS Esplendor', planted on 15 December 2011 in Tangará da Serra, located in the Mato Grosso state of Brazil. The weather variables (maximum and minimum temperature, solar radiation and precipitation), phenological and soil variables were recorded during the season and used in the model calibration to ensure a satisfactory simulation. Following the calibration, simulations were performed for six sowing dates in each of the three seasons. Of the three growing seasons simulated, the wet season had the best grain yields for the dry bean 'BRS Esplendor', the sowing date of December 1st had the highest yields of 3.3 t ha⁻¹. The dry season had the second high simulated yields, and the highest yield into this growing season was 3.0 t ha⁻¹. In the dry season, grain yield decreased as late sowing date occurred, and the lowest simulated yield was 0.1 t ha⁻¹. Finally, the winter season had the lowest simulated yields among the three growing season, with a maximum yield of 0.5 t ha⁻¹. The CROPGRO-Drybean model had a high sensitivity to rainfall events, and drought periods during the reproductive stage of dry bean was the weather parameter that most affected grain yield. The winter season had lower yields than the wet and dry season in consequence of low rainfall events during the simulated crop cycles, the soil moisture was highly affected by precipitation, which directly affected the leaf area index and crop yield in all sowing dates.

Key words: CROPGRO-dry bean, yield, water stress, precipitation, soil moisture

INTRODUCTION

In Brazil, the dry bean (*Phaseolus vulgaris*) is cultivated by small and big farmers around the country, the leguminosae is considerate a subsistence crop that requires low technological development as well as the

use of low seeds quality (Leite et al., 2009).

The Brazilian national growing of dry bean currently comes in three annual harvests, which are wet season, sowing between October and December, the dry Season,

sowing between February and May, and finally the winter season, sowing in June to August (Vieira et al., 1995).

The Mato Grosso state stands out in 2014, as the third highest national yield of dry beans, with 23.4, 82.5 and 36.2 thousands of tons for the wet season, dry season and winter season, respectively. However, the crop cultivation is undergoing by a significant variation in relation to cultivated area, consequences of weather characteristics and market behavior (CONAB, 2014).

Weather characteristics such as temperature and solar radiation are important environmental factors, which affect the crop development. The dry bean has an ideal temperature of 21°C, which determine the crop development (Fancelli, 2009). While the solar radiation lead processes photosynthetic and photo-morphogenetic (Kunz et al., 2007). On the other hand, the stress hydric in non-irrigated agricultural areas is the main factor that has been affecting the dry bean. The high temporal variability may cause an excess or deficit hydric, and in both cases, it is directly influencing the dry bean development and production (Dallacort et al., 2011b).

Current weather variability has led growers and researchers to make decisions on best management practices based on simulation techniques. In this context, the Decision Support System for Agrotechnology Transfer (DSSAT) is increasingly used, and the CROPGRO-Drybean model (Hoogenboom et al., 1994), which is one of several crop development models present at the DSSAT, have been used extensively to evaluate effects of irrigation requirements (Heinemann and Hoogenboom, 2000), sowing dates (Dallacort et al., 2005; Lima Filho, Coelho Filho and Heinemann, 2013) and yield simulation (Dallacort et al., 2011a; Oliveira et al., 2012; Meireles et al., 2002, 2003).

The difference between the daily water uptake by plants and the crop transpiration is the factor that most penalize crop development and yield in the CROPGRO-Drybean. The water stress will affect the crop development through two different physiological factors, the photosynthesis, a less sensitive factor, and the cell elongation, which is highly affected by drought (Hoogenboom et al., 1994).

Dallacort et al. (2005) reported the use of the CROPGRO-Drybean model to determine the optimum planting dates for south of Brazil. The model strongly penalized the grain yield when the crop was submitted to water stress. Authors concluded that accumulative rainfall had a direct influence on leaf area index (LAI), biomass dry weight and yield.

The dry bean aptitude to Mato Grosso state (Marco et al. 2012) and the performance of the CROPGRO-Drybean model to simulate water stress factors (Heinemann and Hoogenboom, 2000; Dallacort et al.,

2005) are already known. However, there is a lack of information on the influence of weather patterns on dry bean planting dates for the Mato Grosso state, therefore, the necessity of crop development stages and yield predictions to the region, which will help growers to better strategy best management practices, is required. The objective of this study was to determine the optimal planting date for each of the three different sowing seasons wet, dry and winter of dry bean to the Tangará da Serrá region, located in the Mato Grosso state, using the CROPGRO-Drybean simulation model.

MATERIALS AND METHODS

Model characteristics

The CROPGRO-Dry bean is a cropping system model from the Decision Support System for Agro-technology Transfer (DSSAT) (Jones et al., 2003). The model was developed by (Hoogenboom et al., 1994) and it simulates the common bean crop growth, development, and yield, as well as weather, genotype and soil properties (Meireles et al., 2003).

The minimum data set required to run the model are the plant genetic coefficients, soil characteristics, weather data and crop management data. The genetic coefficients are comprised by three files: .ECO, which characterize the ecotype, genetic coefficients that differ cultivars of determinate and indeterminate growth, .SPE, which characterize the species, genetic coefficients that determine the photosynthesis, nitrogen uptake capacity, phenology, growth, and senescence, and finally that file. CUL, which characterize the cultivar, such as photoperiod, photosynthetic rate, leaf area index (LAI), grain mass, trefoil maximum area, mean of grain per pod, period between emergence and first flower, first flower and first pod, first flower and first grain, first grain and maturation and first flower and end of leaves expansion.

The CROPGRO-Drybean uses physical soil characteristics as field capacity, permanent wilting point and saturation to calculate the soil water balance for the soil layer based on the water from irrigation, precipitation, and drainage. Furthermore, the model estimates the soil water evaporation (Es), plant transpiration (Ep) and crop evapotranspiration (ETc) in mm day⁻¹, using the orientated-model of the soil water balance developed by Ritchie (1985).

The weather data required is maximum and minimum temperature, rainfall and solar radiation, which are stored in two files: Station, WTH and station CLI. While the soil characteristics data, such as chemical analysis and physical-hydric analysis stored in the file SOIL.SOL. Finally, the crop management data for fertilizer applications, irrigation events, tillage and sowing dates are separately stored in the X file.

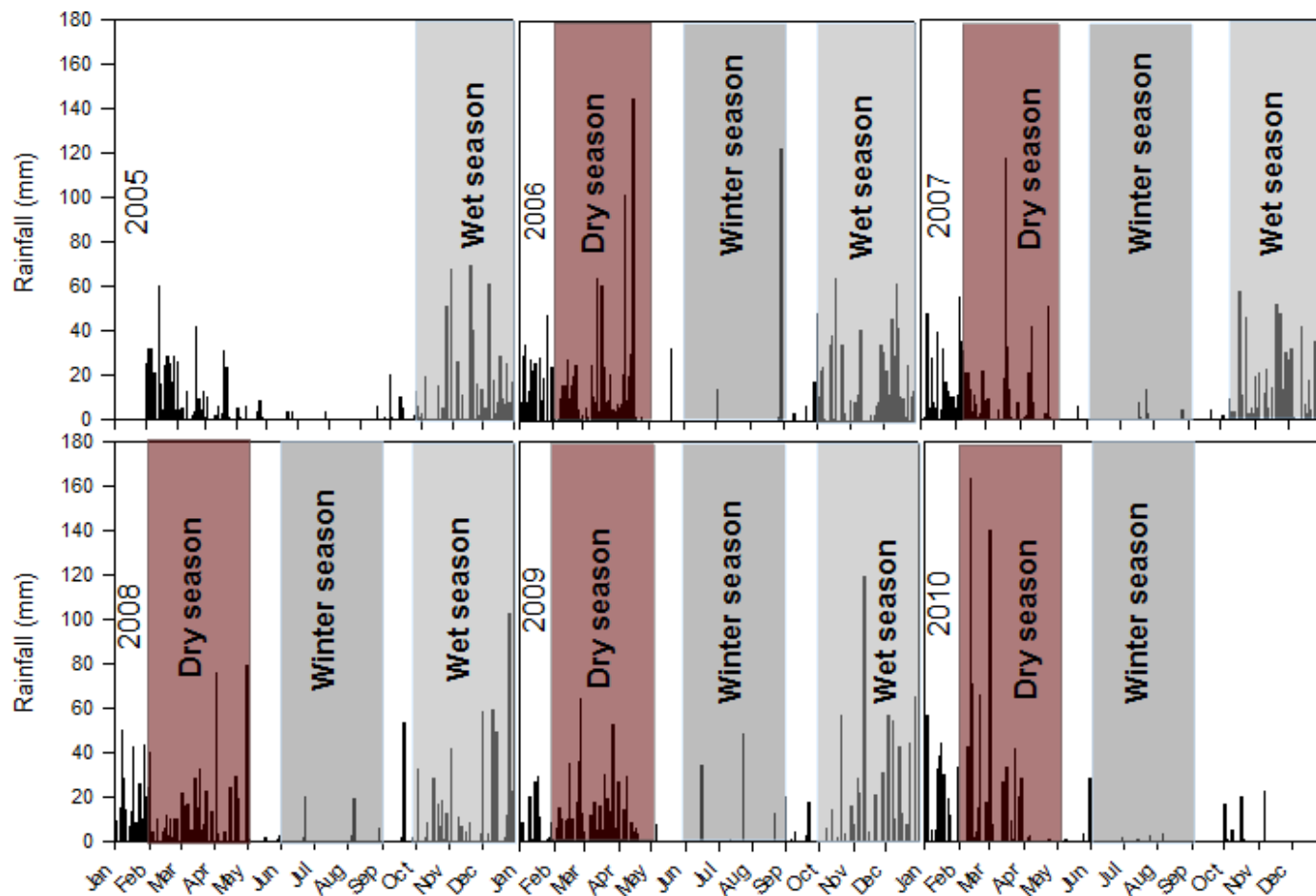
Experimental procedures

The field trial was carried out during 2011/2012 dry bean season in the experimental field of UNEMAT (Mato Grosso State University) at Tangará da Serrá, Mato Grosso state, latitude 14° 39' 55" S, longitude 57° 25' 05" W and altitude of 321.5 m. The research area has the soil classified as Oxisol, with 1 % of slope. The soil has a

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Table 1. Soil chemical analyses for 0-30 cm soil depth at the experimental area.

Soil depth (cm)	pH		cmol _c /dm ³				mg/dm ³	
	H ₂ O	CaCl ₂	Al	H + Al	Ca + Mg	Ca	K	P
0-30	5.90	5.10	0.00	2.88	2.34	1.42	0.12	1.50

**Figure 1.** Rainfall events during wet, dry and winter sowing seasons in the period of 2005 and 2010.

clay texture, with the proportion of particle fractions of 67%, 7 and 26% of clay, silt and sand, respectively. The soil physical parameters, such as field capacity ($0.301 \text{ cm}^3 \text{ cm}^{-3}$), permanent wilting point ($0.239 \text{ cm}^3 \text{ cm}^{-3}$) and bulk density (1.09 g.cm^{-3}), and the soil chemical analyses (Table 1) were determined by soil samples.

The studied region has two well-defined weather seasons, which is a dry season from May to September and a wet season October to April (Dallacort et al., 2011b). The minimum weather data required by the model was collect in a meteorological station from UNEMAT located in site, and six years data set, from 2005 to 2010 used to model simulation. The 2011 data set was used to model calibration. During the experimental periods and simulations, rainfall events were the only source of water (Figure 1) for all dry bean harvest seasons (wet, dry and winter season).

The experimental purpose was to collect data to calibrate the CROPGRO-Drybean model; therefore, the crop management practices followed growers activities and local crop recommendation. No irrigation events occurred at any period of crop

development. The dry bean seeds (var. 'BRS Esplendor') were planted on December 15th, 2011. Seeds were planted in-row spacing of 0.45 m and 12 plants per linear meter. The total experimental area was four replications of 6 m of length by 6 dry bean rows.

The fertilizer application was split into three applications: Initially, 240 kg ha^{-1} of the N, P, K formulated 5-25-15 was applied before planting at 20 cm of soil depth. The second application of 50 kg ha^{-1} of urea occurs 15 days after plant emergence, and the last application was 28 days after plant emergence with 50 kg ha^{-1} of urea. The grain harvest occurs in the four center rows of each replication, the average yield used to model calibration.

The data of genetic coefficients (Table 2) required by the model were collected through frequent field inspections. The genetic coefficients collected were critical day length (CSDL), response inclination regarding development for the photophase with time (1/h) (PPSEN), period between plant emergence and the appearance of the first flower in photothermal days (EM-FL), period

Table 2. Calibrated genetic coefficients for cultivar BRS Esplendor.

Cultivar	CSDL	PPSEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF
BRS Esplendor	12	0	28.7	3	9.5	28.5	16.84
LFMAX	SLAVR	SIZLF	XFRT	WTPSD	SFDUR	SDPDV	PODUR
1	308	133	1	0.251	13	5.2	9.1

between the appearance of the first flower and the first pod in photothermal days (FL-SH), period between the appearance of the first flower and the start of seed formation in photothermal days (FL-SD), period between the start of seed formation and physiological maturity in photothermal days (SD-PM), period between the appearance of the first flower and the end of leaf expansion (FL-LF), maximum leaf photosynthesis rate at an optimal temperature rate of 30°C (LFMAX), specific leaf area under standard growth conditions in cm² (SLAVARN), maximum size of completely expanded leaf in cm² (SIZLF), maximum fraction of the daily growth that is partitioned between the seed plots the pod (XFRT), maximum weight per seed in g (WTPSD), duration of the grain swelling period in the pods, under standard growth conditions in photothermal days (SFDUR); mean seeds per pod (SDPDV), and time necessary for the cultivar to reach ideal pod conditions in photothermal days (PODUR). During the model calibration the genetic coefficients were adjusted following the methodology proposed by Boote (1999).

Simulations

The simulations were performed to Tangará da Serrá region for six different planting dates in each of the three harvest seasons during the six years of weather data set, from 2005 to 2010. The planting date was determined to occur every 15 days for all harvest season. The wet season was comprised by October 1st (10/01) and 15th (10/15), November 1st (11/01) and 15th (11/15), and December 1st (12/01) and 15th (12/15). The dry season sowing dates were January 15th (01/15), February 1st (02/01) and 15th (02/15), March 1st (03/01) and 15th (03/15), and April 1st (04/01). Finally, the winter season sowing dates were April 15th (04/15), May 1st (05/01) and 15th (05/15) June 1st (06/01) and 15th (06/15), and July 1st (07/01).

The simulated grain yields in response to the planting dates were analyzed in a cumulative probability distribution for each studied growing season to determine the best planting dates for each season (wet, dry and winter season).

RESULTS

Highest average yield (2.3 t ha⁻¹) were simulated for the planting dates of the wet season in the six years studied, followed by the dry season (1.3 t.ha⁻¹). Lowest grain yields were simulated for the winter season (average of 0.2 t.ha⁻¹) (Table 3). The average rainfall for each harvest season studied; during the 6 years were 678, 742 and 60 mm for the wet season, dry season and winter season, respectively. The lower average of rainfall presented by the wet season compared to the dry season is explained by an atypical wet season in 2010, in which the total rainfall amount was 212.9 mm during all season.

The wet season had in 2007 the highest total rain accumulation during the full season, with 1,131 mm well

distributed during all season (Figure 2), the average dry bean yield from all planting dates was 3.0 t.ha⁻¹. The winter season had a highest average yield of 0.2 t.ha⁻¹ in 2009, when rain accumulation was only 183 mm.

The wet season planting date of 01/12/2010 showed the highest grain yield (3.3 t.ha⁻¹). The maximum LAI simulated for the planting date was 2.8 m².m⁻² (Figure 3), however, this LAI was considerate smaller than the average of other planting dates from the wet season (4.0 m².m⁻²). The soil depths of 5, 15 and 30 cm had an average soil moisture content of 0.16, 0.29 and 0.32 cm³ cm⁻³ (Figure 4), respectively, during the vegetative stage. Between flowering and harvest (a period of 40 days), the average soil moisture in the same soil depths were 0.3, 0.34 and 0.34 cm³ cm⁻³ (Figure 3), respectively.

In contrast, the winter season had the highest grain yield for the planting date of 06/01/2009; the yield was 0.5 t.ha⁻¹. The maximum simulated LAI for this planting date was 1.2 m².m⁻² (Figure 3). Soil moisture content (Figure 4) was below the wilting point (0.239 cm³ cm⁻³) most of the crop development at the first soil layer (5 cm). At 15 and 30 cm of soil depth, the soil moisture was higher than the 5 cm during the vegetative stage; the averages were 0.31 and 0.33 cm³ cm⁻³, respectively. After the flowering stage, the soil moisture decreased because of the reduction in rainfall events, the averages were 0.26 and 0.28 cm³ cm⁻³, respectively.

The comparison between planting dates within the wet season, simulations indicated that when dry bean was planted in 01/12 yields increased, the average yield for this planting date was 2.9 t.ha⁻¹ (Figure 5). The planting date of 01/10 presented the lowest simulated yields, and the average was 1.6 t.ha⁻¹ (Figure 5). The cumulative probability analysis for the wet season (Figure 6) indicated that higher grain yield could be achieved with the planting date of December 1st (01/12), and yield decreases as early as planting occurs in the season. Lowest yields will most likely occur with the planting date of October 1st. Simulated data of 2010, when the cumulative rainfall was 593 mm concentrated during the late season, had grain yields of 0.2, 0.1, 0.4, 1.0, 3.3 and 2.6 t.ha⁻¹ for 01/10, 15/10, 01/11, 15/11, 01, 12 and 15/12, respectively.

The most appropriate simulated planting date for the dry season was 15/01, followed by 01/02, which showed highest yields (Figure 5). The lowest yields of dry season were obtained by the planting date of 01/04. The planting date of 01/15 showed higher yield than the other planting

Table 3. Simulated grain yield of each planting date during all six year studied for all dry beans growing season in Brazil.

Planting date (Year)	Wet season					
	10/01	10/15	11/01	11/15	12/01	12/15
	Grain yield t ha ⁻¹					
2005	2.5	2.9	3.2	2.5	3.2	2.7
2006	0.9	1.5	2.7	3.1	2.8	2.9
2007	3.0	3.2	3.2	3.2	3.0	2.9
2008	1.1	1.5	2.7	2.5	2.1	1.5
2009	2.1	3.1	3.1	2.7	3.1	2.5
2010	0.2	0.1	0.4	1.0	3.3	2.6
Year	Dry season					
	01/15	02/02	02/15	03/01	03/15	04/01
	Grain yield t ha ⁻¹					
2005	1.4	1.1	0.4	0.1	0.2	0.1
2006	1.9	2.5	2.6	1.4	0.8	0.3
2007	2.1	1.7	1.4	1.3	0.7	0.2
2008	2.5	2.9	3.0	3.0	1.5	0.3
2009	2.9	2.8	3.0	0.9	0.3	0.2
2010	2.4	2.5	1.2	0.2	0.2	0.3
Year	Winter season					
	04/15	05/01	05/15	06/01	06/15	07/01
	Grain yield t ha ⁻¹					
2005	0.2	0.2	0.2	0.1	0.1	0.1
2006	0.3	0.2	0.2	0.1	0.1	0.4
2007	0.1	0.1	0.2	0.2	0.2	0.1
2008	0.3	0.3	0.2	0.1	0.1	0.1
2009	0.3	0.4	0.4	0.5	0.4	0.2
2010	0.2	0.2	0.2	0.1	0.1	0.1

dates, under the cumulative probability of 100% (Figure 6). When planting occurs at 02/01 yields were higher for all other cumulative probabilities (75, 50, 25 and 0%). Under 75% of cumulative probability, grain yields were 1.7, 1.8, 1.1, 0.3, 0.1 and 0.1 t.ha⁻¹ for planting dates of 15/01, 01/02, 15/02, 01/03, 15/03 and 01/04, respectively (Figure 6).

The winter season is unfeasible (Figure 5), because of the low precipitation during this year period (Figure 1). Simulated yields were not higher than 0.5 t.ha⁻¹, and the planting date that showed highest yield at the cumulative probability of 75% was 15/04 (Figure 6).

DISCUSSION

The main weather variable that influenced plant development and grain yield was the rainfall. The high yields of the wet season (Table 3) can be explained by the rainfall events typically occurring during the season

period (Figure 1). The crop development variables affected by water stress are reported in the comparison between the highest precipitation year for the wet season (planting date of 01/12/2010) and the typical year of the winter season (planting date of 06/01/2009).

The planting dates of wet season had plenty rainfall events associated with a good rain distribution, which increased soil moisture and dry bean yield. However, the low and non-uniform rain distribution observed in the winter season resulted in a soil drought during crop flowering and maturation (Figure 3). Nascimento (2004) reported that a reduction in soil available water of 40% during the reproductive stage could reduce pod number, pod size and number of grain per pods. In addition, Guimaraes et al. (2011) and Bastos et al. (2011) showed an average yields loss of 58% when irrigated dry bean plants were compared to non-irrigated plants.

The water stress in the first soil layer presented during the vegetative stage, when leaf number is produced, may reduce LAI and biomass accumulation (Nascimento,

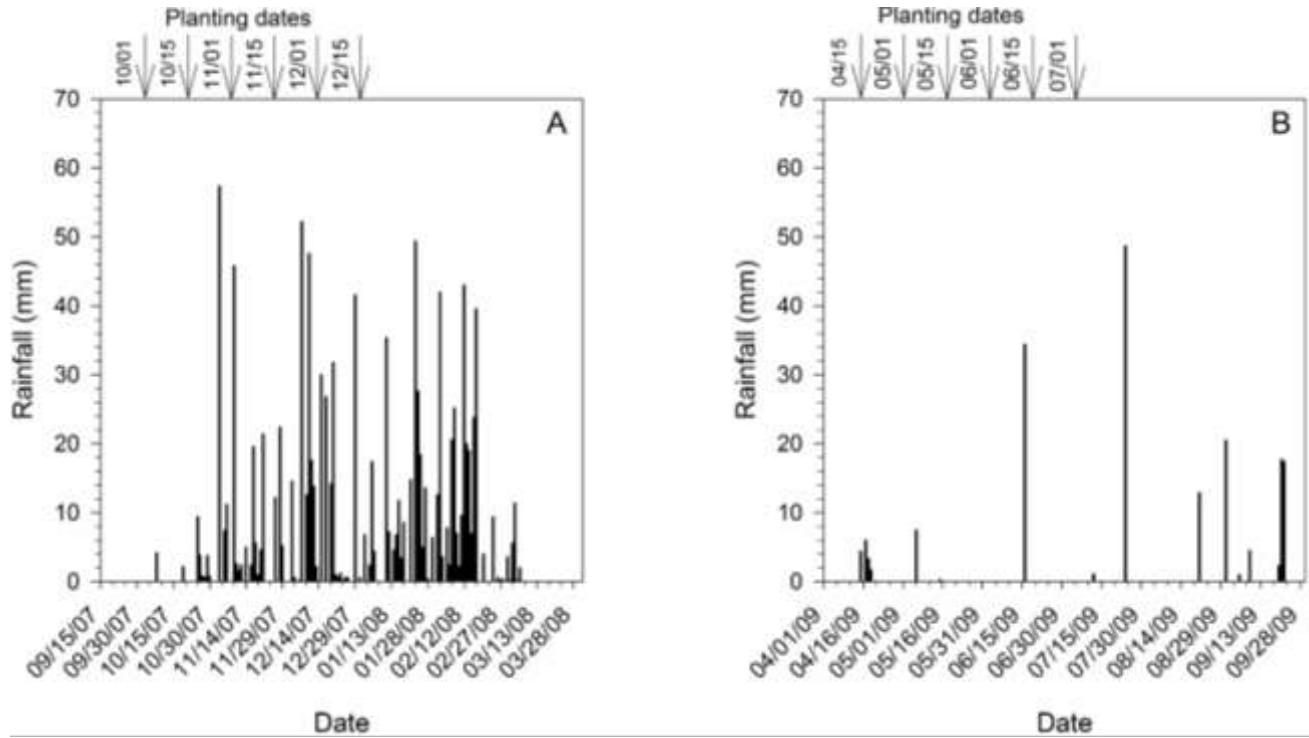


Figure 2. Rainfall events during the wet season of 2007 for all planting dates (graph A), and rainfall events during the winter season of 2009 for all planting dates (Graph B).

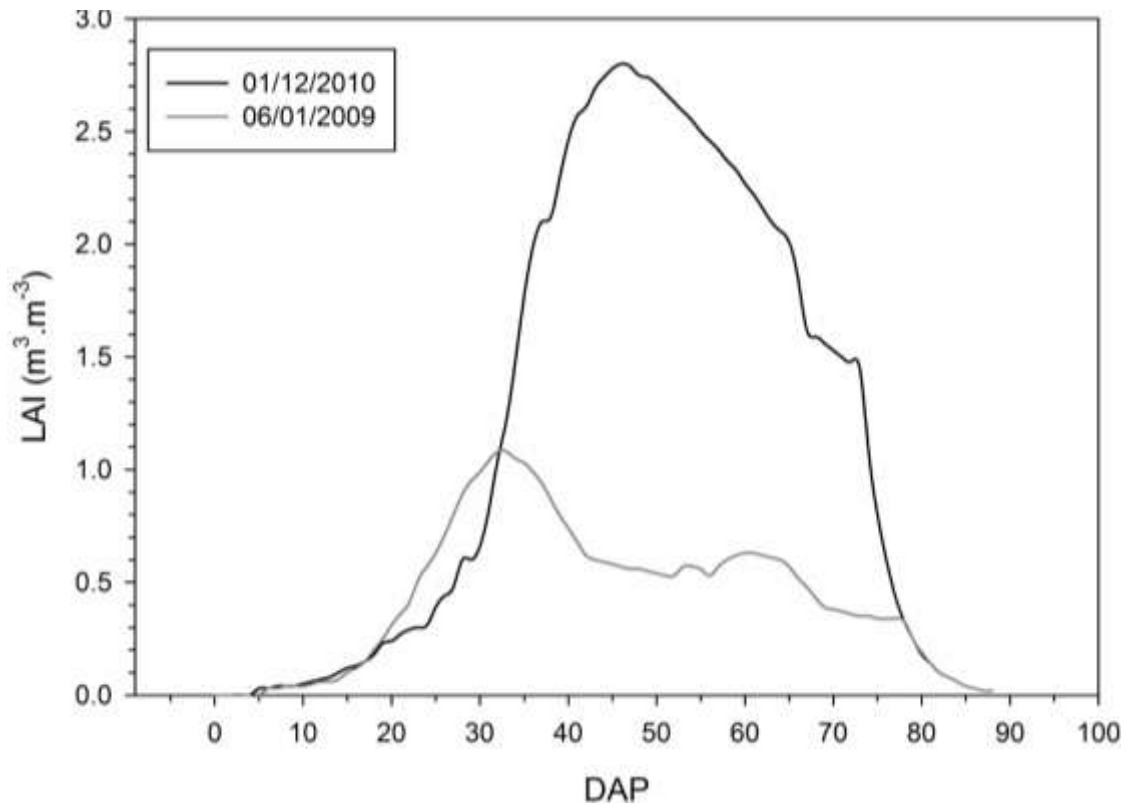


Figure 3. Simulated LAI in days after planting (DAP) for the lowest and highest simulated grain yield planting date, 01/12/201 and 06/01/2009, respectively.

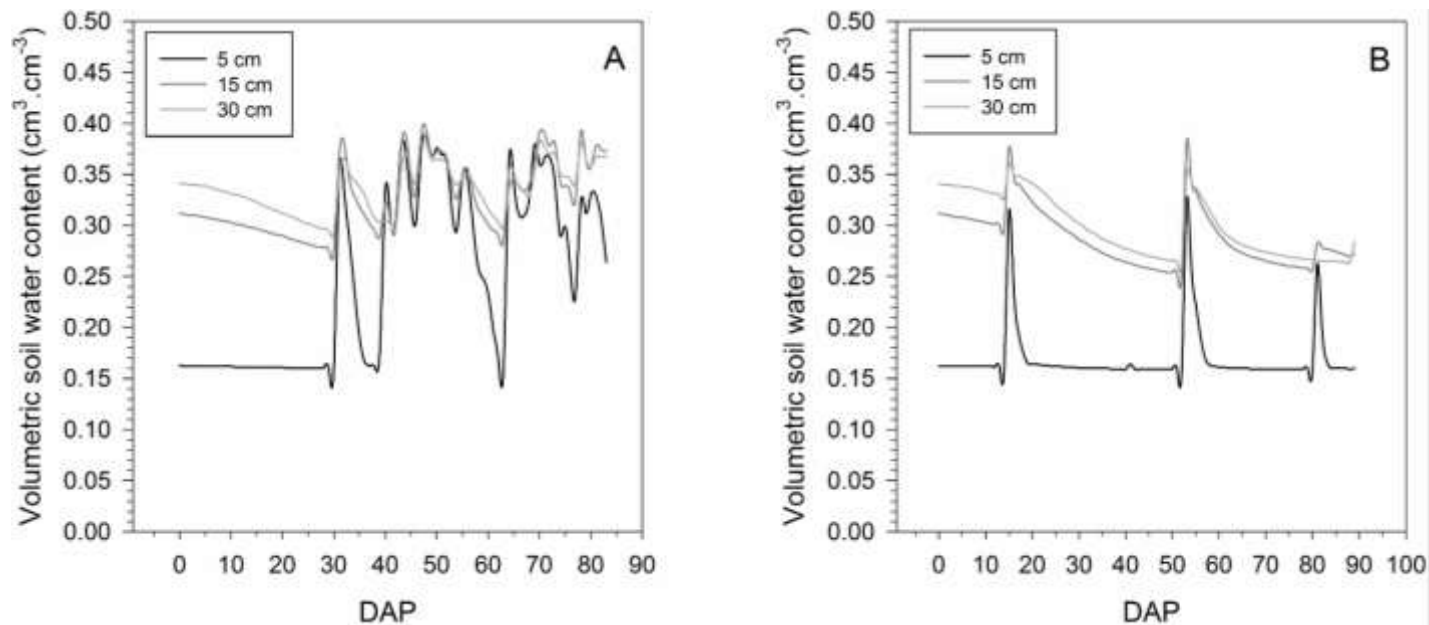


Figure 4. Simulated soil moisture for 3 depths (5, 15 and 30 cm) in days after planting (DAP) for the highest simulated grain yield planting date and year (01/12/2010) (graph A), and lowest simulated yield production planting date and year (06/01/2009) (Graph B).

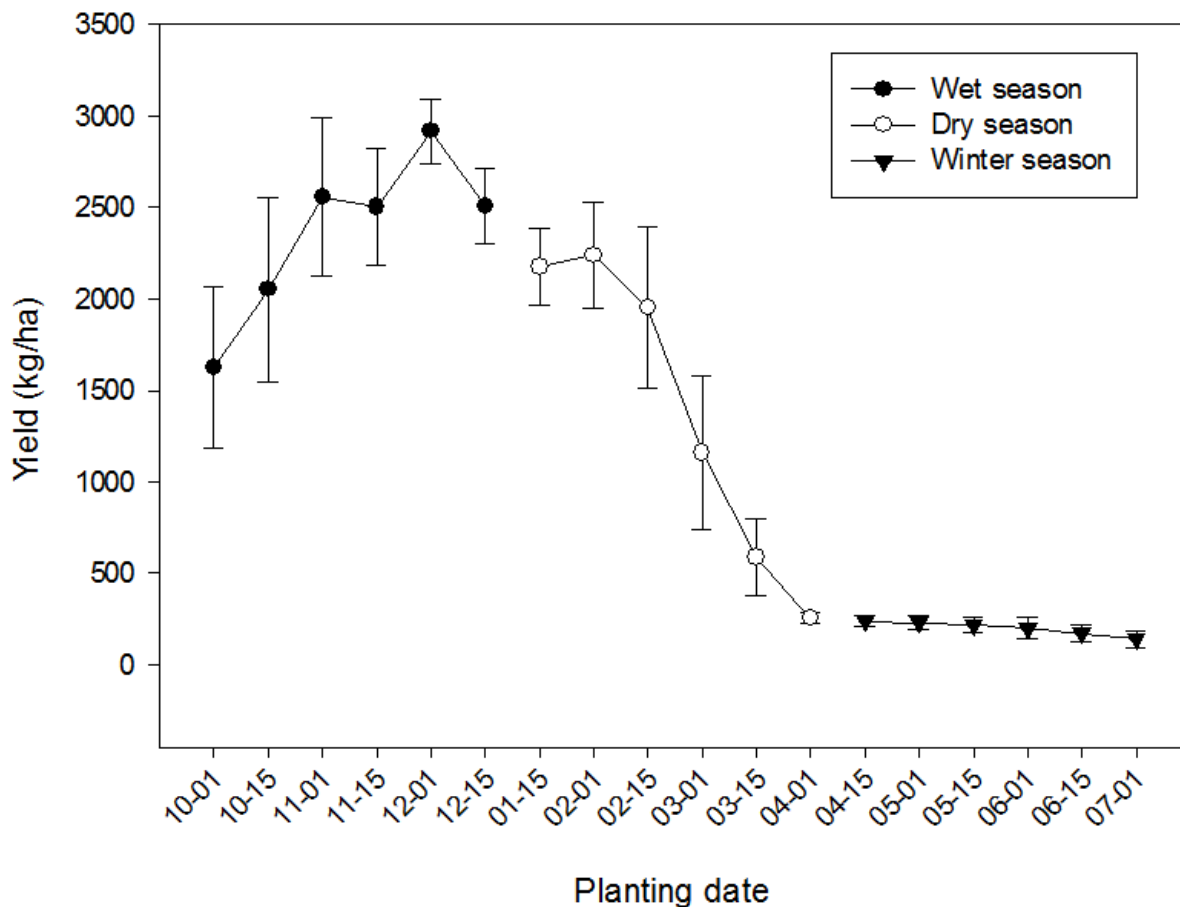


Figure 5. Average simulated grain yield of studied years (2005 to 2010) for each planting date of all dry bean growing season in Tangará da Serra - MT. Error bars represent ± standard errors from the mean, n=6.

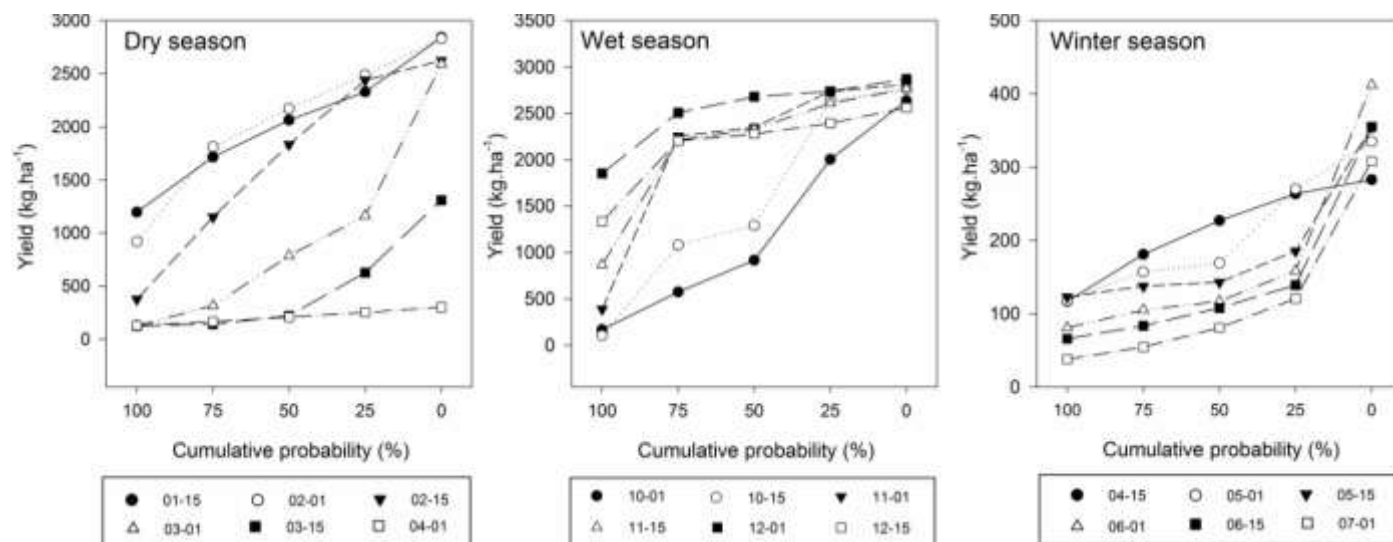


Figure 6. Cumulative probability distribution of grain yield production in each planting date for all three dry bean growing season in Tangará da Serra -MT.

2004; Miorini et al., 2011). In the present study, wet and winter seasons had a water stress in the initial stages of crop development for the planting dates of 01/12/2010 and 06/01/2009, respectively, which decreased LAI (Figure 4). However, the planting date of the wet season (01/12/2010) had the highest grain yield, explained by the increasing in rainfall events during the reproductive stages (Guimaraes et al., 1996). The planting date of 06/01/2009 had a low precipitation during all crop development, therefore lower yield.

Overall, most of the low simulated yields were consequence of soil water stress between flowering and pod maturation, growth stages that water shortage can strongly reduce grain yield (Araujo, 1996; Dallacort et al., 2010). In addition, planting dates of the winter season received rainfall amounts smaller than the dry bean water demand recommendation of 300 to 600 mm during all crop development. The dry bean daily water consumption is from 3 to 4 mm per day, requiring 100 mm monthly (Fancelli, 2009).

In the wet season, the grain yield increased as late as planting occurs, which is consequence of a well-distributed rainfall events in the late of the season, according to the six years studied. The planting date of December 1st had the highest average yield for all cumulative probabilities. At 75% of cumulative probability, the grain yield was 2.5 t ha⁻¹. The regular rainfall distribution during the crop season of the planting date of wet season supply the dry bean water demand (Fancelli, 2009) mainly at the reproductive stages, when water stress most penalize grain yield (Guimaraes et al., 2011).

The dry season has an opposite weather pattern than the wet season, high precipitation and better rain distribution is presented in the early moment of the dry season. However, plentiful soil moisture content only

during the early season can reduce grain yield. The soil water stress at reproductive stages will decrease nutrients uptake and grain yield (Nascimento, 2004). Therefore, late planting dates were most affected by a water stress after flowering. The grain yield of 1.7 and 1.8 t ha⁻¹ at 75% of cumulative probability was simulated for the early planting dates of January 15th and February 1st, respectively, planting dates that had rainfall events well distributed over all crop development.

The drought periods during the plant development of all planting dates from the winter season affected the nutrient uptake and biomass accumulation (Santos and Carlesso, 1998, Fiegenbaum et al. 1991). The effects of drought start when plants evapotranspiration is higher than water absorption by the root system (Vieira et al., 2006). Irrigation practices are an option to supply plants water requirement and consequently increase grain yields for the winter season.

Conclusion

Despite several available models, like the DEMANDAsis, which determine best management practices through the soil water balance, the CLIGEN, which simulate agricultural managements based on weather parameters, and several other crop models. The CROPGRO-Drybean model demonstrated to be an excellent tool to help research and growers to increase dry bean yields. The CROPGRO-Drybean model showed high sensitivity to precipitation events, in which high rainfall events well distributed over the crop development increased the dry bean grain yield. The drought stress during the reproductive stages for all seasons was the environmental variable that most affect dry bean productivity simulation.

The wet season had the highest simulated grain yields, consequence of high rainfall events well distributed over the season. Furthermore, as late planting occurs in the wet season higher were the probability to achieve high yields. The planting date of December 1st provided the highest simulated grain yield within the wet season. In the dry season, planting dates of January 15th and February 1st are the best planting date for growers achieve higher yields, those planting dates had the highest likelihood to attend the crop water demand through rainfall events. Finally, the winter season requires irrigation practices for all simulated planting dates to increment dry bean grain yield

Conflicts of Interests

The authors have not declared any conflict of interests.

REFERENCES

- Araujo RS (1996). Cultura do feijoeiro comum no Brasil. Potafos.
- Bastos EA, Nascimento SPD, Silva EMD, Freire FFR, Gomide RL (2011). Identification of cowpea genotypes for drought tolerance. *Rev. Ciência Agron.* 42:100-107.
- Boote KJ (1999). Concepts for calibrating crop growth models. *DSSAT version 3*:179-199.
- CONAB (Campanha Nacional de Abastecimento) (2014). Acompanhamento da Safra Brasileira, Safra 2013/2014. Junho 2014.
- Dallacort R, Freitas PS, Faria RTD, Gonçalves AC, Jácome AG, Rezende R (2010). Soil water balance simulated by CROPGRO-Drybean model for edaphoclimatic conditions in Maringá. *Rev. Bras. de Engenharia Agríc. Ambiental* 14(4):351-357.
- Dallacort R, Freitas PSLD, Faria RT, Goncalves ACA, Rezende R, Guimarães RML (2011). Simulation of bean crop growth, evapotranspiration and yield in Paraná State by the CROPGRO-Drybean model. *Acta Scientiarum. Agronomy* 33(3):429-436.
- Dallacort R, Martins JA, Inoue MH, Freitas PSL, Coletti AJ (2011b). Distribuição das chuvas no município de Tangará da Serra, médio norte do Estado de Mato Grosso, Brasil. *Acta Scientiarum. Agronomy* 33:193-200.
- Dallacort, R., Rezende, R., Freitas, PSL, Faria RT, Azevedo TLF, Júnior JBT (2005). Utilização do modelo Cropgro-drybean na determinação das melhores épocas de semeadura da cultura do feijão para a região de Maringá, Estado do Paraná, Brasil. *Acta Sci. Agron.* 27:353-359.
- dos Santos DSB, Mello VDC, dos Santos FBG, Tillmann MAA, da Silva JB (1991). Influência do déficit hídrico sobre os componentes de rendimento de três cultivares de feijão. *Pesqui. Agropecu. Bras.* 26:275-280.
- Fancelli AL (2009). Feijão: tópicos especiais de manejo. Piracicaba: ESALQ/USP/LPV, P 208.
- Fiengenbaum V, Dossantos DSB, Melo VDC, Filho BGD, Tillmann MAA, Dasilva JB (1991). Influence of water deficit on the yield components of 3 bean cultivars. *Pesqui. Agropecu. Bras.* 26:275-280.
- Guimarães CM, Brunini O, Stone LF (1996). Adaptação do feijoeiro (*Phaseolus vulgaris* L.) à seca: I. Densidade e eficiência radicular. *Pesqui. Agropecu. Bras* 31(6).
- Heinemann AB, Hoogenboom G (2000). Optimization of the capacity of center pivot irrigation systems based on the dry bean model CROPGRO. *Ann. report-bean improve. Coop.* 43:132-133.
- Hoogenboom G, Jones JW, Wilkens PW, Batchelor WD, Bowen WT, Hunt LA, Pickering NB, Singh U, Godwin DC, Baer B (1994). Crop models: DSSAT. *Crop models: DSSAT 3(2)*:95-244.
- Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Ritchie JT (2003). The DSSAT cropping system model. *Euro. J. Agron.* 18:235-265.
- Kunz JH, Bergonci JI, Bergamaschi H, Dalmago GA, Heckler BMM, Comiran F (2007). Uso da radiação solar pelo milho sob diferentes preparos do solo, espaçamento e disponibilidade hídrica. *Pesqui. Agropecu. Bras.* 42:1511-1520.
- Leite LFC, de Araújo ASF, do Nascimento CC, Ribeiro AMB (2009). Nodulação e produtividade de grãos do feijão-caupi em resposta ao molibdênio. *Rev. Ciênc. Agron.* 40:492-497.
- Filho AFL, Filho MAC, Heinemann AB (2013). Determinação de épocas de semeadura do feijão caupi no Recôncavo Baiano através do modelo CROPGRO. *R. Bras. Eng. Agríc. Ambiental* 17(12):1294-1300.
- Marco K, Dallacort R, Faria Junior CA, Freitas PSL, Villela TG (2012). Aptidão Agroclimática e características agrônômicas do feijão-comum semeado nas safras das águas em Tangará da Serra – MT. *Enciclopedia Biosfera* 8(15):160-170.
- Meireles E JL, Pereira AR, Sentelhas PC, Stone LF, Zimmermann FJP (2002). Calibration and test of the cropgro-dry bean model for edaphoclimatic conditions in the savanas of Central Brazil. *Sci. Agric.* 59:723-729.
- Meireles E JL, Pereira AR, Sentelhas PC, Stone LF, Zimmermann FJP (2003). Risco climático de quebra de produtividade da cultura do feijoeiro em Santo Antônio de Goiás, GO. *Bragantia* 62:163-171.
- Miorini TJJ, Saad JCC, Menegale ML (2011). Supressão de água em diferentes fases fenológicas do feijoeiro (*Phaseolus vulgaris* L.). *Irriga, Botucatu*, 16(4):360-368.
- Nascimento JT, Pedrosa MB, Tavares SJ (2004). Efeito da variação de níveis de água disponível no solo sobre o crescimento e produção de feijão caupi, vagens e grãos verdes. *Horticul. Bras.*, 22:174-177.
- Oliveira ECD, Costa JMND, Júnior P, Ferreira WPM, Justino FB, Neves LO (2012). The performance of the CROPGRO model for bean (*Phaseolus vulgaris* L.) yield simulation. *Acta Sci. Agron.* 34:239-246.
- Ritchie JT (1985). A user-orientated model of the soil water balance in wheat. Day W, Atkin RK (eds.). *Nato Asi (Advanced Science Institutes) Series Series a Life Sciences, Vol. 86. Wheat Growth and Modelling; Advanced Research Workshop, Bristol, England, Apr. 9-12, 1984. Xii+407 Plenum Press: New York, N.Y., USA; London, England. Illus pp. 293-306.*
- Santos RF, Carlesso R (1998). Déficit hídrico e os processos morfológicos e fisiológicos das plantas. *Rev. Bras. de Engenharia Agríc. Ambiental, Campina Grande* 2:287-294.
- Vieira C, Vieira RF (1995). Épocas de plantio para o feijão e propostas de nomenclatura para designá-las. *Rev. Ceres, Viçosa*, 42:685-688.
- Vieira C, Paula Junior TJ, Borém A Feijão (2006). 2 ed. Atual. – Viçosa: UFV, P 600.