# ADJUSTMENT AND EVALUATION OF CROPGRO-SOYBEAN AND CERES-MAIZE FOR DIFFERENT GENETIC MATERIAL IN A REGION OF MATO GROSSO STATE, BRAZIL†

# [AJUSTE Y EVALUACIÓN DE CROPGRO-SOYBEAN Y CERES-MAIZE PARA DIFERENTES MATERIALES GENÉTICOS EN UNA REGIÓN DEL ESTADO DE MATO GROSSO, BRASIL]

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## SUMMARY

Considering the importance of the use of crop models as an aid measure in the management of the agricultural production system, the objective of this study was to assess the performance of a soybean and maize models, CROPGRO-Soybean and CSM-CERES-Maize, respectively, for different genetic materials and water regime in the two annual cropping seasons in a region of Mato Grosso state, Brazil. Models were adjusted and evaluated, respectively, with field experiments under irrigated and rainfed conditions, by using crop production parameters and phenology. Model performance was generally variable in the rainfed conditions, especially when water deficit was more pronounced during the season. Values of coefficient of agreement, d, varied between 0.22 – 0.50 and 0.10 – 0.80 and maximum RMSE of grain yield were of 2.5 and 2.7 t ha$^{-1}$ for soybean and maize, respectively. Results indicated model's sensibility to water stress, which was more accentuated in the second agricultural season, when maize is usually cultivated. In an overall analysis, the soybean and maize crop models provided satisfactory results regarding simulation of crop growth and development, indicating to be a useful agricultural management tool for the most important agricultural crops in Mato Grosso state, although adjustments regarding parameters of soil water availability would increase models' performances.

**Keywords:** DSSAT; *Glycine max* (L.) Merr.; *Zea mays* L.; simulation; Cerrado; Mato Grosso.

## RESUMEN

Considerando la importancia del uso de modelos de cultivos como medida de ayuda en el manejo del sistema de producción agrícola, el objetivo de este estudio fue la calibración, validación y análisis de los modelos de maíz y soya, CROPGRO-Soybean y CSM-CERES-Maize, respectivamente, se realizaron para diferentes materiales genéticos y fechas de siembra en las dos temporadas agrícolas en una región del estado de Mato Grosso, en Brasil. Los modelos fueron calibrados y evaluados con experimentos de campo en condiciones de irrigación y de secano, respectivamente. Los parámetros de producción de cultivos y la fenología se utilizaron para el ajuste del modelo y su rendimiento se evaluó estadísticamente. El rendimiento del modelo fue generalmente variable en las condiciones de secano, especialmente cuando el déficit de agua fue más pronunciado. Los valores de coeficiente de acuerdo, d, variaron entre 0.22 - 0.50 y 0.10 - 0.80 y el RMSE máximo del rendimiento de grano fue de 2.5 y 2.7 t ha$^{-1}$ para la soja y el maíz, respectivamente. Los resultados indicaron la sensibilidad del modelo al estrés hídrico, que se acentuó más en la segunda temporada agrícola, cuando generalmente se cultiva el maíz. En un análisis general, los modelos de cultivos de soja y maíz proporcionaron resultados satisfactorios con respecto a la simulación del crecimiento y desarrollo de los cultivos, lo que indica que es una herramienta útil de manejo agrícola para los cultivos agrícolas más importantes en el estado de Mato Grosso, aunque los ajustes en los parámetros de disponibilidad de agua en el suelo aumentarán el rendimiento de los modelos.

**Palabras clave:** DSSAT; *Glycine max* (L.) Merr.; *Zea mays* L.; simulación; Cerrado; Mato Grosso.

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## INTRODUCTION

Crop models have established their importance as a tool for assistance in management decisions in agricultural production systems, especially since the year 2000 and are also constantly subject of study and research (Keating and Thornburn, 2018). For its profitable use, it is of recognized importance that the model is adjusted to local conditions, comprising environment, management and genetic material traits, which promote some variation in crop development and production. In a crop model, knowledge of cultivar specific factors, known as genetic coefficients, is a primary step for predicting crop daily growth and development under different environmental and crop management conditions (Jones *et al.* 2003). Although the models' overall yield trend predicting capacity is worldwide recognized, the extent of the necessity of required experimental data and the approach that provides best model performance is subject of question (Seidel *et al*., 2018). Mavromatis *et al.* (2001), when assessing a widely used soybean model (CROPGRO-Soybean), pointed to its successful performance when simulating the "average" genotype x environment interactions trends, but a lower performance in environments with very high or very low crop yields. Salmerón and Purcell (2016), when using the same soybean model, pointed to a similar model performance between using the model's generic genetic coefficients (function of maturity group) and when adjusting the model through some of their coefficients. Monteiro *et al.* (2017) showed the overall accuracy of a widely used maize model (CERES-Maize) for predicting general maize yield trends under different management and water availability conditions for all main regions in Brazil.

In the past decades, crop models have stood out in terms of technological tools used in agriculture to assist the planning and management of agricultural activities (Jones *et al.*, 2003, Kassie *et al.*, 2014, Soler *et al.* 2007). By using a minimum of input data for local characterization, they can mimic the growth and development of plants in a diversity of conditions. The Decision Support System for Agrotechnology Transfer, DSSAT (Hoogenboom *et al.*, 2015, Jones *et al*., 2003) is a software dedicated to simulate growth and development of a variety of crops, including staple crops like soybean (by means of CROPGRO-Soybean model) and maize (by means of CERES-Maize model), ones of the first crops to compose the referred set of crop models. Both models have a established use worldwide (Kassie *et al.,* 2014, Mavromatis *et al.,* 2001, Salmerón and Purcell, 2016) and less frequent in Brazilian conditions (Amaral *et al.*, 2015, Dallacort *et al.*, 2006, Soler *et al.*, 2007). In Brazil, their use has been more concentrated on model parametrization and management assessment (Amaral *et al*., 2015, Dallacort *et al*., 2006, Pereira *et al*., 2010, Rodrigues *et al*., 2013, Soler *et al*., 2007) and lately few studies assessing climate change impacts on crops (Justino *et al*., 2013).

In Brazil, Mato Grosso state stands out in the national farming scenario. In terms of staple crops, the production of soybean and maize is commonly performed in a succession system during the agricultural year (soybean in the first and maize in the second agricultural season). In the 2017/2018 agricultural year, the state produced 32.3 million tons of soybean in the first season (starting around mid-September-October, along with the rainy period of year) and 26.2 million tons of maize in the second season (starting around February, right before the rainy season starts to decline). The total production of soybean and maize reached 27 and 48% of the country's total production, respectively (Conab, 2018). The state, one of the largest in area in Brazil, can be divided into seven macro regions, sharing proximity and common characteristic concerning the farming industry profile. Major shares of areas of soybean and maize production in Mato Grosso state are located in its northern regions, while the southern comes after, but still representing ~ 30% in state area of production of both crops (Imea, 2017). The southernmost region of the state also present economic importance, including the state capital and relevant national livestock production, thus the improvement in production of these staple crops is of interest for the macro region (Imea, 2017). In that context, crop models can be considered an interesting approach to assess crop production in areas with potential for production improvements.

Considering the previous considerations on the soybean and maize production importance for Mato Grosso state and Brazil, as well as the necessity for using tools that aid in understanding and managing the environment for better crop production, such as crop models, this study was carried during an agricultural year for both crops. The main objective of this study was to assess a soybean and maize models behavior related to different maturity of genetic material in different water regime for a central-southern region of Mato Grosso state, Midwestern main region of Brazil. This objective was accomplished through the adjustment of the models to local conditions and the evaluation of the simulations under different management practices, comprising genetic material, sowing dates and water availability.

## MATERIALS AND METHODS

### Site characterization – soil and climate

The present study was carried for the region of Tangará da Serra (14º39' S; 57º25' W), located in the central-southern portion of Mato Grosso state, Brazil, at 440 of altitude according to the National Institute of Meteorology (Inmet, 2018). The climate of the region, as defined by Köppen, is the tropical metamorphic wet (Aw), and the average annual rainfall is of 1830 mm, with higher rainfall rates from October to March and the dry season established from April to September (Dallacort *et al.*, 2011). The soil classification, according to methodology of Embrapa (2013) is a dystroferric red Latosol with a very clayey texture. Main soil properties were measured before the installation of the experiments and used as input in the crop model, as follows: clay content = 58%; silt content = 15.6%; pH ($H_2$) = 5.9; Organic matter content = 35 g dm$^{-3}$; Bulk density = 1.28 g cm$^{-3}$.

Meteorological data was obtained by means of an automated station, installed at the University, equipped with a Data Logger CR1000 (both Campbell Sci. Inc., Logan, UT) and sensors to measure/characterize meteorological variables. Daily data of maximum and minimum temperatures, solar radiation, wind, humidity and rainfall were used as input in the crop model

## Experimental description and crop management

The experiments were conducted for both soybean and maize in succession, or “double-cropping” system, in 1st and 2nd agricultural seasons, respectively at the experimental area of CETEGO-SR (“Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto aplicado à produção de Biodiesel”) located at the State University of Mato Grosso, university campus of Tangará da Serra. Soybean experiments were sown in four different dates for each cultivar: 09/22/2015 (mm/dd/YY), 10/06/15, 10/21/15 and 11/05/15 using three cultivars: ST 815 (maturity group 8.1), ST 820 (maturity group 8.2) and TMG 1188 (maturity group 8.8), with plant population of 18, 20 e 14 pl m$^{-1}$, respectively. Soybean harvests were performed according to the cycle of each cultivar and its specific sowing date. Maize experiments were also sown in four different dates: 01/27/16, 02/09/16, 02/25/16 and 03/11/16 using three hybrids: AG 7088 (early maturity), AS 1555 (super early maturity) and DKB 390 PRO (early maturity), all with final plant population of 60.000 pl ha$^{-1}$. Maize harvests were performed according to the cycle of each hybrid and its specific sowing date.

The experimental design used for the cultivation of both crops was of randomized blocks in a factorial scheme of 4x3x2, consisting of four sowing dates, three cultivars and two water management conditions: irrigated and non-irrigated, with four replications. Each treatment consisted of six lines of 12 m, with spacing of 0.45 m between rows for each crop, a total plot size of 32.4 m$^2$. Crops’ phenology and material evaluations were performed during their cycles. The irrigated experiments were used for model calibration while rainfed experiments were used for model evaluation (Amaral, 2015), for both assessed crops. Both water-related treatment’s experiments were conducted in order to provide general optimum conditions for crops’ growth and development. In the irrigated experiments, water management provided 130% of reference evapotranspiration, as proposed by Penman-Monteith (Allen and Pruitt, 1986). Rainfed experiments were then used to assess model’s capabilities of simulation under such water-limited conditions, which is the usual management used in most part of maize and soybean production systems in Mato Grosso state and Central-Southern Brazil.

## Model adjustment and evaluation

The software of Decision Support System for Agrotechnology Transfer, DSSAT version 4.6.1.0, (Jones *et al.*, 2003, Hoogenboom *et al.*, 2015) was used to run crop simulations. Besides the primary modules contained in the system used for soil, weather, crop management and their interactions in simulations, the Soybean (CROPGRO-Soybean) and maize (CERES-Maize) models were used. Experimental information characterizing crops’ phenology, development and production were collected and used to adjust models’ performance by means of their genetic coefficients, characterizing the calibration and validation processes (Hunt and Boote, 1998, Jones *et al.*, 2003). The coefficients were mainly related to phenological dates: emergence, flowering, physiological maturity and to growth and development parameters: number of grains per plant, grain filling rate and others. Phenology parameters were adjusted before production parameters (Amaral *et al.*, 2015, Kassie *et al.*, 2014), following that same order for both crops.

Each crop model was adjusted separately for each genetic material due to their specificities regarding cycle length and production performance. Genetic coefficients vary with the crop and their cycle characteristics, thus experimental information was inserted in each model according to their coefficients. In model calibration of both crops, only the sowing dates that provided the best crop performance (i.e., higher yields) were used: 10/21/15 and 01/27/16, for soybean and maize, respectively. Irrigated experiments were used for adjustment of models, aiming to set it to the best possible conditions for crop development, while the rainfed experiments, considering all four sowing dates, were used for model evaluation. During model adjustment, genetic coefficients were changed aiming to minimize the errors associated with statistical indices, while close as possible to the observed values. Model performance was then assessed by means of three goodness-of-fit statistics for the phenological and production values: Wilmott's index of agreement, "d", (Willmott *et al.*, 1985), mean absolute error (MAE) and root mean square error (RMSE) (Eq. 1,2 and 3).

(1)

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(Pi - Oi)^2}{\sum_{i=1}^{N}(|P'i| + |O'i|)^2}\right]$$

(2)

$$MAE = \sqrt{\sum_{i=1}^{n}\frac{(Pi - Oi)}{n}}$$

(3)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Pi - Oi)^2}{N}}$$

Where: N = number of observations; Pi = estimated value; Oi = observed value; M = average of observed variable; P'i = Pi – M; O'i = Oi - M

The statistical parameters were calculated for each crop and its genetic material separately. MAE and RMSE range from zero to infinity, with zero indicating a perfect match, while d ranges from zero to one, and one indicates a perfect match.

## RESULTS

### Climate conditions during the 2015/2016 agricultural year

Of primary importance regarding the evaluation of the model and plant development in the field, observed daily meteorological data during the entire agricultural year of 2015/2016 (both cropping seasons) can be observed in Figure 1.

For soybean crop cultivation in first season, by assessing rainfall, maximum and minimum temperatures, greater variability was found for rainfall, when compared to temperature, for each cultivar across the four different sowing dates. Accumulated rainfall varied > 200 mm for all cultivar cycles. For the ST815 cultivar, values regarding accumulated rainfall, average maximum and minimum temperatures corresponding to each sowing date (starting at the earliest sowing date), respectively, were of 685, 824, 884, 1005 mm; 33, 32.6, 32.3, 32°C and 22°C. For the ST 820 cultivar, these values were of 751, 845, 958, 1008 mm; 32, 32.5, 32.3, 32 and 22°C. For the TMG 1188 cultivar, these values were of 898, 1050, 1133, 1060 mm; 32.6, 32.5, 32, 32 and 22°C (Figure 1).

During maize cultivation in second season, by assessing rainfall, maximum and minimum temperatures, greater variability was also found for rainfall (when compared to temperature) for each hybrid experiment across the four different sowing dates. However, accumulated rainfall presented variability across sowing dates but almost nothing between hybrids cycles. Accumulated rainfall varied > 350 mm across different sowing dates. For the AG7088 hybrid, values regarding accumulated rainfall, average maximum and minimum temperatures for each sowing date, respectively, were of 507, 436, 328, 164 mm; 31.4, 31, 31, 30.6°C and 21, 20.6, 20.4, 20°C. For the AS1555 and DKB 390 hybrids, all values were equal, except for accumulated rainfall at the first sowing date, which was of 530 mm.

### Adjustment and evaluation of soybean model

According to field observations of crop phenology, growth and development variables, genetic coefficients of the soybean model were adjusted for the crop cultivars.

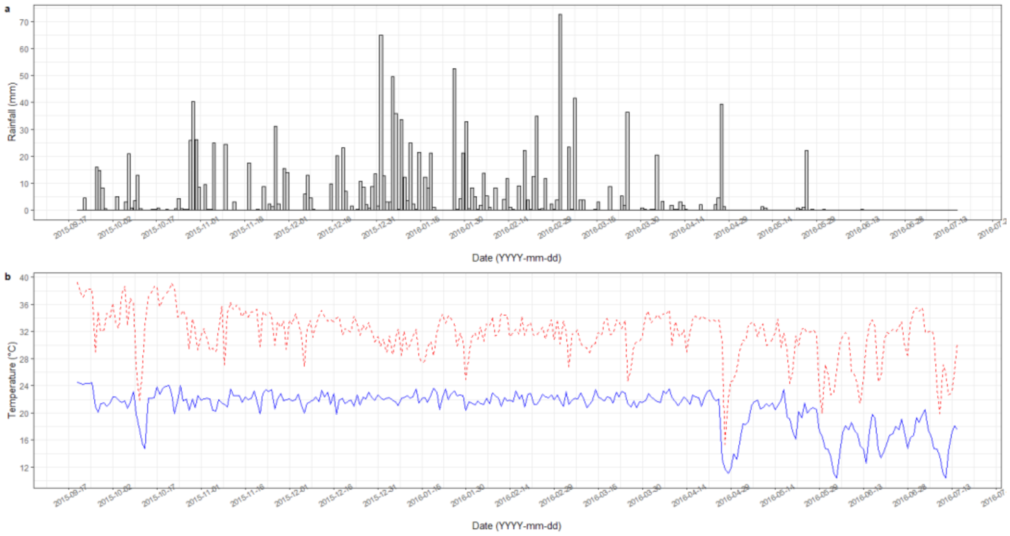


Figure 1. Variability of observed rainfall and maximum and minimum temperatures during the agricultural year of 2015/2016 in the region of Tangará da Serra, Mato Grosso state, Brazil. Solid and dashed line indicates minimum and maximum daily temperatures, respectively.

In Table 1 is possible to observe the genetic coefficients after model adjustment for the three genetic materials. Genetic coefficients that were not adjusted (PODUR, XFRT, SIZLF, SLAVR) were adopted from the model default as the specific for their maturity group (see Material and Methods).

Some of the genetic coefficients were used in the model as the same values as they were collected from experiments, i.e., without alteration in the model adjustment process. This occurred with the coefficients EM-FL, SD-PM, SIZLF and SDPDV. Variability on the model evaluation coefficients of different cultivar and maturity cycles, as found in this present study, was also observed by others (Rodrigues et al., 2013, Confalone et al., 2016, Talacuece et al., 2016) when using the CSM-CROPGRO-Soybean. The model showed sensibility concerning the occurrence of crop phenological events (Rodrigues et al., 2013), which also contribute to the variability of growth and development due to the different periods in which the crop is in the field.

Table 1. Soybean model genetic coefficients of three cultivars in the conditions of soil and climate in a region of Mato Grosso state, Brazil.

| Crop cycle | Genetic coefficients | Cultivars | | |
|---|---|---|---|---|
| | | ST 815 | ST 820 | TMG 1188 |
| Growth | CSDL | 13.00 | 13.00 | 14.00 |
| Vegetative stage | PPSEN | 0.27 | 0.27 | 0.34 |
| | EM-FL | 29.40 | 29.30 | 29.60 |
| | FL-SH | 14.90 | 14.10 | 22.60 |
| | FL-SD | 15.50 | 15.50 | 29.50 |
| | SD-PM | 43.18 | 43.82 | 48.02 |
| | FL-LF | 17.96 | 17.85 | 28.93 |
| | LFMAX | 1080.00 | 1030.00 | 1030.00 |
| | SLAVR | 375.00 | 375.00 | 375.00 |
| | SIZLF | 180.00 | 180.00 | 180.00 |
| | XFRT | 1.00 | 1.00 | 1.00 |
| Reproductive stage | WTPSD | 0.18 | 0.18 | 0.20 |
| | SFDUR | 30.00 | 26.70 | 19.60 |
| | SDPDV | 2.03 | 2.10 | 2.28 |
| | PODUR | 10.00 | 10.00 | 10.00 |
| | SDPRO | 0.40 | 0.40 | 0.40 |
| | SDLIP | 0.20 | 0.20 | 0.20 |

Where CSDL: Critical Short Day Length below which reproductive development progresses with no daylength effect (for shortday plants) (hour); PPSEN: Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour); EM-FL: Time between plant emergence and flower appearance (R1) (photothermal days); FL-SH: Time between first flower and first pod (R3) (photothermal days); FL-SD: Time between first flower and first seed (R5) (photothermal days); SD-PM: Time between first seed (R5) and physiological maturity (R7) (photothermal days); FL-LF: Time between first flower (R1) and end of leaf expansion (photothermal days); LFMAX: Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO2/m2-s); SLAVR: Specific leaf area of cultivar under standard growth conditions (cm2/g); SIZLF: Maximum size of full leaf (three leaflets) (cm2); XFRT: Maximum fraction of daily growth that is partitioned to seed + shell; WTPSD: Maximum weight per seed (g); SFDUR:Seed filling duration for pod cohort at standard growth conditions (photothermal days); SDPDV: Average seed per pod under standard growing conditions (#/pod); PODUR: Time required for cultivar to reach final pod load under optimal conditions (photothermal days). *p.d.: phototermal days.

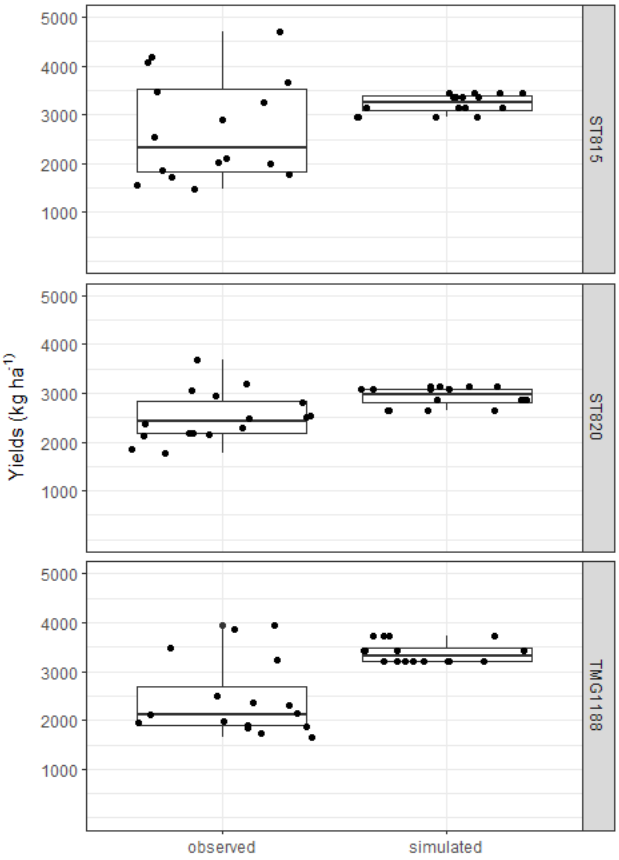
Absolute differences between simulated and observed main events (i.e., days from emergence to flowering and days from emergence to physiological maturity) can be observed in Table 2.

Overall, absolute differences were lower for vegetative crop growth phase than reproductive phase, as observed by other studies (Mercau et al., 2007)., and similar among irrigated and rainfed experiments In the model evaluation, absolute differences between simulated and observed values varied between 0 – 15% (5 – 15% for model adjustment) for DFA and between 7 – 16% (9 - 17% for model adjustment) for DFM. Comparing periods from emergence to beginning of reproductive phase, simulated days tended to be more like the observed ones than when simulating days to achieve the end of the cycle. Variability of soybean yields in the evaluation experiments of the different cultivars and sowing dates, as well as model performance can be observed in Figure 2.

Table 2. Absolute differences between simulated and observed phenology events in the adjustment and evaluation processes of the soybean model CROPGRO-Soybean for three cultivars in a region of Mato Grosso state, Brazil.

| Experiment | Material | Absolute differences (days) | |
|---|---|---|---|
| | | DFA | DFM |
| Irrigated | ST815 | 3 | 10 |
| | ST820 | 2 | 13 |
| | TMG1188 | 5 | 25 |
| Rainfed | ST815 | 5 | 8 |
| | ST820 | 4 | 11 |
| | TMG1188 | 0 | 23 |

DFA: days from emergence to flowering; DFM: days from emergence to physiological maturity.



Statistical parameters for each genetic material were as following, d: 0.47; 0.52; 0.36; RMSE: 1125; 636; 1313 kg ha$^{-1}$; MAE: 970; 538;1170 kg ha$^{-1}$ for the rainfed experiments and for the cultivars ST815; ST820 and TMG1188, respectively.

Figure 2. Relationship between observed and simulated grain yields of the soybean model evaluation of the soybean model for three cultivars in the region of Tangará da Serra, Brazil.

The overall performance of soybean model evaluation was relatively higher and less variable, when compared to the field experiments, as observed in Figure 2. In general, the deviation found among simulated and observed average grain yield values varied between 16 – 22% (4 – 19% for model adjustment). The absolute differences among simulated and observed average grain yield values varied between ~ 400 – 950 kg ha$^{-1}$, relatively more variable than the irrigated experiments (500 – 800 kg ha$^{-1}$). However, each of the presented results and panels presented in Figure 2, are related to all different sowing dates performed for each cultivar, thus, representing broader climate variability to the model performance.

Other variables related to crop yields were used to evaluate model performance, as can be observed in Table 3.

## Adjustment and evaluation of maize model

According to field observations of crop phenology, growth and development variables, genetic coefficients of the maize model were adjusted for the three hybrids. In Table 4 is possible to observe the genetic coefficients after model adjustment for the three genetic materials.

All coefficients, except P2, were changed according to field observations and adjustment process. The P2 coefficient was not altered, since the day length during the time of the year the crop was sown was lower than the critical photoperiod (12.5 hours) (Soler, 2005). The coefficient P5 was used in the same way as observed from field experiments. In terms of crop phenology, in Table 5 is possible to observe the absolute differences between simulated and observed main phenology stages of maize.

Table 3. Coefficients of the soybean model evaluation related to crop production variables of the soybean model CROPGRO-Soybean for three soybean cultivars in a region of Mato Grosso state, Brazil.

| Cultivar | Number of grains per pod | | | Grain (unit) weigth | | | Number of grains m$^{-2}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | d | MAE | RMSE | d | MAE | RMSE | d |
| ST815 | 0.08 | 0.10 | 0.41 | 0.06 | 0.06 | 0.22 | 1616.29 | 2095.51 | 0.44 |
| ST820 | 0.12 | 0.14 | 0.43 | 0.03 | 0.03 | 0.32 | 2465.89 | 2789.06 | 0.39 |
| TMG1188 | 0.11 | 0.13 | 0.26 | 0.03 | 0.03 | 0.35 | 2533.00 | 2624.28 | 0.26 |

The agreement between simulated and observed of the development variables presented in Table 3 was also considered satisfactory in an overall view. The deviation in number of grains per pod, grain weigth and number of grains per m2 varied between -1 to 5%, 15 to 30% and ~60% among simulated and observed values, respectively. Deviation in number of grains per m2 was overall the lowest agreement found among assessed variables of crop production.

Table 4. Maize model genetic coefficients of three hybrids in the conditions of soil and climate in a region of Mato Grosso state, Brazil.

| Crop cycle | Genetic coefficients | Hybrids | | |
|---|---|---|---|---|
| | | AG 7088 | AS 1555 | DKB 390 |
| Vegetative stage | P1 | 250.90 | 250.70 | 250.30 |
| | P2 | 0.50 | 0.50 | 0.50 |
| | P5 | 963.00 | 961.60 | 981.30 |
| Reproductive stage | G2 | 980.00 | 900.60 | 700.80 |
| | G3 | 5.85 | 5.60 | 6.00 |
| Phylochron | PHINT | 45.00 | 50.00 | 50.00 |

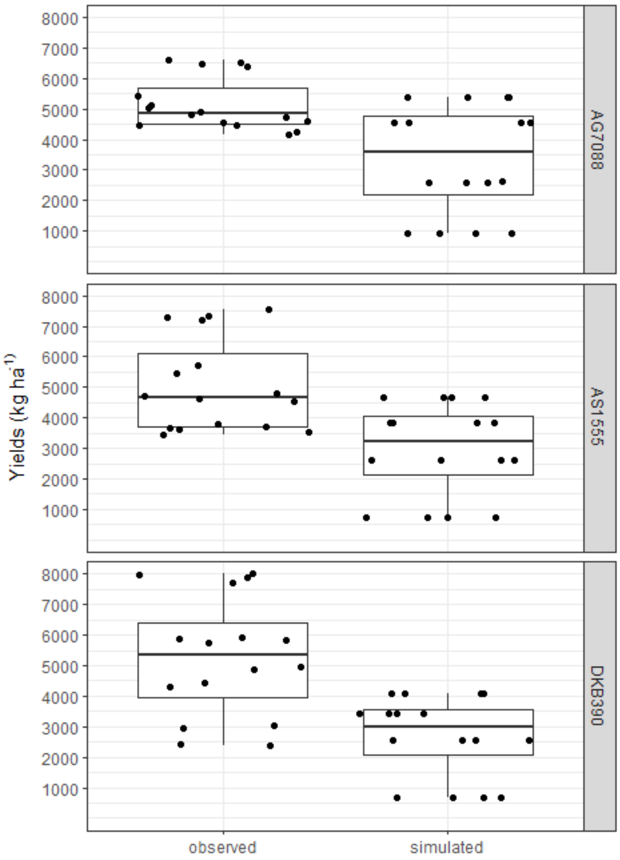
Where P1: Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 deg.C) during which the plant is not responsive to changes in photoperiod; P2: Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours); P5: Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 deg.C); G2: Maximum possible number of kernels per plant; G3: Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day); PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

The general absolute differences during the reproductive stage were more accentuated than on vegetative stage, as found for soybean. However, values found for maize suggested a better agreement between simulated and observed than for soybean, indicated by lower values of absolute differences between simulated and observed days in phenological phases. In the model evaluation, absolute differences between simulated and observed values varied around 4% (0% for model adjustment) for DFA and between 1 – 6% (3 – 7% for adjustment) for DFM. A relatively low disagreement between phenological main stages (beginning of reproductive phase and achievement of physiological maturity) was also found for maize in other studies using the same model (Amaral et al., 2015).

Variability of maize yields in the evaluation experiments for the different hybrids across sowing dates, as well as model performance can be observed in Figure 3.

Table 5. Absolute differences between simulated and observed phenology events in the adjustment and evaluation processes of the maize model CSM-CERES-Maize for three maize hybrids in a region of Mato Grosso state, Brazil.

| Experiment | Material | Absolute differences | |
|---|---|---|---|
| | | DFA | DFM |
| Irrigated | AG7088 | 0 | 4 |
| | AS1555 | 0 | 3 |
| | DKB390 | 0 | 9 |
| Rainfed | AG7088 | 2 | 2 |
| | AS1555 | 2 | 1 |
| | DKB390 | 2 | 7 |



Statistical parameters for each genetic material were as following, d: 0.51; 0.51; 0.65; RMSE: 2127; 2498; 2700 kg ha$^{-1}$; MAE: 1789; 2161; 2590 kg ha$^{-1}$ for the rainfed experiments and for the cultivars AG7088; AS1555 and DKB390, respectively.

Figure 3. Relationship between observed and simulated grain yields of the maize model CSM-CERES-Maize for three maize hybrids in a region of Mato Grosso state, Brazil.

The overall performance of model evaluation for maize was relatively lower and less variable, when compared to the field experiments, as observed in Figure 3. Due to the relatively more accentuated water deficit found for the latest sowing date and for the hybrid with longer cycle, the deviation of simulated from observed values could reach -100%. In the irrigated conditions this deviation ranged between 9 – 22%. While in rainfed conditions the absolute differences among simulated and observed average grain yield values varied between 1700 – 2500 kg ha$^{-1}$, in the irrigated conditions they varied between 600 – 2000 kg ha$^{-1}$. Other variables of crop development were used to evaluate model performance through statistical parameters, as can be observed in Table 6.

The agreement between simulated and observed of the development variables presented in Table 6 was also considered satisfactory in an overall view. The deviation in number of grains per ear, grain weight and leaf area index varied between -50 to -80%, >100% and -20 - -30% among simulated and observed values, respectively. Deviation in grain weight was the overall lowest agreement found among the assessed crop production variables.

## DISCUSSION

### Climate

During the first agricultural season of the year, in which soybean is commonly cultivated, water deficit tends to be less harmful to crops than on second season, since the former is also the rainy period of the year in Mato Grosso state (Dallacort *et al*., 2011) and in most part of the Central-Southern portion of the country. It was possible to observe that sowing dates around mid-October to November provided the highest amounts of rainfall with low variability of temperatures. However, the earliest sowing date promoted the lowest amount of rainfall, since during mid-September and beginning of October, the rainfall season may not have fully started yet.

Regarding the rainfed experiments, accumulated rainfall was considered satisfactory for soybean development, including scenarios well above the upper limit (in the range of 450 – 800 mm) (Oliveira et al., 2011) considered ideal for crop development; but its distribution may not have been the optimum for the crop, i.e., considering water availability during crop’s critical stages. In terms of maximum temperatures, average values did not present much variation, staying between 32 - 33°C during the growing season However some variability was observed during the overall cycle (Figure 1) indicating the existence of days with relatively higher temperatures (e.g., above 33 °C), which can be harmful for the crop especially when its occurrence takes place during the plant’s reproductive stage (Puteh *et al*., 2013). Average minimum temperatures were similar for all experiments and presented low variability during the season when compared with maximum temperatures.

During the second agricultural season of the year, in which maize is commonly cultivated after soybean harvest, water deficit tends to be a significant problem in the region (Dallacort *et al*., 2011) since rainfall starts to decrease around March, which is also the occurrence in major share of Central Brazil. Unlike soybean cropping cycles, similar (and relatively low) amount of accumulated rain was found for most of the cropping cycles of maize, considering their different sowing dates and genetic material. It was possible to observe the accentuated decrease of rainfall as maize sowing was delayed. At the latest sowing dates, only 164 of rainfall was provided for the rainfed experiments during the entire cycle, a value well below the recommended range of water supply for maize, of approximately 400 – 700 mm, depending on local conditions (Bergamaschi and Matzenauer, 2014). Even at the performed earliest sowing dates, although the values of accumulated rain are narrowly within the recommended range, if the distribution is not adequately assisting crop’s most critical phase, the reproductive stage, especially during anthesis-silking (Bergamaschi and Matzenauer, 2014), water deficit becomes a serious yield limiting factor. In average terms, temperatures did not present much variation, staying around 30 - 31°C and 20 - 21°C for maximum and minimum temperatures, respectively, during the entire cycle among cycle duration of the different genetic materials. However, it was possible to observe in Figure 1 a more accentuated variability of maximum and minimum temperatures starting mid-late April, related to the change of climate season.

Table 6. Coefficients of the maize model evaluation related to crop production of the maize model CSM-CERES-Maize for three maize hybrids in a region of Mato Grosso state, Brazil.

| Hybrid | Number of grains per ear | | | Grain (unit) weigth | | | Leaf area index | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | d | MAE | RMSE | d | MAE | RMSE | d |
| AG7088 | 119.02 | 153.18 | 0.72 | 0.19 | 0.20 | 0.25 | 0.93 | 1.13 | 0.10 |
| AS1555 | 115.45 | 125.85 | 0.77 | 0.26 | 0.26 | 0.21 | 1.13 | 1.26 | 0.53 |
| DKB390 | 172.56 | 216.22 | 0.65 | 0.19 | 0.20 | 0.35 | 0.50 | 0.62 | 0.36 |

Although relatively low temperatures (i.e., < 10°C) are not observed in this region of the country, minimum temperatures can present a relative drop in some days, situation not observed during spring and summer. This magnitude of minimum temperatures does not present negative impact for the crop (Bergamaschi and Matzenauer, 2014). Thus, rainfall was the most likely variable to have negative influence on the development of the crop.

## Soybean experiments and simulations

The overall model performance in rainfed conditions was considered satisfactory for capturing local conditions tendencies on crop growth and development, although some specific variables did not present a relatively good agreement. Regarding crop growth and phenology, field experiments are usually harvested with some remaining grain moisture (~13%), while the model simulates totally dry biomass. Thus, considering the date when the grains were harvested in the field in this study, about 2 weeks of additional time should be considered for the grains' dry-down of all cultivars and hybrids, which would lead to a better agreement between observed and simulated days for physiological maturity. Considering variables related to crop production, agreement between soybean simulated and observed yields was overall satisfactory, as denoted by the statistical parameters. The greater variability of observed yield values when compared to the lower variability of simulated ones should be highlighted. This is not an uncommon result in crop modeling, since the model did not capture some conditions that may occur even in well-managed experiments, and compromise yields, such as occasional occurrence of pests, diseases, bedding, among others. Some of these occurrences, such as pests, diseases and other pressures can be incorporated in crop models such as DSSATs' (Jones *et al*., 2017), but were beyond the scope of this study. These results led to the variable model performance among soybean genetic materials with different cycle duration, as other studies have presented (Rodrigues et al., 2013). Variability in the magnitude of agreement between simulated and observed is also pointed by other studies (Talacuece et al., 2016). General model's performance was poorer in rainfed conditions when compared irrigated conditions (used for model calibration). Variability of performance indicators have been found in other studies that used CROPGRO

## Maize experiments and simulations

In an overall view, maize model performance should be analyzed with caution. Accentuated yield variability was found both for observed and simulated scenarios, and such variability is expected for the crop during second season in rainfed conditions in several parts of Central-Southern Brazil (Soler et al., 2007). The latter authors, by using CERES-Maize, performed a model adjustment with relatively more and more detailed experimental information, but found average difference values between simulated and observed yields > 1000 kg ha$^{-1}$, especially in rainfed conditions. Bao et al. (2017), by using limited variety trials data, found RMSE values in the range of 1000 – 3000 kg ha$^{-1}$ in irrigated conditions using DSSAT and EPIC crop models for maize. The variability in the observed yields is strongly related to seasonal rainfall availability, demonstrating the impact that water deficit can provide on maize in second agricultural season. Although the model was able to capture similar variability of yields due to climate, the average values of yield and production parameters of the simulated experiments were generally lower than the observed ones. This was also more accentuate in the latest sowing date, which was in the scenario with the strongest water deficit and presented the lowest simulated yields (yields ~1000 kg ha$^{-1}$, see Figure 4), contributing to the worsening of the performance parameters of the model. Accentuated sensibility and yield penalization of DSSAT maize model is also pointed by other studies. Pereira et al. (2010) tested Ceres Maize performance in Brazil, considering different hybrid maturity and sowing dates. The latter authors concluded that the model has an overall good performance for simulating phenology and production parameters, but in the sowing dates that provided the least favorable climatic conditions in terms of water availability, model performance was more variable and inferior than other sowing dates. The disagreement between observed and simulated may also be related to the absence of in-depth soil data regarding water holding parameters. While the model uses a pedo-transfer function suited for temperate climate-soil environments, this may have under predicted actual plant-soil behavior in a tropical environment with clayey soil type, i.e., high water holding capacity when in good physical conditions. Concerning the agreement of crop production variables, presented in Table 6, in a general manner model performance on rainfed conditions was intermediate and variable, as found for soybean. Model performance also presented variability according to the assessed crop variable. Number of grains per ear was best predicted than other variables, which may have been less penalized by water deficit than the other two variables.

## Overall conclusions on experiments and model performance

For both crops, agreement between simulated and observed values of growth and production were higher for irrigated experiments. Seasonal amount of rainfall of all experiments may not have been enough for both crops since model evaluation, performed in rainfed conditions, revealed a moderately satisfactory performance, with variable agreement of results among assessed crop's variables. In model performance, agreement was also generally higher in conditions with relatively lower water deficit, such as sowing dates that provided higher amount of rainfall, especially during first cropping season. An accentuated crop yield penalization due to water stress by the model was observed, especially for maize, since its cultivation period occurs during a period of water deficit. This water stress context contributed also to a more accentuated simulated variability, not found for irrigated conditions. Model adjustment and evaluation, performed for four different sowing dates, but only one year, may also have some impact on relative model performance. By using only one year, we are imposing a relative poorer climate variability to the model when compared to the use of more than one agricultural year experimental data.

Studies have presented the general good performance of DSSAT models of staple crops such as soybean and maize, especially under irrigated conditions. However, they also pointed for the necessity of model adjustments regarding parameters related to soil water availability in rainfed conditions when in tropical environment like Brazil, since water deficit significantly affects its performance efficiency for estimating crop production (Pereira *et al*., 2010) especially in no-tillage systems, in which soil moisture can be significantly saved (Martorano *et al*., 2012). As these findings point to the sensibility of the model in water-limited conditions for different crops, results also point to the necessity of further detailing soil conditions in-depth.

The model also showed the tendency of minimizing yield variability when compared to observed occurrences. This was more noticeable for soybean and could also have been related to this crop's greater water availability during its cycle, when compared to lower water availability and greater simulated variability of rainfed maize yields at the assessed region. In general, occurrences that penalize crop yields, such as occasional pests, nutrition and soil compaction may have influence on observed yields lower than simulated ones (as observed for soybean), even on an experimental level, where crop management is at an optimum level.

Despite the variable agreement between observed and simulated yields, DSSAT is a model with good overall predicting power for maize and soybean, indicating to be an important tool for planning the management of agricultural production systems. In the case of Brazilian agricultural activity, specifically for Mato Grosso state, this is of great importance since the practice of double-cropping systems (i.e., soybean and maize in succession) has its profitability heavily dependent on the junction of the operations and cycle of both crops, so that both can take advantage of the best possible climatic conditions of each agricultural year. Acknowledging that all models already have their own uncertainties (e.g, parameters and processes estimations) (Seidel *et al*., 2018), for future studies providing best agreement between experimental and simulated conditions, the following points are highlighted (i) make use of as much local soil parameters as possible, avoiding models' estimations, especially regarding water holding capacity; (ii) make use of additional experimental years, in order to add more climate variability on model adjustment and evaluation and (iii) make use of greater variety of experimental data (i.e., growth and development) during crops' cycle.

## CONCLUSIONS

It was demonstrated that CSM-CROPGRO-Soybean and CSM-CERES-Maize performed satisfactorily regarding simulated phenology, development and grain yields of soybean and maize in a Central-Southern region, of predominantly tropical environmental characteristics, in Mato Grosso state, Brazil. The model demonstrated sensibility to water deficit when simulating yields and yield components of soybean and maize for different genetic material across usual local sowing dates, especially when in the context of accentuated water deficit. In the rainy (first) agricultural season, the model predicted overall higher and less variable yields when compared to observed ones. In the dry (second) agricultural season, the model predicted overall variable but lower than observed maize yields, evidencing the important role of that water deficit takes place in the model and the importance of detailing soil water parameters in depth on crop simulations.

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