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Sensitive parameters for EPIC model evaluation and validity under soil water and nutrients limited conditions with NERICA cropping in West Africa

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Crop models known to be based on the theory of crop physiology for describing the dynamic process of crop growth are recently explored for their uncertainties in model application under resource limited conditions. The aim of this study was to test Environmental Policy Integrated Climate (EPIC), on upland land rice production by taking into account seasonal variability in Guinean and Guinean-Sudanian zones in Benin and Nigeria (West Africa). A range of data available under farmer or experimental conditions in rainfed agriculture were measured or used from literature. The results show the accuracy of the model to simulate LAI, total above ground biomass and grain yield of upland rice for 2 NERICA rice cultivars. After calibration, the model showed average mean relative error between 0.06 and 0.15 with the model efficiency up to 0.98% in the case of LAI. The assessment of the model performances about sensitivity to N or P fertilizer application is also discussed under Ultisols. Large root mean square (RMSE) in calibration and the validation (>100) process suggested that robustness of the model became restrictive under severe environmental conditions such as in drought or flooding condition. Performance of the model at large scale should be executed of with land marginality classification.

Key words: Environmental Policy Integrated Climate (EPIC), modeling, upland rice, West Africa.

INTRODUCTION

The operation of crop growth models is of interest for filling gap between information needed and that created by traditional experimental trials in soil and agronomic research or for extrapolating results gained on experimental stations leading to better integration of knowledge.

Beside, simulation modeling represents a research tool for assessing climatic change patterns and their impacts on crop growth and yield. Modeling a cropping system requires to understand the complex crop-water-soil interaction and to suggest some empirical parameters which can be applicable to diverse conditions and environments. However, the attempt to use crop growth models under extremely unfavourable growth conditions that is, water scarcity combined with low soil fertility or with indigenous management practices remains a

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*Corresponding author. E-mail: omonlola@yahoo.fr challenge in tropical cropping systems such as in Africa or in Latin America (de Barros et al., 2004; Gaiser et al., 2010).

Indeed, for the single crop rice that has a relatively long history in modeling, model development is now geared to the issue of resources limitation due to expansion of rainfed rice systems. For instance the water and nitrogen modules in the latest version of ORYZA2000 formerly developed for estimating potential rice production suggest repeated model simulations with real-world data in order to increase the confidence in the suitability of the model for a certain purpose (Bouman and Van Laar, 2006). Even the agroecological system models such as Environmental Policy Integrated Climate (EPIC), which addresses crop simulation in response to weather, and nutrient cycling, is still not widely used to explore management strategies (Probert, 2004). As result, in rainfed low-input systems such as smallholder farms in West Africa, models developed for optimal management conditions fail to meet the needs of researchers and extension workers. That can be a key issue in Africa where about 80% of the rice production depends on rainfed conditions.

Although the basic use of crop models was to calculate crop growth and development for a single field, there is increasing interest in studies that concern multiple fields (Leenhardt et al., 2007; Hartkamp et al., 1999). This depends on the assumption that field scale model can be useful for evaluating management strategies at a broader scale. In rainfed upland systems in West Africa, rice yield is seldom above 2 Mgha^{-1}. Constraints are shown to be in addition to rainfall uncertainty in West Africa, weeds and soil nitrogen availability. Indeed soil nutrient availability for upland rice culture has also been described to be related to land use and ecology (Becker and Johnson, 2001). It is then important for crop modeling targeted on upland rice to be tested on various environmental and management conditions to provide more confidence for further upscaling exercises. The adopted upland rice is NERICA cultivars that have been showed relatively high yieldsyield which vary in a controlled environment from 4.0 to 7.0 Mgha^{-1} (Akintayo et al., 2008). NERICAs are developed from interspecific crosses and tested for their ability to overcome drought (Asch et al., 2005) or to tolerate temporary inundation via flash flooding (Kawano et al., 2009) or for low nitrogen environment (Saito and Futakuchi, 2009; Oikeh et al., 2008). New cultivars including NERICA 1 and NERICA 4 are assessed through the participatory varietal selection (PVS) in order to identify genotypes that perform well across or within a specific target environment.

The objective of this study was a multisite calibration and validation of the EPIC model for NERICA cultivars in contrasting ecological condition and the identification of site-specific model sensitive parameters. For this purpose we analyzed the sensitivity of the crop model to fertilizer and water input with data from experimental and on farm fields in Guinean and Sudanian zones in Benin and Nigeria (West Africa). The EPIC model was chosen due to its capacity to consider the effect of limiting water stress and of nutrients such as nitrogen and phosphorus on rice production (Gaiser et al., 2010).

MATERIALS AND METHODS

Study area

The model evaluation followed a calibration and validation process. Experimental data were collected from 8 experiments carried out in 2004-2010 in Benin and in Nigeria, West Africa (Table 1). The locations are listed from South to North: (The International Institute for Tropical Agriculture (IITA), Cotonou) (4), Tohoué (8), Ikenne (1, Nigeria), Niaouli (3), Bohicon (2), Kpakpazoumé (6), Tchankpéhoun (7) and Pingou (5). The calibration dataset is obtained from sites 1, 4, 6, 7 and 8. Validation plots concerned sites 2, 3 and 5.

The experiments ranged from the Guinean to the Sudanian Zone (Table 2) toward the North. The Guinean zone has two rainy seasons and the Sudanian Zone has a monomodal rainfall distribution. The annual precipitation is about 1100 mm with slightly declining rainfall in northward direction; there is regionally higher rainfall close to the Atacora mountain range for the case of Pingou and Tchankpéhoun (Röhrig, 2008). The length of growing season decreases also from South to North, from 250 to 130 days. In general, the rainfall distribution allows cultivation of two crops per year in the southern areas (Igué, 2000).

Model data input and source

Crop management dates are summarized in Table 3. For the experiments in site 1 through 4 experimental layouts and number of replications are described and published in previous works (Oikeh et al., 2008; Saito and Futakuchi, 2009; Sokei et al., 2010; Koné et al., 2008). For 5 to 8 sites, the experimental design varies according to the area. Plots of 3 m x 15 m were used in Kpakpazoumé and Pingou. The farmland in Tohoué occupied 1250 m² and 5000 m² in Tchankpéhoun. In all experiments cultivar ‘NERICA1’ or ‘NERICA4’ were used.

Soil information was provided from soil profiles dug during the fallow period in 2009 for sites 8, 3, 2 and 4. Atchade (2006) reported chemical and physical characteristics of soil profiles in IITA, Niaouli and Bohicon (Cana Sud). The top soil properties (0 to 15 cm) were adapted according to Saito and Futakuchi (2009) at IITA. Two fields were used at IITA: one with low soil fertility (IITA_{low}) and the other with high soil fertility ($\text{IITA}_{\text{high}}$). Soil data in Ikenne were obtained from Heuberger (1998). The profile was described during the fallow period in Kpakpazoumé, Pingou and Tchankpéhoun in 2009. Topsoil sample were randomly collected from the fields at 5 points of 0 to 20 cm depth along a profile down to the root-table. The samples were sieved to pass through a 2 mm mesh before analysis. The pH was determined using a soil-water ratio of 1:2. The organic carbon and organic N were analysed using the elemental analysis for Kpakpazoumé and Pingou (Fujine, 2014). The dichromate oxidation method of Walkley and Black (1934) was used for Kobli and Tanguiéta. Exchangeable bases (Mg, K, Ca, and Na) were extracted with 1 mol L^{-1} NH4 Acetate; Ca and Mg in the extract were measured using the atomic absorption spectrophotometer (AAS) while Na and K were determined by flame photometry. The potential cation exchangeable capacity was determined by extraction with 1 mol L^{-1} $BaCl_2$. Ikenne, Niaouli have sandy textured topsoil. However, except Tohoué, all the sites have loamy to clayey subsoils (Alfisols and Ultisols).

Table 1. Dataset for calibration and validation of crop growth simulation. GY: Grain Yield, TAB: Total Aboveground Biomass, LAI: Leaf Area Index, C refers to data used for Calibration and V for Validation.

Site No	Location	Latitude Longitude	Elevation (m)	Year	Variables for simulation	Activity	References
1	Ikenne	6°54´N 3°42´E	71	2004	GY	C	Oikeh et al. (2008)
2	Bohicon	7°11´N, 2°04´E	77	2006, 2007	GY	V	Sokei et al. (2010)
3	Niaouli	6° 44´N 2° 07´E	81	2005, 2006	GY	V	Koné et al. (2008)
4	IITA	6° 20´N 2° 20´E	457	2006, 2007	LAI, TAB, GY	C	Saito and Futakuchi, 2009)
5	Pingou	10° 45´N 0° 59´E	100	2009, 2010	GY	V	
6	Kpakpazoumé	7° 55´N 2° 15´E	174	2009, 2010	GY; TAB	C	
7	Tchankpéhoun	10° 45´N 0° 59´E	187	2009, 2010	GY; TAB	C	
8	Tohoué	6° 25´N 2° 40´E	14	2009	GY; TAB	C	

The soils were usually acid with low nitrogen content except in Bohicon and IITA$_{high}$. The soil type was sandy to sandy loam (Table 2). Down to 15 cm, soil organic carbon level was classified in the order :

Bohicon>IITA$_{high}$>Kpakpazoumé>Pingou>Ikenne>Tchankpéhoun>Niaouli>IITA$_{low}$> Tohoué.

Daily meteorological data (maximum and minimum air temperature and global solar radiation) were collected from the synoptic weather station nearest to the fields (Table 2). For synoptic data in Ikenne, the model weather generator was used from FAO climate database LocClim for monthly mean for temperature. Solar radiation at Ikenne was derived from Apkadio and Etuk (2002) and the Hargreaves (Hargreaves and Samani, 1985) method was used for ETP estimation. For all other sites, Penman Monteith Method was applied. All these methods have been successfully tested for ETo estimation in (Rahimi et al., 2015; Valipour, 2014a, b, c;d; e; f;g;h, Valipour, 2015). Daily rainfall was retrieved from the closest rainfall gauge.

Modeling with EPIC

The version 3060 of the EPIC model (Williams et al, 1990) was used to simulate rice productivity. EPIC is a field-based model designed to simulate crop production based on information about soil, crop rotation and management system. A full description is presented in the model documentation by Izaurralde et al (2006). Among various subroutines, the model considers N and P cycling by flows between inorganic and organic stocks. For N mineralization, EPIC couples C and N cycling in the soil. Simulated C and N compounds in EPIC are stored in either biomass, slow, or passive soil organic matter pools. Direct interaction is simulated between these pools as the function of soil moisture, temperature, nutrient content and clay content functions (Izaurralde et al., 2006; Gaiser et al., 2010). For P mineralization, the model uses the approach given in Jones et al. (1984). Two sources of mineralization are considered: the fresh organic P pool, associated with crop residue and microbial biomass, and the stable organic P pool, associated with the soil humus. The mineral P is then transferred among three pools: labile (which comprises fertilizer), active mineral, and stable mineral. Flow between the labile and active mineral pools is governed by the equilibrium equation that implies the mineral P flow, the amount in the active mineral P pool and P sorption coefficient defined as the fraction of fertilizer P remaining in the labile pool after the initial rapid phase of P sorption is completed.

Model evaluation

The evaluation of the model was firstly done by graphical presentation of the agreement between measured and calculated values for crop model by producing linear regressions between measured and simulated variables and calculating the coefficient of determination (R²) derived from 1:1 regression line where data are considered to meet independence assumption. The different comparison methods in Table 4 that highlight the feature of data and the model response were also used. The mean error (ME), the mean relative error (MRE), the mean absolute error (MAE) and the root mean square were presented where n is the sample number, x is the observed, y is the simulated value. The MRE is positive when the model in total overestimates compared to observation. The negative sign is related to underestimation. The root mean square error (RMSE) estimates the precision and reliability of the prediction for single yield estimation points. Model efficiency is used to assess the predictive power of the model taking into account the variability inside the observation data set. All these calculations were done in Microsoft Excel sheet.

RESULTS AND DISCUSSION

Calibration of crop parameters

The calibration and validation runs started with a warm

Table 2. Pedoclimatic conditions of test sites used for model calibration and validation.

Sites	Climate zone	Rainfall[1] (mm)	Synoptic station	Station	Soil type FAO/US classification	Texture[2]	Soil organic carbon (%)²	References for soil profile
1	Guinean	1287	FAO	Ibeju-Ode	Typic Haplustult/Ultisol	S	0.86	Heuberger (1998)
2	Guinean	1208	Bohicon	Bohicon	Haplic Alisol/Alfisol	SL	2.38	Atchade (2006); CENAP
3	Guinean	1065	Cotonou	Niaouli	Acrisol/Alfisol	S	1.89	Atchade (2006); Koné et al. (2008)
4	Guinean	1352	Cotonou	IITA	Haplic Alisol/ Alfisol	S /SC	1.96/0.7	Atchade (2006); Saito and Futakuchi (2009)
5	Soudan-Guinean	1103	Natitingou	Matéri	Dystric Plinthisol /Alfisol	SL	0.84	Our results
6	Soudan-Guinean	1209	Savé	Kpakpazoumé	Dystric Plinthisol /Alfisol	SL	0.91	Our results
7	Soudan-Guinean	1103	Natitingou	Matéri	Luvisol/Alfisol	LS	0.82	Our results
8	Guinean	1082	Cotonou	Porto Novo	Dystric Cambisol / Inceptisol	S	0.65	Our results

1. Rainfall in site 1, in 2005, in site 2 is average 2007 and 2008, in site 3 is average 2005 and 2006, in site 4 is average 2006, and 2007, in site 5 and 7 are average 2009 and 2010, in site 6, average 2009 and 2010, site 8 refers to 2009,

2. Texture ans soil organic carbon in 0-20cm or 15 cm depth.

up period of 8-9 years in order to stabilize the soil organic carbon pools in the model. The approach used for the calibration was to modify some initial values of the model parameters in order to iteratively fit simulation values as close as possible to the observed yield values. Therefore, we adjusted the default crop parameters for rice to the NERICA cultivars. However no cultivar distinction was taken into account in the crop file. The NERICA 1 and 4 passport data published by the Africa Rice Centre represented no feature for distinguishing the two cultivars in the crop file of the EPIC model such as the number of days to maturity which determine the Potential Heat Unit (PHU) or flowering age.

In the process of LAI calibration, the parameters DLAP1 and the DLAP2 were used to control the crop growth. The DLAP1 was changed from 30.01 to 30.20 and the DLAP2 from 70.95 to 60.95 for the two cultivar cultivars. The plant population density has been also modified from 12600 to 50.600 in PPC1 and 250.600 to 250.900 in PPC2. Félix (2006) considered that the sub-model of EPIC for LAI development is based on a strong amount of empiricism, as the mechanism that controls the rate of development of LAI is not yet well understood.

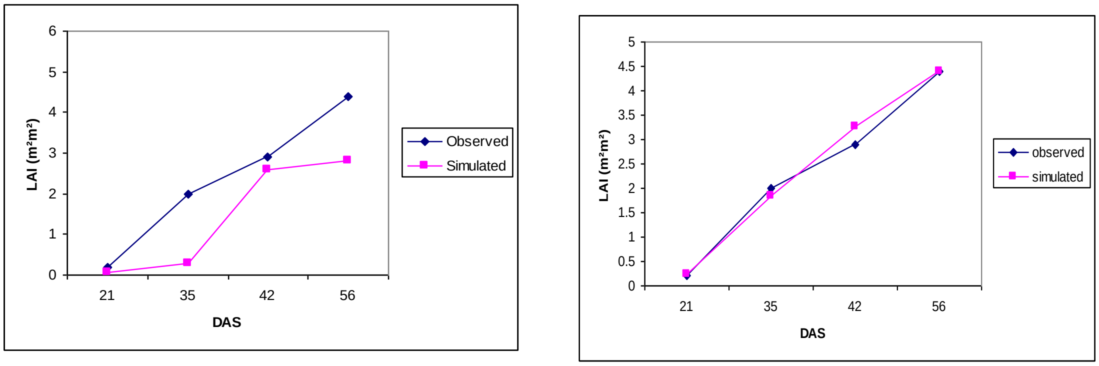
As result, the model outputs and the observations with regard to the LAI before and after the calibration were graphically compared. Figure 1 shows that the model first underestimated the values of LAI with a negative mean error of -0.22 (Table 6). After calibration the average relative difference between the observed values and simulated LAI was approximately 6% with a model efficiency of 98%. The LAI development was rather satisfactory calibrated similar to Yoshida et al (2007) using a complex and detailed phenological model as a function of relative crop growth rate, leaf nitrogen content and air temperature. The LAI was estimated under full irrigation at relatively high soil fertility level compared to farmers field as described in Table 2 (Corg =19.6 gkg^{-1} and total nitrogen up to 2.2 gkg^{-1}). The observed value is average of 5 cultivars including NERICA1 grown under high soil fertility conditions (Saito and Futakuchi, 2009). The authors detected no difference in rice cultivars in LAI at 42 and 56 DAS and no traits from the early vegetative stage were observed related to grain yield. The relative increase of measured LAI at mid stage (DLAP1) compared to the default value in the model is in line with the high weed competitiveness feature demonstrated for

Table 3. Description of the experiments with field operation. N1 and N4 refer to Nerica1 and Nerica4 respectively.

Site	Year	Cultivar	Planting density	Amount of inorganic fertilizer (kgha^{-1})			Sowing date	Irrigation application
			(cm x cm)	N	P	K		
Research station								
1. Ikenne (Oikeh et al., 2008)	2004	N1	20x20	0	0	25	16 Jun	no
				30	0	25		
				60	0	25		
				120	0	25		
				0	26	25		
				30	26	25		
				60	26	25		
				120	26	25		
2. Bohicon (Sokei et al., 2010)	2007	N1	20x20	60	13	25	29 May	no
	2008			0	0	0	31May	
3. Niaouli (Koné et al., 2007)		N4	20x20	0	0	0		no
	2004			100	100	100	3 Jun	
	2005			0	100	100	5 May	
				100	0	100		
4. IITA (Saito and Futakuchi, 2010) (Sone et al., 2009)	2006	N1	20x20	50	13	25	19 Sep	yes
	2007			50	13	25	27 Feb	
On farm –research								
Pingou	2009	N4	30x10	66	14	27	4 Aug	no
	2010			34	-	-	13 Jul	no
6. Kpakpazoumé	2009	N1	30x10	63	14	27	14 Jul	no
	2010			66	17	33	15 Jul	no
Farmland								
7.Tchankpéhoun	2009	N1	30x10	39	14	27	28 Jul	no
	2010			35	7	13	14 Jul	no
8. Tohoué	2009	N1	30x10	44	16	25	27 May	yes

Table 4. Measure of agreement between a model and observed data.

Name	Equation	Optimum value
Mean error	$\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)$	0
Mean relative error	$\mathrm{MRE} = \frac{1}{n}\sum_{i=1}^{n}\frac{(y_i - x_i)}{x_i}$	0
Mean absolute error	$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}(\lvert y_i - x_i \rvert)$	0
Model efficiency	$\mathrm{EF} = \frac{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2 - \sum_{i=1}^{n}(y_i - x_i)^2\right]}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$	1
Root mean square	$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2\right]^{0.5} \times \frac{100}{\bar{x}}$	0



(a) (b)

Figure 1. Comparison between simulated and observed leaf are index (LAI), (a) situation before and (b) after calibration.

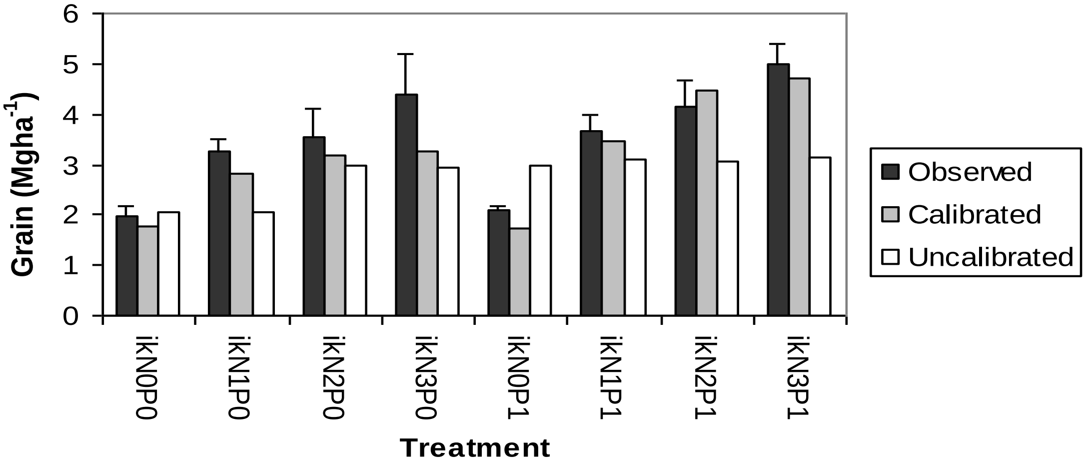


Figure 2. Model sensitivity to supply of N and P before and after calibration for Ikenne site in 2004 (N0, N1, N2, N3 is 0, 30, 60 and 120 kgNha^{-1}, P0 and P1 is 0 and 26 kgPha^{-1} respectively).

NERICA lines (Ekeleme et al., 2009).

Model sensitivity for soil parameter

Before calibration, the model showed low sensitivity to the supply of inorganic N and P on a highly weathered and strongly acid low-activity clay soils at Ikenne (Figure 2), as the experimental layout was made to test the effect of fertilizer application in the humid forest zone on Ultisols (Table 3). Leenhardt et al. (2006) suggested the use of pedotransfer functions to estimate soil properties during the simulation process as solution for unavailable data. However, Gaiser et al. (2010) using sensitivity analysis estimated the fraction of microbial biomass across some different soil types under cropland in West Africa. The fraction of biomass in the soil organic matter pool (FBM) triggers the mineralisation of soil nitrogen, which is the main growth constraint in low-input small-holder systems in West Africa. The authors set a value of FBM to 0.01 instead of 0.04 that is more representative for soils with high organic matter content (Niu et al., 2009). The recommended value of 0.01 was then used for all sites.

In addition, the fraction of humus in the passive pool expresses the proportion of carbon (and nitrogen) in the soil organic matter pool that has a low turnover rate. It was set to 0.99 making less nitrogen available to the plant, thus generating more response of the crop to additional nitrogen supply.

More sensitivity of yield to fertilizer P application in the model was found when initial labile phosphorus concentration in the first layer for the acid Ultisol was set to a value of 0.05 ppm. Labile phosphorus (CSP) is considered to have contributions to be correlated to P uptake (Sharpley, 1985). The labile P concentration factor allows optimum uptake rates when CSP is above

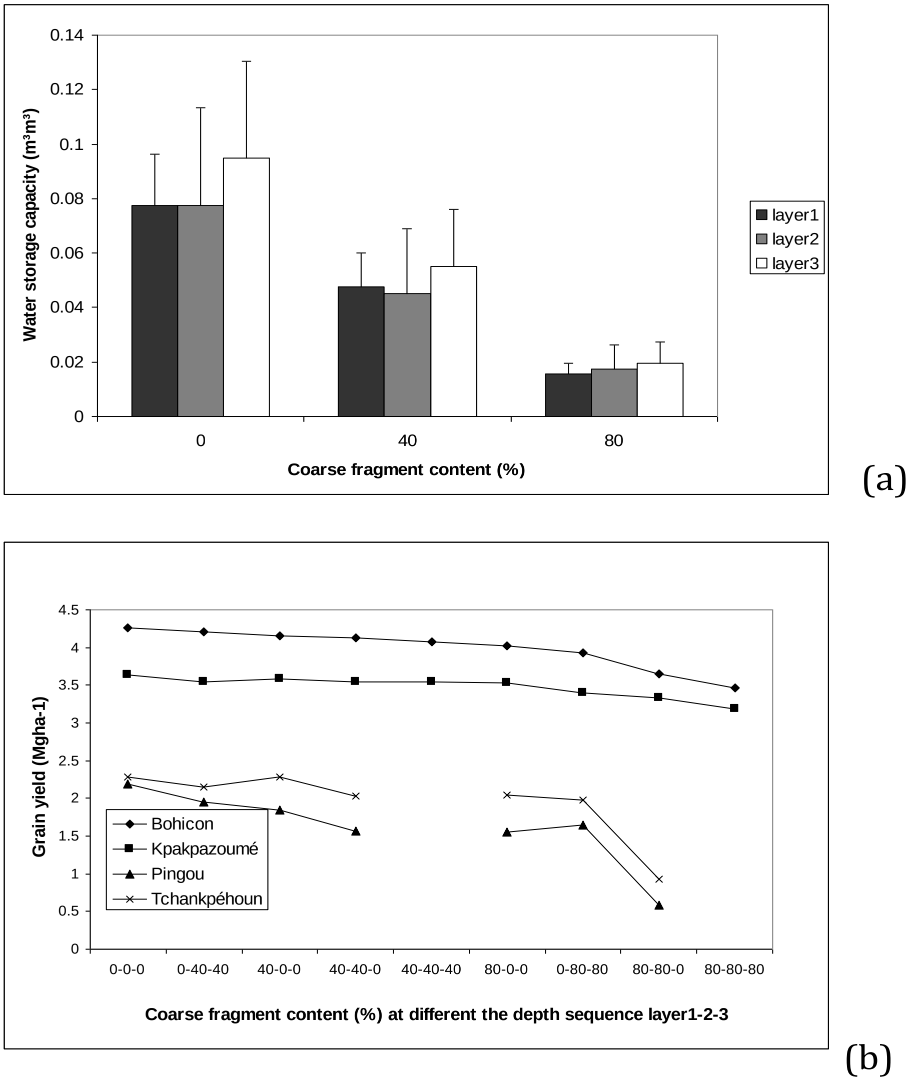
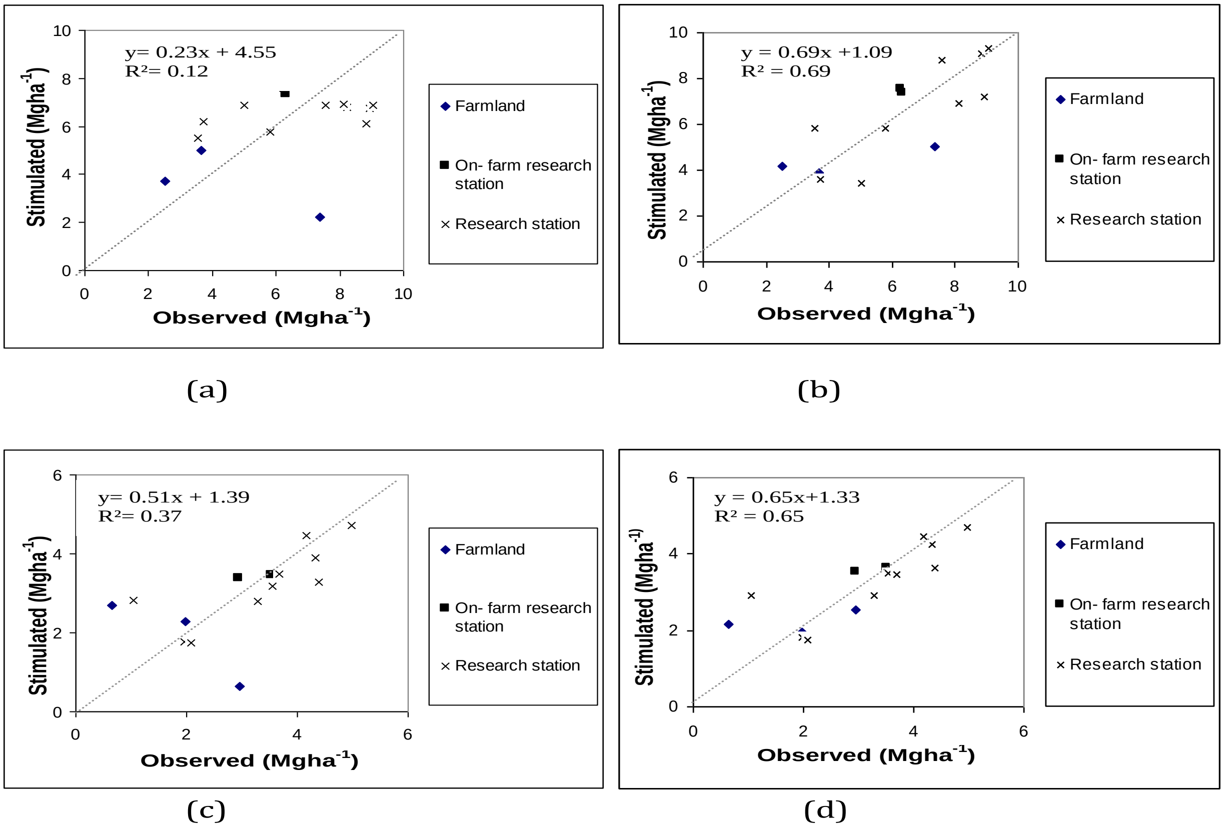


Figure 3. Sensitivity analysis of coarse fragment content on: (a) mean water storage capacity of Bohicon, Pingou, Tchankpéhoun and Kpakpazoumé (b) grain yield with the variations of coarse fragment content value at different soil layers.

20 ppm which was the default value used as critical labile P concentrations for a range of crops and soils. The soils in Ikenne are classified by USDA as Ultisols: They are considered to be low in CEC and bases due to the translocation of the clay in the subsoil and high leaching. They present a high P sorption to Fe and Al-hydroxides in the subsoil (Mokwunye, 1979) or kaolinite in the clay fraction (Wisawapipat et al., 2009). Daroub et al. (2004) in developing a soil-plant P model for highly weathered soils recorded for maize an overestimation of the P uptake by the model. Apparently, their model was not able to reproduce P fixation which is much higher than in less-acid soils developing in temperate climates.

The analysis of rainfed upland system refers also to evaluation of the water availability with depends on soil texture. The coarse fragments influence soil physical hydraulic properties. In EPIC, the role of this parameter addresses directly to the water erosion engine but it has soil functioning oriented for estimation of water storage capacity at the same stand as the bulk density. In fact Chow et al. (1997) observed by incorporating 10 to 30% coarse fragments into the plow layer of the Northen American Podsol, it increased significantly the soil bulk density and this increase reduced the porosity and soil water-holding capacity. The sensitivity analysis of coarse fragments content was done in 4 sites where substantial coarse fragments were identified in soil profile to show influence of this parameter the grain yield.

Figure 3 shows at 2 to 3 soil layers over 4 sites (Bohicon, Kpakpazoumé, Pingou and Tchankpéhoun) variation in coarse fragments content from 0 to 80%. It appeared that strong influence of coarse fragment



(a) (b)

(c) (d)

Figure 4. Scatter plot between observed and simulated total above ground biomass before (a) and after the calibration (b), grain yield before (c) and after calibration (d).

content was obtained when all the layers are concerned by the limitation and the upper layers showed the higher sensitivity for grain yield.

Simulation of total aboveground biomass and grain yield

Figure 2 shows that the model reflects after calibration the effect of N and P application on NERICA yield on Ultisols when P and N are limiting. This is in accordance with Nigerian forest agroecosystems where high split application of 90 to 120 kg N ha^{-1} has been recommended for the rice cultivars to optimize yields (Enwezor et al., 1989). The model results in 7 over 8 treatments were not significantly different from the observed yield of NERICA. The P stress has been simulated adequately to allow the expression of nitrogen stress among the treatments with application and without application of P. By simulating adequately the processes in P deficient soils, the model agrees with the results of Sahrawat et al. (1995) suggesting that P fertilization of acid-tolerant upland rice can significantly improve its productivity under Ultisols. Before the calibration and over all five sites, grain yield and total aboveground plant biomass had a RMSE of more than 30% (Table 6). Farmland fields contributed the most to overestimation of model by 88% for 2 years on average (Figure 4). For the calibration in Tchankpéhoun, the plant density was reduced from the theoretical plant population to the measured plant density at maturity. During the two seasons, heterogeneous planting density translated by the missing of plant hills led to the reduction of the total yield observed. Affholder (2001) pointed out that a model developed in high input environment such as the US where the planting density is very homogeneous need numerous modifications to be applied under the conditions of West Africa where the variability of the densities of sowing is a big factor of the variability of the productivities. Oikeh et al. (2009) did not show relationship between the grain yield and NERICA density whereas density effects appeared only for tiller and panicle densities. This study was undertaken with seasonal differences in rainfall distribution and moisture availability that may reduce simple effects of N and spacing (plant density). Tchankpéhoun got adequate monomodal rainfall supply for the two years. After calibration, the goodness of fit of the model was improved for both total aboveground biomass and the grain yield (Figure 4). Lower RMSE after calibration indicated that a

Table 5. Parameter setting for rice in the EPIC crop file: original defaults and values after calibration (WA, biomass-energy conversion factor; HI, potential harvest index; WSYF, minimum harvest index; LAImax, maximum leaf area index; PPC1/PPC2, plant density, LAI parameters DLAP1, DLAP2).

Parameter	Explanation	Original	Used in the parameterization
WA	Radiation use efficiency (kg ha^{-1}/MJm^{-2})	25	25
HI	Harvest index (decimal fraction)	0.50	0.55
PHU	Potential heat unit (degree days)	1500	1500
WSYF	Minimum harvest index under water stress condition (decimal fraction)	0.25	0.01
LAI max	Potential maximum leaf area index (m^2 m^2)	6	6
DLAP1	First point on optimal leaf area curve .Percentage of heat unit	30.01	30.20
DLAP2	Second point on optimal leaf area curve .Percentage of heat unit	70.95	60.95
PPC1	1st point of plant population density for crops (plants m^2)/Fraction of potential leaf area index at 1st point (decimal fraction)	125/600	50/600
PPC2	2nd point of plant population density (plants m^2)/PPT2 Fraction of potential leaf area index at 2nd point (decimal fraction)	250/900	250/600

higher fraction of the measured variations were accounted by the model (Table 6).

Model validation

The calibration of the EPIC model for upland rice was focused on nitrogen and phosphorus as main constraints to crop growth. The validation was carried out on three sites (Niaouli, Bohicon and Pingou) over two seasons. At Niaouli the experiment tested different levels of N and P input, at Bohicon NPK application was tested and Pingou was an on-farm field experiment (reference in Table 3).

The validation of the model showed that a relatively high gap between averages simulated and observed yield (Table 7). The mean error was 1.2 Mg ha^{-1} whereas the mean relative error was 3.0 Mg ha^{-1}, which showed a very large overestimation of the simulated yields at plot level. The variation of the individual plots was also quite high resulting in root mean square error of more than 100%. The observed grain mean grain yield was lower than the average in the calibration suggesting various stress effects. Indeed some causes of rice failure attributed to floods and drought were reported b for NERICA evaluation on 5 locations with similar pedoclimatic conditions to these experiments in Benin republic (JAICAF, 2007). Therefore, before the use of the model in the assessment of impacts of and adaptations to climate variability and climate change in spatial studies, there is still a need for improvement in the amount and quality of available data collection.

Figure 5 showed a scatter plot of the observed and estimated value of sites used for model validation. The average yield in plots used for validation was relatively low, this is due to crop failure in 2006 in Niaouli where the average yield was below 1 $Mgha^{-1}$ leading to the model overestimation. In fact, the experimental design was originally set up to evaluate the tolerance to drought with nutrients application for NERICA cultivar. Niaouli is located in the sub humid zone with bimodal rainfall pattern. The mid-season rainfall pattern associated with the sandy topsoil texture induced severe drought stress. The soil type “terre de barre” was described by Azontonde (1991) as soil with good physical hydraulic characteristics but with low water storage and their structure can be rapidly destroyed when there is no proper technique for maintaining organic matter.

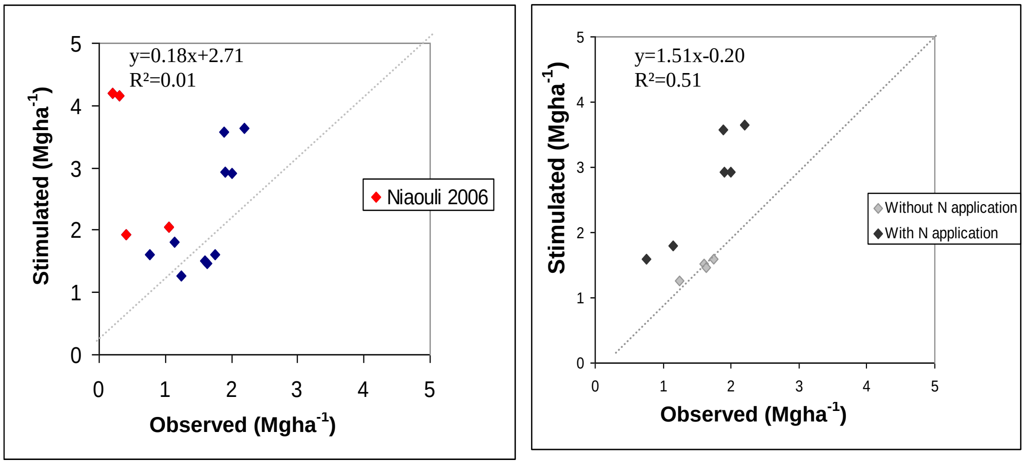
The sensitivity of NERICA cultivar to water stress is well documented. Akinbile et al. (2007) showed that with NERICAs yield decreased under optimal satisfactory conditions almost linearly with evapotranspiration thus indicating that water application remained dominant factor at all the stages of production. In EPIC model, the potential harvest index is adjusted daily according to water stress suffered by the crop (Williams, 1995). During the calibration, the sensitivity of model was increased by setting the water stress impact (WSYF parameter), which allowed harvest index to drop to 0.01 in case of severe drought. The effect of water stress could be in fact limited to HI reduction. Fuji et al. (2004) reported that some

Table 6. Mean simulated and observed rice LAI (m^2m^2), total above ground biomass (TAB), grain yields in Mg ha^{-1} as well as mean error (ME in Mg ha^{-1}), mean relative error (MRE), mean absolute error (MAE), model efficiency (EF) and mean root square error (RSME) before and after model calibration over 6 sites.

Sites	n	Obs.	Sim.	ME	MRE	MAE	EF	RMSE
				Before calibration				
LAI (m^2m^2)	4	2.38	2.16	-0.22	0.07	1.55	0.00	32.84
TAB(Mg ha^{-1})	15	6.33	6.04	-0.30	0.04	1.55	0.09	30.15
GY(Mg ha^{-1})	15	3.03	2.97	-0.06	0.23	0.71	0.32	33.13
				After calibration				
LAI (m^2m^2)	4	2.38	2.44	0.06	0.06	0.14	0.98	8.39
TAB(Mg ha^{-1})	15	6.33	6.33	0.00	0.05	1.55	0.61	21.10
GY(Mg ha^{-1})	15	3.03	3.15	0.11	0.24	0.47	0.67	23.01

Table 1. Validation of the EPIC model with respect to yield of rice in Mg ha^{-1}. Obs. is observed and sim. is simulated value, n is the number of pair of observed and simulated grain yield, a is the regression slope. The mean error (ME in Mg ha^{-1}), mean relative error (MRE), mean absolute error (MAE) and mean root square error (RSME) are calculated over 3 sites.

Grain yield (Mg ha^{-1})						
N	**Obs.**	**Sim.**	**ME**	**MRE**	**MAE**	**RMSE (%)**
14	1.3	2.5	1.2	3.0	1.2	116.30



(a) (b)

Figure 5. Scatter plots for NERICA validation, (a) represents model validation for all plots, (b) refers to plot without the particular year Niaouli 2006.

Nerica lines showed high dry matter production under drought condition among other rice cultivars, and this have been correlated with stomata conductance (r=0.63**). However, intensive rains of short duration followed by long dry spells that occurred during the flowering period which lead to increased sterility and decrease in grain weight (O´Toole and Moya, 1981). De Barros et al. (2005) observed slight overestimation of grain yield by the EPIC simulations was attributed to high rates of floral abortion caused by dry spells during the flowering periods since this factor is not considered in the model.

Table 8. Validation data results without Niaouli 2006 , with reference to fertilizer treatment, year and observed grain yield, + symbol refers to presence and - the absence of fertilizer input.

Year	Site	Treatment (fertilizer)		Grain yield (Mgha^{-1})	
		N	P	Observed	Simulated
2007	Bohicon	-	-	1.64	1.49
2008	Bohicon	-	-	1.24	1.36
2007	Bohicon	+	+	2.20	3.74
2008	Bohicon	+	+	1.88	3.67
2009	Pingou	+	+	1.14	1.80
2010	Pingou	+	+	0.73	1.60
2005	Niaouli	-	-	1.60	1.51
2005	Niaouli	-	+	1.75	1.60
2005	Niaouli	+	-	1.90	2.62

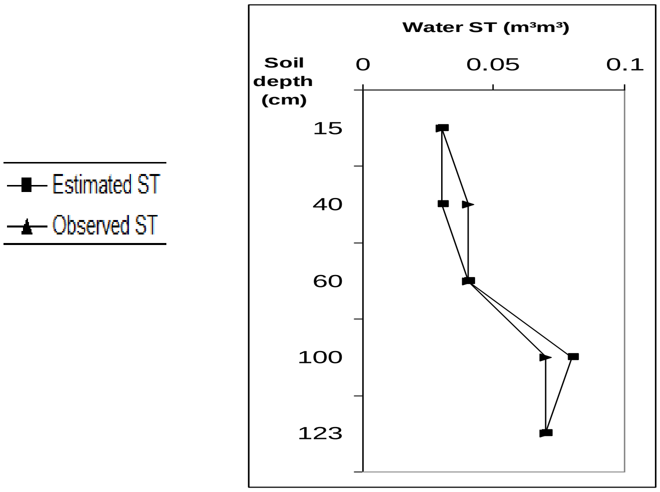


Figure 6. Water storage capacity simulation after content in the layers for drought experiment in Niaouli in the rooting zone.

After removing the plots with crop failure induced by drought in 2006 in Niaouli, the goodness of the fit of the model was improved from 0.01 to 0.51. Table 8 lists the simulation results of the remaining plots. Pingou siteo held in 2010 the lowest yield below 1 Mgha^{-1}. In this year it was observed a shallow groundwater during the wet season at sowing (end of July) and was followed by transplanting. Therefore the first possibility for the model overestimation is that the model could not consider transplanting shock that caused a delay in phenological development resulting in reduced vegetation period in the field. No reported analyses on negative impact of flooding on upland NERICA were available. In controversy Fofana (2008) highlighted the recovery and the improvement possibility of NERICA1 production after short and intense moisture stress at the seedling emergence stage. The presence of ferric cuirasses in Pingou may result in low saturated conductivity at the middle soil depth, thus increasing the submergence and runoff risk. The relatively high soil moisture should have been the explanation of low yield due to direct seeding in 2009. Indeed Ogunremi et al. (1986) demonstrated direct-seeded rice was adversely affected by the transient flooding conditions during the seedling stage on Ultilisol in Southern Nigeria. The obtained grain yield decreased indeed with increasing penetrometer resistance.

The tendancy of overestimation remained of yield response to fertilizer was observed in Bohicon and Niaouli. Even at Niaouli in 2005, where experiment also applied relatively high amount of NP (100 kg ha^{-1}) that were less efficient in observation than in modeling. Under limiting water conditions there could be less capacity of crop to continue water uptake that can probably reduce transport to the roots through mass flow. Indeed some traits of upland rice (japonica type) related to less adventious roots per hill result in relatively week ability in N uptake (Zhang, 2008). In addition, a severe drought that occurred just after the application of the first split of N could have induced urea volatilization resulting from the lack of N dissolution Oikeh et al. (2008).

From data drawn from the upland experiments, the EPIC model was calibrated and parameterized for a multisite evaluation, which is particularly important for rice production because of its high dependency to nutrients and water. In the model validation the variations of individual plots also were higher than the observed. The model overestimated the yield under drought condition in the site of Niaouli. The model indeed estimated effective lower water retention in the first soil depths by the use of texture. Figure 6 shows the relatively good agreement of the model estimation for water storage capacity in the Niaouli site that allowed condition for water stress experiment. However, it has been also reported in the sensitivity analysis of the model that coarse fragment content had more or less high influence on water storage capacity in the soil layers. In four sites out of eight sites, the model was parameterized with coarse fragment content limiting water storage capacity in different layers.

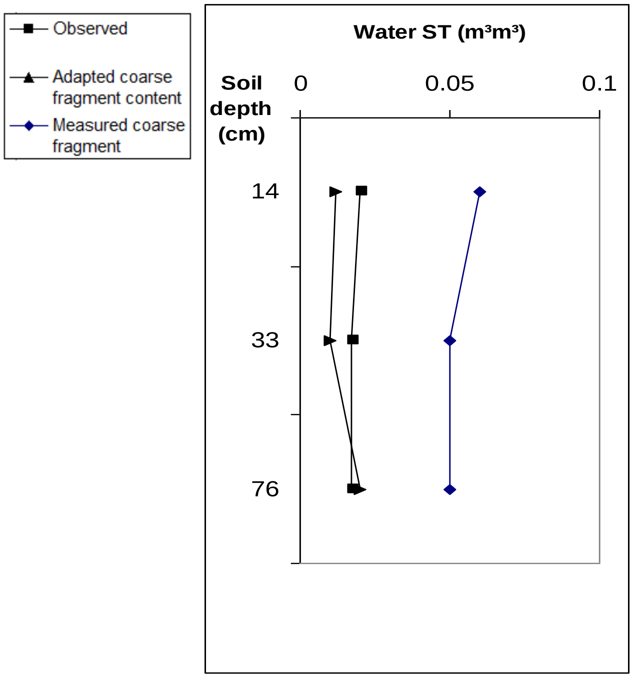


Figure 7. Comparison between water storage model estimation after adjustment of water storage capacity in Bohicon.

Adapted value was needed in case of Bohicon while the model still overestimated the water retention capacity with the measured variables. The results of final calibration are shown in Figure 7. Indeed, the model estimation of water storage required modification in Bohicon and reduced the yield gap between observed and simulated value from 3 to 2 Mgha^{-1} on average. As consequence, when simulating rainfed rice it appear to be a prerequisite to provide detailed site-specific soil input parameters including water retention among soil physical characteristics.

At the level of discussion of plant nutrition causes on the overestimation of the model, if the model was adequately tested to respond to NP fertilizer from calibration there is still issue of the simulation of micronutrients. Several experiments conducted on highly weathered soils in Africa showed that as sufficient N and P is applied in maize, micro nutrient deficiencies may appear (Gaiser et al., 1999). Voortman et al. (2000) estimated micronutrients deficiencies on about 60% of the cropland in sub-Saharan Africa. This confirms the requirement to improve micronutrient effects in crop models. Furthermore, Koné et al. (2009) proved that there was also a significant (P = 0.004) decreasing effect of Zn (28%), N (34%) and K (36%) exclusion on the mean grain yield in the Ferralsol soils Benin. These results attested the existence of Zn and K deficiencies which may reduce the sustainability of upland rice production.

In the study through the modeling tool, interspecific genotypes were evaluated under with local farmer's conditions which include in addition to low inherent soil fertility, the occurrence of drought or flood. This multisite evaluation did not show any type of interaction between variety and environment that should be seen in the simulation outputs. Several kind of stress may limit varietal selection progress under unfavourable environments (Banziger and Cooper, 2001). In fact, Mandel et al. (2010) found smaller genetic variance for grain yield under low-input conditions in India.

The higher effect of soil texture input on grain yield confirmed the importance of water capacity retention estimation as a key soil parameter indicating that management of water supply (bunds building or reduction drainage) are likely to be useful for improving rice production

Conclusion

The EPIC model was tested with mix of collected and secondary data from an experimental station, on farm research field and farmland in the tropical humid with P fixing soils to semi-humid zones. The study showed the relevant crop and soil parameters for calibration in upland rice cropping conditions, in particular different pools of nitrogen and phosphorus in the soil. In calibration, the model presents a good response to the application of N and P mineral fertilizers. A multiple year calibration for multiple variables such as plant biomass, leaf area index and yield improve our confidence in the model calibration. Although the EPIC shows the sensitivity of rice to seasonal rainfall, its robustness under severe water stress become limited. With a multiple year calibration for multiple variables such as plant biomass, leaf area index and yield, the uncertainty in the model prediction in validation is related at first place, to the lack or quality on input data (estimation of impact drought spells on grain yield) and secondly on the model weakness (reduction of HI linked to crop phenology and fertilizer responsiveness under low input environments).

Conflict of Interest

The authors have not declared any conflict of interest.

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