ADJUSTING A SIMPLE CROP MODEL TO PREDICT MAIZE AND SORGHUM YIELD IN THE NORTHEAST BRAZIL

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ABSTRACT: Rainfed agriculture in the Northeast of Brazil has been frequently affected by adverse weather and climate conditions. To anticipate the occurrence of crop failure, this study aimed to adjust a crop model for maize and sorghum crops at Serra Talhada and Araripina, both in the state of Pernambuco, Brazil. We used the water balance model of the CPTEC/INPE, including information to estimate crop failure, as proposed by Doorenbos and Kassam (1979). The analysis showed an agreement index of 80%, classified as very good, and an error below 30%, classified as acceptable, which suggests that the adjusted model can also produce satisfactory estimates for the whole Northeast region.

Key words: rainfed agriculture, crop model, semi-arid, Brazil.

AJUSTE DE UMA MODELO DE CULTURA SIMPLIFICADO PARA PREVER RENDIMENTO DE MILHO E SORGO NA REGIÃO NORDESTE DO BRASIL

RESUMO: A agricultura de sequeiro no Nordeste do Brasil tem sido frequentemente afetada pelas condições adversas de tempo e clima. Para antecipar a ocorrência de um colapso na produção agrícola o presente trabalho objetivou ajustar um modelo agrometeorológico para as culturas de milho e sorgo nos municípios de Serra Talhada e Araripina, ambos no estado de Pernambuco. Foi utilizado o modelo de balanço hídrico do CPTEC/INPE, incluindo informações para estimar colapso de safra, como proposto por Doorenbos e Kassan (1979). A análise apresentou um índice de concordância de 80%, classificado como muito bom, e um erro menor que 30%, classificado como aceitável, o que sugere que o modelo ajustado possa também produzir estimativas satisfatórias pra toda região Nordeste.

PALAVRAS-CHAVE: agricultura de sequeiro, modelo agrometeorológico, semiárido, Brasil.

1. INTRODUCTION:

According to the most recent census (IBGE, 2012), the population of the Semi-Arid Region of Brazil is more than 22.5 million habitants. With a demographic density of 23.1 hab km^{-2}, it is considered one the world's most populated semi-arid regions (SUDENE, 2010). The rural population is almost 40% of the population (IBGE, 2012), who depends on rainfed agriculture for their subsistence. Intraseasonal and interannual variability of rainfall have a major influence on crop yield. Severe droughts cause crop failure and food insecurity in rural areas. Besides the vulnerability to droughts, several climate change scenarios suggest large areas of the Brazilian Semi-Arid could become unfeasible for rainfed subsistence agriculture, making poor populations more vulnerable because of a reduced food supply (MARENGO, 2010).

Although rainfed agriculture in the Semi-Arid has low economic relevance for the Brazilian economy, it is highly important from a social point of view because of the large low-income population living in rural areas.

Considering the high dependence on the crop yield with the climatic variations, many studies suggested that agrometeorological models could be used with reasonable accuracy in the identification of strategies for reduction of the impacts of the climatic variations on yields crops (SILVA, 2002), (HANSEN; INDEJE, 2004), (SOLER, 2007). Therefore, the goal of this paper was to adjust a simple crop model to predict maize and sorghum yield in several locations of the Brazilian Semi-Arid.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The crop model was adjusted for the locations of Araripina (8º 25' S latitude, 37 º4' W longitude and 622 m altitude) and Serra Talhada (7º 59' S latitude, 38º 19' W longitude and 429 m altitude), both in the Semi-Arid Region of the state of Pernambuco, Brazil (Figure 1). Araripina has a Bsh climate according to the Koppen classification, with an annual rainfall of 742 mm concentrated from December through April and a mean temperature of 24º C. Serra Talhada has a Bsh climate according to the Koppen classification, with an annual climatological value of 837 mm, mostly between January and April, and a mean annual temperature of 26º C.

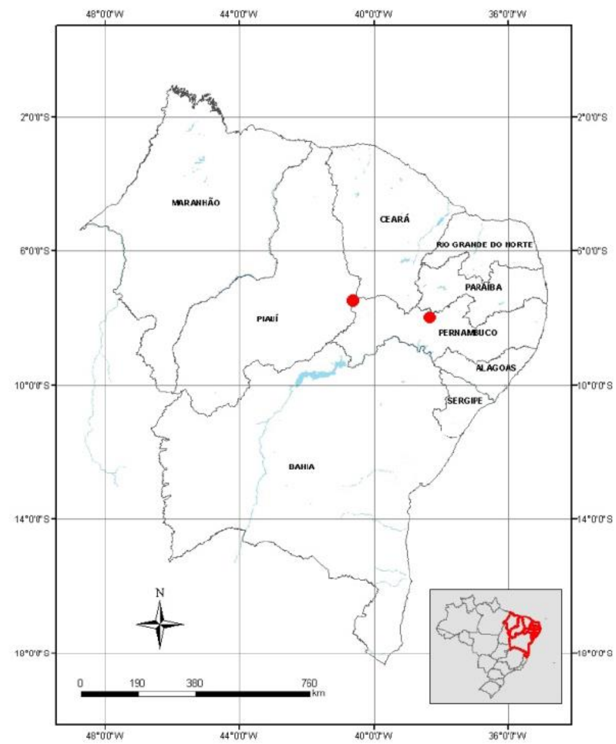

Figure 1: Study area
Fonte: Adaptaded from Barros (2010).

2.2 SOIL, WEATHER AND CROP DATA

Weather and crop yield data was provided by the Agronomic Institute of the State of Pernambuco (IPA) and by the Brazilian Agriculture Research Corporation (EMBRAPA). The weather daily data used were wind speed at a height of 2 m, maxima and minimum temperature, rainfall and solar radiation. Planting dates were at the beginning of the wet season in each region. The crop yield data used in this paper are averages of cultivars widely used by local agriculture and adapted to local conditions. Soil physical properties, including saturated hydraulic conductivity and others parameters for determinate the soil water retention curve were obtained from Barros (2010).

2.3 WATER BALANCE MODEL

We used the water balance model-WBM similar to WBM of the Center for Weather Forecasting and Climate Studies at the National Institute for Space Research (WBM - CPTEC/INPE) and we include information to estimate crop failure, as proposed by Doorenbos and Kassam (1979). The WBM - CPTEC/INPE considers that the rate of water loss by evapotranspiration ranges linearly with the water storage in the soil (TOMASELLA; ROSSATO, 2006).

The reference evapotranspiration was derived from the Penman-Monteith equation using the parameterization recommended by Allen et al. (1998)

We assumed the actual evapotranspiration was equal to the crop evapotranspiration when the soil plant available water storage was above a critical moisture value $S_{crít}$ and below the maximum soil storage capacity, calculated by integrate the saturated water content along the soil depth S_{max}. The difference between S_{max} and S_{crit} defines the readily available soil water (FEDDES, 1978). For the soil storage below critical moisture, but larger than wilting point moisture, it is assumed that we assumed that the water uptake decreases linearly with water potential to zero, in other words, the relationship between actual to crop evapotranspiration, ETa/ETc, decrease linearly from critical moisture ($S=S_{crit}$) to permanent wilting point moisture. Mathematically, this is expressed as:

$$ETR = S/S_{crit} * ET_p, \quad \text{if } S < S_{crit} \qquad or \qquad Etr = ET_p, \quad \text{if } S \geq S_{crit} \qquad (Eq.\ 1)$$

The water storage in soil was derived from the soil water retention curve from Equation 1. The critical moisture (S_{crit}) and the permanent wilting point moisture were established according to Barros (2010), who determined the pressure head values for sorghum and maize considering this soil dataset. Thus, S_{crit} adopted was -35kPa and -75kPa for maize and sorghum, respectively, and permanent wilting point moisture was -1000 kPa and -1200 kPa for maize and sorghum, respectively. The water storage in soil was calculated using the weighted mean of the soil moisture in each 0.2m layer, considering four layers for Oxisol in Araripina, PE and three layers for Neosol in Serra Talhada, PE. Thus, the effective root zone was 0.8 m for Oxisol, while for Neosol it was 0.6m, due to the physical properties of each soil type.

The deep drainage was insert in WBM - CPTEC/INPE to consider the dynamics of soil saturation. This value is a surplus generated by the soil saturation. Then, the deep drainage is calculated assuming that the soil profile releases water at unit gradient, as presented in equation 2.

$$D_t = K_{sat}\,(S/S_{max})^{\eta} \quad (Eq.2)$$

Where Dt is the range of deep drainage (mm), K_{sat} is the saturated hydraulic conductivity (mm d^{-1}), arithmetically averaged along the soil profile, and η is a dimensionless Brooks-Corey's parameter calculated from:

$$\eta = 2.5 + \frac{2}{b} \qquad (3)$$

2.3 CROP MODEL

We have inserted into WBM - CPTEC/INPE an equation of crop loss. This crop model used was proposed by Dooenbos and Kassan (1979), and it is known as FAO crop model, represented by equation 4. It relates the crop loss ranges linearly with the water stress and the crop yield is maximum when the water stress is minimum.

$$Y_r = Yp * \prod_{i=1}^{4}[\,1 - K_{yi}\,(1 - ETr_i / ETp_i)] \quad (Eq.4)$$

Where Yr is the actual yield; (Kg ha^{-1}), Yp is the maximum yield (Kg ha^{-1}) and Ky is the yield response factor, which was assumed variable through crop development stages.

The original model proposed by Doorenbos and Kassam (1979) assumed the deficiency factor is equal to one in equation (4), maximizing the yield when the soil water deficit is zero. Experimental data from the Northeast of Brazil revealed that actual yield was close to maximum productivity, even for those cases where the soil water deficit was moderate. In other words, actual yield was maximum even when relative evapotranspiration was slightly less than zero. This is probably related to the fact the data used in this study are cultivars adapted to the climate of the Brazilian Semi-Arid, and can tolerate strong deficits without significant yield loss.

The adjusted relationship can be seen in equation 5:

$$Y_r = Y_p * \prod_{i=1}^{4} [1 - K_{yi} (fd - ETr_i / ETp_i)] \quad (Eq.5)$$

Where fd is a parameter known as the deficit factor. The deficit factor can be expressed as:

$$fd = 1 - Dh_{min} \quad (Eq.6)$$

Where $Dh_{mín}$ is the minimum value of the relative evapotranspiration that makes the actual yield equal to maximum productivity.

Alternative formulas of the original Doorenbos and Kassam (1979) models have been proposed by Camargo et al. (1988) for other regions of Brazil.

The yield response factor, ky, represents the sensitivity of a particular cultivar of a certain crop to water supply deficit. It depends on the development stage but also on local conditions; Andrioli and Sentelhas (2009), for instance, determined Ky for maize and sorghum for each stage and for the most common cultivars used in Brazil.

The value of Yp was estimated from climatic data and it is generally used to identify the site yield potential. In this paper, we used the method of Wageningen – MWA, as proposed by Doorenbos and Kassam (1979).

2.4 GOODNESS-OF-FIT

The approach to assess the goodness-of-fit consisted in analyzing the correlation coefficient (r), measure of precision, agreement index (d), measure of accuracy and performance index (ic), jointly evaluates the correlation coefficient and agreement index. Precision was quantified by Pearson's correlation coefficient (r) and interpreted according to Santos (2007). Accuracy was quantified by Willmott's agreement index (d), which varies from zero for no agreement, to one for perfect agreement (WILLMOTT, 1982). Performance was quantified by the (c) performance index (CAMARGO; CAMARGO, 2000), defined as a product between (r) and (d) and interpreted according to Camargo and Sentelha (1997). The error was measured by root mean square error (RMSE) expressed in percent, calculated according to Loague and Green (1991) and interpreted according to Jamieson et al. (1991).

3. RESULTS AND DISCUSSIONS

3.1 MODEL ADJUSTMENT

Measured yield data shown that, for a total of 54 complete cycles (11 complete cycles of maize and 43 cycles of sorghum) in all experimental sites, the relationship between actual and potential evaporation never exceeded 0.9, even when actual yield was almost maximum (Figure 2).

Since the method proposed by Doorenbos and Kassan (1979) predicts that any reduction in the ratio between actual and potential evapotranspiration is associated with a proportional reduction in crop productivity, a deficiency factor was introduced in the original model. The deficiency factor takes into account that yield is maximum when the soil water deficit is not significant, and based on historical data (Figure 2) was set to 0.1.

The deficiency factor indicates that, for the Brazilian Semi-Arid, it is not necessary for the water supply to reach the atmospheric demand to achieve maximum productivity, and it indicates that the cultivars of the Semi-Arid are able to cope with mild soil water deficits without significant reductions in productivity.

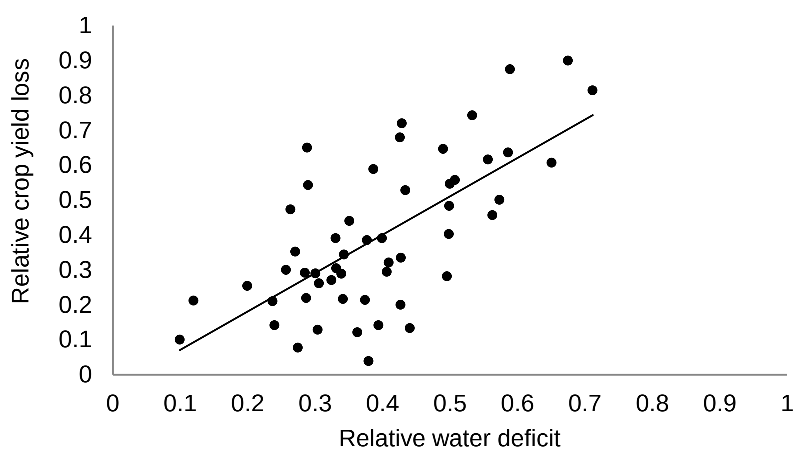

Figure 2 – Relationship between relative crop yield loss (1-Yr/Yp) and relative water deficit (1- ETa/ETc), for determining the minimum water deficit.

The analysis of the maize and sorghum data in Araripina and Serra Talhada, PE, was made considering the specific coefficients for each crop and locality. The estimates for the two localities in the study can be seen in Figure 3.

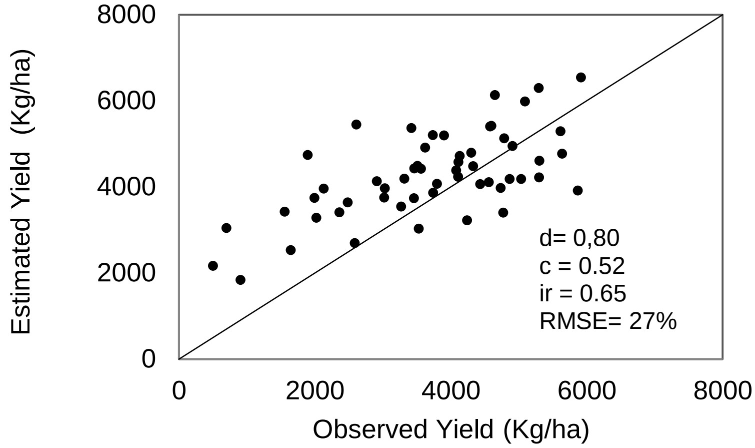

Figure 3- Relationship between the observed and estimated maize and sorghum yields in Araripina and Serra Talhada, PE.

While the correlation coefficients were found to be 0.65, the performance index was found to be 0.52. However, the agreement index was found to be 0.80, classified as very good (Willmott et al. 1982). The results obtained with the adjusted model were similar to results obtained by Barros (2010). This author also jointly evaluates data from the locations considered in this study, and also considered other locations. However, the correlation indices (r = 0.45 to 0.60) were lower than the results presented by the adjusted model (r = 0.65), while the agreement index presented better results in Barros (2010) (d=0.82 to 0.87) than in present study (d=0.80).

We highlight the simplicity of the model used in this study compared to other studies cited here, however the results showed its good relationship between simplicity and accuracy.

The deficit factor added into the equation of Doorenbos and Kassam (1979) helps to reduce the errors to acceptable levels and still raise the precision, accuracy and performance of the generated estimates. Camargo et al. (1988) also included a correction factor for excess water into the Doorenbos and Kassam (1979) model, which allowed the satisfactory estimation of the soybean potential yield.

Others models also showed deficiencies in estimates when dealing with extreme water, as observed in the study of Freitas et al. (2005) who found that the model underestimated yield in treatments in which water deficit occurred and overestimated yield in treatments with excess water.

According to the results obtained in this study, the adjusting of this crop model is justified, in conformity with the water conditions of each region, aiming to improving the yield estimates.

4. CONCLUSION

It is noteworthy that the model, even accounting for simple processes, provided reasonable estimates of maize and sorghum yield in the Semi-Arid of Brazil.

The estimates, generated by the adjusted model of Doorenbos and Kassam (1979) coupled to a water balance model conceptually similar to MBH CPTEC / INPE, are indicative of variables that can comprise a satisfactory methodology for analyzing crop failure of maize and sorghum in the studied region.

The estimates generated by the simple adjusted model in this study were similar to estimates generates by complexity models. These results demonstrate the importance of key processes in the simulations. In this study, we can consider the water balance and its components and also the climatic characteristics that influence the potential yield. Often, it is not necessary that the simulations represent complex processes, but rather, represent the processes that most affect yield crop considering the edaphoclimatic conditions of the region.

The joint evaluation of variables should be seen as a form of, besides generating a more consistent forecast of crop yield, having a better representation of the physiological plant processes that involves the relationships among water, soil, plants and the atmosphere.

ACKNOWLEDGEMENTS: Earth System Science Center – National Institute for Space Research -CCST/INPE and Coordination for the Improvement of Higher Education Personnel -CAPES

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