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Adaptation, calibration, and validation of the agro-ecological zone model for *Urochloa humidicola* pastures[1]

Adaptação, calibração e validação do modelo da zona agroecológica para pastagens de *Urochloa humidicola*

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ABSTRACT - The agro-ecological zone model (AZM-FAO) is used to describe agricultural scenarios and the impact of climate risk on crops and, when adapted, can be used to simulate the yield of forage species under adverse conditions. The study aimed to test the performance of the AZM-FAO model to simulate the yield of *Urochloa humidicola* grass in Mato Grosso. The model was adapted for two locations with different soil and climate conditions, with data from two experiments (E1 and E2). The morphophysiological variables of the pastures, the physical-hydric variables of the soil, and the meteorological data of the experimental period were analyzed. The model calibration was based on changes in the yield response coefficient to water (Ky) and the minimization of deviations between simulated and observed data. The model presented a satisfactory performance for the two analyzed locations. In experiment E1, the RMSE was 29.86% (acceptable), and the *c* index was 0.86 (optimal) in the calibration phase, maintaining the same results in the validation. In E2, there was an improvement in the performance of the model, with RMSE and *c* index going from 30.74% (poor) and 0.84 (very good) in the calibration to 17.50% (good) and 0.92 (very good) in the validation step, respectively. The AZM-FAO model adapted for *Urochloa humidicola* grass can be used with good accuracy to simulate the forage yield of this forage in the southern region of Mato Grosso.

Key words: Tropical forage. Agrometeorological modeling. Income simulation.

RESUMO - O modelo da zona agroecológica (MZA-FAO) é utilizado para descrever cenários agrícolas e o impacto do risco climático sobre as culturas e, quando adaptado, pode ser utilizado para simular o rendimento de espécies forrageiras em condições adversas. Objetivou-se testar o desempenho do modelo MZA-FAO para simular o rendimento do capim *Urochloa humidicola* no Mato Grosso. O modelo foi adaptado para duas localidades que apresentam condições edafoclimáticas distintas, com dados de dois experimentos (E1 e E2). Foram analisadas as variáveis morfofisiológicas das pastagens, físico-hídricas do solo e dados meteorológicos do período experimental. A calibração do modelo baseou-se nas alterações do coeficiente de sensibilidade da cultura ao déficit hídrico (Ky) e na minimização dos desvios entre dados simulados e observados. O modelo apresentou desempenho satisfatório para as duas regiões analisadas. No experimento E1, o RMSE foi de 29,86% (aceitável) e o índice *c* de 0,86 (ótimo) na fase de calibração, mantendo os mesmos resultados na validação. No E2, houve uma melhoria no desempenho do modelo, com RMSE e índice *c* passando de 30,74% (pobre) e 0,84 (muito bom) na calibração, para 17,50% (boa) e 0,92 (ótimo) na etapa de validação, respectivamente. O modelo MZA-FAO adaptado para o capim *Urochloa humidicola*, pode ser utilizado com boa precisão para simular o rendimento de forragem dessa forrageira na região sul de Mato Grosso.

Palavras-chave: Forrageira tropical. Modelagem agrometeorológica. Simulação do rendimento.

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INTRODUCTION

In Mato Grosso, tropical pastures predominate mainly in the Cerrado and, thus, are subject to the various factors inherent to this environment, which according to Sette (2005), are formed by the association of different characteristics, such as topography, relief, altitude, soil, drainage, and climate.

Of these, soil and climate exert the most significant influence on the forage yield of pastures, mainly due to the annual seasonality of rainfall and the capacity of soils to store water. In Mato Grosso, seasonality occurs in two well-defined seasons, a rainy season in spring-summer and a dry season in autumn-winter.

Despite the environmental variations in different state regions, some forage species stand out in these areas due to their greater adaptation, such as those of the genus *Urochloa* (RIBEIRO *et al.*, 2016). Considering the relevance of this genus in Mato Grosso, studies evaluating its yield under different conditions become essential to understanding and optimizing irrigated and rainfed pasture systems.

Therefore, crop growth and development simulation models emerge as essential analysis tools, helping to integrate the biophysical processes that act in the soil-water-plant system (LORENÇONI; DOURADO NETO; HEINEMANN, 2010).

According to Monteith (1996), crop models are conventionally classified as mechanistic, in which the quantified processes have a solid physical or physiological basis, and empirical, which consists of functions chosen casually to adjust field or laboratory measurements.

Among the most used mechanistic models for forage species, the CROPGRO Perennial Forage and the Agricultural Production Systems Simulator (APSIM) stand out (BOSI *et al.*, 2020; BRUNETTI *et al.*, 2021).

Some empirical models were adapted to simulate forage yield in pastures, and among them are the climatic growth index (CRUZ *et al.*, 2011), the photothermal units model (FU), and the agro-ecological zone model (AZM-FAO) (COSTA; OLIVEIRA; MORAES, 2011).

The latter simulates the performance from meteorological variables, such as solar radiation, air temperature, and photoperiod, and morphophysiological characteristics of a crop, such as leaf area index, respiration, harvest index, and moisture content.

This information is used to simulate the potential yield (*Y*mp) of a crop, which is then penalized for simulating the real yield (*Y*a) according to the yield response coefficient to water (Ky) and the relative evapotranspiration deficit (1 – ETr/ETm), where ETr is the actual evapotranspiration, and ETm is the maximum evapotranspiration of the crop.

As it is a simple model with low input data requirements, the AZM-FAO model has already been adapted for several crops, including eucalyptus (FREITAS *et al.*, 2020), corn (BUSKE *et al.*, 2019), coffee (ALMEIDA; SEDIYAMA; ALENCAR, 2017), and forage cactus (CARVALHO *et al.*, 2017).

The *Urochloa humidicola* grass, the object of this study, shows evident adaptation to the Cerrado region due to its tolerance to drought and brief floods and resistance to pests (DEMINICIS *et al.*, 2010). However, climatic seasonality directly affects the yield of this forage, which demonstrates the importance of research in this region that relates pasture development to the effects of edaphoclimatic variations.

Thus, this study aimed to adapt, calibrate, and validate the AZM-FAO model to simulate the forage yield of *Urochloa humidicola* grass cultivated in two locations in the southern region of Mato Grosso, with different soil and climate characteristics.

MATERIAL AND METHODS

Location and experimental features

To evaluate the AZM-FAO model, two identical experiments were analyzed simultaneously, from March 2019 to March 2020, in two locations in the Center-South Mesoregion of the state of Mato Grosso, the first (E1) at Fazenda Experimental at the Federal University of Mato Grosso, Campus of Cuiabá, MT, located in Santo Antônio de Leverger – MT, at 15º51' S, 56º04' W, and altitude of 141 m above sea level, Aw-type climate (KÖPPEN; GEIGER, 1928) and soil classified as PLANOSSOLO NÁTRICO Órtico vertissólico (SANTOS *et al.*, 2018), and the second (E2) at the Federal Institute of Education, Science, and Technology of Mato Grosso, Campus of São Vicente, at 15º49' S, 55º25' W, and altitude of 800 m above sea level, Aw-type climate (KÖPPEN; GEIGER, 1928) and soil classified as LATOSSOLO VERMELHO-AMARELO Distrófico (SANTOS *et al.*, 2018).

The experiments were installed in *Urochloa humidicola* grass pastures established over thirty years ago and used exclusively for grazing horses and cattle. The design used was randomized blocks (RBD) with 24 treatments (cutting ages) and three replications, with a total area of 10.0 x 61.5 m, helpful area of 6.0 x 48.0 m, and plots measuring 2.0 x 2.0 m, with 0.5 m between the plots and 1.0 m between the blocks and at the border.

Variables analyzed from grass and soil and meteorological data

Initially, a standardization cut was performed in each experiment, at 0.1 m height from the soil surface, on 03/31/2019 (E1) and 04/01/2019 (E2). From these dates, the evaluations began, with a difference of one day between the experiments, every 14 days.

In each plot, the variables of *Urochloa humidícola* grass were evaluated: forage yield (kg ha^{-1}) and leaf area index (LAI in m^2 m^{-2}); and soil: overall density (Dg in kg m^{-3}), saturated hydraulic conductivity (K_0 in cm h^{-1}), soil moisture at field capacity (FC in m^3 m^{-3}), soil moisture at point of permanent wilting (PPW in m^3 m^{-3}) and soil water storage (SWS).

The forage yield was measured by cutting the pasture in an area of 1.0 m^2, which was then weighed on an analytical balance to obtain the fresh matter (FM) and dried in a forced circulation oven at 55 ºC for 72 hours to obtain forage dry matter (DM), according to Silva and Queiroz (2002). The DM was considered the observed forage yield (*Y*obs) of the *Urochloa humidícola* grass in the model analysis.

With the values of FM and DM, the moisture retained by the pasture in each period was calculated (SILVA; QUEIROZ, 2002).

To obtain the LAI, the specific leaf area (SLA) was first measured, measuring the length and width of 20 leaves per plot with a graduated ruler, thus calculating the leaf area (LA), as proposed by Stickler (1961), for the family Poaceae. Then, the leaves were weighed fresh and dried in a forced circulation oven at 55 ºC for 72 hours to obtain the dry matter of leaves (DML). SLA was calculated as the product of the division between LA and DML.

LAI was calculated by multiplying the SLA by the DM and dividing it by the sampled soil area.

For soil physical-hydric variables, the procedures were carried out according to the methodology proposed by Teixeira *et al.* (2017). Deformed and undisturbed samples were collected in a trench central to the experiments at three depths: 0-0.30; 0.30-0.60 and 0.60-0.90 m. For the deformed samples, 0.2 kg of soil was removed at each depth, which was used to estimate the PPW in the WP4C psychrometer at the matrix potential of -1,500 kPa. The undisturbed samples were removed from cylindrical stainless steel rings, with the aid of a Kopecky-type auger, with four repetitions per depth, which is used to estimate the FC (at the matrix potential of -6 kPa), K_0 and Dg. With the FC and PPW data, the soil available water capacity (AWC) was calculated at a depth from 0 to 0.90 m. The soil physical-hydric variables are described in Table 1.

The SWS was obtained by gravimetry, with deformed samples, considering the three depths mentioned above, in three repetitions, in the profile from 0 to 0.90 m, and calculated according to Libardi (2005).

The meteorological variables used in the model (Figure 1) were obtained at the Padre Ricardo Remetter conventional meteorological station and the automatic station of the National Institute of Meteorology (NIMET), both located in the same area as experiments E1 and E2, respectively.

Adaptation of the AZM-FAO model to simulate the potential yield of *Urochloa humidícola* grass

Equation 1, proposed by Doorenbos and Kassam (1994), was used to simulate the potential yield.

$$Ymp_i = cL_i \times cN_i \times cH_i \times G_i \times \left[F \times (a + b \times ym_i) \times yo_i + (1 - F) \times (c + d \times ym_i) \times yc_i\right] \quad (1)$$

The *c*L is the correction coefficient for the leaf area index and, as there is variation during crop development, equation 2, proposed by Barbieri and Tuon (1992), was used for LAI < 5 and LAI ≥ 5, cL = 1.

$$cL = 0.0093 + 0.185 \times LAI_i - 0.0175 \times LAI_i^2 \quad (2)$$

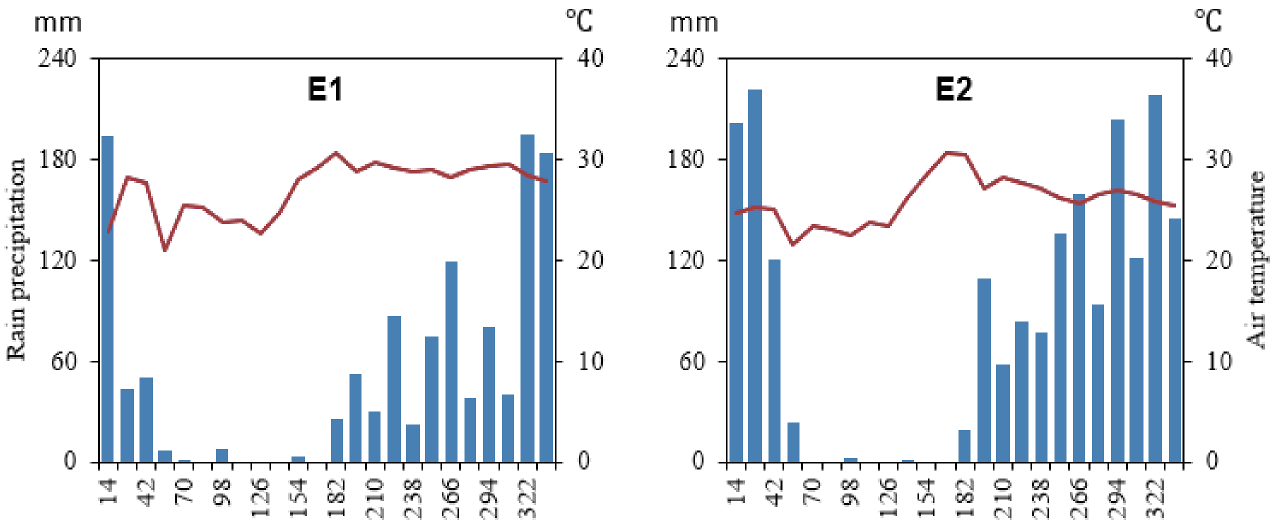
The *c*N is the respiration correction coefficient and varies according to the average air temperature (T), using a value of 0.6 for cold conditions (T < 20 ºC) and 0.5 for hot conditions (T ≥ 20 ºC). The *c*H is the coefficient of correction of the harvest index, considered as 0.9; *G* is the number of days in the cycle; F is the fraction of the day with cloudiness, calculated considering an atmospheric transmittance of 80%, according to Doorenbos and Kassam (1994).

Table 1 - Mean values of soil physical-hydric variables in the experiments at three depths

	Depth (m)	D_g (kg m^{-3})	K_0 (cm h^{-1})	FC (mm)	PPW (mm)	AWC (mm)
	0 – 0.30	1,925	0	0.2780	0.0488	
E1	0.30 – 0.60	1,871	0.1035	0.2568	0.0289	181.3
	0.60 – 0.90	1,851	0.0762	0.1644	0.0170	
	0 – 0.30	1,458	0.0880	0.3561	0.1132	
E2	0.30 – 0.60	1,418	0.1124	0.3728	0.1170	211.5
	0.60 – 0.90	1,342	0.1534	0.3468	0.1136	

Dg - overall density; K0 - saturated hydraulic conductivity; FC - soil moisture at field capacity; PPW - soil moisture at permanent wilting point; AWC - available water capacity

Figure 1 - Rainfall and air temperature observed during the experimental period in areas E1 and E2 between 2019 and 2020



The *ym* corresponds to 20 kg CH_2O ha^{-1} $hour^{-1}$ for a standard plant species; however, it is variable due to the effect of air temperature and the plant species. Thus, relationships were used for species from group III, with C4 metabolism and adapted to high temperatures.

The coefficients of equations *a*, *b*, *c*, and *d* are 0.8; 0.01; 0.5 and 0.025 if ym > 20 kg CH_2O ha^{-1} $hour^{-1}$ or 0.5; 0.025; 0 and 0.05 if *y*m < 20 kg CH_2O ha^{-1} $hour^{-1}$.

To estimate the values of *y*o and *y*c, Equations 3 and 4 were used, respectively, as proposed by Campelo Júnior, Caseiro, and Herbster (1990) for the study region:

$$yo = 31.66 + 13.139 \times AC_i \tag{3}$$

$$yc = 107.0 + 21.53 \times AC_i \tag{4}$$

AC is the photosynthetically active radiation incident on the earth's surface (MJ m^{-2} day^{-1}).

Finally, to obtain the potential yield, the correction was made for the moisture of the harvested part, dividing the *Y*mp by the forage moisture obtained in the experiments.

Calibration and validation of the AZM-FAO model for *Urochloa humidícola* grass

Considering that the experiments were evaluated in a rainfed system, the calibration and validation of the model were carried out only for the real yield (*Y*a) of the pastures.

In the calibration step, Ky values were adjusted to simulate *Y*a at each cutting age to obtain the slightest difference between *Y*a and *Y*obs. Calibration was performed for the *Y*obs data from run 1, and the calibrated Ky values were used to simulate the *Y*a from run 2.

In the validation step, *Y*a was simulated for the *Y*obs data from repetition 3, with Ky values calibrated for repetition 1.

To estimate the *Y*a, equation 5 was used, which is based on the *Y*mp penalty for water deficit:

$$Ya = Ymp_i \times \left[1 - ky_i \times \left(1 - \frac{ETr}{ETm}\right)\right] \tag{5}$$

The ETr was estimated by the method of the sequential water balance of the crop, proposed by Thornthwaite and Mather (1955).

The ETm was calculated by multiplying the reference evapotranspiration (ET_0) and the crop coefficient (Kc). To calculate the ET_0, the Hargreaves and Samani equation (1982) was used. The interpretation of Ky values was based on the classification proposed by Doorenbos and Kassam (1994), in which: Ky < 0.85 = low; 0.85 < Ky < 1 = low/medium; 1 < Ky < 1.15 = medium/high and Ky > 1.15 = high. The water balance output variables are shown in Figure 2:

Kc was obtained using the methodology proposed by Driessen and Konijn (1992), in which the relative developmental stage (*RDS*) of *Urochloa humidicola* grass was calculated as a function of the accumulation of daily thermal sum, considering a basal temperature lower than 15 ºC, according to found by Villa Nova *et al.* (2007) for the grass *Urochloa brizantha* cv. Marandu, and from the thermal sum to flowering, which was 3,587 °C in experiment E1 and 3,503 °C in experiment E2.

Then, the reference Kc (Kc_{ref}) was calculated for a hypothetical plant species, according to equation 6:

$$Kc_{ref} = 0.33 + 0.73 \times RDS_i + 1.93 \times (RDSi)^2 - 2.33 \times (RDS_i)^3 \quad (6)$$

The correction for the effect of air turbulence was performed using the turbulence coefficient (*TC*), considering a maximum turbulence coefficient (*MTC*) equal to 1.2, according to equation 7:

Figure 2 - Extract the sequential water balance of the crop in experiments E1 and E2, used to analyze the AZM-FAO model for *Urochloa humidicola* grass

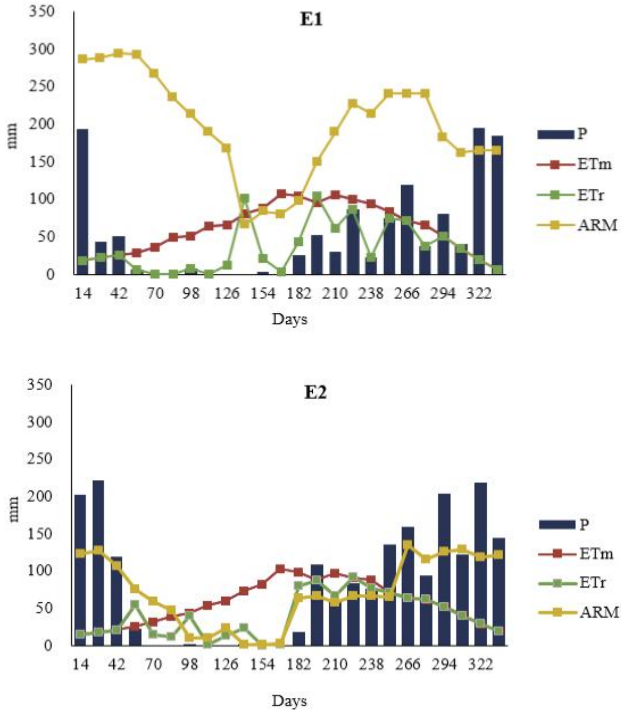
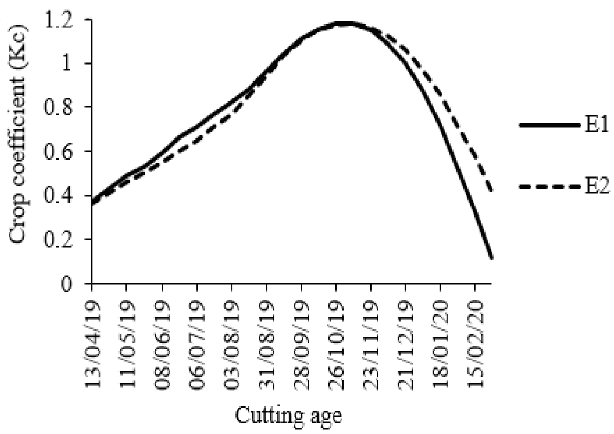


Figure 3 - Variation of the crop coefficient values calculated for *Urochloa humidicola* grass during the experimental period



$$TC = \frac{1 + (Kc_{ref} - 0.33) \times (MTC_i - 1)}{0.67} \quad (7)$$

Kc was then calculated by multiplying Kc_{ref} by *TC*. The Kc values used to adapt the model are shown in Figure 3.

*Y*a was considered equal to *Y*mp when the sequential water balance of the crop indicated no water deficit at a given cutting age; thus, it was assumed that the soil had adequate moisture for the pasture to express its yield potential.

Statistical analysis

Forage yield and LAI variables were submitted for analysis of variance ($p < 0.05$). To analyze the performance of the model, the following statistical parameters were used: coefficient of determination (R^2), Willmott's concordance index (*d*) (WILLMOTT *et al.*, 1985), Pearson's correlation coefficient (*r*), root mean square error (RMSE in %), mean absolute error (MAE), and confidence index (*c*) (CAMARGO; SENTELHAS, 1997).

RESULTS AND DISCUSSION

Analysis of variance for forage yield and LAI

There was an effect of cutting age on forage yield and LAI in both experiments ($p = 0.000$). For the block, there was no significant effect in E1 ($p > 0.05$); however, in experiment E2, a significant effect was observed for both variables ($p < 0.05$), as can be seen in Table 2.

It is noted that both experiments presented good precision in the functional relationship between forage yield and cutting age (Figure 4).

The highest value observed for forage yield in experiment E1 was 46.6% higher than the highest value observed in E2. This is probably attributed to the higher soil water availability observed in experiment E1, which provided the highest forage accumulation.

In E1, as it is located in a lowland area, the pasture is subject to periodic flooding, which may have contributed to its greater performance since the *Urochloa humidicola* grass has a satisfactory adaptation to floodplain environments (QUEIROZ *et al.*, 2012).

In experiment E2, the pasture is located in a mountainous area, oscillating in soil depth, facilitating surface water runoff. This explains the low SWS values and, consequently, lower LAI (Figure 5).

Calibration of the AZM-FAO model for *Urochloa humidicola* grass

Table 2 - Summary of analysis of variance for forage yield and LAI of *Urochloa humidicola* grass according to cutting age

Exp.	S.V.	Forage yield			LAI		
		DF	Fc	p-value	DF	Fc	p-value
E1	Cutting age	23	24.641	0.000*	23	11.827	0.000*
	Block	2	1.763	0.183^{ns}	2	1.787	0.1789^{ns}
	Residue	46	-	-	46	-	-
	Total	71	-	-	71	-	-
	CV (%)	6.66	-	-	8.91	-	-
E2	Cutting age	23	17.936	0.000*	23	15.427	0.000*
	Block	2	4.993	0.0109*	2	6.061	0.0046*
	Residue	46	-	-	46	-	-
	Total	71	-	-	71	-	-
	CV (%)	5.75	-	-	6.05	-	-

* Significant at 5% probability; $_{ns}$ not significant; CV - coefficient of variation

Figure 4 - Linear regression models for forage yield (kg ha^{-1}) of *Urochloa humidicola* grass in experiments E1 and E2 according to cutting age

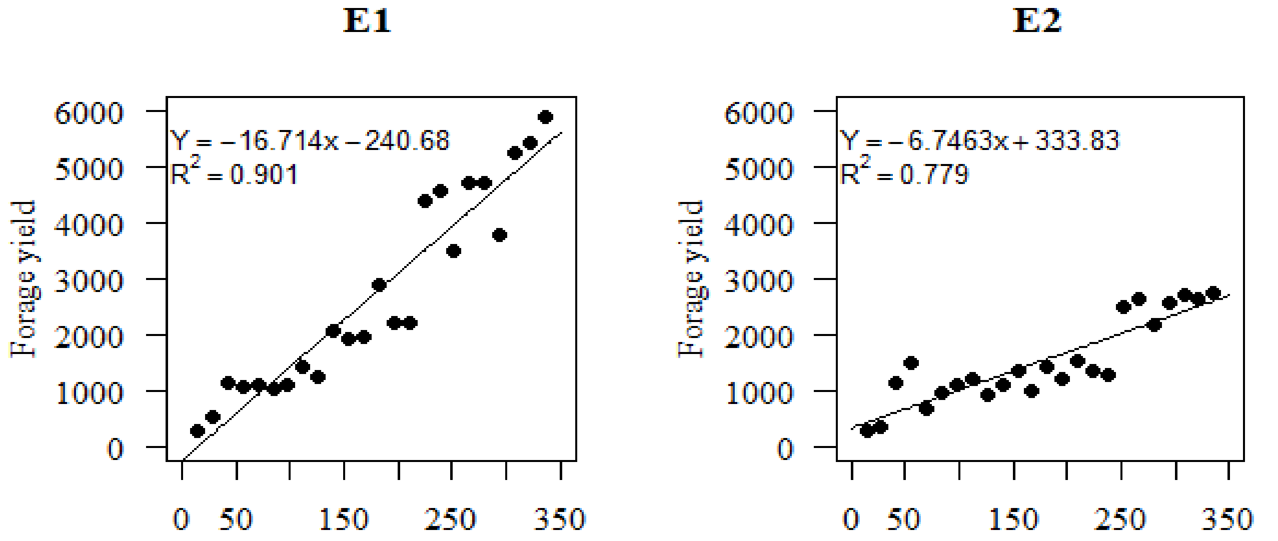
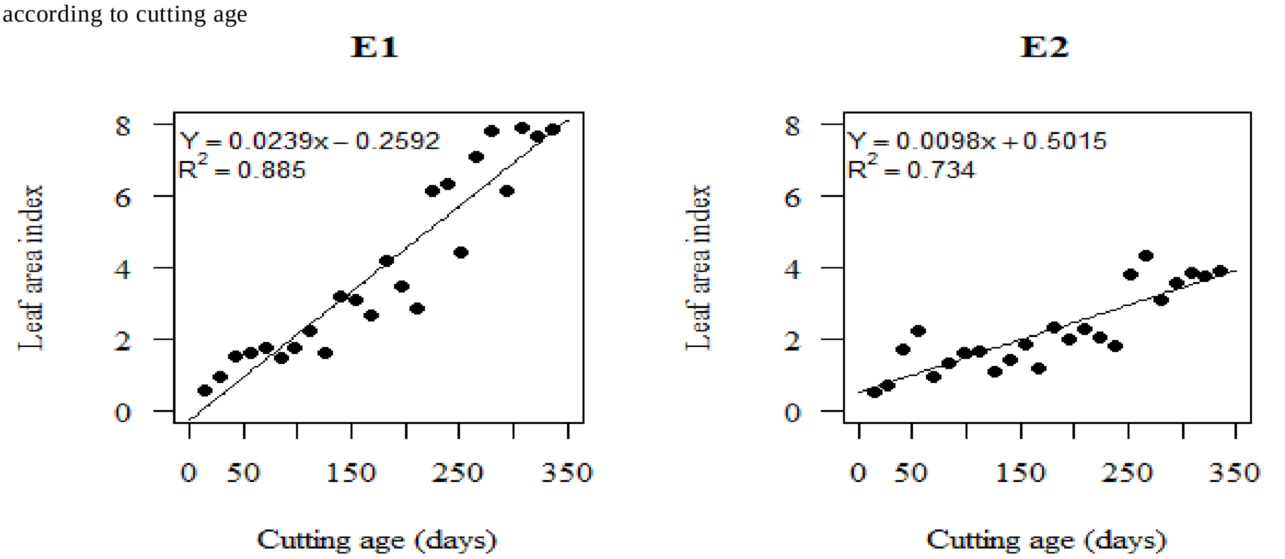


Figure 5 - Linear regression models for Leaf area index (m m^{-2}) of *Urochloa humidicola* grass in experiments E1 and E2 according to cutting age



In both experimental areas, there was underestimation and overestimation of simulated values about observed ones, however, with similar trends (Figure 6).

The *Y*mp variation was greater concerning the *Y*obs data when compared to *Y*a, probably due to the cutting ages that presented low water availability in the soil, which affected the yield potential of the pastures.

At E1, Ky values ranged between 0 and 1.9, while at E2, this variation ranged from 0 to 2.4. At E1, the highest Ky value was observed in November (T16), indicating a high yield response coefficient to water in this period (Ky > 1.15); however, in the other months, Ky values were below 0.47, indicating low yield response coefficient to water (Ky < 0.85).

In E2, Ky values were observed, indicating high sensitivity to water deficit (> 1.15) in July (T7), September (T13), and November (T17), being 2.4, 1.66, and 2.14, respectively.

In this experimental area, a Ky value equal to 1.0 was also observed in October (T15), indicating a medium/high yield response coefficient to water (1.0 < Ky < 1.15). In the other months, Ky was below 0.85, indicating a low yield response coefficient to water.

These results demonstrate that the yield response coefficient to water of *Urochloa humidicola* grass varies between regions with different edaphoclimatic characteristics.

Mombach *et al*. (2019) observed approximate Ky values when evaluating the yield response coefficient to water of two forage species. The authors found an average Ky of 1.05 for Mombaça grass, ranging from 0.01 to 2.23, and for Marandu grass, an average Ky of 0.63, ranging from 0 to 2.05.

By analyzing the AZM-FAO model to simulate corn yield in Rio Grande do Sul, Buske *et al*. (2019) observed poor performance of the model, with a *c* index ranging from 0.45 to 0.47, being classified as ''bad''. The authors attributed the results to the fixed Ky values used throughout the crop cycle, demonstrating the importance of calibrating this index in the simulation result.

The model showed good precision (Figure 7) and accuracy (Table 3) in the two experimental areas, as seen in the R^2 and *d* index values, respectively.

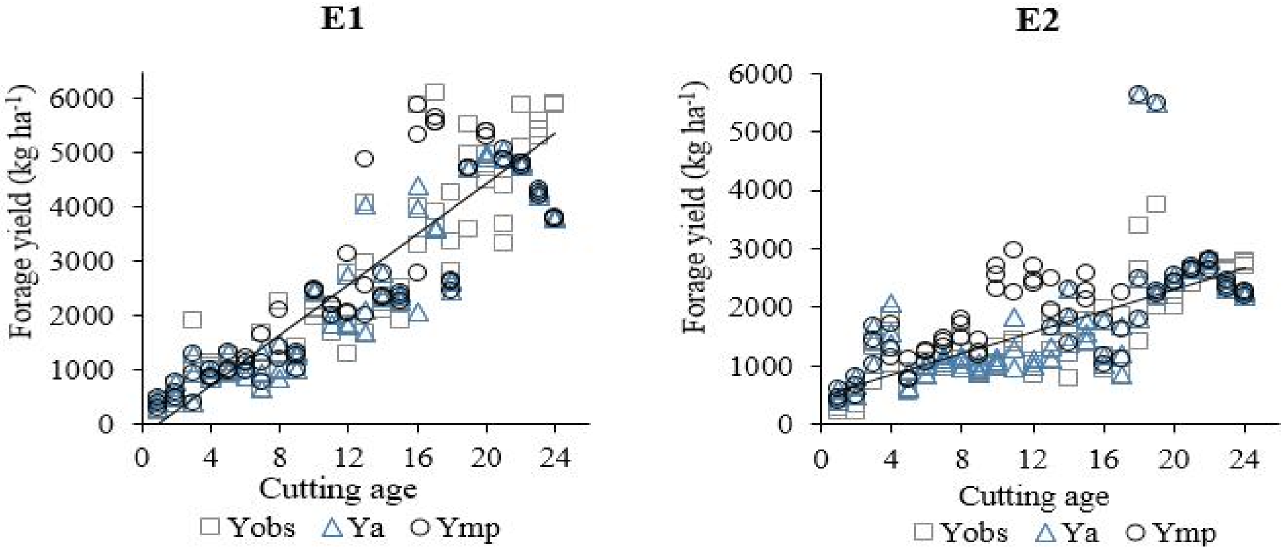
This indicates that the water deficit affected the forage yield in both regions; although a situation of *Y*a = *Y*mp occurred at some cutting ages, the low water availability influenced the forage yield, which generated a good relationship between *Y*obs and *Y*a.

In the AZM-FAO model study to simulate sugarcane yield, Oliveira *et al*. (2012) observed R^2 values of 0.77 and 0.89 and *d* index of 0.94 and 0.95 in the model calibration phase for plant cane and ratoon cane, respectively.

Approximate results during model calibration were also observed in a study by Almeida, Sediyama, and Alencar (2017), in an analysis of the AZM-FAO model for irrigated coffee trees, with *d* index values ranging from 0.93 to 0.94, as observed in this study, and R^2 varying between 0.79 and 0.95.

In E1, the MAE showed a deviation from the mean higher than that of experiment E2, despite the lower accuracy of the model in the latter, while for the RMSE of experiment E2, the forecast was classified as "poor" and the *c* index as "very good".

Figure 6 - Distribution of observed (*Y*obs), real (*Y*a), and potential (*Y*mp) forage yields of *Urochloa humidicola* grass during the experimental period



This result observed in experiment E2 probably resulted from the overestimation of the model in treatments 18 and 19. At these cutting ages, the highest *Y*obs values were observed during the experimental period, which generated even higher simulated values.

The influence of these treatments on the RMSE was confirmed by calculating it with the absence of these data for a total of 22 cutting ages, generating a new RMSE value equal to 16.9% and changing the classification to ‘’good’’. However, as the MAE value was lower and the model’s performance demonstrated good results by the *c* index, the amount of original data was maintained.

The *c* index values in both experiments were higher than those observed by Buske *et al.* (2019) during the calibration of the corn crop model, demonstrating the good results of the calibrated model for a perennial crop under different edaphoclimatic conditions.

The AZM-FAO model can be applied to different plant species; however, some authors demonstrate that adaptations are necessary to improve the performance of the model, as is the case of the study by Carvalho *et al.* (2017) for the cactus pear crop in which they observed better results from the modified AZM-FAO model when compared to the original.

In this study, the values of Kc and Ky were explicitly calculated for the forage under study, under field conditions, which may have contributed to improving the performance of the model in calibration.

Validation of the AZM-FAO model for *Urochloa humidicola* grass

Table 4 shows model validation results between simulated and observed data in both experiments.

The values of *d*, *r,* and *c* were maintained in experiment E1 and increased in experiment E2, improving the performance of the model. The same was observed for the R^2 values (Figure 8).

Oliveira *et al.* (2012) observed in the validation phase of the AZM-FAO model a reduction of the R^2 to 0.55 and of the *d* index to 0.80 after the model correction. Even with a reduction in statistical indexes, the authors concluded that the model performed well and can be used to simulate sugarcane yield in Minas Gerais, provided that the necessary corrections are made.

Figure 7 - Calibration of the AZM-FAO model between observed (*Y*obs in kg ha^{-1}) and real forage yield (*Y*a in kg ha^{-1}) of *Urochloa humidicola* grass for the southern region of Mato Grosso

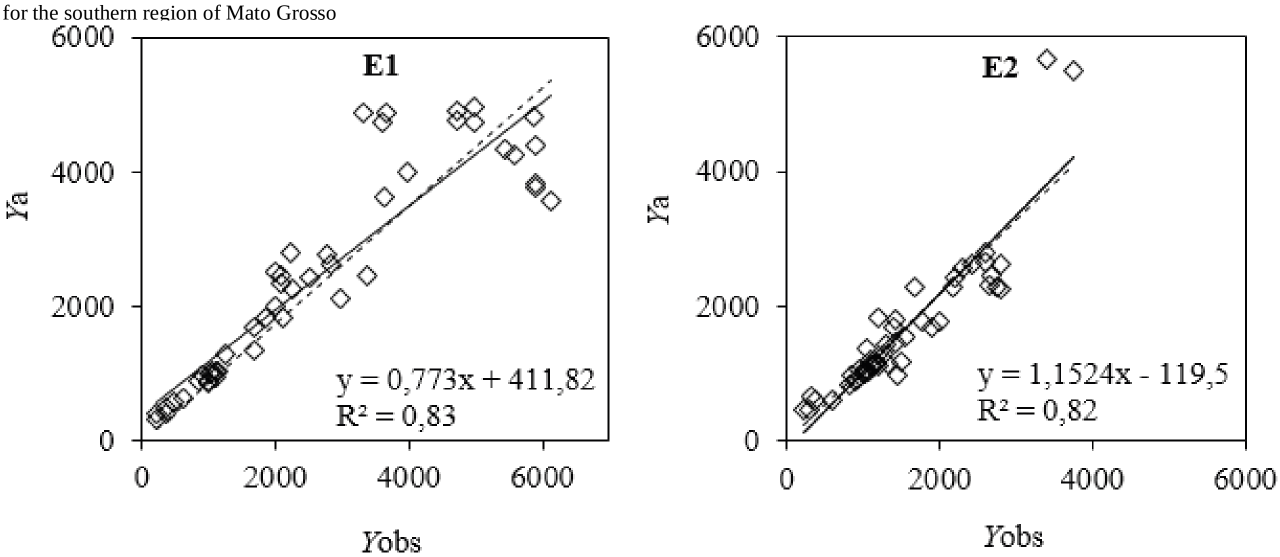


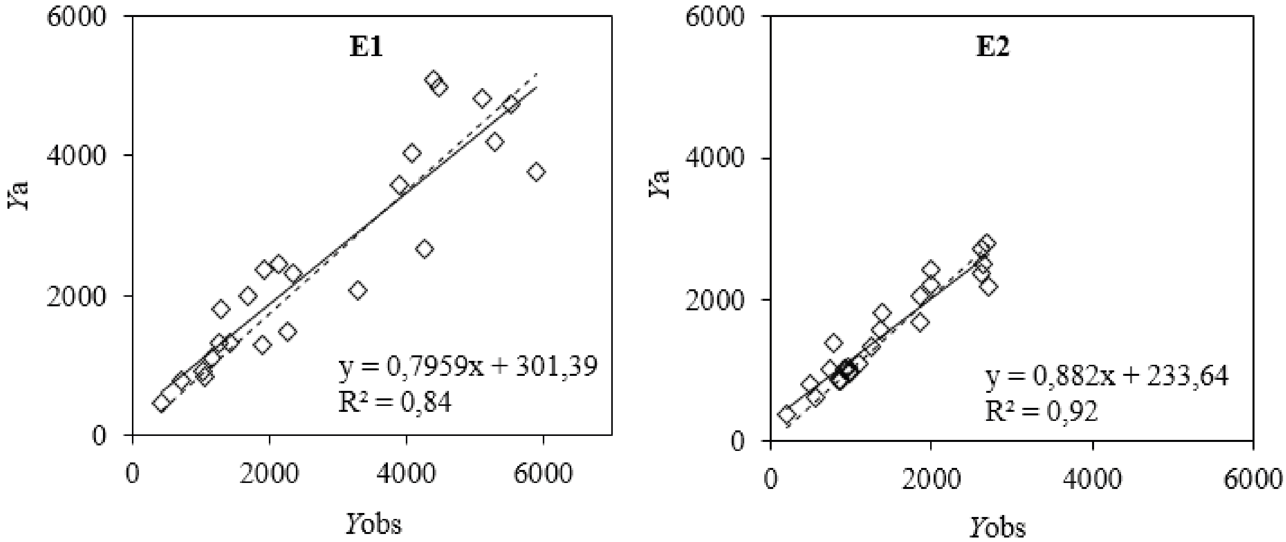
Table 3 - Statistical indexes and parameters relative to the performance of the AZM-FAO model in the simulation of the real yield (*Y*a) of *Urochloa humidicola* grass in the calibration phase

Exp.	MAE	RMSE	Classification	*d*	*r*	*c*	Classification
E1	455.23	29.86	acceptable	0.94	0.91	0.86	excellent
E2	253.76	30.74	poor	0.93	0.90	0.84	very good

Table 4 - Statistical indexes and parameters relative to the performance of the AZM-FAO model in the simulation of the real yield (*Y*a) of *Urochloa humidicola* grass in the validation phase

Exp.	MAE	RMSE	Classification	d	r	c	Classification
E1	513.89	26.41	Acceptable	0.94	0.91	0.86	Excellent
E2	190.3	17.50	Good	0.97	0.95	0.92	Excellent

Figure 8 - Validation of the AZM-FAO model between observed (*Y*obs in kg ha^{-1}) and real (*Y*a in kg ha^{-1}) forage yield of *Urochloa humidicola* grass for the southern region of Mato Grosso



In an analysis of the AZM-FAO model to simulate the yield of eucalyptus clones, Freitas *et al.* (2020) observed an improvement in the accuracy of the model, with R^2 going from 0.82 in calibration to 0.86 in validation and the *d* index remaining at the same calibration accuracy value (*d* = 0.93), aligning with the results obtained in this study.

The MAE showed an increase in the overestimation of the model in experiment E1 and a decrease in experiment E2. As for the RMSE values, there was a reduction in both experiments, improving the classification of the performance of the model.

These results indicate that in the validation phase, with independent data, the model showed improvement, with the error parameters indicating lower rates of increase and a significant reduction concerning the calibration phase, mainly in experiment E2.

Freitas *et al.* (2020) also observed an increase in the *c* index value, from 0.84 (very good) in calibration to 0.87 (excellent) in model validation.

The Ky variability found in the present study and also reported by Mombach *et al.* (2019), as also the variability of the performance parameters of models found here and in the other studies already cited, can be attributed to the use of evapotranspiration in the AZM-FAO model as a parameter for assessing the need and consumption of water.

Probably because transpiration is more directly associated with plant response than evapotranspiration, but separating the components of evapotranspiration requires information on soil shading by the plant, which was not provided in these studies.

The state of the art of plant response studies to reduced relative water consumption indicates that authors have sought to utilize transpiration, using more complex models such as Aquacrop, a software that uses daily meteorological data, various other soil and plant, in addition to soil water balance by layers. However, when not all the necessary information is available, there is the option of using empirical equations, such as pedotransfer functions and estimation of plant growth based on degree days. In any case, exhaustive calibration and validation study for this model constitutes a strong recommendation from most authors, considering the high number of empirical parameters involved.

The AZM-FAO model, although simpler and subject to the exact calibration and validation needs, requires a smaller number of empirical parameters and, as a result, can be used on a larger scale by technicians and producers.

CONCLUSIONS

After the calibration and validation steps, the AZM-FAO model showed satisfactory results and can be used with good precision to simulate the forage yield of *Urochloa humidicola* grass in the southern region of Mato Grosso.

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