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Calibration and validation of AquaCrop model for cowpea crop under water stress[1]

Calibração e validação do modelo AquaCrop para a cultura do feijão-caupi sob estresse hídrico

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HIGHLIGHTS:

The AquaCrop model is efficient in estimating cowpea crop yield.
The use of irrigation is crucial for increasing cowpea yield in both rainy and dry seasons.
New management strategies can be adopted for cowpea after parameterization with AquaCrop.

ABSTRACT: Cowpea is a legume crop cultivated in diversified production systems, under different conditions of climate, soil, cultivars and technological level. Although the crop is resistant to water stress, lack of moisture in the soil profile during its reproductive stage causes significant losses in its yield. The objective of this study was to calibrate and evaluate the AquaCrop model in the simulation of cowpea yield under water stress in two cropping seasons (rainy and dry) under no-tillage system condition. Experiments were carried out in two cropping seasons (rainy and dry) with five forms of water stress (without water stress, water suspension for 5, 10 and 15 days and rainfed cultivation), under no-tillage system. Regardless of the cowpea cropping season, water stress reduced grain yield and biomass yield, which was more pronounced in the dry season. The Aquacrop model simulated cowpea yield well for the rainy and dry seasons, with root mean square error of 16 and 9.1%, respectively. Aquacrop model showed poor performance for simulation of dry biomass production in both cropping seasons, overestimating the values obtained in the field.

Key words: agricultural modeling, agricultural production, semiarid region, water use efficiency

RESUMO: O feijão-caupi é uma leguminosa cultivada em diversificados sistemas de produção, sob diferentes condições de clima, solo, cultivares e nível tecnológico. Apesar da cultura ser resistente ao estresse hídrico, a falta de água durante sua fase reprodutiva, traz perdas expressivas em sua produtividade. O estudo teve como objetivo calibrar e validar o modelo AquaCrop na simulação da produtividade do feijão-caupi sob estresse hídrico em duas safras (chuvosa e seca) em sistema de plantio direto. Foram realizados ensaios em dois períodos de cultivo (chuvoso e seco) com cinco formas de estresse hídrico (sem estresse hídrico, suspensão de água de 5, 10 e 15 dias e plantio de sequeiro), em sistema de plantio direto. Independentemente do período de cultivo do feijão-caupi, o estresse hídrico proporcionou redução de produtividade grão e biomassa, sendo mais evidenciada na época seca. Os resultados da calibração indicaram que o modelo simulou bem o rendimento feijão-caupi para o período chuvoso e período seco, com valores de RSME de 16 e 9,1%, respectivamente. O modelo apresentou desempenho péssimo para simulação da produção de biomassa seca em ambos períodos de plantio, superestimando os valores obtidos em campo. O AquaCrop pode ser utilizado na simulação da produtividade da cultura do feijão-caupi sob condições de sequeiro e/ou irrigação com déficit, melhorando assim a gestão e eficiência do uso da água para agricultura.

Palavras-chave: modelagem agrícola, produção agrícola, semiárido, eficiência do uso da água

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Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.), belonging to the Fabaceae family, with Africa as its center of origin (Gupta et al., 2019), is an annual herbaceous legume, cultivated mainly in the dry areas of the tropics in Latin America, Africa and South Asia, where it is a valuable source of protein in the diet of millions of people (Boukar et al., 2018). For being resistant to hot and drought-prone environments (Lonardi, 2019) and having association with nitrogen-fixing bacteria, cowpea has a wide adaptation, which enables its cultivation in places with annual rainfall of about 300 mm or even less (Boukar et al., 2018).

Cowpea is grown in diversified production systems, under different conditions of climate, soil, cultivars and technological level. In Brazil, for being a rainfed subsistence crop, its cultivation is mostly practiced by family farming, which accounts for 70% of the production (MAPA, 2019). The North and Northeast regions are the largest producers of cowpea, representing together 90% of the total area cultivated with the crop (CONAB, 2020), but due to lower levels of management technologies and adverse climatic conditions (Batista et al., 2018), its yield is low, ranging from 300 to 400 kg ha^{-1} (Freire Filho et al., 2011).

In the Brazilian semi-arid region, cowpea cultivation is carried out along the short rainy season but, due to rainfall annual variability in this region, its yield is frequently compromised (Luna et al., 2021). Water stress tends to drastically reduce its yield, especially if it occurs during the flowering and grain filling stages (Boukar et al., 2018).

Many studies have been carried out using cowpea yield prediction models for different conditions of climate, soil, cultivars, sowing time and water restriction. Among these models, AquaCrop has been used in an incipient way in Brazil to predict the yield of cowpea, as it produces excellent results when well calibrated, helping to choose the best strategies for the cultivation of cowpea according studies carried by Vieira et al. (2020), Costa et al. (2021) and Nunes et al. (2021).

The objective of this study was to calibrate and evaluate the AquaCrop model in the simulation of cowpea yield under water stress in two cropping seasons (rainy and dry) under no-tillage system condition.

Material and Methods

Two experiments were carried out, the first from February 2 to May 14, 2021 (rainy season) and the second from September 1 to November 9, 2021 (dry season), at the Experimental Station (EstAgro) belonging to the Academic Unit of Atmospheric Sciences (UACA) of the Universidade Federal de Campina Grande (UFCG), in the state of Paraíba, Brazil, located at coordinates 07° 13' 50" S latitude and 35° 52' 52" W longitude, at 526 m altitude. The experiments were carried out under the effect of La Niña (NOAA, 2021).

The experimental area had 10 masonry beds with dimensions of 8 x 1 m, with two PVC access tubes of 40 mm in diameter and 0.8 m deep, to give access to the capacitance probe (Diviner 2000® - Sentek Pty Ltd, Australia), which measured soil moisture every 10 cm.

Prior to planting, a chemical-physical analysis of the soil was performed in the 0-20 cm layer of the profile, for chemical characterization following the methodology described by Teixeira et al. (2017) with: pH in water – 6.2; organic matter – 11.12 g kg^{-1}; base saturation (V) – 68.75%; Na^+, $H + Al^{3+}$, Ca^{2+} and Mg^{2+} - 0.04, 2, 2.27, and 1.7 cmol$_c$ dm^{-3}; and P and K^+ - 30.95 and 142.51 mg dm^{-3}, respectively. The soil of the area has a sandy texture and its moisture contents at field capacity (-0.01 Mpa) and permanent wilting point (-1.5 Mpa), considering the 0-0.4 m layer, were 7.3 and 4.6% on a volume basis, respectively.

Experiments were carried out in two cropping seasons (rainy and dry), under no-tillage system condition, with five forms of water stress: a) rainfed cultivation, b) full irrigation and c) deficit irrigation with watering suspension for 5, 10 and 15 days. Treatments consisted of two cropping seasons (rainy and dry) and five forms of water stress: without water stress (T1), water suspension for 5 (T2), 10 (T3) and 15 days (T4) and rainfed cultivation (T5), under no-tillage system, using crop residues present in the experimental area.

The planting holes were opened using a hoe, with spacing of 0.5 m between rows and 0.5 m between plants, and three to four seeds were planted in each hole, so as to leave only three plants per hole, for a final stand of 120,000 plants ha^{-1}.

For plots that received water deficit treatments, the suspension of irrigation was performed in the flowering stage of the crop, considering the moment when 70% of the plants had at least one flower, which usually occurs 34 days after planting (Freitas et al., 2019).

Water replacement, except for rainfed cultivation, was based on 100% ET_0, which was estimated using the equation proposed by Allen et al. (1998) and crop evapotranspiration according to Bernardo et al. (2009), with Kc values of the cowpea crop determined by Silva et al. (2016). The data needed to estimate the reference evapotranspiration (ET_0) were collected daily through an automatic agrometeorological station (Irriplus, E5000 model) installed in the experimental area.

Irrigation was performed by a drip irrigation system with flow rate of 4.5 L h^{-1} at a service pressure of 200 kPa, adopting an application efficiency of 90%. The system had two lines per bed and one dripper per hole. A two-day interval between irrigations was adopted. The irrigations were always carried out in the morning, between 6 and 8 a.m.

The cowpea variety chosen for planting was 'Costela de vaca' (heirloom), because it is one of the most accepted and cultivated cultivars in family farming systems in the Northeast region of Brazil (Silva & Neves, 2011).

During the crop cycle, weeds were controlled manually. For the control of insects and diseases, agroecological and alternative practices were adopted aiming at a production free of agrochemicals.

As each plot reached physiological maturity, between 71 and 80 days after sowing, grain yield and biomass yield analyses were performed, also evaluating water use efficiency, which represents the relationship between grain yield and the total amount of water applied.

To obtain biomass (Eq. 1) and final crop yield (Eq. 2), the AquaCrop model requires several parameters, including: meteorological, crop, soil and management (Raes et al., 2009).

- Meteorological: daily data of maximum and minimum air temperatures (°C), maximum and minimum air relative humidity (%), daily rainfall (mm per day), wind speed (m s^{-1}) and solar radiation (W m^{-2});

- Crop: dates of sowing and harvest, duration of crop phenological stages (day, emergence, flowering, senescence and physiological maturity) and plant population (plants ha^{-1}), plant spacing (m), height, plant canopy expansion and decline, maximum root depth (m), biomass production, and finally, harvest index;

- Soil: data referring to physical characteristics of the soil, such as texture, moisture at permanent wilting point, moisture at field capacity, water content at saturation and saturated soil hydraulic conductivity, as well as soil salinity, soil type and number of horizons (soil layers), and the model allows entering up to five horizons;

- Management: data related to irrigation such as date of irrigation, volume applied (mm), water quality and electrical conductivity of water (ds m^{-1}), in addition to percentage of soil cover by mulch, bed height (m) and groundwater table depth, as well as cultural practices that avoid surface runoff, fertilizer use, among other parameters related to crop management.

$$B = WP \sum Tr \tag{1}$$

$$Y = B \cdot HI \tag{2}$$

where:

WP - water productivity (kg m^{-2} mm^{-1});
Tr - crop transpiration;
B - shoot dry biomass (kg);
Y - final yield (kg); and,
HI - harvest index (%).

These input parameters of the AquaCrop model are divided into two groups:

- Conservative: applied to a wide range of conditions and specific for a given cultivar, these parameters were obtained for high-yield cultivars, without water and fertility limitation, which results in greater applicability, robustness and transferability of these model parameters for different regions of the world (Heng et al., 2009; Hsiao et al., 2009). The conservative parameters used in the calibration of AquaCrop model for cowpea crop are shown in Table 1.

- Non-conservative: parameters that depend on location, cultivar used and management practices and can be modified by the user at the time of model calibration (Steduto et al., 2012).

Table 1. Conservative parameters used in AquaCrop calibration for cowpea crop

Conservative parameters	For all treatments in both cropping seasons
Basal minimum temperature (Tn) (°C)	10
Basal maximum temperature (Tb) (°C)	30
Plant density (plant ha^{-1})	120000
Crop water productivity normalized for ETo and CO_2 (WP*) (g m^{-2})	17

During the process of entering the variables in the model, the accumulation of errors in the different parameters, in addition to errors in the equations of the model, is common, which can lead to different results from those obtained in the field. Thus, the solution to this problem is model calibration, which consists of estimating some parameters for better fit between simulated data and field data. AquaCrop model allows changes only in non-conservative parameters, which are those that are not easily measured in the field, such as root system depth, duration of crop phenological stages (day; emergence, flowering, senescence and physiological maturity, expansion and decline of plant canopy and also those related to management, such as the interference of weed competition on the development of the main crop.

After the model was satisfactorily calibrated, the simulated grain yield and biomass yield were compared with the actual yields observed, in kg ha^{-1}, by means of simple linear regression analyses, and the model fit was evaluated based on the magnitude of the coefficient of determination (R^2, decimal), considering excellent fit when $R^2 > 0.8$ (Sugiyono, 2017).

The statistical indices used for performance analysis of the model in the validation were: prediction error (Pe) (Eq. 3), Nash-Sutcliffe efficiency index (NSE) (Eq. 4), Mean absolute error (MAE) (Eq. 5), Normalized root mean square error (NRMSE) (Eq. 6), Willmott's index (d) (Eq. 7), and Pearson's correlation coefficient (r) (Eq. 8).

$$Pe = \frac{(S_i - O_i)}{O_i} \times 100 \tag{3}$$

$$NSE = 1 - \frac{\sum_{i-1}^{n} (O_i - S_i)^2}{\sum_{i-1}^{n} (O_i - \bar{O})^2} \tag{4}$$

$$MAE = \sqrt{\sum_{i-1}^{n} \frac{(O_i - S_i)^2}{n}} \tag{5}$$

$$NRMSE = \sqrt{\frac{\sum (S_i - O_i)^2}{n}} \times 100 \tag{6}$$

$$d = 1 - \left[\frac{\sum_{i-1}^{n} (S_i - O_i)^2}{\sum \left(|S_i - \bar{O}| + |O_i - \bar{O}| \right)^2} \right] \tag{7}$$

$$r = \frac{\sum_{i-1}^{n} \left[(O_i - \bar{O}) \cdot (S_i - \bar{S}) \right]}{\sqrt{\sum_{i-1}^{n} (O_i - \bar{O})^2 \cdot \sum_{i-1}^{n} (S_i - \bar{S})^2}} \tag{8}$$

where:

Si and Oi - simulated and observed values, respectively;

S - average value of Si;
O - average value of Oi; and,
n - represents the number of observations.

The test performance indexes NSE, d and r; NRMSE and MAE are considered positive when the values approach the unit and zero, respectively. Simulation is considered excellent if NRMSE is less than 10%, good if it varies between 10 and 20%, reasonable if it is between 20 and 30%, and poor when it is higher than 30%.

The data obtained were subjected to analysis of variance ($p \leq 0.05$). When significant, comparison of means was performed by Tukey test ($p \leq 0.05$). The analyses were performed using PAleontological STatistics software version 3 (PAST 3) (Hammer, 2017).

Results and Discussion

The meteorological data collected daily during the experiments can be visualized in Figure 1.

The meteorological data observed in the rainy and dry seasons showed similar patterns in the maximum and minimum air temperatures, global solar radiation (Figure 1C) and reference evapotranspiration (Figure 1D), with their highest values observed at the end of the crop cycle, and relative air humidity (Figure 1B) showed higher values in the rainy season. The average maximum and minimum air temperatures (Figure 1A) for the rainy and dry seasons were 30.2 and 22 °C, and 30.6 and 22.8 °C, respectively. The average values of relative humidity were 74.2 and 71.9% for the rainy and dry season, respectively. Global solar radiation (Figure 1C) showed average values of 221.9 and 238.8 W m^{-2} for the rainy and dry seasons, respectively. The mean values of ET_0 (Figure 1D) were 4.2 mm per day in the rainy season and 4.7 mm per day in the dry season, an increase of 10.4%. Mantovanelli et al. (2020) explain that solar radiation and average temperature are the meteorological variables with the greatest impact on ET_0 estimate. In addition, during the dry season, the incidence of higher temperature and solar radiation is more common.

Due to the more critical meteorological conditions that occurred in the dry season, the total water depths applied to all treatments were higher than those applied in the rainy season, which can be explained by the higher total volume of precipitation during the experiment conducted in the rainy season, which was 205.9 mm, while in the dry season it was only 18 mm, which directly influenced the total number of irrigations (Table 2).

Precipitation and soil moisture data are shown in Figure 2.

During the experiments, there was irregular distribution of precipitation in both cropping seasons, but with more

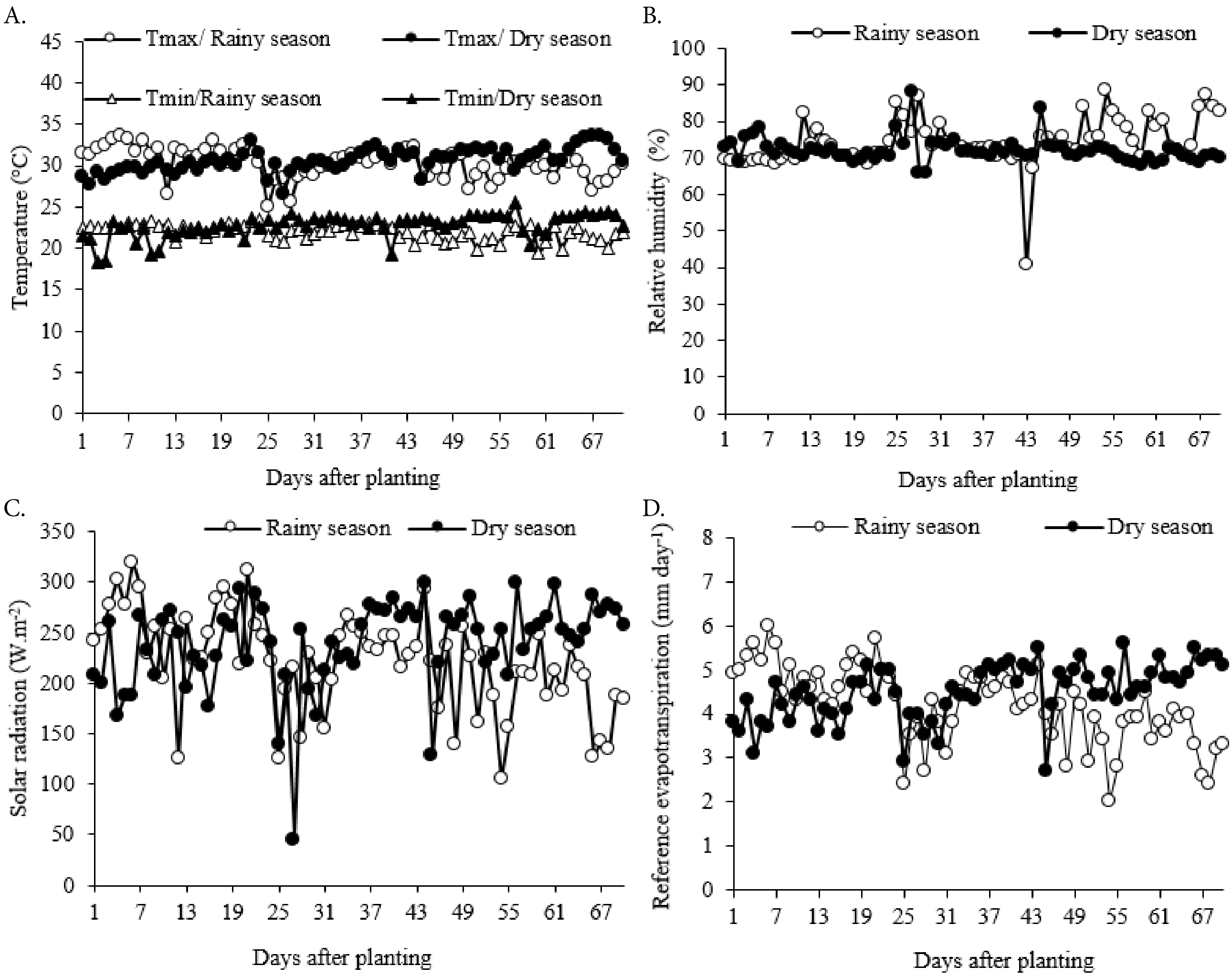


Figure 1. Meteorological conditions during the experiments conducted in rainy and dry seasons. Maximum and minimum air temperatures (A), relative air humidity (B), solar radiation (C) and reference evapotranspiration (D)

Table 2. Total crop evapotranspiration (ETc), total accumulated precipitation (TAP), irrigation depth applied (IDA), number of irrigations (NI) and total water received in each treatment in the rainy and dry season

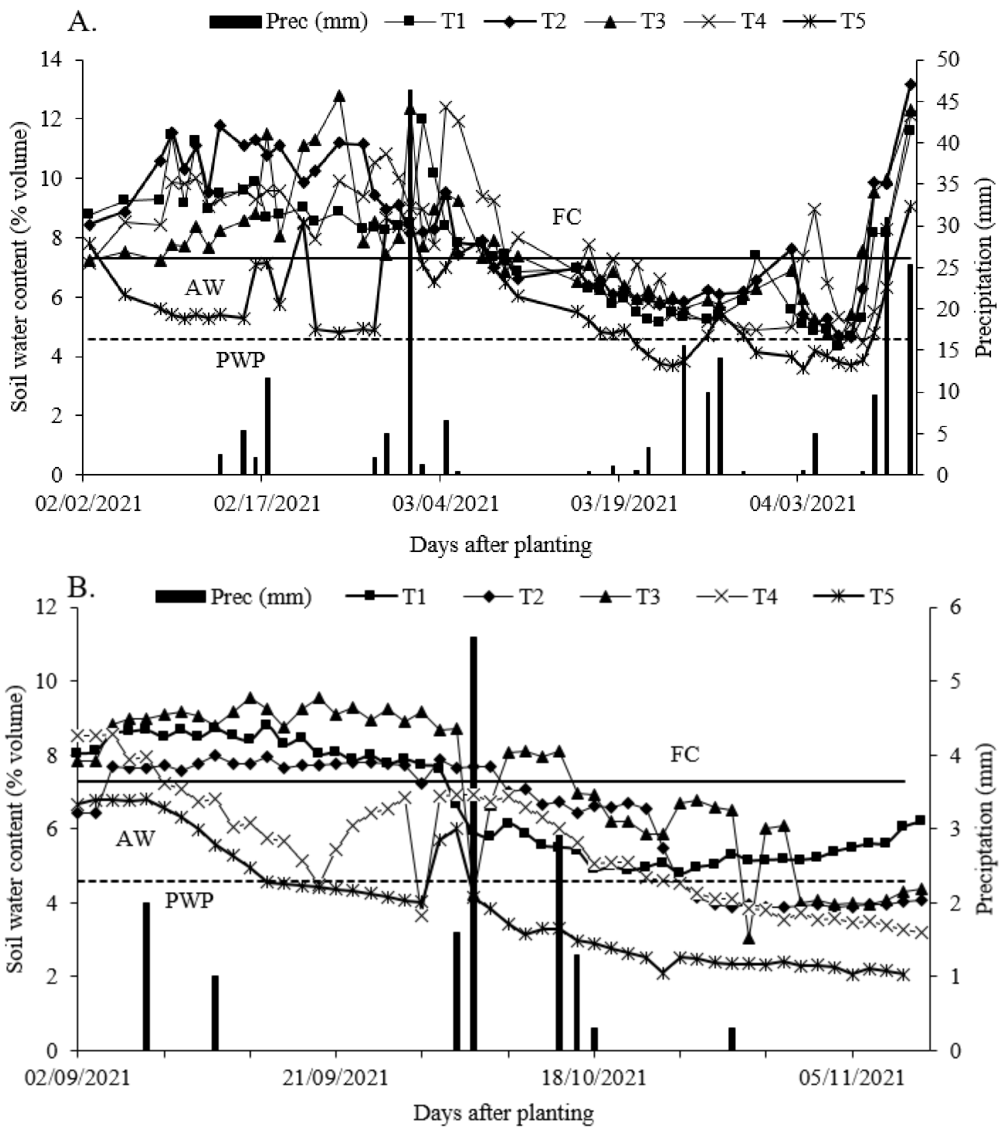
Experiment	Treatments	Water depth (mm) ETc	TAP	IDA	NI	Total
Rainy season	T1	262.8	205.9	243.1	54	449.0
	T2	262.8	205.9	224.1	39	430.0
	T3	262.8	205.9	209.6	34	415.5
	T4	262.8	205.9	202.7	29	408.6
	T5	262.8	205.9	0	0	205.9
Dry season	T1	292.0	18	307.5	68	325.5
	T2	292.0	18	282.5	63	300.5
	T3	292.0	18	258.5	58	276.5
	T4	292.0	18	234.7	53	252.7
	T5	292.0	18	0	0	18

T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 - Water suspension for fifteen days; and T5 - Rainfed cultivation

significant volumes in the rainy season. While in the dry season (Figure 2B) the maximum daily precipitated volume was almost 6 mm, in the rainy season (Figure 2A) it was 46 mm, which was directly reflected in the difference in soil moisture behavior in the experiments.

In the rainy and dry seasons, at the beginning of crop development, soil moisture always remained above the field capacity, reaching maximum values of 14% in the rainy season (Figure 2A), due to the precipitations that occurred and because the crop was still in its initial stage. However, when the crop started the flowering and grain filling stages, at which time the treatments began, soil moisture tended to decrease, reaching values lower than the permanent wilting point of the soil in the dry season (Figure 2B), which did not occur in the rainy season. Kanda et al. (2021) explain that water availability in the crop root zone is fundamental to boost the transpiration process, which is directly proportional to biomass production and, later, to yields.

The soil cover used in the no-tillage system certainly contributed to the maintenance of soil moisture in both cropping seasons, but in the dry season this cover was not able to maintain soil moisture, due to the absence of significant precipitation and unfavorable weather conditions, with high temperatures and solar radiation. Rocha et al. (2020) explain that adequate soil cover tends to preserve soil moisture, favoring growth, grain yield and shoot dry mass production of cowpea.

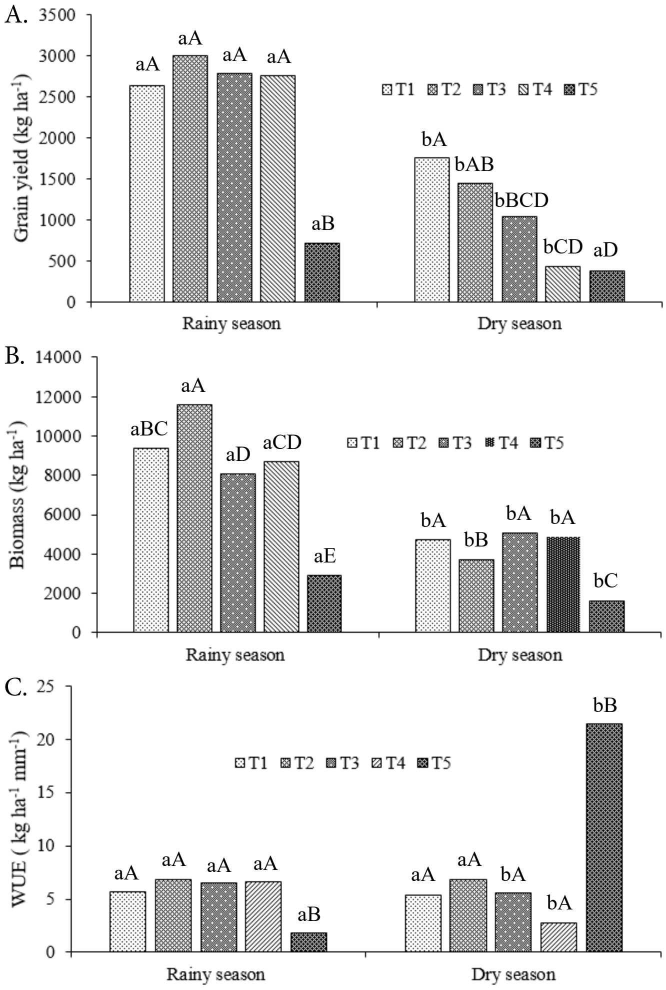


FC - Field capacity; PWP - Permanent wilting point; AW - Readily available water for the 0-0.4 m depth; T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 – Water suspension for fifteen days; T5 - Rainfed cultivation

Figure 2. Soil water content and precipitation during the rainy season (A) and dry season (B)

Interference of the cropping season and water stress on grain yield (GY), biomass (B) and water use efficiency (WUE) were observe for cowpea crop (Figure 3).

Grain yield (Figure 3A) and biomass yield (Figure 3B) values were higher in the rainy season, due to differences in meteorological characteristics between cropping seasons (Figure 2). Grain yield in the rainy season was on average 56% higher than in the dry season, and this superiority was 84% in treatment 4 (Figure 3A). The highest grain yield, despite water stress, was achieved in treatment 2 in the rainy season, almost 3000 kg ha^{-1}, while the lowest grain yield was achieved in the rainfed treatment, 385 kg ha^{-1} (Figure 3A). Anyia & Herzog (2004) explain that, when plants experience stress during the reproductive stage, after reestablishment of irrigation, there is a greater gain in yield and biomass compared to plants that did not undergo water stress.



Bars with the same uppercase letter in the same set of bars and lowercase letter in different sets of bars do not differ statistically from each other by Tukey test at p ≤ 0.05. T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 – Water suspension for fifteen days; and T5 - Rainfed cultivation

Figure 3. Grain yield (A), biomass (B), water use efficiency (C) as a function of planting time and water stress of cowpea

Water use efficiency ranged from 2 to 21 (kg ha^{-1} mm^{-1}), values referring to rainfed treatments of the rainy and dry season, respectively (Figure 3C). Treatment 5 had a WUE of 21 kg ha^{-1} mm^{-1}, which was much higher than values of the other treatments, meaning that this treatment, despite being rainfed, managed to make better use of the volume of precipitation in the area; however, water contamination from the other plots may have certainly occurred, since treatment 5 is in the last position and the experimental area has a slight slope (Figure 3C).

The average WUE for the other treatments was 6.4 kg ha^{-1} mm^{-1} in the rainy season and 5.1 kg ha^{-1} mm^{-1} in the dry season (Figure 3C). Costa et al. (2021) found WUE values for cowpea as a function of water stress ranging from 6.9 to 9.9 kg ha^{-1} mm^{-1}, but with reduction in water replacement throughout the crop cycle, and not with total water suspension as in the present study.

The values of non-conservative parameters obtained after calibration of the AquaCrop model are shown in Table 3.

The non-conservative parameters obtained by the AquaCrop simulation result from the water-soil-plant-atmosphere interaction, which is based on soil water balance as its main crop development-driving process, and this process is influenced by water stress (Raes et al., 2009).

Table 3 shows that the maximum canopy cover and yield as a function of evapotranspired water were lower during the dry season, a direct consequence of water restriction and also of the meteorological conditions in this period. The harvest index (HI), which evaluates the amount of photoassimilates (biomass) directed to grain production, showed lower values in the rainy season, indicating that during this period this conversion was not so satisfactory, so the harvest index was negatively correlated with excess precipitation. Kawano (1990) explains that low HI values may indicate a poor adaptation to the environment.

After calibration of grain yield and biomass results by AquaCrop software, it was possible to assess the performance of the model through statistical tests. The measures of the prediction error evaluate the performance of the model by comparing the actual values to the simulated values. Prediction error values can be positive, that is, the model overestimates the actual value, and also negative, when the model underestimates the actual value. Tables 4 and 5 show the prediction errors of the AquaCrop model in the simulation of grain yield and biomass for cowpea crop in the rainy and dry seasons, respectively. Overall, variations in prediction errors are within the expected for grain yield. The model tended to overestimate the final

Table 3. Results of non-conservative parameters after calibration of the AquaCrop model for cowpea crop subjected to water stress and cultivated in rainy and dry season

Non-conservative parameters	Rainy season					Dry season				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Maximum canopy cover (CCx) (%)	70.5	92.7	70.1	71.0	29.9	67.3	53.0	94.0	94.0	25.4
Canopy cover if infested with weeds (CCw) (%)	67.0	88.1	64.2	67.1	20.8	56.3	43.4	77.8	77.8	21.9
Reference harvest index (HI) (%)	28.1	25.9	34.4	31.7	13.1	36.6	38.1	21.2	9.3	22.8
Water productivity based on evapotranspiration (WPet) (kg m^{-3})	0.98	1.02	1.05	1.02	0.2	0.71	0.64	0.41	0.18	0.45

T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 – Water suspension for fifteen days; and T5 - Rainfed cultivation

Table 4. Prediction errors for grain yield and biomass after calibration of the AquaCrop model for cowpea cultivated during the rainy season

Treatment	Grain yield (kg ha^{-1})			Biomass (kg ha^{-1})		
	Observed	Simulated	Pe (±%)	Observed	Simulated	Pe (±%)
T1	2.663	2.619	-1.65	9.373	9.525	1.63
T2	2.997	3.044	1.57	11.567	11.458	-0.94
T3	2.780	2.781	0.04	8.075	8.045	-0.37
T4	2.760	2.803	1.56	8.718	8.698	-0.22
T5	0.713	0.725	1.68	2.932	5.919	101.88

T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 – Water suspension for fifteen days; and T5 - Rainfed cultivation

Table 5. Prediction errors for grain yield and biomass after calibration of the AquaCrop model for cowpea cultivated during the dry season

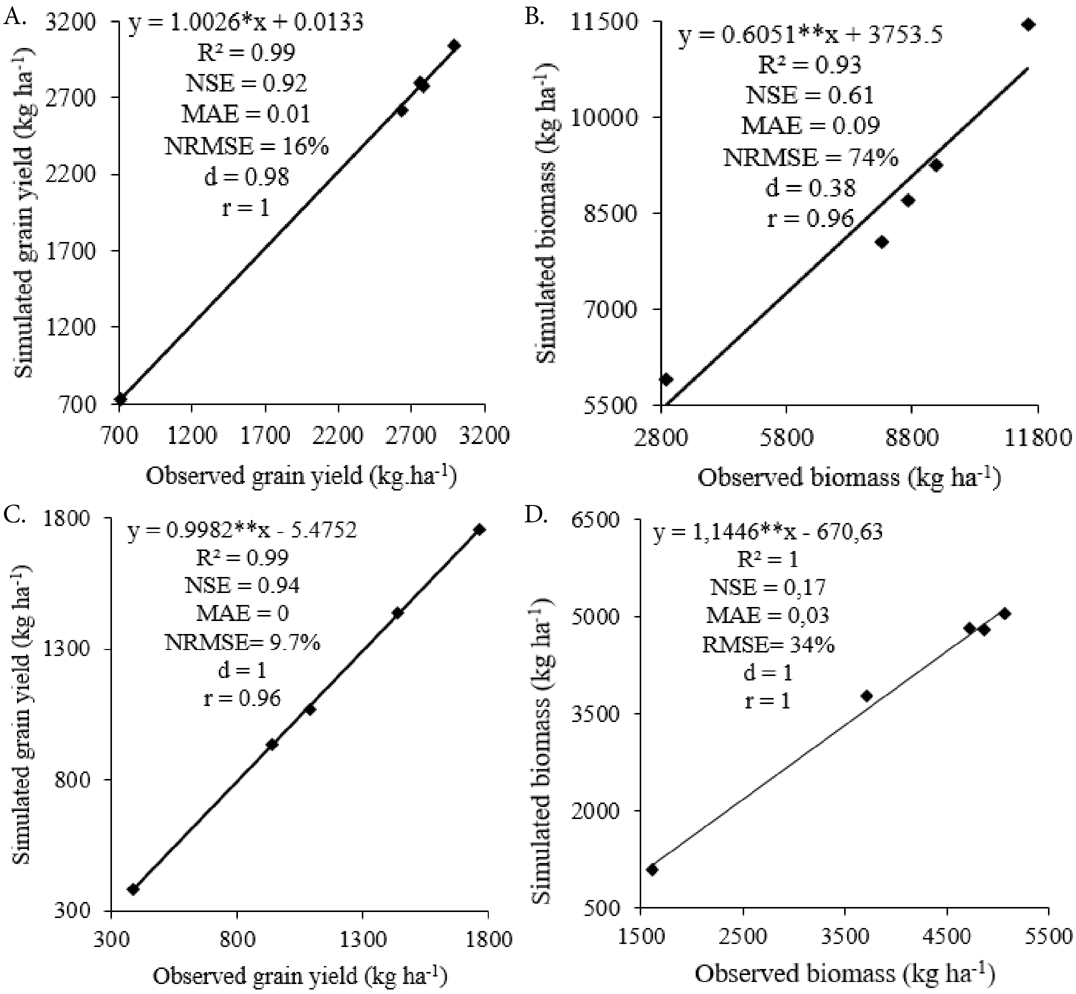
Treatment	Grain yield (kg ha^{-1})			Biomass (kg ha^{-1})		
	Observed	Simulated	Pe (±%)	Observed	Simulated	Pe (±%)
T1	1.763	1.757	-0.31	4.723	4.807	1.79
T2	1.440	1.437	-0.21	3.710	3.770	1.62
T3	1.037	1.067	2.84	5.060	5.034	-0.51
T4	0.943	0.933	-1.06	4.867	4.799	-1.41
T5	0.385	0.384	-0.26	1.602	1.686	5.21

T1 - Without water stress; T2 - Water suspension for five days; T3 - Water suspension for ten days; T4 – Water suspension for fifteen days; and T5 - Rainfed cultivation

biomass production for the rainfed treatment by more than 100% in the rainy season and 5.21% in the dry season.

The values of the other statistical indexes used to assess the efficiency of the AquaCrop model in the simulation of grain yield and biomass of cowpea subjected to water stress in two cropping seasons are shown in Figure 4.

The values of the statistical indexes showed that the AquaCrop model simulated well the grain yield under the



* and ** Significant at p ≤ 0.05 and at p ≤ 0.01 by F test, respectively; R² - Coefficient of determination; NSE - Nash-Sutcliffe efficiency index; MAE – Mean absolute error; NRMSE - Normalized root mean square error; d - Willmott's index and; r - Pearson's correlation coefficient

Figure 4. Comparison between the observed and simulated values of grain yield and dry biomass after calibration, for validation of the AquaCrop model for cowpea crop subjected to water stress, cultivated in rainy season (A and B) and dry season (C and D) in no-tillage system, respectively

water stress conditions of the experiments in the rainy season (Figure 4C) and dry season (Figure 4D), with NRMSE values of 16% (good performance) and 9.7% (excellent performance), respectively. Many studies have shown the efficiency of the AquaCrop model in the simulation of cowpea yield under the most varied climate, soil and water deficit conditions (Alves et al., 2021; Costa et al., 2021; Kanda et al., 2021; Conceição et al., 2022). This demonstrates once again that the model was able to simulate well the grain yield of cowpea for other meteorological and cultivar conditions, this time using a hybrid variety.

AquaCrop did not simulate well the final biomass of cowpea in both cropping seasons under water stress, showing poor performance in biomass simulation in the present study, with RSME values of 74 and 34% for the rainy (Figure 4A) and dry seasons (Figure 4B), respectively. It is inferred from these results that the excess precipitation that occurred in the rainy season promoted higher biomass production for all treatments, but with greater errors in their determinations by the model, whereas in the dry season, these errors were lower.

Kanda et al. (2021) also observed that AquaCrop overestimated the final biomass values under deficit irrigation conditions, due to the slight overestimation of the model in the initial simulation of canopy expansion and canopy decline, and attributed this to the indeterminate growth habit of cowpea, as senescence is delayed due to water availability. Costa et al. (2021) associate the overestimation in the simulation of final biomass with the fact that AquaCrop model considers the accumulation of dry mass as continuous and increasing, but under real field conditions, there is a reduction in biomass as photoassimilates are directed to grain production, until the grains reach appropriate moisture for harvest.

Conclusions

1. The AquaCrop model shows good and excellent performance in simulating the yield of cowpea grown under water stress conditions in the rainy and dry seasons, respectively.

2. The highest grain yield (2997 kg ha $^{-1}$) is observed in the rainy season in the treatment that underwent water restriction of five days. The greatest water use efficiency was verified in the dry season treatment (21 kg ha^{-1} mm^{-1}).

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