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A regional model for integrated water management in twinned river basins

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Tested submodel for crop productivity and environmental impact in the Oueme basin, Benin

EPIC 3060

terrafusca
Ingenieurbüro und Consulting

Prepared by the Lead Contractor

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Summary

This deliverable report describes the research activities of the contractor terra fusca (11) during the second year of the RIVERTWIN project. The main research activities of workpackage task 4.4 have been the simulation of agricultural productivity and environmental impact based on land management, climate and soil conditions. Our main objective was to test the reliability of the EPIC model under tropical sub-humid regions. The submission of data to the project database, preparation of a literature review, data mining and modelling work was also part of the research work.

The Erosion Productivity Impact Calculator (EPIC) version 3060 was validated at representative sites and the uncertainties of model results were quantified at the field scale. Over 43 cropping seasons with various fertilizer inputs under contrasting soil and climate conditions were simulated to test the EPIC model in the Oueme Basin.

The EPIC simulations were based on daily weather data recorded close to the research sites, as well as detailed soil information and daily records on farming activities. It is crucial for the simulation accuracy of the EPIC model to get the detailed initial conditions (sowing date, plant density, initial soil water content, etc.) and management information (fertilizer schedule, tillage schedule, irrigation schedule etc). The first problem encountered in attempting to use EPIC for research in Benin is that such data as are necessary for creating program files are not easily available. The establishment of the database has been slowed down by difficulties in data supply from Benin, in addition to the fact that only few field data are available for the region. Finally the database was completed by research of own TF staff, but remains unsatisfactory as compared to the Neckar-Basin database.

The Epic model predicted crop yields for sites with good data coverage with reasonable accuracy. However, a poor correlation between simulated and observed data was found on marginal sites and crop production with local varieties. These sites were mainly located on farmer fields and accurate data regarding soil characteristics and cultivated crop varieties were not available. Crop yields where significantly overestimated on these sites. Consequently, our recent modelling work concentrated on adjusting parameters connected to local crop varieties, to make more realistic simulations.

Moreover, the user Interface of the EPIC model has been further improved, towards a practicable model design.

The tested submodel EPIC 3060 for crop productivity and environmental impact simulation – on the field scale, will be handed over to WP subtask 2.4 land resource information system (SLYSIS) for further validation and calibration - on the regional scale. The overall objective is to simulate agricultural crop rotations to identify potential problems of particular cropping systems and to support local authorities to explore possible scenarios for sustainable landuse strategies.

1 Conceptual Framework

In tropical subhumid countries like Benin, the preconditions differ significantly to those found in temperate regions like Germany concerning climate and soil characteristics, land use practices and fertilizer inputs. The soils are of low fertility because of the long soil formation period with the main part of the nutrients being stored in the above ground vegetation. Under agricultural production, nutrient outputs are in general higher than the amounts being applied to the soil by crop residues or fertilizer. In the past, the recovery of soil fertility was assured by implementing a fallow period of mostly 5-20 years after a short cultivation phase of agricultural crops (mostly 1-3 years) according to Kühne (1993). Nowadays, the population pressure leads to a shortening of the traditional fallow period and an intensification of agricultural production. To guarantee the sustainability of the production, adequate management systems are needed that provide sufficient food on the one hand - also by applying mineral and/or organic fertilizers - but that don’t harm soil fertility and environment on the other hand.

The main objective of this study is to simulate crop productivity and the impact of specific cropping systems on the nitrogen dynamics under varying climate and soil conditions and different fertilization levels.
The specific objective of the study is to evaluate the potentials of the EPIC model to support the understanding of N dynamics of specific cropping systems to avoid the risk of N leaching from agricultural sites, without sacrificing crop yield at the same time.
This study is focused on the simulation of crop productivity, biomass and solute transport under different types of soil and climate in the Oueme basin. To reach these overall objectives the following research activities were defined:

- preparation of a relevant literature review
- data mining and data digitalizing
- simulation and testing work
- provide a substantial input to the SLYSIS Model which addresses the modelling at the regional scale
- support local authorities to explore possible scenarios for sustainable landuse strategies and
- contribute to the scientific literature and stimulate further research

We therefore conducted intensive validation studies of the EPIC (Erosion Productivity Impact Calculator / Environmental Policy Integrated Climate) model to simulate various parameters like crop yields, soil water and nitrogen dynamics as well as ground-water recharge in agricultural areas of the Oueme river basin in Benin. Simulation runs were realised for more than 43 cropping seasons with various fertilizer inputs under contrasting soil and climate conditions.

2 Agricultural Simulation Models

Simulation models describe the dynamic processes of a specific part of the reality. In the models, current knowledge and insights from different disciplines (including crop physiology, agro meteorology, soil science, agronomy, phytopathology) are integrated to make dynamic simulations of crop, animals and agricultural systems. The models are used to test alternative hypotheses, analyse current production techniques, predict the effect of changes in environmental conditions, crop management practices and support to choose optimal strategies and tactics of farm management (Plentinger and Penning de Vries, 1996/2005).
There are several models dealing with crop productivity simulation. The following list is only a selection of available models.

Table 1: Crop simulation models

Model name (Author)	Climate	Water availability in the soil	Nutrient avail-ability	Toxic elements (Al, salt)	Pests, diseases	Mixed cropping
SORGF (Arkin et al. 1976)	+	+	-	-	-	-
SUCROS (van Keulen et al. 1982)	+	+	-	-	-	-
CERES (Richie and Otter 1983, Jones et al. 1986)	+	+	N	-	-	-
CENTURY (Parton et al. 1987)	+	+	N,P,S	-	-	-
SIMRIW (Yoshino et al. 1988)	+	-	-	-	-	-
CROPWAT (Smith 1989)	+	+	-	-	-	-
WOFOST (van Diepen et al. 1989)	+	+	(N,P,K)	-	-	-
EPIC (www.brc.tamus.edu/epic)	**+**	**+**	**N,P,(K)**	**+**	**(+)**	**+**
QUEFTS (Janssen et al. 1990)	-	-	N,P,K	-	-	-
DSSAT (www.icasanet.org)	+	+	N	-	-	-
APSIM (CISRO 1995)	+	+	N,P	-	(+)	-
Theseus (2004)	+	+	N,P,K	-	-	-
Opus (2004)	+	+	N,P,K	-	-	-
ALMANAC (Kiniry et al., 1992)	+	+	N,P,(K)	+	weeds	+
SWAP (Alterra and Wageningen Agricultural University)	+	+	solutes	+	-	-
SWACROP (Wesseling et al., 1989)	+	+	-	-	-	-
GLEAMS (Leonard et al., 1987)	+	+	nutrients	pesticides	-	-
MACROS (Penning de Vries et al., 1989)	+	+	-	-	-	-
ORYZA 2000 (IRRI, Wageningen University and Research Centre (WUR) 2001)	+	+	N	-	-	-
SOYCROS (Penning de Vries et al. 1992)	+	+	-	-	-	-
WATCROS (Aslyng and Hansen, 1982)	+	+	-	-	-	-

Source: actualised according to Gaiser (1999, not publ.)

In this study, we used the **EPIC (Erosion Productivity Impact Calculator / Environmental Policy Integrated Climate)** model to simulate crop productivity and environmental impact of agricultural activity in the Oueme river basin in Benin.

EPIC is widely used as simulation model for crop productivity and environmental impact. Initially, the Epic model was developed in 1981 to support assessments of soil erosion impacts on soil productivity for different soil, climate, and cropping conditions. The model has continuously evolved since that time and the range of EPIC applications has expanded including studies of surface runoff and leaching estimates of nitrogen and phosphorus losses from fertilizer and manure applications, leaching and runoff from simulated pesticide applications, soil erosion losses from wind erosion, climate change impacts on crop yield and erosion, and soil carbon sequestration assessments. "The EPIC acronym now stands for Erosion Policy Impact Climate, to reflect the greater diversity of problems to which the model is currently applied ". (Gassmann et al., 2005)
Example applications of the Epic model include assessment of sediment and nutrient losses as a function of different tillage systems, crop rotations, and fertilizer rates (Phillips et al. 1993; King, Richardson, and Williams 1996); nutrient losses from livestock manure applications (Edwards et al. 1994; Pierson et al. 2001); nitrate-nitrogen (NO3-N) losses through subsurface tile drainage (Chung et al. 2001; Chung et al. 2002); nutrient cycling as a function of cropping system (Cavero et al. 1999; Bernardos et al. 2001); soil loss due to wind erosion (Michels et al. 1997; Potter et al. 1998; Bernardos et al. 2001); climate change impacts on crop yield and/or soil erosion (Favis Mortlock et al. 1991; Brown and Rosenberg 1999, Adejuwon 2004); losses from field applications of pesticides (Williams, Richardson, and Griggs 1992; Sabbagh et al. 1992); irrigation impacts on crop yields (Cabelguenne, Jones, and Williams 1995; Rinaldi 2001; Guerra et al. 2004); estimation of soil temperature (Potter and Williams 1994; Roloff, de Jong, and Nolin 1998) and evapotranspiration (Hauser et al. 2005); and soil carbon sequestration as a function of cropping and management systems (Lee, Phillips, and Liu 1993; Izaurralde et al. 2001; Apezteguía, Izaurralde, and Sereno 2002; Potter et al. 2004; supplemented according to Gassmann et al., 2005).

3 Characteristics of the study area

3.1 Geographical location

The Republic of Benin is situated between latitude 6° - 13° N and longitude 1° - 4° E, in West Africa. It has borders with Burkina Faso and Niger in the North, Nigeria in the East and Togo in the West, and is limited in the South by the Atlantic Ocean. Benin is divided into twelve departments: Alibori (main city Kandi), Atacora (Natitingou), Atlantique (Ouidah), Borgou (Parakou), Collines (Savalou), Couffo (Dogbo-Tota), Donga (Djougou), Littoral (Cotonou), Mono (Lokossa), Oueme (Sakete) and Zou (Abomey). The study area, the Oueme river basin, is stretched across the whole country from north to south and marks an area of about 1 000 km² (www.fao.org).

Figure 1: Location map of the study area

3.2 Climate

Benin is located in the tropical zone of West Africa. That means, that average annual temperatures are about 25°C, with monthly temperature amplitude of 3-4°C (Stahr, 2000; Ernst-Schaeben, 1994). However, within the country, different climatic zones can be found: the Southern Sudan Savannah zone with semi-arid tendency and a single summer rainy season in North and Central Benin; the subequatorial moist savannah zone (Guinea-Savannah) in (Central-) South Benin, and the humid subequatorial zone in the South, which both show bimodal rainfall patterns (Stahr, 2000; Yabi, 2004). The climatic differences are mainly due to rainfall distribution, which is unimodal and determined by the level of rainfall, temperature and winds. Humidity can reach in its maximum 100% and never drops below 40% during the rainy season. However, in the dry season it may be less than 10% (Stahr, 2000). The total rainfall at the coast is about 1300 mm (distributed into 700 – 800 mm for the first rainy season from March/April till July, and 400 – 500 mm for the second one from September till November) and decreases in general by 1 mm per km on the way north-west (according to Stahr, 2000 and Ernst-Schaeben, 1994).

3.3 Soils

According to Kühne (1993) the major part of the soils in West-Africa is highly weathered and impoverished in nutrients -particularly nitrogen, phosphorus and sulfur (Okigbo 1995)- due to the long period of soil formation. The main characteristic of these soils is the high kaolinitic content and the low water holding and cation sorption capacity. Thus, productivity of these soils depends mainly on the organic matter content (Ernst-Schaeben, 1994) and the recycling of the nutrients stored in the above ground biomass.

The landscape of the subhumid part of Benin can be divided into two major zones: the sedimentary zone with sandstone, shale and marl in the South of Benin which extends from the coast (ca. 6°) to a northern latitude between 7° and 7.5°, and a crystalline basement zone with granite, migmatite, gneiss and in some areas basic rocks which cover the central part of Benin. With the exception of valleys or low peneplains, the soil characteristics of comparable landscape units differ considerably between the two geological zones. In general, the soils in the sedimentary zone are deeply weathered with low exchange capacity clay and low mineral reserves, but offer a large rooting volume to perennial crops. In the crystalline zone, the majority of the soils are less developed with a smaller soil volume for water storage and rooting, but have higher nutrient reserves. In both zones, the soils in the valley bottoms or lower landscape positions show improved water availability through lateral flow from the surrounding areas making them more favourable for agricultural production. (Gaiser et al., 2000)

3.4 Agricultural Systems

Corresponding to the rainfall patterns, there is one cropping period in North and Central Benin, and two in the South. Main staple crops are maize, yams, cassava, beans and sorghum, rice and vegetable as secondary crops. The cash crops are cotton, groundnut and cashew (Carder-Zou, 1999, cited in Igue et al., 2000). Farming systems and therefore land use systems differ according to environmental conditions. Several agroecological zones are currently differentiated: a southern guinea savannah food crop area (Mono, Atlantique, Ouémé, southern Zou), a central soudano-guinean savannah food and cotton growing area (northern Zou), a southern sudanian food and cash crop area (southern Borgou), a northern sudanian cotton area (Borgou North) and a mountain sudanian area (Atakora)(Igue et al., 2000).

The predominating agricultural production systems are bush fallow systems, which are divided into two phases, according to Kühne (1993): the short cultivation phase of agricultural crops (mostly 1-3 years) and the long fallow phase (mostly 5-20 years). The spontaneous fallow vegetation consisting in bushes and trees causes bit by bit the regeneration of soil fertility (Prinz, 1986), accumulating nutrients from deeper soil levels in the biomass and thus protecting them from being leached. During the fallow period, a part of the nutrients is admitted back to the topsoil by litter. Finally, by slashing and burning the fallow vegetation, the nutrients accumulated in the biomass are available for the following crops (Kühne, 1993). Bush fallow is a sustainable agricultural production system under low population density of 25-30 peope/m² (Agbo, 1999). In the last decades, increasing demographic pressure has lead to an intensification of agricultural production and to the shortening and even abandonment of the traditional fallow period. This is causing severe problems: decline in the amount of nutrients added to the soil through ash or mineralized from organic matter, which leads to the decline of land productivity and crop yields. Nowadays, land use values of present bush fallow in coastal regions are incapable of sustaining crop production at a level adequate to support increasing food demands. Application of mineral fertilizer can help filling the lack of nutrients, but continuous application of high rates of mineral nitrogen and phosphate fertilizers leads to rapid soil acidification and high nutrient losses by leaching and runoff (Akondé, 1995).

4 Modeling Method

4.1 The Epic Model

EPIC = **E**rosion **P**roductivity **I**mpact **C**alculator
= **E**nvironmental **P**olicy **I**ntegrated **C**limate

The EPIC Model[1] was developed in the 1980's, originally with the objective to assess the impact of agricultural land use and the associated soil erosion on long term productivity of US soils. Including the estimation of effects of soil erosion on productivity, effects of management on soil, water pesticide movement, as well as the combined effects on soil loss, water quality and crop yield (Putnam et al., 1988; USDA, 1989; Williams, 1990; Williams, 1995).

Today, the EPIC model continues to be updated and refined. It is capable of simulating major soil and water processes regarding crop growth and environmental impact of farming activities. For our simulation studies we used the most recent version 3060.

The EPIC model has become an important agro-environmental simulation model, used worldwide by many scientists (Putman et al., 1988; Stockle et al., 1992; Chang et al., 1994; Lacewell et al., 1993; and Wu et al., 1995).

Williams et al. (2004) simulated historical cropping systems (from native pristine grassland to modern agriculture) in central Texas, for a considerable period of 120 years. The main research objective was the comparison of simulated soil organic carbon content with measured values to validate the new EPIC simulation model carbon sequestration routine.

An extension of the EPIC model is the "Agricultural Policy/Environmental eXtender" (APEX). It was developed to facilitate the simulation of large complex farming systems with multiple crops and soil types (Williams et. al, 2000; Williams, 2002).

As outlined in detail below the EPIC model is composed of three principle structural components Soil, Climate and Landuse. They include weather simulation, hydrology, erosion/sedimentation, nutrient cycling, pesticide fate, plant growth, soil characteristics, tillage, plant environment control and economics. EPIC operates on a daily time step, considering daily weather data, soil characteristics, and farming activities like planting tillage and fertilization. Also on a daily basis, EPIC simulates water movements, the cycling of nitrogen/phosphorus/carbon and soil erosion.

The simulation work and the following description are based on the model documentation and user manuals by the EPIC developers (Williams et. al, 1989 and 2003).

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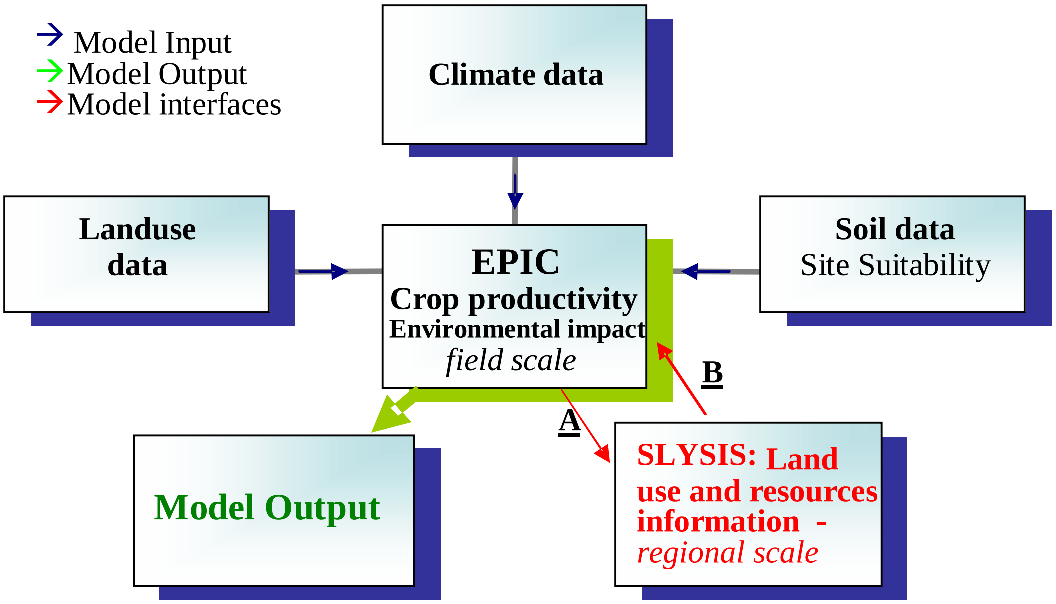
[1] For more detailed information on the EPIC model, see:
Williams, J. (1990) and www.brc.tamus.edu/epic



Exchange Parameters:
A yield, biomass, water/nutrient balance and transport, water consumption, pesticide load
B soil, terrain, climate and vegetation information

Figure 2: The EPIC model structure

EPIC Model component description

The complete Set of submodels consists of the following components:

- Weather generator
- Hydrology submodel (run-off, soil water, percolation, subsurface flow etc.)
- Nutrient submodel (N, P, (K))
- Crop growth model (80 crops incl. major tropical food crops)
- Management (tillage, irrigation, fertilization, liming, pesticides)

The hydrological submodel

Runoff, percolation, infiltration, lateral subsurface flow, evaporation, and snow melt are simulated. Several methods can be selected to estimate peak flow, runoff, and potential evapotranspiration.
The model uses 4 different Potential evapotranspiration methods:

- Penman
- Penman-Monteith
- Priestley Taylor
- Hargraeves

In this study potential evapotranspiration was estimated using the Hargreaves method, runoff was estimated using the SCS Curve Number method, and peak flow using the modified rational method.

The SCS curve number is computed with the equation:

$$Q = \frac{(R - 0.2s)^2}{R + 0.8s} \qquad R > 0.2s$$

$$Q = 0.0 \qquad R \leq 0.2s$$

where Q is the daily runoff, R is the daily rainfall, and s is a retention parameter.

A specific problem concerning the hydrological submodel is the storage routing approach („bucket approach“) for the estimation of percolation. It does not allow for upward movement of water through the soil matrix. The mathematical processes behind the routing equation:

$$SW_l = (SW_{ol} - FC_l) \exp(-\Delta t / TT_l) + FC_l$$

where SW and SW_o are the soil water contents at the end and the start of time interval Δt (24h) and TT is travel time through layer l (h).

The nutrient submodel

Nutrient cycles are simulated for the organic and mineral fractions of nitrogen (N) and phosphorus (P). The transformations between the nutrient additions and losses are calculated through a series of attached equations on a daily time-step. These equations are closely linked to other model components, particularly to the hydrology component, which regulates transport processes, and the plant growth component, which is connected to nutrient uptake.

The nitrogen demand is simulated with the equation:

$$UND_i = (C_{NB})_i \ (B)_i - \sum_{k=1}^{i-1} UN_k$$

where UND is the nitrogen demand of the crop (kg/ha/d), C_{NB} is the optimal N concentration of the crop (kg/t) - related to the growing stage, B the accumulated biomass (t/ha) for day I, and UN is the actual N uptake rate (kg/ha/d).

The nutrient submodel concerning the nitrogen cycle consists of the following parameters:

- N2-Fixation
- N-mineralisation
- N-immobilisation
- Denitrification
- Leaching/subsurface flow
- N surface runoff
- N uptake

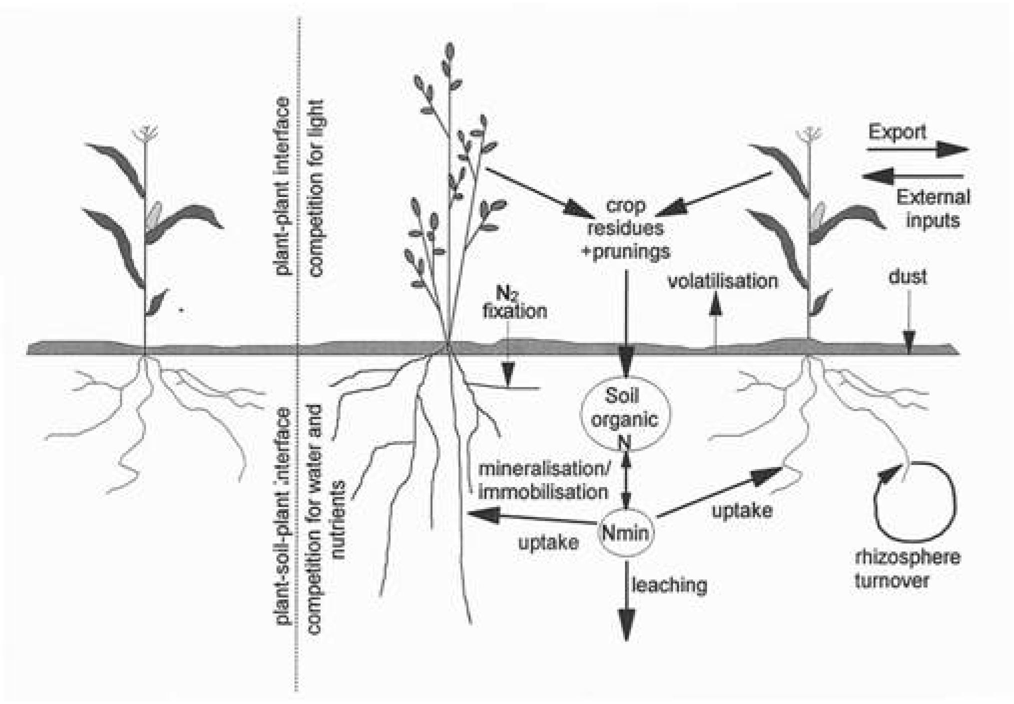


Figure 3: Nitrogen cycling in intercropping systems (Gaiser, 1999)

For estimating the nutrient stress the following equation is used (for N):

$$SN_{S,i} = 2\left(1 - \frac{\sum_{k=1}^{i} UN_k}{(C_{NB})i\ (B)i}\right)$$

where SNs is a scaling factor for N stress, UN is the crop N uptake rate on a day k (kg/ha/d).

The crop growth submodel

The plant growth model simulates the growth and harvest of a crop. This submodel can simulate agronomic crops, trees and pastures. Plant growth is modelled with a basic heat unit system that correlates temperature with plant growth. The phenological development is computed by using the equation:

$$HU_k = \left(\frac{T_{mx,k} + T_{mn,k}}{2}\right) - T_{b,j} \qquad HU_k \geq O$$

Other factors affecting the potential growth of the selected crop include temperature, solar radiation, soil moisture, soil aeration, labile nitrogen and phosphorus, and soil strength. 47 Crop-specific parameters are available for 80 crops, and the crop growth model can simulate complex crop rotations.

Parameters, which are most sensitive to biomass production:

- Potential energy to biomass conversion factor
- Maximum potential leaf area index
- Leaf area development points
- Index of crop tolerance to aluminium saturation (in highly acid soils)
- Maximum stomatal conductance
- Maximum root depth
- Normal fraction of nitrogen in crop biomass at emergence/mid-season/maturity
- Normal fraction of phosphorus in crop biomass at emergence/mid-season/maturity
- Threshold of vapor pressure deficit for decrease of energy-biomass-conversion factor
- Threshold of vapor pressure deficit for decrease of maximum stomatal conductance
- Fraction of root weight at emergence/maturity

Management
A database of chronological management information was established based on our literature review. Soil tillage affects nutrient cycling, soil hydrology, pesticide fate, and root growth. EPIC simulates many crop variables with a variety of management practices.

- specific crop characteristics and plant populations
- dates of planting, tillage and harvest
- fertilization rates, methods, and timing
- irrigation and artificial drainage systems
- pesticide application
- conservation practices and liming

4.2 Data Requirements

The process of developing the EPIC simulations necessitates the construction of a range of model-specific datasets.
Based on results of the literature review detailed soil, climate, and landuse data were collected for the modelling work.
The digitalized input data is handled through the MS-DOS-Modus. The user interface of the EPIC model contains various input and control files.
The EPIC-Model is run with the order “Epic3060” directly in MS-DOS-Modus.

Hydro-meteorological Data

The EPIC model can generate daily weather from monthly climate statistics or measured data can be digitalized and read in. The user can also specify atmospheric content for nitrogen and CO2.
Daily weather data for the years of simulation including precipitation volume, minimum and maximum temperatures, solar radiation, wind speed, and relative humidity were provided by INRAB/CRA (meteorological) stations.

Soil Data

	Recommended Input Parameters	
		
Terrain data		**Soil data**
latitude of watershed		horizon thickness
run off curve number		texture, pH-value
slope length		calcium carbonate
slope steepness		organic carbon
water table depth		bulk density
years of cultivation		coarse fragments
		sum of bases
		CEC

4.3 Model Output

The printed output file starts with the listing of the input variables: general information, terrain, weather, soil and management data.
The potential list of model output variables that can be analyzed is large, only outputs that are important to the RVERTWIN objectives will be described and discussed in this delivery report. The main part of the printed output provides the listing of the dynamic output variables on a monthly basis.
The output variables are grouped in 4 output files:
a. Hydrological and erosion parameters
b. Dynamic variables in the nitrogen and phosphorus cycle
c. Dynamic variables related to crop growth
d. Summary of crop related results for one cropping cycle

4.4 Significance of the Research Work

Intended End-use and Application of the EPIC Model

Results of the EPIC model will provide a substantial input to the SLYSIS Model which addresses the modelling at the regional scale. The land resource information system SLISYS will be used to upscale the results of the EPIC model. It consists of a soil and climate database that follows the SOTER approach (Soil and terrain digital database) recommended by FAO. CORINE data as well as additional satellite images (LANDSAT TM) from the river basin will be classified and interpreted to produce land use/cover maps for different vegetation periods.
The results of our studies are also being discussed and made available to the authorities, on a regular basis.

5 Model Simulation Results in the Oueme-Basin

Over 43 cropping systems, with various N inputs under contrasting soil and climate conditions were simulated to calibrate the EPIC model. Several sites within the Oueme River Basin were selected, where a detailed database of management histories existed.

Several PhD-works, master theses and reports from research stations were identified as having sites with a detailed combination of management and soil data datasets. In addition, literature describing agricultural field studies was utilised. Among the crops whose productivity has been simulated with the crop model are West Africa’s important food and cash crops: maize, sorghum, rice, peanut, cowpea, soybean and cotton. The following list and the figure (next page) provide more details about the study area and the simulated crop rotations.

Table 2: Overview about research Sites and simulated Crops
(Reference, see chapter 7)

Site	Soil Type	Landuse	Crop/Year	Site Coordinates	
Niaouli (C1)	Ferrali - Haplic Acrisol	Niaouli RS °	Corn,1990	6°42`N	2°07`E
Niaouli (AR1)	Ferrali - Haplic Acrisol	Niaouli RS	Peanut,1990	6°42`N	2°07`E
IITA-Benin (C2)	Ferrali - Haplic Acrisol	IITA-Benin RS°°	Corn, 1986-89	6°24`N	2°20`E
IITA-Benin (C5)	Ferrali - Haplic Acrisol	IITA-Benin RS	Corn, 1990-91	6°24`N	2°20`E
Aguagon (C3)	Ferric - Lixisol	Farmer Field°°°°	Corn, 1992	7°58`N	2°18'E
Parakou (SOR1)	Acrisol	Research Station	Sorghum, 1983	9°20`N	2°37`E
Doguè (C6)	Gleysol	Farmer Field	Corn, 2002	9°05`N	1°55`E
Doguè (C12)	Plinthosol	Farmer Field	Corn, 2002	9°05`N	1°55`E
	Lixisol				
Doguè (SOR2)	Plinthosol	Farmer Field	Sorghum, 2002	9°05`N	1°55`E
	Lixisol				
Ahohoué (C8)	Acrisol	Research Station	Corn, 2004	6°50'N	1°46'N
Attotinga/Tokpa (C9)	Ferrali - Haplic Acrisol	Farmer Field	Corn, 1999	6°39’N	2°09’E
Eglimé (R1)	Ferrali - Haplic Acrisol	Research Station	Rice, 2003	7°05`N	1°40`E
Akouègba (R2)	Plinthosol	Farmer Field	Rice, 1998	7°43'N	2°12'E
Akouègba (R-BF)	Gleysol				
Hayapka (COW 0-1)	Nitosol	Farmer Field	Cowpea, 1999	6°33`N	2°08`E
Hayapka (SOY)			Soybean, 2000		
Savalou (CO1)	Plinthosol	Research Station	Cotton, 2001	7°55'N	1°58'E
Djougou (CO2)	Plinthosol	Research Station	Cotton, 2000	9°42`N	1°40`E
Abomey-Calavi (AR2)	Ferralsol	University ES °°°	Peanut, 1985	6°27`N	2°21`E
Abomey-Calavi (AR3)	Acrisol	IITA sub-station	Peanut, 1988	6°27`N	2°21`E

° Niaouli Research Station
°° International Institute for Tropical Agriculture (IITA-Benin)
°°° Experimental Station of the University Abomey-Calavi
°°°° Farmer Field, researcher managed

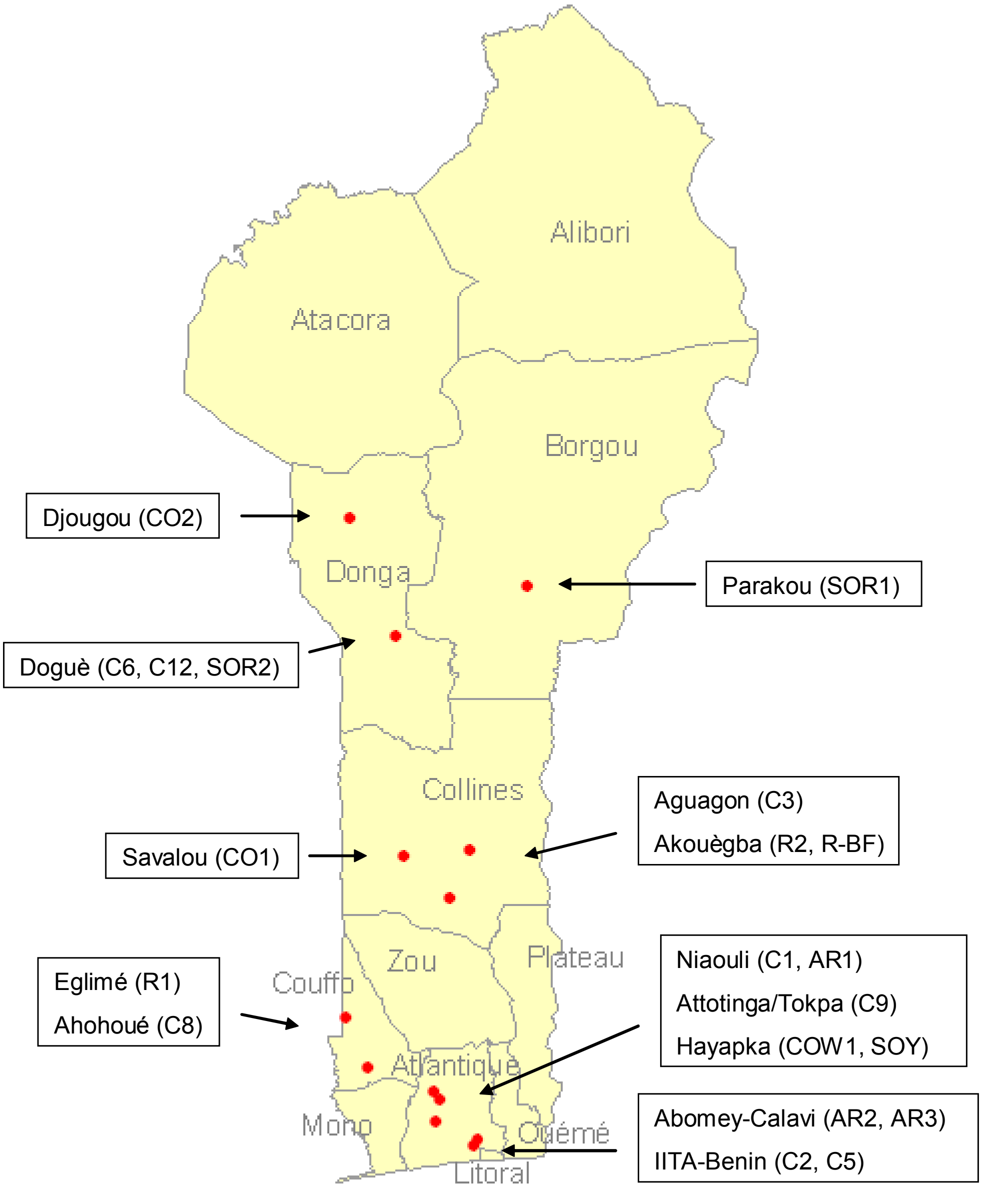


Figure 4: Location of research Sites in the Oueme-Basin

5.1 Sites at Research Stations

In EPIC, yields are expressed as a fraction of biomass, which in turn is a function of solar active radiation and leaf area. Leaf area is simulated as a function of heat unit accumulation, crop development stage, and crop stress. *Stress factors* that reduce biomass growth are lack of nitrogen, phosphorus, and water, as well as inadequate temperature, soil compaction, excessive soil acidity, and aluminium toxicity.

The application of EPIC in the Oueme-Basin produced a variety of model outputs, some of the model outputs were selected for the model calibration and validation. Selected model outputs and comparison with available data are shown in the tables and figures below.
First, sites located within research stations are presented and later research sites located within farmer fields. *The simulation results based on data from Research stations will be presented in detail since there is best data coverage for these sites.*

Crop yields at the research stations were accurately predicted. During most years, corn yields were confined to the range between 3.5-4.7 t/ha for the +NPK treatments and 1.1-3.6 t/ha for the –NPK (NPK=0/0/0) treatments.

IITA-Benin

The field trial where our simulations are based on was conducted on the substation of the International Institute of Tropical Agriculture (IITA) at Calavi in southern Benin. For the testing of the EPIC model research data of two fertilizer treatments (with and without NPK) was compared with the EPIC simulations.

The simulation of the corn yield in the years 1986-1991 was realistically predicted – at sites with fertilizer application. According to simulation results at sites without fertilizer application corn yields after the first cropping season were underestimated, due to N-deficit. In EPIC the maximum yields are not reached if stress due to N-, Water- and Temperature is present and is indicated by EPIC through the stress days.

Table 3: Crop yields and stress factors simulated by EPIC site IITA-Benin

Site	Year	Soil Type	Crop	Yield (t/ha) Simulated	Yield (t/ha) measured	Diff.	NPK (kg/ha)	Stress° due to
				+ NPK				
C2.1	1986	Acrisol	Corn	**3.7**	4.1	-0.4	90/90/90	-
C2.2	1987	Acrisol	Corn	**3.8**	3.9	-0.1	90/90/90	-
C2.3	1988	Acrisol	Corn	**3.6**	3.4	0.2	90/90/90	-
C2.4	1989	Acrisol	Corn	**3.8**	3.8	0	90/90/90	-
C5.1	1990	Acrisol	Corn	**3.7**	3.3	0.4	90/90/90	-
C5.2	1991	Acrisol	Corn	**3.5**	3.9	-0.4	90/90/90	-
				- NPK				
C2.1-0	1986	Acrisol	Corn	**3.6**	3	0.6	0	-
C2.2-0	1987	Acrisol	Corn	**1.7**	3.1	-1.4	0	N31
C2.3-0	1988	Acrisol	Corn	**1.6**	2	-0.4	0	N32
C2.4-0	1989	Acrisol	Corn	**1.7**	2.5	-0.8	0	N25
C5.1-0	1990	Acrisol	Corn	**1.4**	1.9	-0.5	0	N35
C5.2-0	1991	Acrisol	Corn	**1.1**	1.9	-0.8	0	N38

***Stress Factors:** **W**ater,**T**emperature, **A**ir, **N**-deficit*

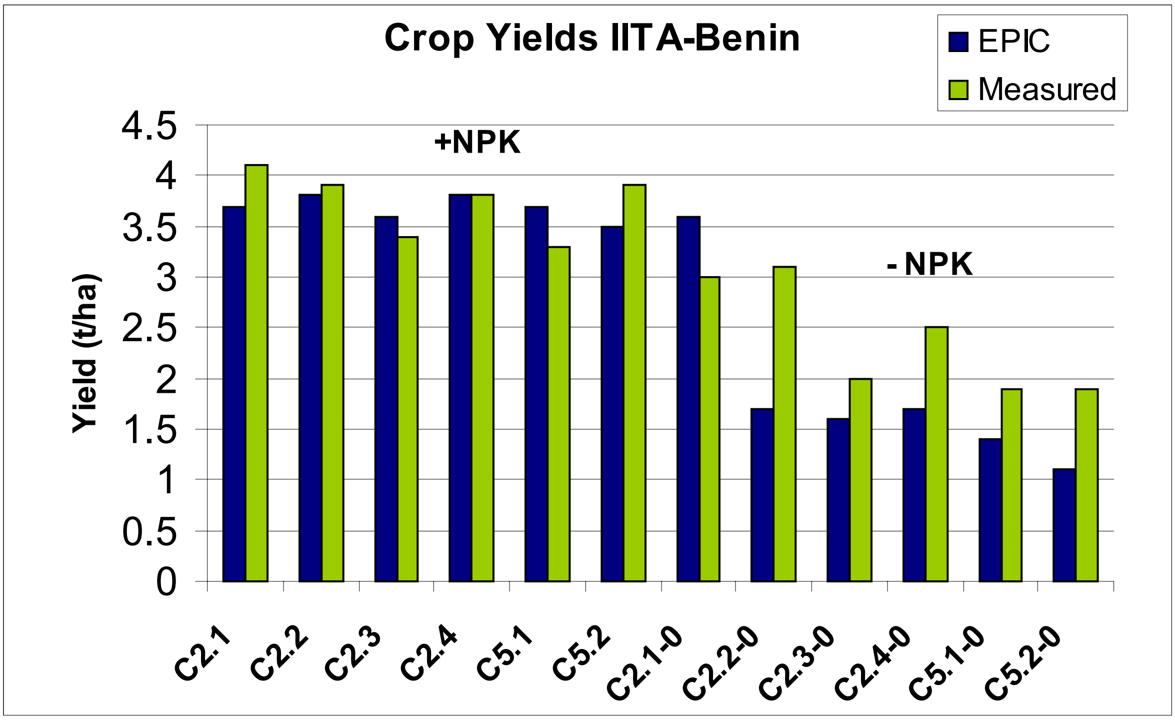


Figure 5: Simulated crop yields Site IITA-Benin

For the simulation of biomass production data was only available for the years 1986-1989. EPIC overpredicted the biomass production in 1988 and 1989 (+NPK), while significantly underestimating biomass productivity in the –NPK treatment in 1987.

Table 4: Biomass production simulated by EPIC at site IITA-Benin

Site	Year	Biomass t/ha simulated	Biomass (t/ha) measured	Diff.	NPK (kg/ha)
+ NPK					
C2.1	1986	**10**	10.2	-0.2	90/90/90
C2.2	1987	**10.4**	10	0.4	90/90/90
C2.3	1988	**9.9**	8.1	1.8	90/90/90
C2.4	1989	**9.5**	7.7	1.8	90/90/90
- NPK					
C2.1-0	1986	**9.9**	8	1.9	0
C2.2-0	1987	**4.7**	8.4	-3.7	0
C2.3-0	1988	**4.5**	4.5	0	0
C2.4-0	1989	**4.6**	5.4	-0.8	0

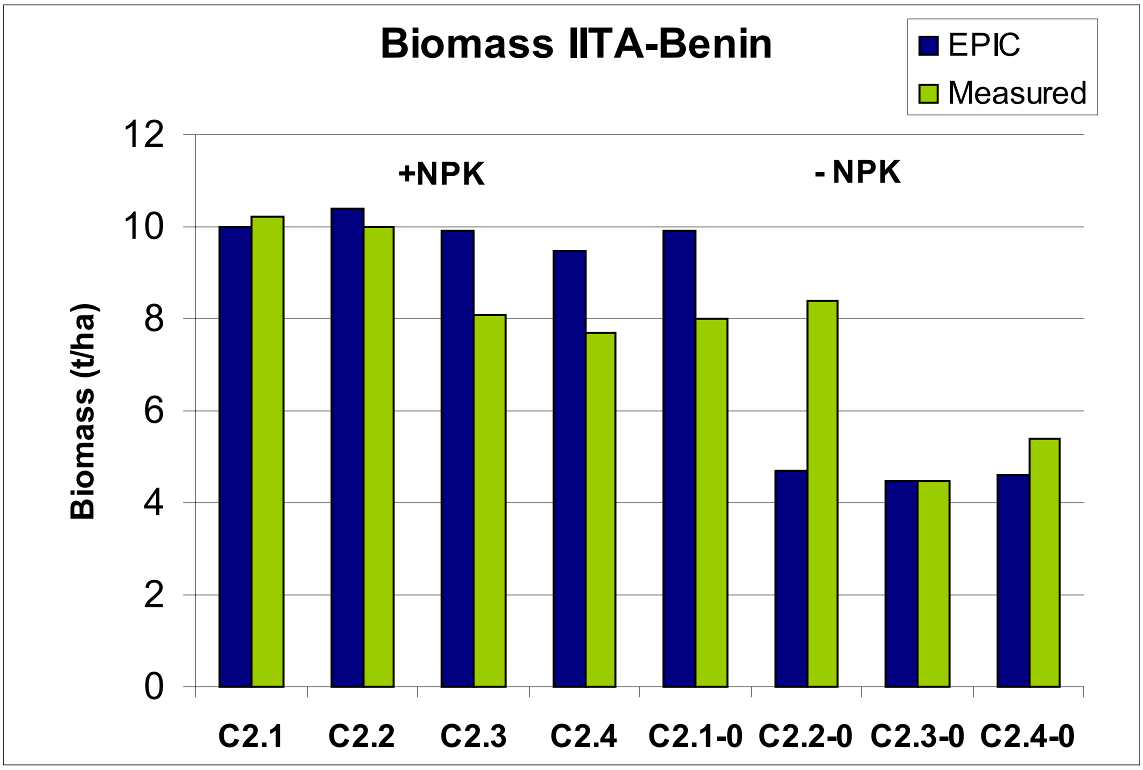


Figure 6: Biomass production simulated by EPIC (site: IITA-Benin)

Research Station Niaouli

Simulation results at the national Research Station Niaouli were (similar to the IITA research station) well predicted. Observed corn yields in the range between 3.4-4.8 t/ha were the highest simulated yields during our simulations in the Oueme-Basin.

Table 5 : Crop yields and stress factors simulated by EPIC site Niaouli Research Station

Site	Year	Soil Type	Crop	Yield (t/ha) Simulated	Yield (t/ha) measured	Diff.	NPK (kg/ha)	Stress° due to
C1	1990	Acrisol	Corn	**4.7**	4.8	-0.1	120/40/60	W 7
C1b	1990	Acrisol	Corn	**4.3**	3.4	0.9	0/40/60	N 9
C1c	1990	Acrisol	Corn	**4.6**	4	0.6	60/20/60	W 6
AR1	1990	Acrisol	Peanut	**1.4**	1.5	-0.1	60/20/60	W 9
AR1b	1990	Acrisol	Peanut	**1.4**	1.5	-0.1	0/40/60	W 9
AR1c	1990	Acrisol	Peanut	**1.4**	1.8	0.4	120/40/60	W 9

°Stress days due to: N (Nitrogen). W(Water)

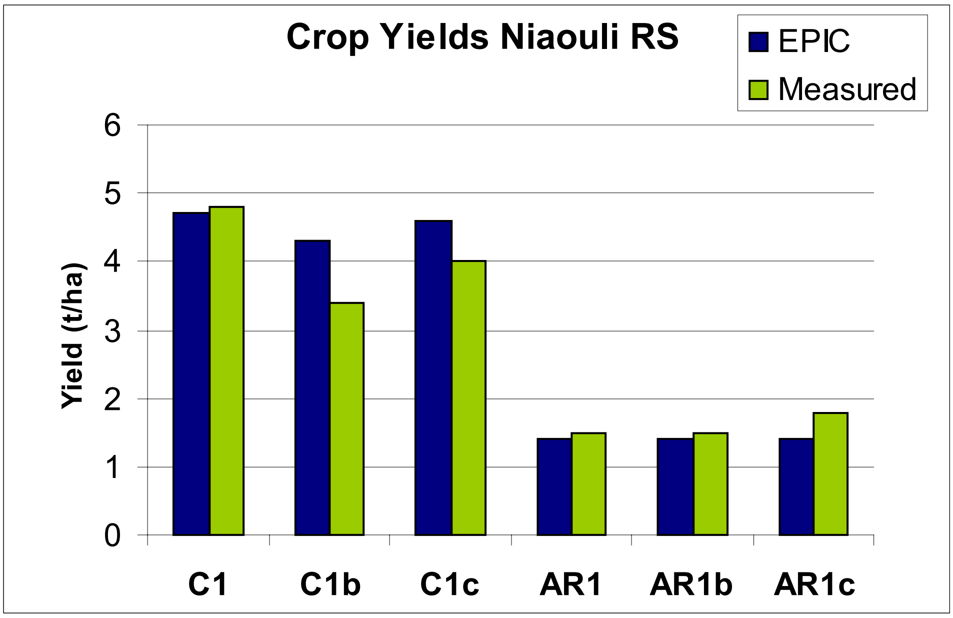


Figure 7 : Predicted and measured crop yields (site: Niaouli Research Station)

Other Research Stations

The next table presents the yield simulation results from other research stations for various crops on different soil types. Crop Yields at nearly all sites (R1, CO1, CO2, AR2, AR2-O, AR3 AR3-0) were realistically predicted. Only the yield at sites C8 and R1-0 was significantly overestimated.

Table 6 : Simulation Results from other Research Stations
(Yields of various food crops and different soil types)

Site	Year	Soil Type	Crop	Yield (t/ha) Simulated	Yield (t/ha) measured	Diff.	NPK (kg/ha)
R1	2003	Acrisol	Rice	**2.6**	2.5	0.1	90/60/45
R1-0	2003	Acrisol	Rice	**1.8**	0.9	0.9	0
CO1	2001	Plinthosol	Cotton	**1.1**	1.4	-0.3	95/69/45
CO2	2000	Plinthosol	Cotton	**0.8**	0.7	0.1	95/69/45
AR2	1985	Ferralsol	Peanut	**1.3**	1.6	-0.3	20/80/60
AR2-0	1985	Ferralsol	Peanut	**1.3**	1.4	-0.1	0
AR3	1988	Acrisol	Peanut	**1.3**	1.2	0.1	0/90/0
AR3-0	1988	Acrisol	Peanut	**1.3**	1.2	0.1	0
C8	2004	Acrisol	Corn	**4.4**	3.6	0.8	74/46/28

5.2 Farmer fields

Yield simulation results for the following less favourable sites located on farmer fields were poor and yields were overpredicted in most cases except for R-BF, SOY, SOY-0.

The studies were conducted at different farmer fields, according to the reports *most of these sites are degraded and extensively managed by farmers*. The rather low soil fertility (multiple nutrient deficiencies) and perhaps the inadequate management could lead to site specific stress factors, which are not considered by the EPIC model.

The experiments included the testing of various fertilizer inputs, but the observed yields at the farmer fields were extremely low even with high doses of NPK application. It could be observed that the model partly failed to simulate crop growth and yield performance on less favourable sites.

Table 7 : Yield simulations at Farmer Fields

Site	Year	Soil Type	Crop	Yield (t/ha) simulated	Yield (t/ha) measured	Diff.	NPK (kg/ha)
C3	1992	Ferric-Lixisol	Corn°	**2.7**	1.1	1.6	0
C3b	1992	Ferric-Lixisol	Corn	**3.8**	no data	-	45/20/37
C3c	1992	Ferric-Lixisol	Corn°	**4**	2.6	1.4	90/39/74
C3d	1992	Ferric-Lixisol	Corn	**4**	no data	-	180/78/144
C12F	2002	Ferric-Lixisol	Corn°	**3.6**	2.3	1.3	0/0/0
C12P	2002	Plinthosol	Corn°	**3**	2.3	0.7	45/20/37
C12-0	2003	Plinthosol	Corn°	**1.6**	0.8	0.8	0/0/0
SOR2F	2002	Ferric-Lixisol	Sorghum°	**2**	0.7	1.3	90/39/74
SOR2P	2002	Plinthosol	Sorghum°	**2**	0.7	1.3	180/78/144
R2	1998	Plinthosol	Rice	**1.7**	1.6	0.1	130/90/60
R-BF	1998	Gleysol	Rice	**2.8**	3.2	-0.4	130/90/60
SOY	2000	Nitosol	Soybean	**0.4**	0.7	-0.3	0/15/40
SOY-0	2000	Nitosol	Soybean	**0.4**	0.5	-0.1	0
C9	1999	Acrisol	Corn°	**3.3**	1.5	1.8	60/43/50
C9-0	1999	Acrisol	Corn°	**2.1**	1	1.1	0
SOR	1983	Acrisol	Sorghum°	**1.2**	0.7	0.5	0
COW1	1999	Nitosol	Cowpea°	**2.3**	1.1	1.2	0/27/40
COW0	1999	Nitosol	Cowpea°	**2.2**	1	1.2	0

° = Local Varieties

Local Varieties

The crop simulation model EPIC has been developed in the USA for modern agriculture based on fertilizers and improved germplasm.
After the application of the model in the Oueme-Basin, our simulation results show that the model is less reliable in extensive systems where crop performances depend on the natural fertility of the soil and local crop varieties.
However, concerning the simulation results at farmer fields only for the following sites accurate information on the cultivated crop varieties were available. Therefore, these sites were selected in order to conduct further calibrations specifically for local varieties.

The rather weak agronomic performance generally observed is probably a result of the local varieties.
The simulated local crop cultivars had a low internal nutrient utilization efficiency which was related to a low harvest index. For these reasons the harvest index (HI) and the WSYF in the maize and sorghum crop files were adapted to the extensive agricultural conditions present on the farmer fields. The table below shows that with this revision the simulation results improved, but the measured yields of the local crop varieties are still lower than the simulated yields. Indicating that perhaps other site specific stress factors, like multiple nutrient deficiencies, are not being considered by the EPIC model.

Table 8 : Corn Yields as simulated with the original and the generally revised version of EPIC

Site	HI	HI-Revised	WSYF	WSYF Revised	Yield EPIC	Yield EPIC Revised	Yield measured
C9	0.5	0.35	0.4	0.01	3.3	**2.3**	1.5
C9-0	0.5	0.35	0.4	0.01	2.1	**1.5**	1
SOR	0.5	0.35	0.35	0.01	1.2	**0.8**	0.7
COW1	0.45	0.3	0.05	0.01	2.3	**1.5**	1.1
COW0	0.45	0.3	0.05	0.01	2.2	**1.4**	1
C3	0.5	0.35	0.4	0.01	2.7	**1.9**	1.1
C3c	0.5	0.35	0.4	0.01	4	**2.8**	2.6
C12F	0.5	0.35	0.4	0.01	3.6	**2.5**	2.3
C12P	0.5	0.35	0.4	0.01	3	**2.1**	2.3
C12-0	0.5	0.35	0.4	0.01	1.6	**1.6**	0.8
SOR2F	0.5	0.35	0.35	0.01	2	**1.4**	0.7
SOR2P	0.5	0.35	0.35	0.01	2	**1.4**	0.7

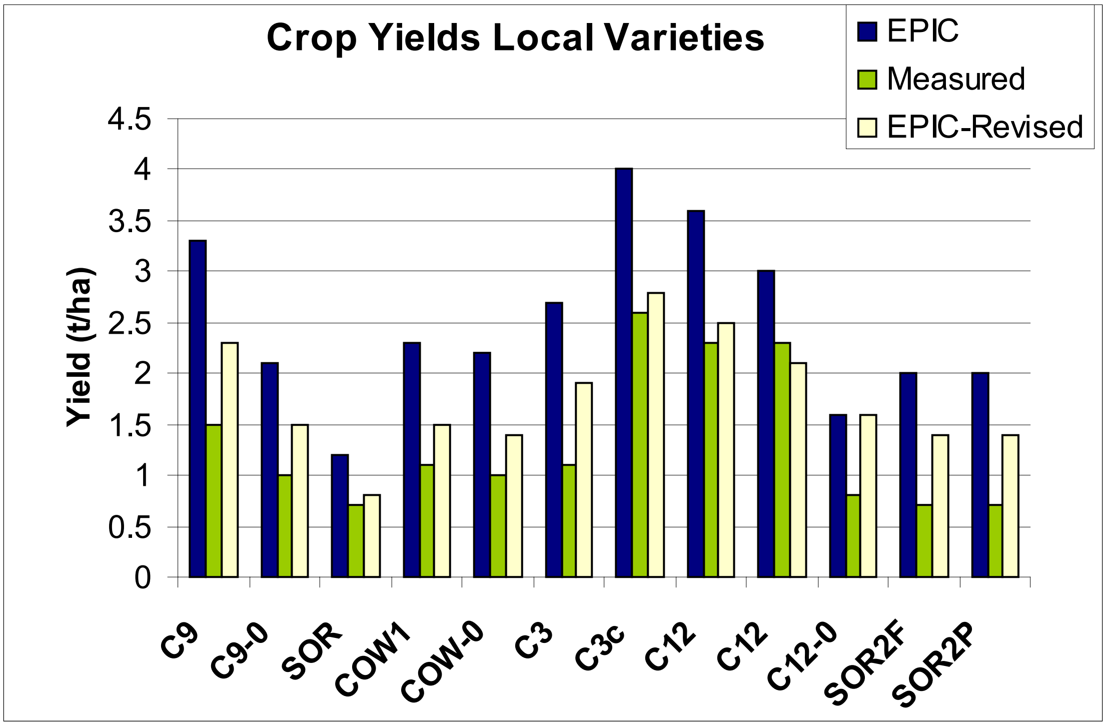


Figure 8: Simulated crop yields of local varieties

5.3 Sensitivity Analysis

5.3.1 Crop Variety

The EPIC model comes with a crop file that includes a single, unidentified variety, whereas in reality there are numerous varieties of the same crop.

Planted with the same operations schedule and under the same environmental conditions, each variety is capable of delivering different levels of yield. Therefore, the objective of the study, with regard to local crop varieties, includes the adjustment of the EPIC model to local conditions (see chapter 5.2).

Field surveys are necessary to provide necessary ratios between observed yield of each variety and model simulated yields.

The next tables show the yield deviation of various crop varieties cultivated at one of our simulation sites - the national Research Station in Niaouli.

Table 9 : Yield deviation of different crop varieties at the Niaouli Research Station (Ministère du dévéloppement rural 1990)

Varieties	Yield (t/ha) 1990
Maize	
DMR ESR-W	2.5 (fs°)
SEKOU 85 TZSR-W	2.7 (fs)
POZARICA EV 8445 SR	1.3 (ss°°)
PIRSABAK EV 8430 SR	0.5 (ss)
Peanut	
TS 32-1	0.5 (fs)
TS 32-1	0.4 (ss)
Cowpea	
IT 81 D 1137	1.3 (fs)
IT 82 E 32	1.0 (fs)
IT 84 D 513	1.1 (fs)
IT 82 E 32	0.6 (ss)
IT 81 D 1137	0.2 (ss)

fs ° first cropping season 1990
ss °° second cropping season 1990

Table 10 : Cassava yields of different varieties at the Niaouli Research Station (Ministère du dévéloppement rural 1990)

Cassava variety	yield (total fresh matter)(t/ha) 1990	tubers/ha
TMS 30572 A	14.5	56.7
TMS 30572	21.6	91.9
NIAOULI 84	8.0	40.6
TMS 50395	25.7	80.6
TMS 63397	16.3	66.3
TMS 30001	12.1	57.5
TMS 4 (2) 1425	18.2	55.7
TMS 91934	17.6	62.3
TMS 30555	14.1	57.8
BEN 86052	21.5	82.4
average	17.0	65.2

The differences of average yields at the Research Station of Niaouli greatly varied. These results also suggest that each crop variety needs to be separately modeled. Thus while attempting to bridge the gap between observed and simulated yield, attempts should be made to ensure that the crop parameters in the EPIC model truthfully represent the actual cultivars in the field.

5.3.2 Sensitivity to different levels of ‘Potential Heat Units’

The authors of the model left two ends, accessible to users, in the forms of choices of PHU (potential heat units) and potential evapotranspiration equations, which might be adopted to reduce the gaps between observed and simulated yields.

The parameter, which controls the magnitude of model yield, is potential heat units (PHU). Whenever the average temperature is higher than the base temperature, heat units accumulate. The development of the crop is based on daily heat unit accumulation. Thus there should be a given amount of heat units required for the various stages of development and maturity of a given crop or crop variety. The PHU is within the Operations Schedule file, and can be adjusted for the proper cultivar or crop variety for a location. The choice of PHU is thus left to the user while creating an OPS (operations schedule) file.
In Table 11, we demonstrate the relationship between observed yields of maize at site C2, and the simulated yields corresponding to various values of PHU as adjusted in the ‘Operations Schedule’ file. These results show that simulated yields are closest to observed yields when PHU is set at 1500.

Table 11 : Sensitivity of corn (C2) to different levels of ‘Potential Heat Units’

C2	OBSERVED YIELDS	CROP MODEL OUTPUTS (Varying potential heat units)				
Year		1000	1200	1500	1800	2000
1986	4.1	2.4	2.9	3.7	4.2	5.0
1987	3.9	2.5	3.0	3.8	4.6	5.2
1988	3.4	2.3	2.8	3.6	4.4	4.8
1989	3.8	2.5	3.0	3.8	4.2	4.7

5.3.3 Average nutrient (N, P, K) cycles and balances

The next Table shows the NPK export for +NPK and –NPK treatments on one site, where data was available (site C2). The simulated export of nutrients is lower than the observed values. Hereby, the –NPK treatments results in a N-deficit prediction at the end of each cropping season. With regard to the corresponding yields (Table 12) it can be observed, that the underpredicted N-export and the N-deficit is connected to the underestimation of the corn yields.

Table 12 : Simulation results of N-Export from the field at site C 2

Site	Year	Export (kg/ha) Sim.			Export (kg/ha) Meas.			
		N	P	K	N	P	K	Difference
C2.1	1986	64	9	12	72	19	22	- 8/10/10
C2.2	1987	67	10	12	81	27	36	- 14/17/24
C2.3	1988	64	9	12	83	25	29	- 19/16/17
C2.4	1989	66	9	12	100	28	35	- 34/19/23
C2.1-0	1986	36	5	7	50	10	13	- 14/5/6
C2.2-0	1987	38	6	7	66	25	30	- 28/19/23
C2.3-0	1988	37	6	7	43	10	13	- 6/4/6
C2.4-0	1989	36	5	7	62	15	19	- 26/10/12

To simulate nutrient loss in percolation even less data was available. For that reason Table 13 only show the simulation results for mineral N loss in percolate at site C2. Hereby, EPIC predicts a clear difference between the two treatments with regard to N percolation. For the +NPK treatment significantly higher N loss in percolate was predicted.

Whereas according to the measured data, only C2.4 (1989) displays a significantly high N loss for the +NPK treatment as compared to the –NPK. At site C2.3 even higher N percolation was measured for the –NPK treatment.

Measured data for other nutrients and other study areas were not available.

Table 13 : Simulated Mineral N loss in percolate – site C2

Site	Treatment	Mineral N loss in percolate (kg/ha)		
		Measured	Simulated	Difference
C2.1	+NPK	n.d.	-	-
C2.2	+NPK	20	36	-16
C2.3	+NPK	8	57	-49
C2.4	+NPK	68	50	18
Mean		32	48	-16
C2.1-0	-NPK	n.d.	-	-
C2.2-0	-NPK	9	17	-8
C2.3-0	-NPK	33	16	17
C2.4-0	-NPK	20	15	5
		21	16	+5

n.d. = not determined

Nitrogen cycles

N-cycles are simulated for the organic and mineral fractions of nitrogen. The transformations between the nutrient additions and losses are closely linked to other model components, particularly to the hydrology component, which regulates transport processes, and plant growth component, which is connected to nutrient uptake. Other important factors are the site specific soil characteristics. For example, due to widespread dense soil layers below the rooting depth, mineral N loss in percolate is often relatively low.

In line with the nitrogen cycle simulation (Figure 9) N loss through percolation at site C3 had its peak during the months of May and June, and only small differences between the treatments were predicted. The nutrient cycle simulation also show that at this particular site, the mineral N loss in lateral subsurface flow (Figure10)) is very low. Consequently most of the nitrogen, at site C3 is whether exported by the crop or present in the soil (Figure 11).

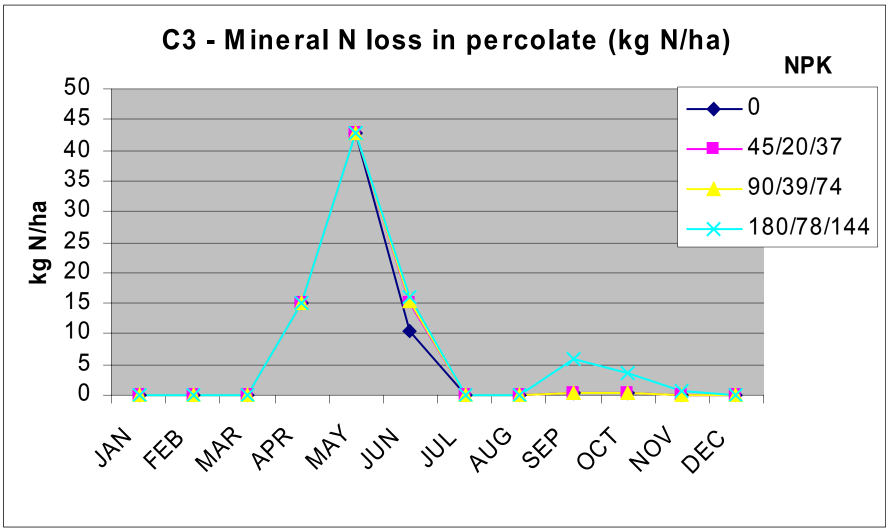


Figure 9: Simulated Mineral N loss in percolate – site C3

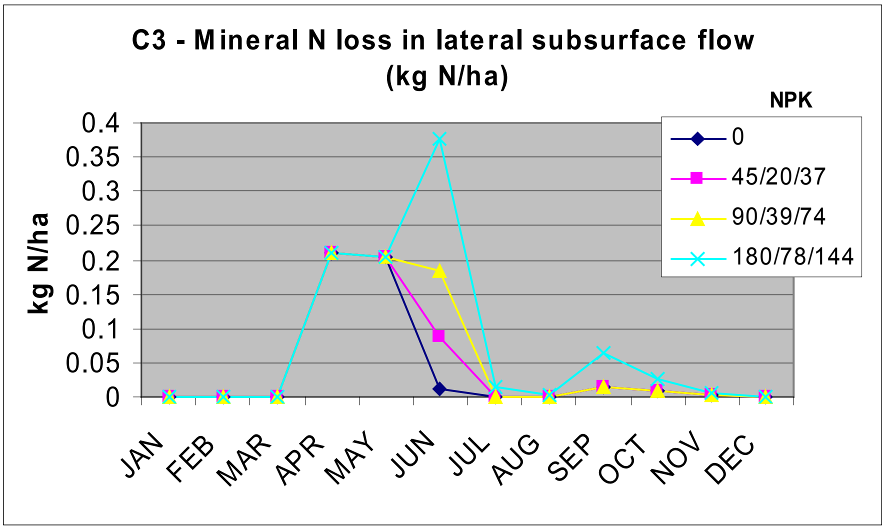


Figure 10: Simulated mineral N loss in lateral subsurface flow – site C3

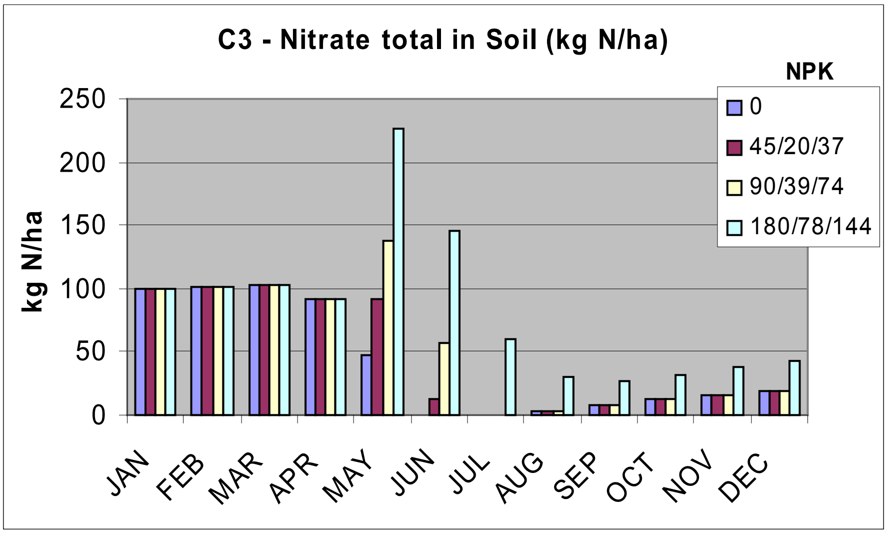


Figure 11: Simulated total nitrate in soil – site C3

5.4 User interface

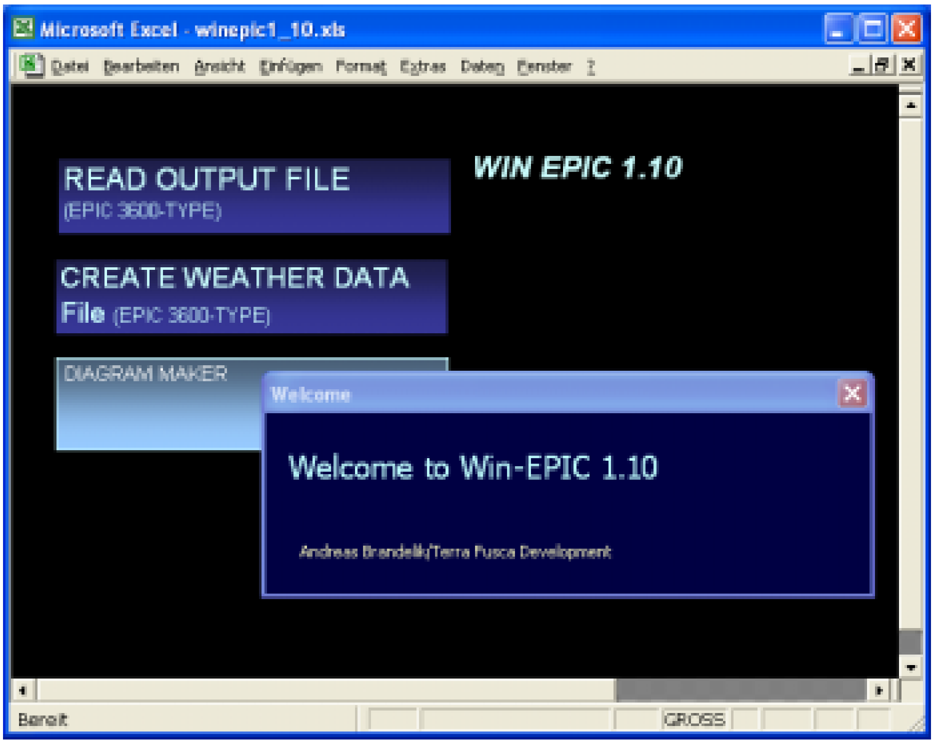
Due to the complexity of the components captured in the model the numerical computations were very time consuming. Therefore during our work with the Epic model new software tools were developed.

An important activity for the development of an improved object-oriented design centred upon the development of the user interface.

In the first year of the RIVERTWIN Project Win-EPIC 1.30 was developed for the Neckar River Basin, later the EPIC software was further improved and the final version Win-EPIC 1.10 was developed.

It was important to develop the model software towards a practicable model design which is important for practicable computations and results sharing.

WIN-EPIC 1.10



Welcome to Win-EPIC 1.10

Andreas Brandelik/Terra Fusca Development

Figure 12: Prototype WIN-EPiC 1.10

In order to provide a user-friendly computer program package for the data analysis of the EPIC runs, the software is adapted to a widespread computer program involving a flexible environment for processing data, extensive graphing capabilities for displaying data, and a high degree of compatibility with graphic and text processing computer programs. Therefore, we decided to use EXCELTM by Microsoft® using the Microsoft® Windows operating system (e.g., Windows 98 to Windows XP). An advantage of this spreadsheet environment is the simplicity with which data can be changed, copied, selected and arranged. In addition, the large number of built-in functions (e.g., mathematical and statistical functions) enables the user to easily perform various kinds of calculations by developing individual worksheet applications. In order to create a user-friendly, but also event-driven and interactive operating system in the EXCELTM environment the powerful programming language "Visual Basic for Applications" (VBA) was used. WINEPIC consists of 3 worksheets. Each sheet is equipped with its own command bar to navigate within the entire program and run different computation procedures. After starting WINEPIC the worksheet "START" is automatically activated.

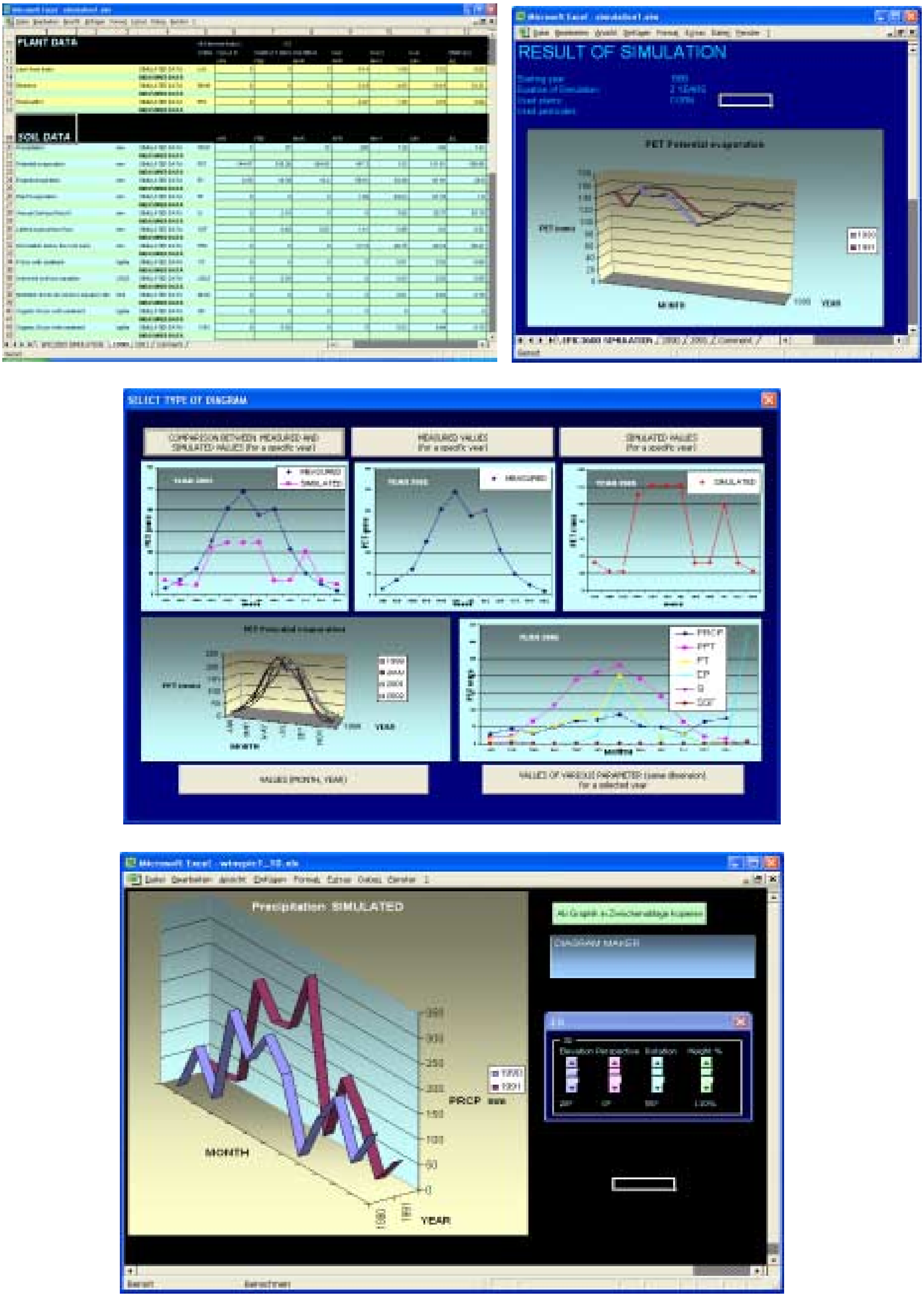


Figure 13: Some screenshots from the new user interface Win-EPiC 1.10

6 Discussion and Conclusions

In order to be considered realistic in their predictions simulation models must be verified against real-world data. *Calibration is a continuing development requiring contributions from users especially in places like Benin with different site conditions than where the model originated.*

For application in our study area, a two-stage approach was adopted to evaluate EPIC. The first stage consisted of validation and the second stage consisted of sensitivity analysis. Validation represents a test of model performance involving the comparison of real world observations with the results of model outputs achieved with conditions similar to those at the time the measurements were made. In sensitivity analysis, changes in model output following changes in site specific factors were evaluated.

Yield Simulations

The Epic model simulated crop yields for the studied sites more or less accurately, depending on the quality of input data, crop variety and site specific conditions.

Results obtained from the Research sites, under improved crop management (improved crop varieties, no weed competition), showed a better correlation between measured and simulated data than the results at farmer fields.

EPIC simulations were evaluated using the percentage error E and coefficient of determination r^2. The EPIC yields were compared to the measured values. Through this analysis we try to evaluate the quality of predictions made by the EPIC model.

The decision factors used by Chung et al. (2001) were used to judge if the model results were statistically acceptable: percentage error (E)<0.3 and the coefficient of determination $r^2>0.5$.

The coefficient of determination (R^2) for all crop yields (R^2=0.75) is in general above our target limit fixed at $r^2>0.5$. On farmer fields, first simulation runs show low correlations between simulated and observed data (R^2=0.55) in a comparison of all treatments.

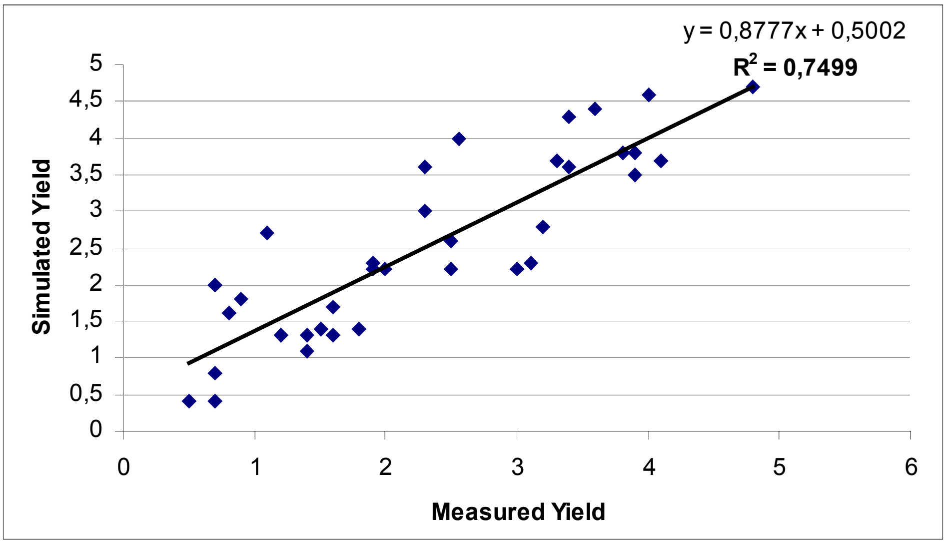


Figure 14: Yield coefficient of determination R² - for all simulated sites

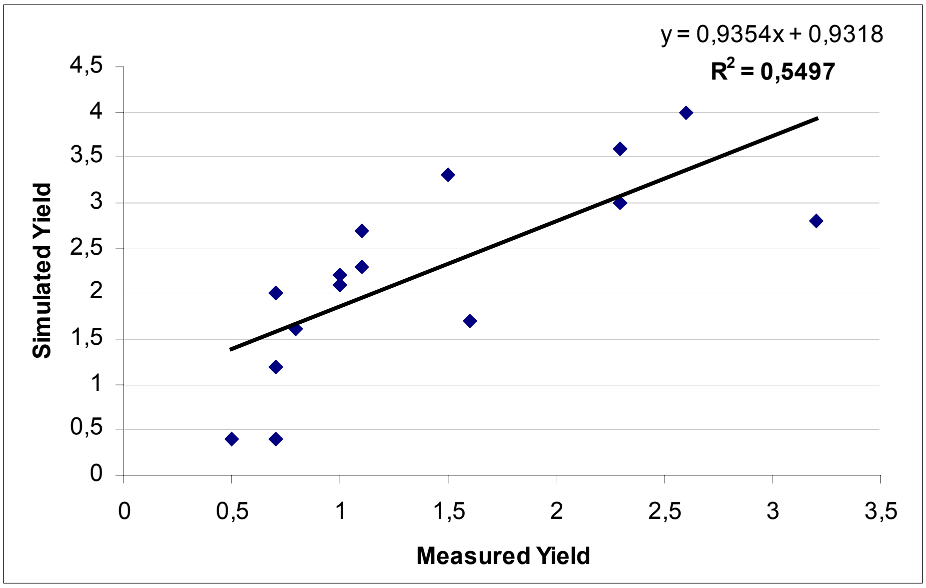


Figure 15: Yield coefficient of determination R² - for farmer fields (including not revised simulations of local varieties)

The fit of regression increased when the farmer fields were excluded from the regression analyses. Consequently the regression between observed and measured values show a satisfactory r^2= 0.86 for Research Stations.

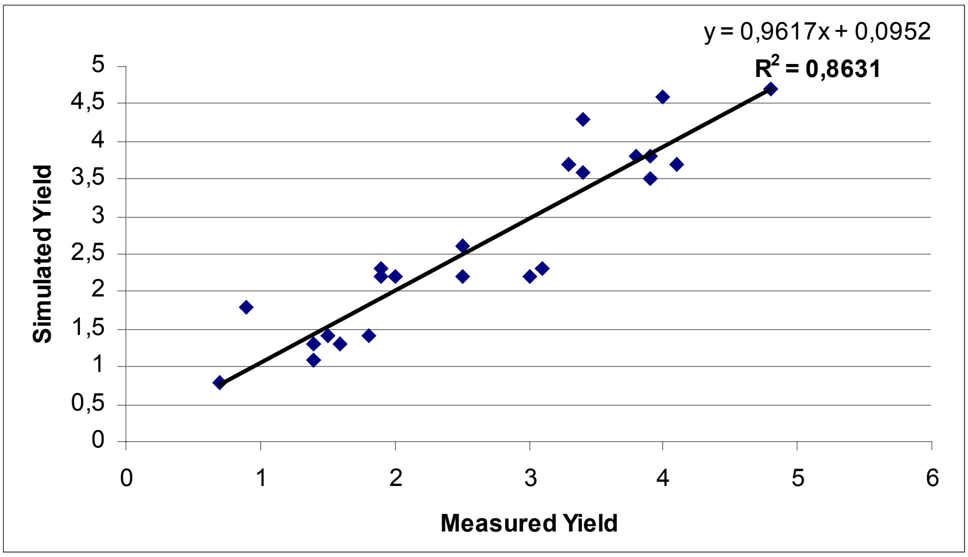


Figure 16: Yield coefficient of determination R² - for the research station plots

The percentage error of 14% for all crop yields is in general below our target limit fixed at 30%. However, yields were highly overpredicted at sites located within farmer fields (including sites with local varieties).

The poorest results were the simulations at farmer fields with local crop varieties with a percentage error of 89%. Whereas, best simulation results were found at the Research Station sites with a percentage error of 0.2 %

The yield simulations at Research Stations fulfilled the percentage error and the coefficient of determination (R^2) requirements for a good prediction of the EPIC model, since there is best data coverage and improved crop management for these sites.

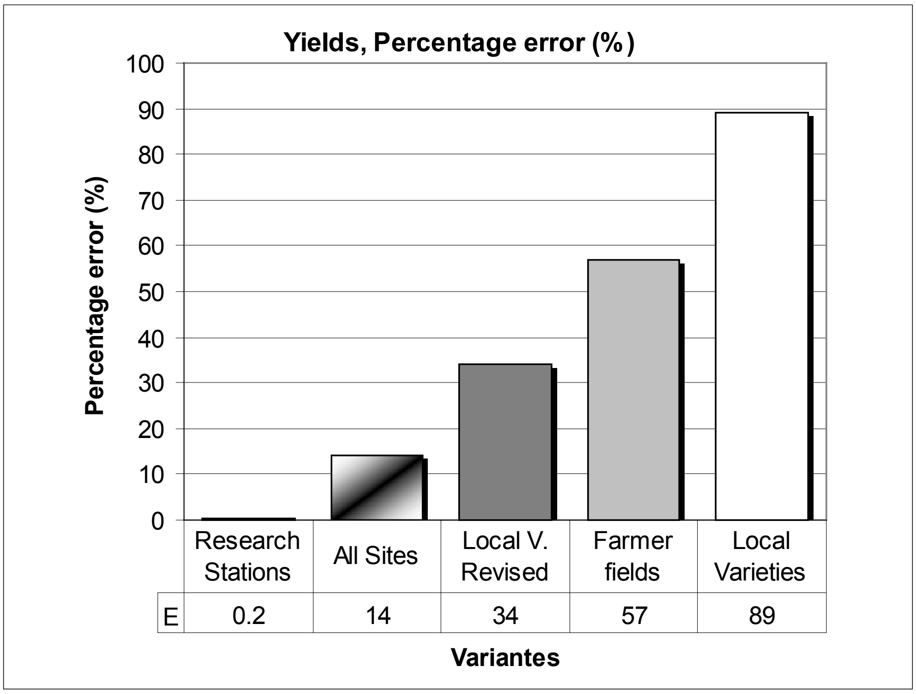


Figure 17: Yield percentage error for the simulated sites (Research Stations, Farmer Fields and All Sites)

Farmer Fields and Local Varieties

According to our findings, the agriculture on research stations is intensive enough to be modelled with EPIC without the need of major calibrations.

But for the case of local varieties the agronomic characteristics of the maize crop, included in EPIC, had to be adjusted to obtain yields closer to observed local yields.

After the adjustment simulated yields were closer (percentage error of 34%) but still higher than the observed yields at the farmer fields.

The yields predicted by EPIC on farmer fields were much higher compared to the measured yields (percentage error of 57%), both for +NPK and –NPK treatments. The rather low grain yields of the local varieties observed is probably due to the modest response to the extra nutrients derived from the applied inorganic fertilizer and perhaps also to the rather low soil fertility (e.g.: micronutrient deficit is not considered by the model).

This was considered an indication that the maize and sorghum cultivars used were not able to respond to fertilizer nutrients in a same way as the hybrids used for the original calibration of the EPIC model. Therefore for the case of local varieties the agronomic characteristics (HI, WSYF) of the maize crop included in EPIC were adjusted to obtain yields similar to local observed yields.

Similar low measured yields of local crop varieties and overestimations by the simulation model QUEFTS were reported by Saidou et al. (2003). The predicted yields by the modified QUEFTS model were closer to the measured yields than those of the original model design, but like in our study yields were still overestimated.

Hilger et al. (2000) evaluated the potential of Epic/Almanac to estimate crop yields under erratic rainfall in NE Brazil. Simulation runs with rice, maize, and cowpea in various environments of NE Brazil by using traditional and improved crop varieties were conducted. On less favourable sites, first simulation runs showed low correlations between simulated and observed data in a comparison of all treatments (rice: R^2=0.35; maize: R^2=0.38; cowpea: R^2=0.33). The fit of regression increased when some of the treatments were excluded from the regression analyses, e.g. burning and mulching in the case of rice, fertilizer application and final spacing in the case of maize and cowpea (rice: R^2=0.86; maize: R^2=0.74; cowpea: R^2=0.82). It could be observed that the model partly failed to simulate crop growth and yield performance with regard to burning, mulching, increased planting density and fertilizer applications on less favourable sites.

Sensitivity Analyses

In chapter 5.3, the sensitivity of the model was analysed considering the parameters potential heat unit, crop varieties, nutrient parameters. The sensitivity analysis demonstrated the relationship between observed yields of maize at selected sites, and the simulated yields corresponding to these parameters.
The objective of the study is the adjustment of the EPIC model to local conditions.

Adejuwon (2004) used the Epic model to simulate maize, rice, sorghum and millet yields in Nigeria. The sensitivities of maize, sorghum and millet to seasonal rainfall were demonstrated with coefficients of correlation significant at over 98 percent confidence limits. Some examples of the authors sensitivity analysis conducted are presented with the following Tables.

Table 14 : Sensitivity of maize to different levels of 'Potential Heat Units' (Adejuwon 2004)

	OBSERVED YIELDS (Varieties)		**CROP MODEL OUTPUTS (Varying potential heat units)**				
Year	Dmr.lsr.y	Suwan.1.sr	1000	1200	1500	1800	2000
1996	1.569	1.440	1.491	1.734	1.965	2.069	1.885
1997	1.022	1.246	1.391	1.549	1.706	1.983	1.821
1998	1.220	1.397	1.260	1.559	1.824	2.159	1.018

Table 15 : Sensitivity of simulated maize Yields based on evapotranspiration equations (Adejuwon 2004)

	OBSERVED YIELDS Varieties of maize		**CROP MODEL OUTPUTS (Varying ET Equations)**				
Year	Dmr.lsr.y	Suwan.l.sr	PenmanM	Penman	Priestly	Hargreaves	BaierR
1996	1.569	1.440	1.734	2.176	2.607	2.651	2.778
1997	1.022	1.246	1.549	1.870	2.314	1.697	2.184
1998	1.220	1.397	1.559	1.842	2.245	2.530	2.990

Table 16 : Sensitivity of simulated crop yield to rainfall in Maiduguri, Nigeria (Adejuwon 2004)

	Rainfall Parameters				**Simulated Yield of Crops in tons/ha**			
Year	Jun-Jul-Aug Rain	Jun Rain	Jun-Jul Rain	Number of rain days	Maize	Sorghum	Millet	Rice
1993	373	19	223	24	2.184	2.011	0.559	0.870
1994	285	50	117	33	1.339	1.204	0.353	0.526
1996	431	58	254	35	2.209	1.989	0.607	0.824
1998	461	60	239	32	2.992	2.504	0.836	0.888
1999	554	24	368	38	3.483	2.789	1.006	0.929

Adejuwon (2004) also described the problems of validation related to the multiplicity of crop varieties with contrasting performances under similar field conditions. In the case of maize and rice, measured yield data were compared with the simulated ones. EPIC-Model simulated yields of maize varied between 97 and 110 percent, simulated yields of rice between 109 and 117 percent of observed yields. The following Tables give an overview of the findings regarding yield variations connected to different crop varieties of this study.

Table 17 : Grain Yield (tons/ha) of upland rice varieties at three locations during 1986 wet season (IITA Rice Research Program; Annual Report 1986)

Locations	**IBADAN**	**IKENNE**	**ONNE**
Varieties	3	1.4	3.07
Tox 955-212-2-102	2.17	1.61	2.48
Tox 1854-02-2-2	1.87	1.55	2.53
Tox 955-208-12-101	0.81	1.29	2.46
ITA 235 (check)	0.8	0.97	1.18
ITA 257 (check)	1.69	1.48	2.17
Standard Deviation	0.84	0.23	0.62
Mean	1.72	1.38	2.31
Coefficient of Variation	49	17	27
EPIC	1.889	1.621	2.518
Epic/Mean %	110	117	109

Scientists have applied EPIC to many tropical conditions and components of EPIC have been calibrated with data collected under tropical conditions. The following literature review gives an overview of some of their findings.

In Zimbabwe, yields of sorghum and pearl millet varieties of the years 1989-1995 were simulated by using the Epic model (Rohrbach and Okwach, 1997). In most of the years, simulated yields correspond fairly well to the measured values or are slightly overestimated, except of one significant outlier related to the difficulty of the EPIC pearl millet module to estimate yield response associated with tillering.

In the study of the Impact Assessment Group (2000), Epic was used to predict yields for the six major crops pearl millet, grain sorghum, maize, cowpea, peanut, and cotton for different simulation environments in Mali, Senegal and Burkina Faso. For most of the cultivars, simulation runs with different fertilizer levels were conducted. In the case of groundnut, two varieties (traditional and improved variety) were simulated. For each scenario and environmental zone, simulations were made through a 20 year period to identify the mean yield. In all three countries, yield estimates for sorghum, maize, and millet were within ±15% of the long-term historical reported yields in 80% of the districts. Simulated yields for groundnuts, cowpea, and cotton were not as consistent. Groundnut yield estimates in Mali were within the ±15% for approximately 80% of the reporting districts, but for Burkina Faso, only 40% of the reporting districts fell within this target range. For Senegal, data for comparison were not available. Cotton simulations were within the ±15% target for approximately 70% of the Burkina Faso regions, but a very low percentage of regions in Mali met the ±15% target. As in contrast to the highly erratic historical yields of cowpea, simulated yields were quite stable. This may be due to the fact that cowpea is often used to replace other crops in severely dry years. In general, simulation results fitted well with the existing historical values.

In a study by Michels et al. (1999) concerning the simulation of pearl millet under environmental and agronomic conditions of the Sahel, modified EPIC gave reasonable results during first test runs in simulating millet growth in Niger. Average millet production in Niger is less than 0.5 t/ha grain yield and the model estimations laid within that range.

Williams et al. (1989) described the results of an updated EPIC crop growth model for simulating barley, corn, rice, soybean, sunflower, and wheat yields at several U.S. locations and for sites in Asia, France, and South America. “The average predicted yields were always within 7% of the average measured yields, and there was no significant difference between any of the simulated and measured yields at the 95% confidence level. However, r2 statistics computed between the simulated and measured yields of the six crops ranged from relatively strong values of 0.80 and 0.65 for wheat and corn to only 0.20 for barley and soybean.”

Cabelguenne et al. (1990) found that the standard EPIC model adequately replicated measured mean yields of corn, grain sorghum, sunflower, and soybean that were grown in complex rotations with varying levels of management in southern France. However, concurrent research by Quinones and Cabelguenne (1990) revealed that EPIC could not adequately simulate some conditions of severe water stress.”

(Gassman et al., 2005)

Agricultural conditions in the study area

As already described the land use systems in the research area is generally not intensive and almost totally dependent on a long natural fallow to restore soil fertility.
According to Dagbenonbakin, 2005, who studied sites in the Upper Oueme catchment of Benin, Nitrogen was the most limiting macronutrient followed by potassium and phosphorous according to DRIS-Evaluation. While the CVM method revealed most of the macronutrients as low or close to the critical level. Negative nutrient balances were observed, as inputs of nutrients were insufficient to compensate outputs.
To summarize the *Nutritional Assessment* all the nutrient levels (except Mn content which was higher in 2002) were close to the critical values reported by FAO (2000). Therefore it could be concluded that *multiple nutrient deficiencies* could be expected according to the critical value method

Table 18 : Nutritional Assessment of crops cultivated (Dagbenonbakin, 2005)

Crops	**DRIS Indices**								**NBI**	**Order of Nutrient Requirement**
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Zn**	**Mn**		
Maize	0.13	0.21	0.18	0.05	-0.15	0.14	-0.26	-0.30	1.41	Mn < Zn < Mg < Ca < N < S < K < P
Peanut	-0.04	-0.14	0.09	0.17	-0.13	0.02	0.01	0.03	0.64	P < Mg < N < Zn < S < Mn < K < Ca
Sorghum	0.08	0.11	0.09	-0.09	-0.18	0.09	0.03	-0.13	0.80	Mg < Mn < Ca < Zn < N < K < S < P
Yam	-0.07	0.01	0.00	0.09	-0.01	-0.36	-0.04	0.37	0.95	S < N < Zn < Mg < K < P < Ca < Mn

In theory, the high- yielding sub-population is a group of plants genetically capable of high yields, under conditions where mineral nutrition (i.e. all the essential elements) is not limiting. Nutrient ratio means were sometimes similar between *low- and high-yielding sub-populations*, therefore the author (Dagbenonbakin, 2005) set a cut-off value of the yield for division into two sub-populations. The next Table describes average nutrient (N, P, K) balances of farming systems for low and high yielding subpopulations of maize in Upper Oueme catchment of Benin (on-farm experiment, 2001 and 2002).

Table 19 : Average nutrient (N, P, K) balances of farming systems in the Oueme Basin (for low and high yielding subpopulations of maize) (Dagbenonbakin, 2005)

Maize	Input	Output			Balance
	Σ	**Out 1**	**Out 2**	**Σ Out**	
N					
Low yielding subpopulation					
T0	0.0	7.4	0.4	7.8	-7.8
T2	17.4	9.1	0.6	9.6	7.8
High yielding subpopulation					
T0	0.0	55.5	3.5	59.0	-59.0
T2	66.3	75.2	3.7	78.8	-12.5
P					
Low yielding subpopulation					
T0	0.0	7.4	0.4	7.8	-7.8
T2	17.4	9.1	0.6	9.6	7.8
High yielding subpopulation					
T0	0.0	11.7	0.5	12.2	-12.2
T2	17.4	18.8	0.6	19.4	-2.0
K					
Low yielding subpopulation					
T0	0.0	9.7	3.0	12.6	-12.6
T2	10.0	11.5	3.7	15.3	-5.3
High yielding subpopulation					
T0	0.0	18.1	5.0	23.0	-23.0
T2	10.0	25.7	5.8	31.5	-21.5

Treatments: T0: Farmer's practice; T2: 60 N 40 P_2O_5 (2001) or 75 N 40 P_2O_5 24 K_2O (2002)
Input: mineral fertilizer
Output: Out 1: output of harvest product; Out 2: output of crop residues (leaves, stems) Σ Out: sum outputs

According to literature, in an extensive number of nutrient cycling and nutrient loss validation and scenario studies, Epic generally made accurate predictions of leached N below the root zone or in tile flow, as compared with measured data.

However, Edwards et al. (1994) found that annual EPIC estimates of nutrient losses were significantly correlated with measured values, except for nitrate-N.

Strong correlation between EPIC-predicted and measured phosphorus (P) losses in runoff was found by Pierson et al. (2001), but predictions for single events were not as accurate.

Long-term trends were accurately predicted by EPIC for conditions at Treynor, Iowa (Chung et al., 1999), although predicted annual losses were not as accurate.

EPIC output did not compare well with measured in-stream loads for two large Lake Erie sub watersheds (Forster et al. 2000), but relative results were correctly predicted except for soluble P. In the study, the authors conclude that EPIC is most effective at simulating the long-term impacts of different cropping systems and management practices, but is less accurate at replicating the effects of single climatic events on erosion and other losses or interannual variability between crop yields and pollutant losses (Gassman et al., 2005).

Validation and Missing Values

One problem has been the missing values of soil data. Dynamic simulation models have from 10s to 1000s input parameters, most of them being set by default or estimated internally. Only few are measured values to characterize the system that is simulated. Therefore there is a need for validation of the most sensitive parameters
As a whole the quality of the data sets for the Oueme Basin is not sufficient for most of the studied sites except the Research Station Sites. Therefore the replacement of missing values became more important. To overcome this problem missing values were replaced or generated by EPIC.
The final evaluation and validation of the EPIC model will be completed in cooperation with the SLYSIS working group.

Generally speaking more or detailed soil and management information was always necessary for best simulation results. However, there are the difficulties in appropriately representing the *microenvironments*, under which crops are locally produced. Thus there is always some gap between observed and simulated yields resulting from data and/or model deficiencies.

Main simulation problems

Our simulation and testing works with the EPIC model meet the following main Problems:

- Low data availability/quality on Farmer Fields regarding:
  - cultivated crop varieties
  - crop management
  - soil data soil characteristics

- Multiple nutrient deficiencies and trace elements like Mn, Zn, Mg Ca were not considered

- Water balance based on water storage model (e.g. upward water movement is not considered)

- Preferential flow is not considered

- No interactions between growth constraints and difficulties in accurately representing microenvironments

Conclusions

Based on the results of the testing of the submodel for crop productivity and environmental impact in the Oueme basin, our conclusion is that the model could be satisfactorily employed in the assessment of agricultural productivity and environmental impact, since the model incorporate as much data as possible based on land management, climate and soil conditions.
Our extensive Literature review also proved the capability of the Epic model to accurately simulate crop production and environmental impact.

However, there is need for further cross-validation under contrasting ecological conditions for maximising the prediction accuracy of the EPIC model.
The simulation studies in the tropical subhumid Oueme Basin were conducted for different land use intensities. Results obtained from the Research sites, under improved crop management (improved crop varieties, no weed competition), showed a better correlation between measured and simulated data than simulations for farmer fields.
According to the scientific reports (see: List of reference data sets for the Ouémé basin, chapter 7), most of the farmer fields are degraded and extensively managed by farmers. The experiment data included the testing of various fertilizer inputs, but the observed yields at the farmer fields were extremely low, even with high doses of NPK application. Crop yields were overpredicted for most sites located at farmer fields and local crop varieties. Therefore for the case of local varieties the agronomic characteristics (HI, WSYF) of the maize crop included in EPIC were adjusted to obtain yields closer to local observed yields.
The main problems of our validation work were related to the multiplicity of crop varieties, with contrasting performances under similar field conditions. The use of the model for estimation of crop production with local crop varieties and for the assessment of site specific stress factors, needs to be checked in association with further simulation surveys and field experimentation.

To summarise the results of testing the EPIC simulation model, the following conclusions can be drawn:

- Crop yields were predicted with reasonable accuracy for sites with good data availability, whereas more research is needed for sites located at farmer fields and local crop varieties
- For the case of local varieties the agronomic characteristics of the simulated crops included in EPIC were adjusted to obtain yields closer to observed yields
- 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
- Generation of supplementary model inputs continue to pose a major task for the Oueme Basin research area
- The user Interface has been further improved, towards a practicable model design

As a next step, a complete inter-comparison for the model will be made for every reference site and the results will be integrated into the SLYSIS model for further validation and extension to regional scale.

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