Adaptation of the crop growth models EPIC and Almanac to local *cowpea* and *maize* cropping systems in Northeast Brazil

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Abstract

In an interdisciplinary approach, the Brazilian-German joint program WAVES *(WATER AVAILABILITY AND VULNERABILITY OF ECOSYSTEMS AND SOCIETY IN SEMIARID REGIONS OF NORTHEAST BRAZIL)* aims at analyzing the interactions between water availability, natural resources and human activities, to predict the impact of climate change on natural and social systems. Therefore, the *SEMI-ARID INTEGRATED MODEL* (SIM) and the *MODEL FOR SUSTAINABLE DEVELOPMENT OF LAND USE* (MoSDEL) were developed for evaluating strategies on state and regional level of a sustained development in Northeast Brazil. A majority of the population in the rural areas depends directly or indirectly on agriculture production. There, crop production is often adversely affected by droughts and low soil fertility levels. *The ENVIRONMENTAL POLICY INTEGRATED CLIMATE MODEL* (EPIC) and it's follow-up version *AGRICULTURAL LAND MANAGEMENT ALTERNATIVES WITH NUMERICAL ASSESSMENT CRITERIA* (ALMANAC) were selected for generating the crop input data of the agricultural sector sub-model of integrated models SIM and MoSDEL.

In 1998, field trials with local *maize* (*Zea mays*) and *cowpea* (*Vigna unguiculata*) varieties were established at representative sites in the municipalities of Picos (Piauí) and Tauá (Ceará) to test the reliability of both models under semi-arid conditions. Growth- and yield-related parameters were periodically determined under traditional and improved crop management and used for comparisons of measured and simulated data. The two important crops maize and cowpea were used to test the models. First simulation runs with EPIC/ALMANAC showed that the leaf area development of both crops was underestimated by the models. After adjusting *leaf area index* related parameters in the models, a better correlation was found. The models were now able to simulate different production levels for better and marginal locations in the region. Focusing on the marginal locations with only low fertile soils, like the chapada, the models, however, showed problems to simulate yield production of maize and cowpea in better years or under improved crop management. Results obtained from the more fertile sites at Tauá showed a better correlation between measured and simulated data, even under improved crop management. An analysis of crop file parameters and output data revealed a high sensitivity of the models to soil acidity related parameters. A strong relationship between low pH, reduction of root formation and days with water stress was found in the models calculations. It was possible to adapt the model partially to this problem, however, failed to simulate the positive response of local varieties on fertilizer applications observed in Picos. This problem relays on the models stress calculation. Following *Liebig's minimum law* only the main limiting factor is considered in the calculation. Under the side conditions of the chapada in Picos, water stress was assumed being more important than the lack of nutrients in the model's calculation. Thus, the model's did not respond to fertilizer applications. In conclusion, both models have the capacity to simulate crop growth under the semi-arid conditions of Northeast Brazil. However, to get reliable results if more than one stress/limiting factor exists, stress and nutrient calculation in the model had to be adapted yet .

Keywords

EPIC, ALMANAC, crop growth models, maize, cowpea, Brazil, semi arid.

1 Introduction

The development of the Northeast of Brazil is strongly influenced by the high climatic variability in this region (Holzborn, 1978). The appearance of dry and rainy seasons showed a great spatial and temporal variation from year to year (Conti, 1995). Regularly, the rainy season itself had only an erratic rainfall distribution. Even in years with a good precipitation, dry spells from up to three weeks might occur and endanger the agricultural production. This leads, together with the often found low soil fertility, to a high risk for agricultural production. Especially small scale farmers, with no access to irrigation or other improved production methods, depend on the natural resources and precipitation. Inquiries from the IBGE (1999) showed that drought reduced production of annual crops in more than one third of the studied areas in Piauí. In extreme dry years, as a consequence of the global El Niño phenomena, total loss can be considered. On the other hand, agricultural production is the most important economic activity in the rural areas of Northeast Brazil. The adverse conditions in this areas lead to a migration process from the rural areas to regional and national urban centers, causing great disturbance in the Brazilian society.

The German Brazilian project WAVES (*WATER AVAILABILITY AND VULNERABILITY OF ECOSYSTEMS AND SOCIETY IN NORTHEAST BRAZIL*) developed two integrated models to describe that situation: (i) SIM (Semiarid Integrated Model) which simulates processes on state level and (ii) MoSDEL (*MODEL FOR SUSTAINABLE DEVELOPMENT OF LAND USE*) which simulates processes on an regional level. The project areas are the Northeast Brazilian states of Ceará and Piauí, with focus regions in Picos, Piauí and in Tauá, Ceará. Both integrated models are composed by various sub-models. This sub-models simulate singular process components, of important factors in the socio, environmental and economic processes in the Northeast of Brazil. WAVES aims to analyze the interactions between water availability, natural resources and human activities and to predicting the impact of climate change on natural and social systems

To simulate the agricultural crop production the EPIC[1] model *(ENVIRONMENTAL POLICY INTEGRATED CLIMATE MODEL*) was chosen among a group of 13 crop growth models, as it considers soil acidity and aluminium toxicity, two important factors which limit crop production in the region beside the adverse precipitation

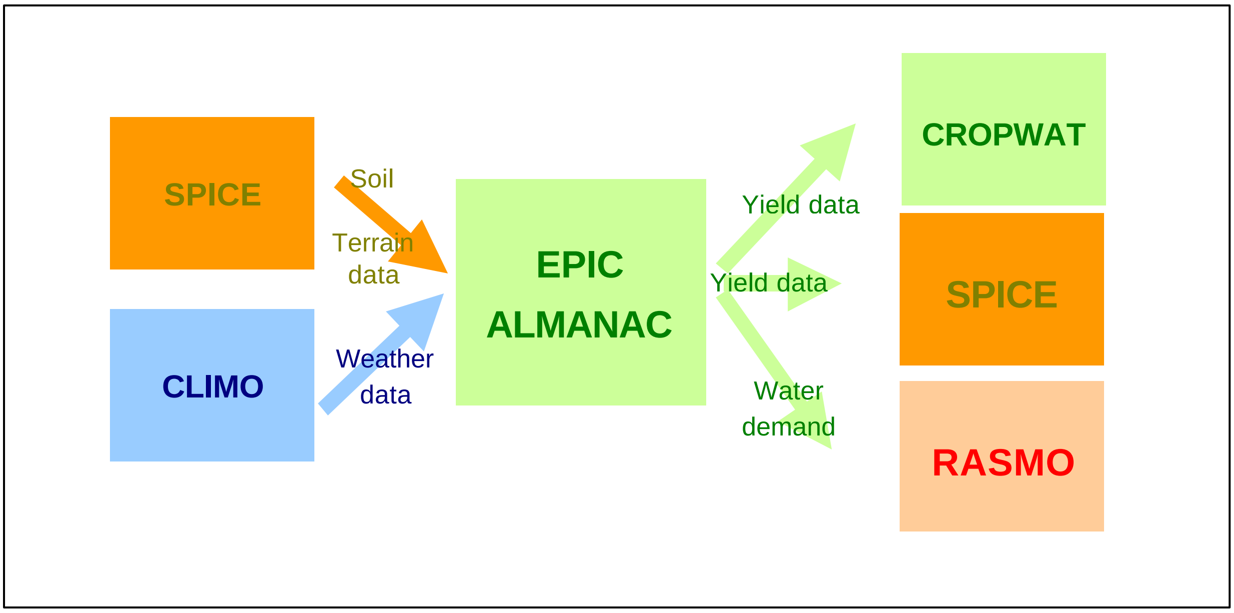

Figure 1: Overview of the links from EPIC/ALMANAC within the integrated models SIM and MoSDEL

SPICE = Soil Terrain Information System for the states of Piauí and Ceará; CLIMO = Climate simulation model, generates long-term weather data for the states of Piauí and Ceará; RASMO = Regional Agricultural Sector Model; CROPWAT = FAO program for irrigation and planning and management.

distribution. Beside this, EPIC had the derivative ALMANAC[2] (AGRICULTURAL LAND MANAGEMENT ALTERNATIVES WITH NUMERICAL ASSESSMENT CRITERIA) which is able to simulate intercropping of several cultures, the main cropping system in rainfield agriculture in Northeast Brazil. Tests with EPIC in other environments showed satisfactory simulation results (Cabelguenne and Debaeke, 1998; Roloff et al., 1998) but EPIC never was tested under the conditions of the Northeast of Brazil. Preliminary test with data from rice on a site in Piauí showed reasonable results for some treatments (Gaiser, T. and T.H. Hilger , 1997):, but also showed the necessity to adapt the model to the local conditions. Therefore, it was the task of the working group AGRONOMY within the WAVES project to test and calibrate the EPIC model to simulate crop production under the conditions of the Northeast of Brazil.

The EPIC model is complete interlinked within the integrated models SIM and MoSDEL. Hilger et al. (1999a) and figure 1 describe the interfaces with other sub-models, the demand of in formations from other models and how the EPIC output is aggregated in other sub-models.

2 Material and Methods

Field data

Only few field data to test the reliability of the EPIC/ALMANAC model simulation for the region are available, so it was necessary to execute field trials in the region to collect sufficient data. From 1998 to 2000, field trials with local *maize* (*Zea mays*) and *cowpea* (*Vigna unguiculata*) varieties were established at representative sites in the municipalities of Picos, Piauí (7 S, 41 W). and Tauá, Ceará (6 S, 40 W) to collect field data for further tests of the models. The field trials in Picos laid in the responsibility of the University of Hohenheim. The trials were installed in various locations around Picos, covering the main landscape components. They ranged from 550m on the chapada to 200m a.m.s.l. in the valley. Beside several smaller trials, basic data collection was obtained from two main trials, one on the chapada, the other in the valley. The trials were installed with local cultivars of maize and cowpea, as they are basic crops for subsistence of local small farmers. The influence of several treatments on development and yield were observed: (i) competition in mixed cropped systems, (ii) effect of fertilizer application, (iii) planting density, (iv) spatial distribution and (v) different cultivars. During growing season, dry matter production and leaf area development were periodically determinated. At harvest, total dry matter production (above ground) and grain yield were determinated. This data were used to test and calibrate the models.

The soils on the chapada were very acid (pH 4.0) *Aluminum-haplic Acrisols*, with high Al^{3+}saturation, whereas soils in the valley were *Eutric Fluvisols*, with no significant Al^{3+}concentrtion and an pH between 6.5 and 7.0. The average yearly precipitation lies around 600 mm but can vary between 200 and 1200 mm. Chemical and physical description of the soil profiles were surveyed by the working group *Soil Science* from WAVES, weather data were measured on climatic stations by the Section *Climatology* and the working group *Soil Science*.

Simulation

To adapt the model’s calculations to the local conditions, two main tools are available. The first is the Main Input File. It considers all side specific data, such as physical and chemical soil characteristics, weather data - generated by the model or as daily input form measured data - and all cultivation data from land preparation to harvest including irrigation and fertilizer application. The second tool is the EPIC file. It contains data blocks for each crop that can be simulated by EPIC. Every block is composed of specie-related data for growth, yield, stress resistance, nutrient uptake and other physiological characteristics. The working group *Agronomy* studied the crop growth and yield-related components in the EPIC file. For the simulations, the EPIC version 0941 and ALMANAC version 1364 were used.

The simulation of maize was started by using the existing EPIC/ALMANAC crop file, for cowpea a preliminary crop file was used, as this species was not considered in the model yet. This first test version for cowpea was developed by the Brazilian counterparts in Fortaleza from the Federal University of Ceará (UFC). It based on the field pea file in the EPIC model.

3 Results and Discussion

First simulation runs showed that leaf area development of both crops was underestimated by the models. Simulated yield data with the measured data for the Picos region showed a low correlation for *maize* and *cowpea*. However, after first adaptations in the EPIC file, the model was able to reproduce the LAI development curve in traditional under traditional management in the region. Also, the models were now able to simulate the different yield levels, which could be observed between the landscape units in the Picos region as shown in figure 2.

The figure also showed that, looking on each landscape unit, simulation results for the valley and the baixio[4] showed more reliability than the results from the chapada. There, in two from three years, the observed *maize* yields were drastically underestimated by the model's simulation. For further examination, it was necessary to exclude other simulation errors in the model. Figure 3 shows the importance of exact weather data on the simulation results. The model offers a weather generator WXGEN to simulate weather data if they are not available. But if solar radiation is generated by the model, yields are underestimated. A better correlation can be found when long-term measurements of radiation are input. Similar problems showed the generation of precipitation. Here, the weather generator is able to reproduce the erratic rainfall distribution from given input data, normally measured long-term average values from a nearby weather station. This measured data determine the maximum and minimum values for the calculation. Within this given rage the generator randomize the precipitation. Obviously, the simulated weather data must not fit exactly to the weather in the year when the field data were observed. But under the extreme conditions in the Northeast of Brazil, one or two rainy days might be of great importance for yield production. Therefore, if the model has to be tested and calibrated, measured weather data should be used. The model except's external weather files as input in the calculation process.

However, using measured daily weather data as input, simulated and observed data still showed contrasting results. A hint for that reason was found comparing soil fertility of the different locations (Hilger et al., 1999b). It was found that the simulation with EPIC/ALMANAC considering more fertile soils, like in the valley area in Picos or in Tauá, showed a better performance, than simulations with the soils on the chapada. The toxic Al^{3+}

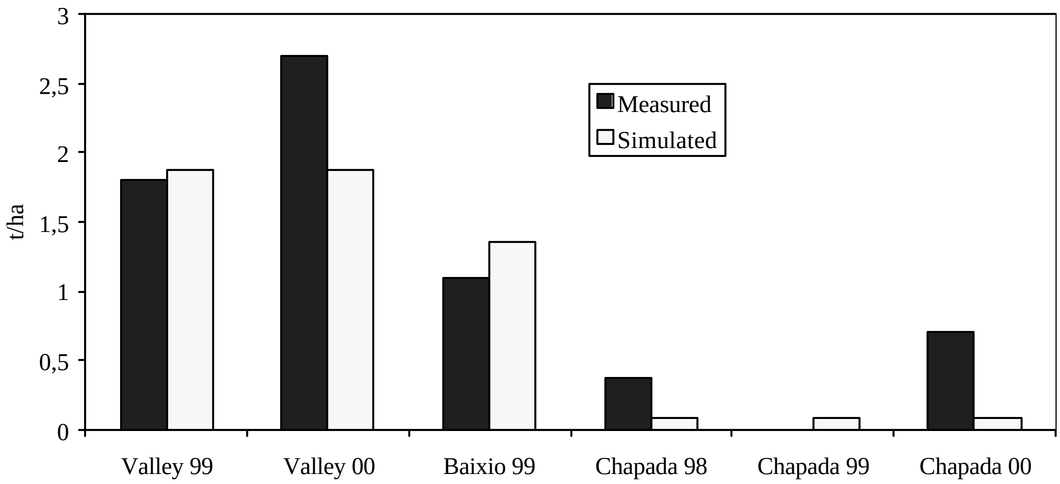

Figure 2. Simulated and observed *maize* yield for several locations in the Picos region, Piauí, Brazil.

Simulated and observed data in t/ha for sole cropped *maize* without fertilizer, Field data were collected between 1998 and 2000 in different locations near Picos PI.

concentration of the very acid soils on the chapada are a limiting factor for crop production. The model considers that fact using an Aluminium Toxicity Tolerance factor (Al^{3+} tol.). It range from 1 = sensitive to 5 = low sensitive to toxic Al^{3+} concentrations in the soil for each crop species used in the model. Figure 4 shows the influence of this factor on yield and dry matter production in the model. Considering a good adaptation of the cowpea to the adverse side conditions on the chapada, high Al^{3+} tol. values showed reasonable simulation results for traditional treatments. But for improved treatments, for example fertilizer application, the model simulation still can not reproduce a benefit effect as observed on the field trials (figure 5).

The problem is the model's calculation of stress factors. Actually, the models calculates the reduction in the daily crop growth rate due to *Liebig´s minimum law*. The current version considers water stress in over 90 %of

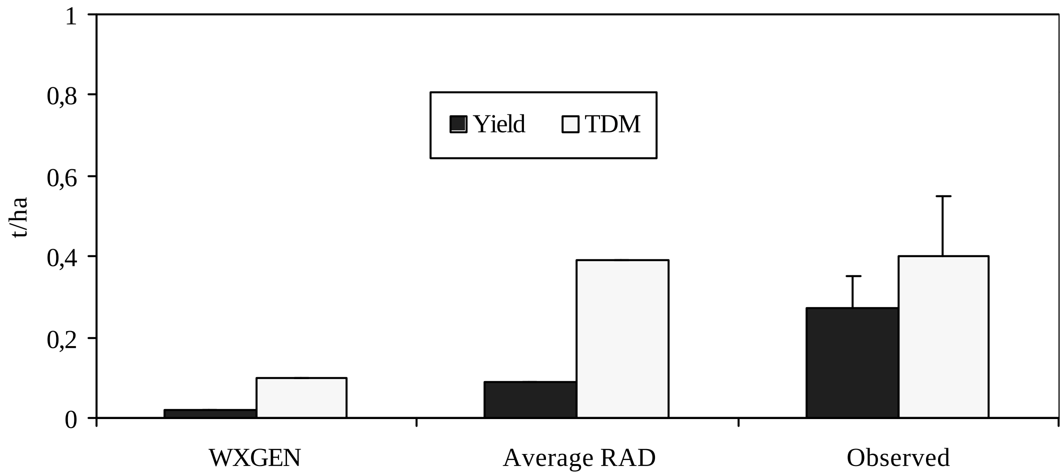

Figure 3: Influence of simulated and measured Solar radiation on yield simulation in EPIC.

Simulated and measured yield of sole cropped *cowpea*, without fertiliser application, on the plateau in the Picos region in t/ha for 1999. First simulation run with solar radiation as created by the EPIC WXGEN. Second simulation run with solar radiation as input data from long term measurements. (Al^{3+} tol.=4.0 in all simulations). Bars show the standard deviation of observed data

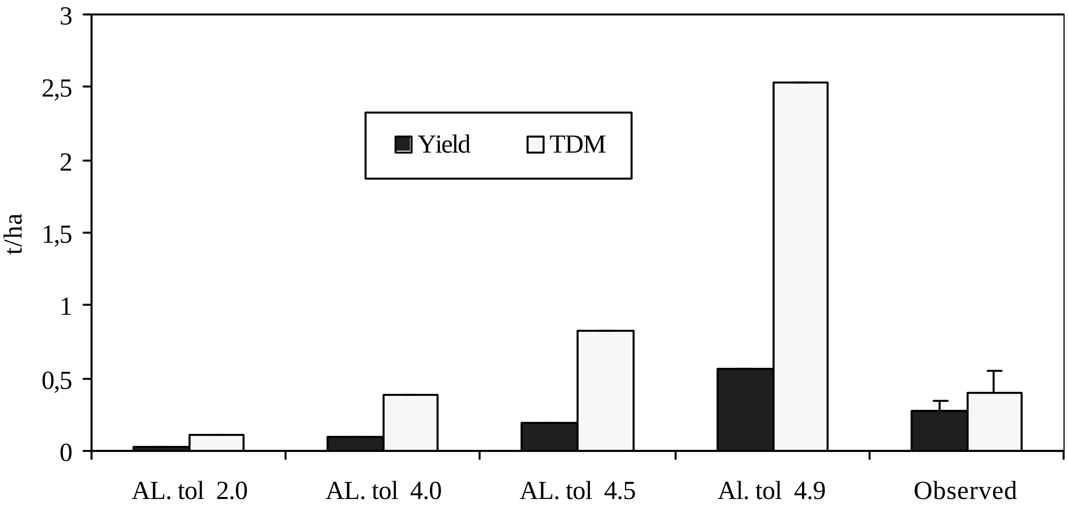

Figure 4: Effect of the Al^{3+} tol. factor in EPIC on simulation of *cowpea* yield and total dry matter production (TDM).

Simulated and measured yield for sole cropped cowpea, without fertilizer application, on the plateau in the Picos region in t/ha for 1999r. Simulation with four different values for the Aluminium Toxicity Tolerance factor. Bars show the standard deviation of observed data the cases, the most important limiting factor on the chapada. Therefore, other factors, as low soil fertility, were not considered. In consequence, fertilizer applications have no effect on the calculation of the crop growth rate in the simulation of the model, considering the conditions on the chapada. But on the field trials, a benefit effect could be observed.

Beside this nutrient, supply in the model is assessed by the relative concentration of specific nutrient in the plant. As, under the conditions on the chapada, the model first reduce drastically the crop growth rate, in regard to the low precipitation, later calculation of the nutrient support of the plant shows no limitation. So, in the model, drought stress reduces crop growth to a rate where even the small amount of nutrients in the chapada soils are sufficient, or the nutrient supply at that level is always in optimum for the model. Therefore, no fertilizer effects are reproduced.

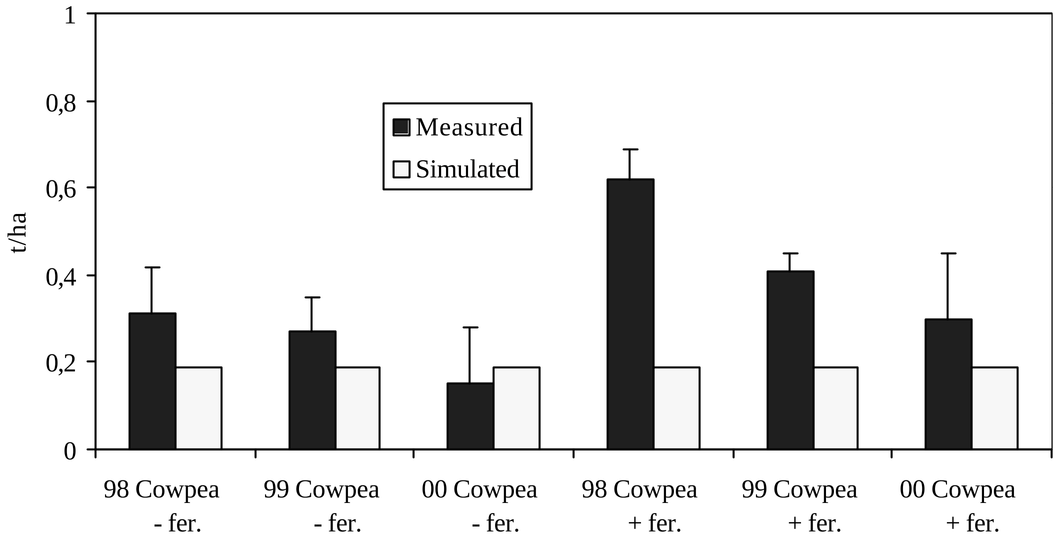

Figure 5: Effect of fertilizer application on simulated and observed *cowpea* yiels.

Simulated and measured yield of sole cropped *cowpea*, with/without fertiliser, on the plateau in the Picos region from 1998 to 2000. Al^{3+} tol . factor in simulation = 4.5. Bars show the standard deviation of observed data

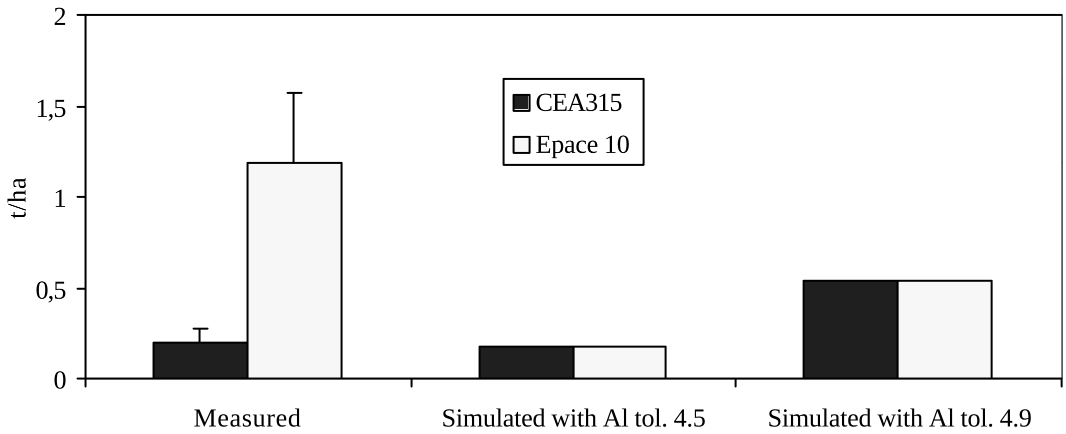

Figure 6: Effect of different cowpea cultivars on yield simulation in EPIC with different Al^{3+} tol. levels.

Simulated and measured yield of the cowpea cultivars CEA 315 and EPACE 10 on the plateau in the Picos region in 2000. Simulation with two different values for the aluminium toxicity tolerance factor. Bars show the standard deviation of observed data

An other problem calibrating the EPIC/ALMANAC model, was the genetic variation between the cultivars (cvs.) of the species. Especially *cowpea* is very rich in local varieties in the region. Figure 5 shows the variation in the yield of two different cultivars under the same growing conditions. It seems to be, that measured and observed data from both cultivars fit better if individual Al^{3+} tol. values for each crop are used. This suggest that different adaptations of the cultivars to the side conditions may be an important reason for different yield levels. As only EPACE 10 is an improved cultivar, other possibilities like the size of the grains might be a possible explication for the different yield levels. The weight of 1000 grains is around 190 g for EPACE 10 and 130g for CEA 130. In every case, it will be impossible to get good reliability for the models only using one crop file for cowpea for all cultivars.

4 Conclusions

The actual performance of the EPIC/ALMANAC model to simulate yield under the conditions of the Northeast of Brazil leads to the following conclusions;

(i) the model is able to reproduce the differences in the production levels between large landscape units with spatial different side conditions;

(ii) under marginal site conditions, the model underestimates the production potential observed on the field trial;

(iii) it is possible to adapt the model to single limiting or stress factors, but

(iv) it is yet not possible for the model to deal with more than one stress factor under the adverse conditions on the chapada;

(v) in consequence of this improved treatments can not be reproduced in the model simulation yet.:

(vi) daily weather data as measured on the side and exact soil data are necessary if reliable tests with the models are planned.

In regard to the found limitations for the model simulation, changes in the model’s stress calculation and nutrient supply calculation are planned. It is expected that after this, the model is able to simulate fertilizer or soil fertility effects on the chapada.

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7 Remarks

[1] Model information on: http://www.brc.tamus.edu/epic/documentation/index.html

[2] The new version of EPIC (ver. 7270) also allows to simulate intercropping

[3] Portuguese expression which describes the landscape unit found on the plateau areas

[4] Baixio; area which lays between the valley and the chapada, normally soil fertility is much better in these regions than on the chapada