Chapter 13
Fertilizer Recommendations for Maize Production in the South Sudan and Sudano-Guinean Zones of Benin

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Abstract The present study aims to determine fertilizer (N-P-K) recommendations for maize (*Zea mays* L.) on Acrisols (south Benin) and Ferric and Plintic Luvisols (centre Benin). Two years experiment (2011 and 2012) were conducted at Dogbo and Allada districts (southern) and Dassa (centre Benin). Six on-farm experiments were carried out in order to validate fertilizer rates simulated by DSSAT simulation model. The experimental design in each farmers' field was a completely randomized bloc with four replications and ten N-P-K rates: 0-0-0 (control), 44-15-17.5 (standard fertilizer recommendation for maize), 80-30-40, 80-15-40, 80-30-25, 80-30-0, 69-30-40, 92-30-40, 69-15-25 and 46-15-25 kg ha^{-1}. The optimum N, P and K rates in both research sites were: 80.5 kg N ha^{-1}; 22.5 kg P ha^{-1} and 20 kg K ha^{-1}. Treatments 44-15-17.5 and 46-15-25 showed the lowest grain and stover yields compared to the other treatments. The observed maize grain yields were highly correlated with the estimated grain yields (R^2 values varied between 80 and 91% for growing season 2011 and between 68 and 94% for growing season of 2012). The NRSME values varied between 12.54 and 22.56% (for growing season

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of 2011) and between 13.09 and 24.13% (for growing season of 2012). The economic strategies analysis for pass 32 years (1980 to 2012) showed that N-P-K rates 80-30-25 (site of Dogbo), 80-15-40 (site of Allada) and 80.5-22.5-20 (site of Dassa) were the best fertilizer recommendations as they presented the highest grain yields and the best return to investment per hectare.

Keywords Soil fertility · Simulation · DSSAT · Acrisols · Ferric and plintic luvisols

Contents

13.1 Introduction

Maize (*Zea mays* L.) is the first cereal produced in the world with over 720 million tons grain produced (FAOSTAT 2004). From 1990 to 2005, it represented in South, East, Central and West Africa countries, about 56% of the cultutivated area (FAOSTAT 2007). In the sub-Sahara Africa, maize constitutes with rice and wheat, one of the three most important cereal crops widely cultivated (Byerlee and Heisey 1997). About 50% of the population of this part of Africa depends for their subsistance on maize which constitutes staple food and source of carbohydrates, protein, iron, vitamin B and minerals (Zeller et al. 2006). Maize is becoming nowadays a cash crop (FAOSTAT 2013), which contributes to the improvement of farmers' livelihood. Based on these statistics, support maize production will ensure successfully food security and improving the economic growth of West African countries (Toléba-Séidou et al. 2015).

In Benin, maize is the principal staple food crop. It is the most consumed cereal ahead rice and sorghun and plays major role for food security. This cereal is also used for animals feeding and constitutes farmers' principal source of incomes (Toléba-Séidou et al. 2015). Therefore, maize contributes for 6.54 and 2.03% respectively to the formation of agriculture Gross Domestic Product (GDP) and national wealth. Maize is a strategic crop in Benin's economy as it provides employment in rural area and it contributes to supply food for a growing population (Saïdou et al. 2012). In general, maize cropping systems are heterogenous in the different agroecological zones (Diallo et al. 2012). Due to the climate variability, short growing cycle maize varieties of 3 months (DMR or EVDT) are widely grown with a potential yield of 6 t ha^{-1} on station. The most limiting factors for maize cultivation in Benin are the erratic rainfall pattern and the low soil fertility (Saïdou et al. 2012; Balogoun et al. 2013; Igué et al. 2013). The main causes of the low soil fertility are the nature of the soil (low organic matter content), the low use of fertilizer, poor soil fertility management practices and monocropping (Saïdou et al. 2012; Balogoun et al. 2013). Maize yield at farmer level is low about 800 kg ha^{-1} (Saïdou et al. 2003) generally without fertilizer application.

Maize cultivation on Benin soils requires high quantity of nutrient N and P. There is therefore a need to develop adequate recommendation in order to achieve the level of productivity that could meet the needs of the increasing population in the rural area. This implies an intensification of the production by controlling the main constraints including farmers' fertilization practices. Indeed, in Benin, fertilizer use as in many other countries of West Africa has been promoted to intensify crop production. Different crop fertilization practices were proposed by research and extension services. Many fertilizer types were used for maize production such as: urea, diammonium phosphate (DAP) and various NPK formes (Adégbidi et al. 2000; Acakpo 2004). Furthermore, to be efficient in term of crop yield improvement in farmer condition, high crop yield variety must be used. Mostly, the same fertilizer rates are recommended for all agroecological zones within the country. Such practices do not take into account soil types and the specificity of farmers' cropping systems and farm ecology. These standard fertilizer rates recommended are old and based on blanket recommendation. Therefore, there is a need to update this fertilizer recommendation for maize production regarding each agroecological zone of Benin, soil types and the economic profitability for the farmer.

The best way to do this is through the establisment of long term experiment which is mostly expensive and time costing (Dzotsi 2002; Dzotsi et al. 2003). Considering this context, agricultural simulation models are one way to assess the risk related to climate hazards and to predict yield components in various agroecosystem to save time and shorten farm trials duration. The relevence of these studies comes from the fact that the model was originally developed, calibrated and validated under different agroecological conditions. Therefore application in other condition will not guarantee the reliabilibty (Miao et al. 2006; Thorp et al. 2007, 2008; DeJonge et al. 2007). The present research was carried out in the framework of the IFDC-Africa fertilizer research program in West Africa. The objectives of the study were to: (i) validate fertilizer rates simulated by DSSAT model in the context of the South and Centre Benin agroecological zones, (ii) determine the optimal N, P and K rates for optimal maize grain yields and (iii) propose an update N-P-K rates for maize production using the CERES-Maize model in DSSAT.

13.2 Materials and Methods

13.2.1 Description of the Study Area

The experiment covered two agroecological zones (AEZ) of the nine in Benin. The transitional Sudano-Guinean AEZ with bimodal rainy season (from mid-april to mid-july and mid-july to october), where yam, cotton, maize, cassava and cashew trees are predominante in the crop rotation systems. Ferric and Plintic Luvisols (FAO 2006) are the dominante soil types. The Sudano-Guinean on "T*erre de barre*" AEZ located in the southern Benin with sub-equatorial bimodal rainy season (from mid-april to mid-july and mid-july to november). The cropping systems are based mainly on slash and burn agriculture, maize and cassava are predominante crops in the cropping systems and soil types are Acrisols.

The on-farm trial consisted to validate fertilizer doses simulated by DSSAT model during two growing seasons (2011 and 2012) in farmers' conditions for maize production. Thus, combining DSSAT and geographical information system (GIS), fertilizer recommendation map for the south and centre Benin was drawn using soil data base of the area (at 1:100,000 scale) established by Igué (2000) and Weller (2002). In the Sudano-Guinean on "T*erre de barre*" AEZ, Sékou and Attogon (municipality of Allada, Atlantique Department) and Dévé and Ayomi (municipality of Dogbo, Couffo Department) were selected villages for the on-farm experiment. In the transitional Sudano-Guinean AEZ (Centre of Benin), Gomé, Minifi and Dovi-Somè (respectively in the municipality of Dassa-Zoumé) in the Collines Department were selected. These villages and farmers were jointly identified with the local extension service. In total six farmers' fields were selected to conduct the experiment. The municipality of Dogbo lies between latitude 6°47′56″ N and longitude 1°50′35" E (58 msl) while the municipality of Allada lies between latitude 6°39'52" N and longitude 2°09′30″ E. Dassa municipality lies between latitude 7°50.4′ N and 2°10′ E.

13.2.2 Field Experiment and Simulation Studies

Two years on-farm experiments were conducted during the rainy seasons (from April to June). In each AEZ, farmers' fields were selected based on the result of the previous crops. Emphasize was put on the field where no fertilizer was applied before. In each farmer's field, a randomized complete block design with 4 replications and 10 treatments was carried out. Plots' size of 8 m × 5.6 m (44.8 m^2) was used. All experimental plots were farmer-managed. The maize variety used was EVDT 97 STRW (90 days growing cycle and attendable yield of 6 t ha^{-1}) planted at the beginning of April of each year at a spacing of 80 cm × 40 cm (two seeds per hole leading to a planting density of 62,500 plants ha^{-1}). Same sources of maize seed and fertilizer were used by all of the farmers' selected. Planting, weeding operations were left up to the farmers after providing them with general guidelines. The source of nitrogen (N) was urea (46% N), phosphorus (P) was from triple super phosphate (TSP, 46% P_2O_5) and potassium (K) was from potassium chlorite (KCl, 60% K_2O).

Four levels of N (0, 40, 80 and 120 kg ha^{-1}), three levels of P (0, 30 and 60 kg ha^{-1}) and three levels of K (0, 40 and 80 kg ha^{-1}) leading 36 combinations of N, P and K simulated were tested. These 36 combinations were put on the fertilizer recommendation maps of the south and centre Benin (Ezui et al. 2011; Igué et al. 2013). The simulations were performed on the scale of 1:100,000 for both AEZ. From these, two fertilizer simulated doses (80-30-40 and 80-30-0) were selected for the two AEZ. In addition to these two simulated doses, the control (0-0-0) and the standard fertilizer recommendation dose (44-15-17.5) and six more N-P-K combinations were considered: 80-15-40 (P adaptability dose), 80-30-25 (K adaptability dose), 69-30-40 (N adaptability dose 1), 92-30-40 (N adaptability dose 2), 69-15-25 (N-P-K adaptability dose 1) and 46-15-25 (N-P-K adaptability dose 2).

In total ten fertilizer (N-P-K combination) rates were validated during the on-farm experiment. Thus, the treatments were the following fertilizer N-P-K rates: 0-0-0 (control), 44-15-17.5 (standard fertilizer recommendation for maize), 80-30-40, 80-15-40, 80-30-25, 80-30-0, 69-30-40, 92-30-40, 69-15-25 and 46-15-25 kg ha^{-1}. The standard fertilizer recommendation for maize consists of 150 kg ha^{-1} NPK 14-23-14 and 50 kg ha^{-1} urea (Dugué 2010).

Composite soil samples were collected at 0–20 cm depth after plowing and before fertilizer application. Fertizer application was done by researcher team. Phosphorus and potassium were applied just before sowing maize while the quantities of urea to be applied were split half 15 days after sowing (DAS) and the second part 45 DAS (after the second weeding period). It was done in a planting hole about 5 cm from the plant collar. Maize was harvested at physiological maturity, plant residues were collected and living plant parts were cut at soil surface to estimate maize grain and stover yields after leaving the two border lines and two border seed holes. Cobs and stover were weighed with handing scale and sample of each part taken were weighed with an electronic scale and dry matter determined after drying at 60 °C for 72 h in the oven at laboratory. Soil chemical analyzes were performed at the Laboratory of Soil Science, Water and Environment of Benin National Research Institute (LSSEE/INRAB).

Soil samples were analysed for pH (water) (using a glass electrode in 1:2.5 v/v soil solution), organic carbon (Walkley and Black method), total nitrogen (Kjeldahl digestion method in a mixture of H_2SO_4, selenium followed by distillation and titration), available phosphorus (Bray 1 method) and exchangeable potassium (1 N ammonium acetate at pH 7 method, after which K^+ was determined by flame photometer). The statistical analyses were performed using SAS v. 9.2 packages. Observed maize grain and stover yield of each growing season and within an AEZ were subjected to a one-way analysis of variance (ANOVA). The Student Newman-Keuls test was performed for means separation at a significance levels of $P < 0.05$.

Decision Support System for Agrotechnology Transfer (DSSAT v 4.5) was used for the simulations. The model requires minimum of input data including: name and geographical position of the field (longitude, latitude and altitude), previous crops grown on the field, crop management informations (tillage, planting date, planting method, sowing density, fertilizer application dates, genetic coefficient of the maize cultivars determined from the physiological parameters and grain yield). Genetic factors were determined through GLUE program of DSSAT (He et al. 2010). Soil analytical characterisitics used were: pH (water), organic carbon, available phosphorus (P-Bray 1), total nitrogen and exchangeable potassium. The daily weather data of 1981–2010 was used for the initial fertilizer dose simulation and daily data of 2011–2012 was used for the on-farm validation of the fertilizer recommendation. These data concerned precipitation, minimum and maximum temperatures and solar radiation. They were collected from ASECNA (*Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar*) synoptic station of Cotonou, Bohicon and Savè close to the research area. A Field results were used to calibrate the genetic coefficient of maize and these model inputs were integrated to provide a framework for simulating and analyzing the outputs. Biophical and economic analysis were also performed in order to determine a series of cost-effective options.

Regression analysis using response curves were performed with Statistical Analysis System (SAS v. 9.2) software to determine the optimum doses of N, P and K. Correlation coefficients (Singh and Wilkens 2001) were determined to assess gaps between simulated yields and those observed, Root Mean Square Error (RMSE) (Du Toit et al. 2001) and Normalize Root Mean Square Error (NRMSE) (Loague and Green 1991; Jamieson et al. 1991) were used to assess the performance of the model. The seasonal analysis (biophysical and economic) from 1980 to 2012 was performed in order to evaluate the long-term rainfall effect on the simulated yields (Jones et al. 2003). This analysis leads to the choice of the best and efficient treatment based on the mean value of Gini coefficient. The financial analysis was done by integrating as input in the model production cost and maize price collected in the study area. Maize price use was that of the market during the harvest period.

13.3 Results

13.3.1 Soil Chemical Parameters in Each Agroecological Zone

Soil chemical analysis of the different farms investigated before planting the maize revealed the following properties: pHwater of 6.51, 6.58 and 6.4 (respectively for Dogbo, Allada and Dassa); organic C of 4.45, 8.08 and 3.99 g kg^{-1} (respectively for Dogbo, Allada and Dassa); total N of 0.74, 0.64 and 0.42 g kg^{-1} (respectively for Dogbo, Allada and Dassa); available P of 82.75, 53.29 and 82.75 mg kg^{-1} (respectively for Dogbo, Allada and Dassa) and exhangeable K 1.05, 1.81 and 1.44 cmol kg^{-1}. In general the soils of the study area are slightly acid and low level of organic matter (C/N ratio of the acrisols varying between 14.06 and 22.42 and that of the Ferric and Plintic Luvisols is 25.95). The consequence of these high C/N ratio is a low level of total N which seems to be with P the most limiting nutrients. Apart the available P, soils of the site of Allada presented lowest chemical properties compared with that of Dogbo and Dassa.

13.3.2 Calibration and Validation of the Model: Observed vs Simulated Maize Grain and Stover Yields in Each Agroecological Zone

In general, the observed maize grain and stover yields of the different N-P-K combinaisons excepted fertilizer rate 46-15-25 (in 2011) were significantly different compared to the standard fertilizer recommendation (44-15-17.5) in the site of Dogbo (Table 13.1). A yield increase of 1.4 compared with the standard recommendation was observed. During this growing season, no significant differences were noticed among the N-P-K combinations but all the treatments had significant yields increased by 1.5 to 2 respectively compared with the control (0-0-0). The stover yields followed the same trend as the grain yields. In the cropping season 2012, the N-P-K combinations studied showed significant effect on both grain and stover yields compared to the control. The lowest values were found on the control field while the highest with 80-30-25, 92-30-40 and 80-15-40 respectively at Dogbo, Allada and Dassa. The standard fertilizer recommendation and 46-15-25 combination showed lowest stover yields compared to the other treatments. Thus, maize grain and stover yields were increased of 1.4 to 1.6, 1.3 to 2 and 1.1 to 1.4 respectively in Dogbo, Allada and Dassa. Regression analysis with N, P and K rates and the observed maize grain yields showed that the quadratic curves explaining relationship between nutrients and both grain and stover yields showed optimum doses of 80.5 kg ha^{-1} of N, 22.5 kg ha^{-1} of P and 20 kg ha^{-1} of K in the three sites (Tables 13.2, 13.3 and 13.4).

Data simulated by DSSAT-CERES model were compared with the real data obtained in 2011 and 2012 in the field in order to determine the suitability for an intended purpose of making site specific fertilizer recommendations. In general maize grain yields simulated by the model were more or less closed to that measured in the field (Table 13.5).

13.3.3 Performance of the Model

Results of t-test for paired sample analysis showed significant ($P < 0.05$ and $P < 0.001$) difference between mean value of observed and simulated maize grain yields in Dogbo and Dassa during both growing seasons (2011 and 2012).

Table 13.1 Average (± standard errors) value of the observed maize grain yield and stover mass regarding the different sites and N-P-K combinations in the growing season of 2011 and 2012

Sites	Treatments	2011		2012	
		Grain yield (t MS ha^{-1})	Stover yield (t MS ha^{-1})	Grain yield (t MS ha^{-1})	Stover yield (t MS ha^{-1})
Dogbo	0-0-0	1.70 ± 0.03 c	2.99 ± 0.17 c	1.16 ± 0.16 d	1.98 ± 0.29 b
	44-15-17.5	2.25 ± 0.15 b	3.73 ± 0.37 b	2.53 ± 0.20 c	4.53 ± 0.48 a
	80-30-40	2.77 ± 0.15 a	4.55 ± 0.29 ab	3.64 ± 0.22 ab	5.13 ± 0.40 a
	80-15-40	2.97 ± 0.16 a	4.21 ± 0.24 ab	3.61 ± 0.23 ab	4.93 ± 0.41 a
	80-30-25	3.04 ± 0.12 a	4.98 ± 0.17 a	3.96 ± 0.20 a	5.18 ± 0.42 a
	80-30-0	3.06 ± 0.14 a	4.44 ± 0.24 ab	3.69 ± 0.27 ab	4.64 ± 0.34 a
	69-30-40	2.97 ± 0.11 a	4.50 ± 0.32 ab	3.45 ± 0.16 ab	4.81 ± 0.47 a
	92-30-40	2.99 ± 0.12 a	4.51 ± 0.08 ab	3.72 ± 0.20 ab	5.23 ± 0.57 a
	69-15-25	3.09 ± 0.13 a	4.46 ± 0.23 ab	2.95 ± 0.14 bc	4.42 ± 0.37 a
	46-15-25	2.56 ± 0.20 ab	4.29 ± 0.14 ab	2.82 ± 0.15 bc	4.23 ± 0.46 a
Allada	0-0-0	1.00 ± 0.12 b	2.20 ± 0.29 b	0.96 ± 0.15 d	2.03 ± 0.22 c
	44-15-17.5	1.90 ± 0.14 a	3.86 ± 0.22 a	1.32 ± 0.13 cd	2.56 ± 0.22 bc
	80-30-40	2.08 ± 0.10 a	4.77 ± 0.39 a	2.14 ± 0.13 b	3.29 ± 0.22 ab
	80-15-40	2.09 ± 0.11 a	4.56 ± 0.23 a	1.85 ± 0.17 bc	3.00 ± 0.37 abc
	80-30-25	1.98 ± 0.10 a	4.35 ± 0.23 a	2.03 ± 0.14 b	3.43 ± 0.41 ab
	80-30-0	2.04 ± 0.20 a	3.94 ± 0.36 a	1.92 ± 0.19 bc	3.50 ± 0.31 ab
	69-30-40	2.21 ± 0.06 a	4.68 ± 0.23 a	1.93 ± 0.14 bc	3.84 ± 0.28 ab
	92-30-40	2.10 ± 0.13 a	3.95 ± 0.31 a	2.62 ± 0.33 a	3.93 ± 0.43 a
	69-15-25	1.87 ± 0.12 a	3.65 ± 0.26 a	1.57 ± 0.12 bc	3.11 ± 0.21 abc
	46-15-25	1.74 ± 0.13 a	3.52 ± 0.23 a	1.41 ± 0.14 cd	2.96 ± 0.23 abc
Dassa	0-0-0	1.44 ± 0.08 b	2.81 ± 0.19 b	0.88 ± 0.09 c	1.70 ± 0.38 b
	44-15-17.5	1.93 ± 0.06 ab	3.59 ± 0.19 ab	1.68 ± 0.13 ab	2.61 ± 0.32 ab
	80-30-40	2.58 ± 0.21 a	4.74 ± 0.47 a	2.11 ± 0.19 ab	3.37 ± 0.41 a
	80-15-40	2.45 ± 0.15 a	4.76 ± 0.37 a	2.30 ± 0.21 a	3.77 ± 0.57 a
	80-30-25	2.55 ± 0.28 a	4.60 ± 0.31 a	2.15 ± 0.23 a	3.54 ± 0.31 a
	80-30-0	2.34 ± 0.16 a	4.08 ± 0.32 a	2.04 ± 0.14 ab	3.27 ± 0.31 a
	69-30-40	2.38 ± 0.20 a	4.36 ± 0.44 a	1.89 ± 0.13 ab	3.23 ± 0.22 a
	92-30-40	2.58 ± 0.21 a	4.67 ± 0.30 a	2.03 ± 0.14 ab	3.50 ± 0.38 a
	69-15-25	2.20 ± 0.10 a	4.08 ± 0.13 a	2.11 ± 0.19 ab	3.46 ± 0.34 a
	46-15-25	2.43 ± 0.16 a	4.31 ± 0.32 a	1.39 ± 0.11 b	2.59 ± 0.21 ab

In a column mean followed by the same alphabetic letters are not significantly different ($P > 0.05$), Student Newman-Keuls test

The model has slightly underestimated maize grain yields at Dassa (growing season of 2011) and Dogbo (growing season of 2012) while data predicted by the model fit well with that of Allada during the growing season of 2012 (Table 13.6). Furthermore, it was observed that, the observed maize grain yields were highly correlated with estimated values by the model. The R^2 values varied between 80% and 91% (for the growing season of 2011) and 68% and 94% (for the growing season of 2012). The NRSME values between the observed and simulated maize grain yields

Table 13.2 Quadratic regression curve of the grain yield and stover mass of maize regarding the applied N doses in each site during the cropping seasons of 2011 and 2012

Sites	Parameters	df	2011		2012	
			Coefficient	Pr > |t|	Coefficient	Pr > |t|
Dogbo	Constant	1	12.77	0.11	−0.34	0.98
	N	1	−0.25	0.22	0.09	0.77
	$(N)^2$	1	0.002	0.21	−0.0005	0.80
	Optimum N (kg ha^{-1})		80.5		80.5	
Allada	Constant	1	6.03	0.37	4.74	0.63
	N	1	−0.09	0.58	−0.10	0.69
	$(N)^2$	1	0.001	0.60	0.001	0.62
	Optimum N (kg ha^{-1})		80.5		80.5	
Dassa	Constant	1	4.19	0.73	−5.78	0.54
	N	1	−0.05	0.86	0.19	0.42
	$(N)^2$	1	0.0004	0.84	−0.001	0.43
	Optimum N (kg ha^{-1})		80.5		80.5	

Table 13.3 Regression curve of the grain yield and stover mass of maize regarding the applied P doses in each site during the cropping seasons of 2011 and 2012

Sites	Parameters	df	2011		2012	
			Coefficient	Pr > |t|	Coefficient	Pr > |t|
Dogbo	Constant	1	3.87	<0.0001	3.58	<0.0001
	P	1	0.02	0.37	0.002	0.93
	Optimum P (kg ha^{-1})		22.5		22.5	
Allada	Constant	1	2.09	<0.0001	1.30	0.0006
	P	1	−0.0004	0.97	0.02	0.22
	Optimum P (kg ha^{-1})		22.5		22.5	
Dassa	Constant	1	2.32	< 0.0001	2.49	<0.0001
	P	1	0.008	0.63	−0.01	0.52
	Optimum P (kg ha^{-1})		22.5		22.5	

varied between 12.54 and 22.56% (for the growing season of 2011) and between 13.09 and 24.13% (growing season of 2012).

13.3.4 Seasonal and Biophysical Analysis

A seasonal analysis of 32 years (1980–2012) was done based on the observed maize grain yields for the different N-P-K combinations (Fig. 13.1). To complete this analysis, the optimal N-P-K dose (80.5-22.5-20) determined from the field results was also included in the treatments to see whether it could be a good option. In general, it was observed from the field data that, maize grain yields are related to the

Table 13.4 Quadratic regression curve of the grain yield and stover mass of maize regarding the applied K doses in each site during the cropping seasons of 2011 and 2012

Sites	Parameters	df	2011		2012	
			Coefficient	Pr > |t|	Coefficient	Pr > |t|
Dogbo	Constant	1	3.06	<0.0001	3.69	<0.0001
	K	1	0.01	0.60	0.03	0.31
	$(K)^2$	1	−0.0004	0.37	−0.0008	0.29
	Optimum K (kg ha^{-1})		20		20	
Allada	Constant	1	2.04	<0.0001	1.60	<0.0001
	K	1	−0.01	0.54	0.002	0.89
	$(K)^2$	1	0.0003	0.51	0.00005	0.91
	Optimum K (kg ha^{-1})		20		20	
Dassa	Constante	1	2.36	<0.0001	2.04	<0.0001
	K	1	0.01	0.72	0.009	0.73
	$(K)^2$	1	−0.0001	0.86	−0.0002	0.78
	Optimum K (kg ha^{-1})		20		20	

variation of the N rates. In the site of Dogbo, treatment 80-30-25 gave the best yield among the treatments considering the quantity of N applied and the minimum and maximum maize grain yields range obtained (1460-3202 kg ha^{-1}). In the site of Allada, treatments 80-30-40 and 92-30-40 were the best options compared to the other treatments tested. It has been noticed that with an increase of N rate of 12 kg ha^{-1}, only 21.1 kg ha^{-1} of maize grain yield were obtained, which was not expected as N is the most limiting nutrient.

From Fig. 13.1 it is also observed that at 75% cumulative probability, in the site of Dogbo, the maximum average maize grain yields of 750, 1750, 2300 and 2500 kg ha^{-1} were obtained when respectively 0-0-0, 46-15-25, 69-30-40 and 80-30-40 were applied. In the site of Allada, the average maize grain yields of 750, 1825, 2200 and 2250 kg ha^{-1} when respectively 0-0-0, 46-15-25, 69-30-40 and 92-30-40 fertilizer rates were applied. Finally, in the site of Dassa, 1500, 2250, 2300 and 2650 kg ha^{-1} of maize grain yields were obtained when repectively 0-0-0, 44-15-17.5, 69-30-40 and 92-30-40 were applied.

13.3.5 Economic and Strategic Analysis

In order to determined fertilizer formula to be proposed for maize cultivation, an economic analysis was done (Table 13.7), based on mean-Gini dominance analysis. This economic strategies analysis for 32 pass years showed that treatments 80-30-25, 80-15-40 and 80-30-0 respectively for the sites of Dogbo, Allada and Dassa were the best fertilizer recommendations as they presented the best return to investment per hectare and the best efficiency. The model suggested no application of K on the soil of Dassa (dominated by Ferric and Plintic Luvisols). This is not

Table 13.5 Observed and simulated maize grain yields (kg ha^{-1}) for 2011 and 2012 growing seasons regarding N-P-K nutrient combinations at Dogbo, Allada and Dassa sites in Benin

Sites	Treatments	2011		2012	
		Simulated	Observed	Simulated	Observed
Dogbo	0-0-0	870	1700	910	1160
	44-15-17.5	2048	2250	2066	2530
	80-30-40	2917	2770	2784	3640
	80-15-40	2917	2970	2784	3610
	80-30-25	2917	3040	2784	3960
	80-30-0	2917	3060	2784	3690
	69-30-40	2736	2970	2627	3450
	92-30-40	3078	2990	2929	3720
	69-15-25	2736	3090	2627	2950
	46-15-25	2110	2560	2124	2820
	Critical value for comparison	2632.3	2632.3	2797.5	2797.5
Allada	0-0-0	232	1000	474	960
	44-15-17.5	1646	1900	1571	1310
	80-30-40	2071	2080	2083	2130
	80-15-40	2059	2090	2083	1850
	80-30-25	2058	1980	2077	2030
	80-30-0	2137	2004	2080	1920
	69-30-40	2181	2210	1940	1920
	92-30-40	2056	2100	2140	2620
	69-15-25	1981	1870	1933	1570
	46-15-25	2087	1740	1576	1410
	Critical value for comparison	1874.1	1874.1	1783.9	1783.9
Dassa	0-0-0	931	1440	711	880
	44-15-17.5	1740	1930	1659	1680
	80-30-40	1943	2580	1861	2110
	80-15-40	1943	2450	1861	2300
	80-30-25	1943	2550	1861	2150
	80-30-0	1943	2340	1861	2040
	69-30-40	1905	2380	1853	1890
	92-30-40	1940	2580	1863	2030
	69-15-25	1905	2200	1853	2110
	46-15-25	1753	2430	1702	1390
	Critical value for comparison	2041.3	2041.3	1783.3	1783.3

sustainable as the K content in these would deplete in the long term. To be rational one could suggest the optimal N-P-K rated (80.5-22.5-20) which showed return to investment per hectare (315,232.1 FCFA ha^{-1}) closed to that of the 80-30-0 (315,749.6 FCFA ha^{-1}). It was observed almost a similarity between fertilizer doses determined from the seasonal and biophysical analysis and that of the economic and strategic anaysis in the site of Dogbo and Dassa.

Table 13.6 Comparison between the observed and simulated maize yield parameters (kg ha^{-1}) in 2 years (2011 and 2012) at Dogbo and Allada (Sudano-guinean zone on terre de barre) and Dassa (transitional Sudano-guinean zone)

	2011			2012		
Variables	Dogbo	Allada	Dassa	Dogbo	Allada	Dassa
Observed (kg ha^{-1})	2740	1897	2288	3153	1772	1858
Simulated (kg ha^{-1})	2525	1851	1795	2442	1796	1708
MD	-215^{*}	−46 ns	-493^{***}	-711^{***}	24 ns	-150^{*}
Ratio	0.90	0.94	0.78	0.78	1.01	0.93
r-Square (%)	91	86	80	94	68	78
RMSE (%)	343.51	285.42	0.675	760.81	279.06	243.30
NRMSE (%)	12.54	15.05	22.56	24.13	15.75	13.09

ns= $P > 0.05$; *= $P < 0.05$; ***= $P < 0.001$

13.4 Discussion

13.4.1 Soil Fertility and Maize Productivity in the South and Centre Benin

The results of soil analysis showed low level of soil fertility for the Ferric and Plintic Luvisols (centre) and the Acrisols (south) as most of the Sub-Saharan Africa's soils. The main characteristic of both soils is their low organic matter level which was also mentioned by several studies (Sanchez et al. 1989; Giller 2002; Saïdou et al. 2003). The high mineralisation rate of the organic matter (Pieri 1989) is mainly the source of lack of nitrogen in these soils. From the result of our study, it was clairely showed that maize grain and stover yields increased proportionally with an increase of the N rates and that of P and K. This corroborated results of Brassard (2007) and Singh et al. (2001). These authors also found that nitrogen is the most limiting nutrient for cereal production in the Sub-Saharan Africa's soils. As mentioned also by previous studies, most of the Africa's soils have low P level (Koné et al. 2009, 2010) due to the nature and the type of the clays that their content (kaolinite for most of the Acrisols). This shows the importance of the supply of N and P to improve maize production in this part of Africa knowing the complementarity of these nutrients for plant.

The quadratic regression between maize grain and stover yields and nutrients applied showed an optimum rate of 80.5, 22.5 and 20 kg ha^{-1} respectively for N, P and K to optimize maize yield in both soils. The optimum rate of N is consistent with that generated by DSSAT model for maize production in southern and centre Benin (Ezui et al. 2011 and Igué et al. 2013). In opposite, the optimal rates of P and K found from the field experiment, were slightly lower than that determined by the model (30 kg P ha^{-1} and 0 to 40 kg K ha^{-1}) (Igué et al. 2013). This could be explained by crop management type by the individual farmer practice during the experiment, the fields' history and the rates of nutrients introduced in the model during simulation process. Indeed, 0, 30 and 60 kg ha^{-1} of P and 0, 40 and 80 kg ha^{-1}

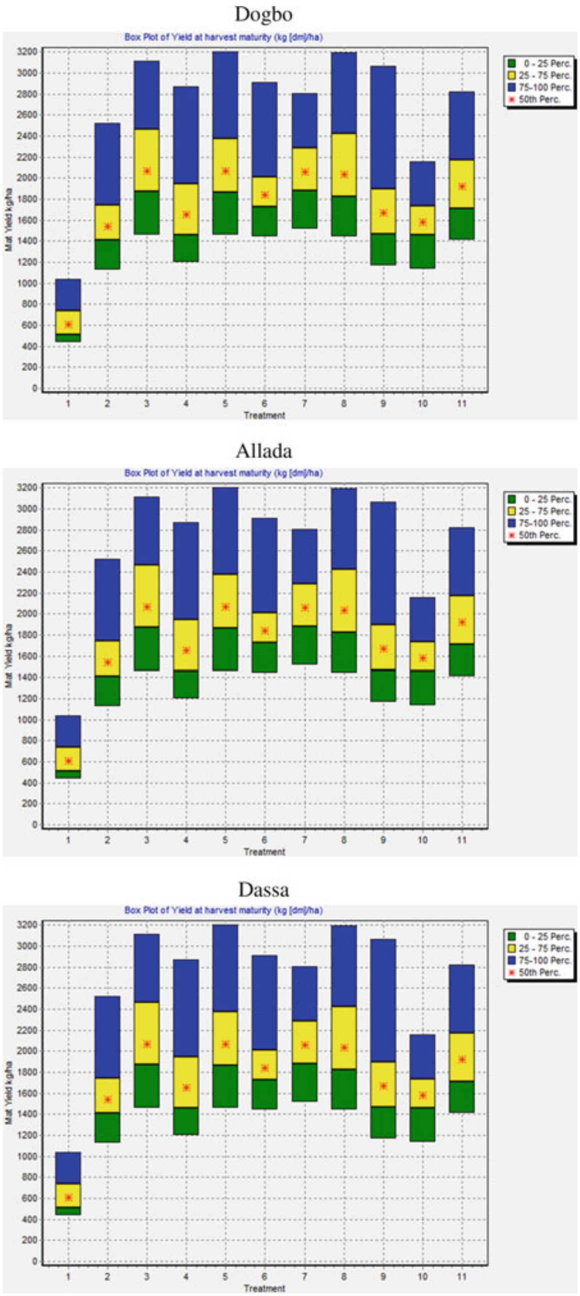

Fig. 13.1 Maize yield as affected by different rates of N-P-K fertilizer for 32 years (1980–2012) seasonal and biophysical analysis using 2011 and 2012 growing season grain yields at Dogbo, Allada and Dassa in Benin (Notes: 1 = 0-0-0; 2 = 44-15-17.5; 3 = 80-30-40; 4 = 80-15-40; 5 = 80-30-25; 6 = 80-30-0; 7 = 69-30-40; 8 = 92-30-40; 9 = 69-15-25; 10 = 46-15-25; 11 = 80-22.5-20)

Table 13.7 Mean-Gini dominance of seasonal partial budget analysis for the different rates of N-P-K fertilizer at Dogbo, Allada and Dassa in Benin

Sites	Treatments	E(x) (F CFA ha^{-1})	E(x) – F(x) (F CFA ha^{-1})	Efficiency
Dogbo	0-0-0	171,950	153906.1	No
	44-15-17.5	295495.4	268367.8	No
	80-30-40	347673.9	305963.7	No
	80-15-40	299605.3	246903.4	No
	80-30-25	351855.3	313378.4	Yes
	80-30-0	324890.9	292694.3	No
	69-30-40	344344.5	309494.2	No
	92-30-40	336991.2	292092.3	No
	69-15-25	320760.4	265567.6	No
	4615-25	289995.0	265987.4	No
	80.5-22.5-20	334011.3	297053.7	No
Allada	0-0-0	165787.9	148060.6	No
	44-15-17.5	339436.3	307102.6	No
	80-30-40	349923.9	312550.1	No
	80-15-40	366509.8	322382.6	Yes
	80-30-25	353293.2	314477.7	No
	80-30-0	355165.2	306664.8	No
	69-30-40	338752.2	302280.6	No
	92-30-40	345544.2	309377.9	No
	69-15-25	361416.4	320968.3	No
	46-15-25	340741.9	310682.1	No
	80.5-22.5-20	360297.6	315264.3	No
Dassa	0-0-0	253612.1	204617.0	No
	44-15-17.5	338387.8	298235.2	No
	80-30-40	319172.4	275081.1	No
	80-15-40	339218.9	292413.6	No
	80-30-25	348553.8	309708.7	No
	80-30-0	359916.7	315749.6	Yes
	69-30-40	294885.5	255355.6	No
	92-30-40	344829.0	306441.2	No
	69-15-25	344471.0	300290.3	No
	46-15-25	333935.9	285802.9	No
	80.5-22.5-20	358976.4	315232.1	No

N.B: E(x) = Mean monetary return per hectare and F(x) = Gini coefficient

of K were rates introduced in the model for the simulation. Futhermore, it was observed that the gap between the two rates of each nutrient was too high, therefore the model had deduced the rate that could provide an optimum maize grain yield. Finally, the model has allowed to select 36 N-P-K combinations from the four levels of N (0, 40, 80 and 120 kg ha^{-1}), three levels of P (0, 30 and 60 kg ha^{-1}) and three levels of K (0, 40 and 80 kg ha^{-1}). This had yielded to two fertilizer formula that gave optimum yield over 30 years simulation.

13.4.2 Performance of DSSAT Model in the Maize Yield Simulation in the South and Centre Benin

The maize grain and the stover yields simulated by DSSAT model fit well with data observed in the field during the two growing seasons (2011 and 2012) in all of our experimental sites. In the site of Dogbo and Dassa, the R^2 values between the observed and simulated results were closed to 100% showing a good performance of the model. There were strong correlation between the simulated and the observed yields (R^2 varying between 80% and 91% for the growing season of 2011 and 68% and 94% for the growing season of 2012). These results corroborate those of Singh et al. (1999), Dzotsi et al. (2003) in Togo ($R^2 = 83\%$), Atakora et al. (2014) in the Guinea savannah zone of Ghana ($R^2 = 91.7\%$) and Tetteh and Nurudeen (2015) in the Sudan Savannah agro-ecology in Ghana (R^2 between 75% and 99%) who found good agreement between the observed maize grain yield and the simulated. The general remark is that, the model was very sensitive to fertilizer rates as mentioned also by Tetteh and Nurudeen (2015) and Atakora et al. (2014). In fact, it was observed that the simulated maize grain yields in the control plots or in the low N rates plots were not so good compared to treatments with high level of N. The maize grain yields were underestimated by the model during both growing seasons in all of the sites. In general, maize yields found in the site of Allada were almost lower than that of the sites of Dogbo (located in the same agroecological zone and same soil type). This could be attributed to the inherant soil fertility. Soil of this area is overexploited due to the high population density (Saïdou et al. 2003). Result of the soil analysis showed low level of organic matter. It is suggested that for this soil type organic matter improvement should be included in the strategy of soil fertility replenishment.

The value of the standardized mean prediction error (NRMSE) between the observed and simulated results varied between 12.54 and 22.56% for the growing season 2011 and 13.09 and 24.13% for the growing season 2012. This mean that DSSAT model has performed in simulating maize grain yields as the NRMSE values calculated were within the acceptable range (Jamieson et al. 1991; Loague and Green 1991). Our findings showed that the model has performed well compared to data found by Nurudeen (2011) with NRMSE and R^2 values respectively of 26.1% and 91.5% between the maize grain yields observed and that simulated by the model. This proves that, with correct inputs of soil and varietal characteristics a decision support tool like DSSAT could perfectly be used to extrapolate fertilizer recommendation data within a large agroecological zone presenting similar climatic characteristics and soil types. The results are also consistent with study carried out by Ritchie and Alagarswamy (2003) and Soler et al. (2007) who found that the CERES-Maize was able to accurately predict the phenology and maize grain yield for a wide range of environmental conditions.

13.4.3 Seasonal and Biophysical Analysis of the Efficiency of the N-P-K Fertilizer Rates on Maize Grain Yield in the South and Centre Benin

The seasonal analysis of the efficiency of the N-P-K fertilizer rates on maize grain yield performed on 32 years of simulation (1980–2012) behind showed that, treatments 80-30-25, 80-15-40 and 80-30-0 respectively for the sites of Dogbo and Allada located on Ferric and Plintic Luvisols and Dassa on Acrisols were the best fertilizer recommendation option. These fertilizer rates presented the best return to investment per hectare and the best efficiency. On the site of Dassa, the level of K found presents a risk in the long term. These N-P-K rates were far from the current standard fertilizer recommendation which does not allow maize crop to satisfy its nutrient requirement considering soil fertility level.

The fertilizer dose generated by the model suggested no application of K in the site of Dassa which seems not sustainable as it will contribute to K mining in these soils (the quantity of K taken up by the plant is not refunded back to the soil). In order to respect fertilization laws, the optimum N-P-K rates calculated (80.5-22.5-20) from the field study were suggested as reasonable recommendation for the area. This treatment presents also high net return per hectare closed to that proposed by the model. What was interesting, is the uniform rate of N (80 kg ha^{-1}) proposed by the model for both soil types. It was also the optimal rate determined from the field experiment. This high quantity of N suggested by the model denotes the low level of N in most of the Benin even West Africa's soils.

During the simulation process, the model did not considered the highest level of N (92 kg ha^{-1}) tested as it was provided low net return per hectare due to the relatively low maize grain yields simulated. Furthermore one can also, considered that the model has been rational in the economy of N utilisation by suggesting a reduce quantity. This observation is in accordance with the findings of Fosu et al. (2012) who stated that a supply of high rate of N leads to N leaching and possible contamination of water and luxury consumption by the plant while reducing the net return. Despite that, the sites of Dogbo and Dassa are located in the same soil types almost twice amounts of P were suggested for the site of Dogbo while in Allada site the model suggested an additional application of K. These results reflected land use types which considerably affect fertilizer use efficiency in the farmers' fields (Saïdou et al. 2012).

The lack of difference in maize grain yields found between fertilizer treatments 80-30-40, 80-15-40, 80-30-25, 80-30-0 and 80.5-22.5-20 suggested that whatever is the rate of P and K, the simulated net returns per hectare were similar when N rate does not vary. This can be explained by the fact that the version 4.5 of DSSAT model is not sensitive to the rates of K during the simulation process. But the model gave a good prediction of N rate to be applied.

For an intensive maize cultivation treatments 80-30-25 and 80-15-40 (for Acrisols of the south) and 80.5-22.5-20 (for Ferric and Plintic Luvisols of the Centre) are more economic for farmers.

13.5 Conclusion

It appears from this study that the optimum levels of N, P and K obtained in the three sites are 80.5, 22.5 and 20 kg ha^{-1} respectively. In general maize grain yields increase with an increase of the N rates. A part the control plot, maize yields predicted were very good (R^2 values more or less close to 100%) compared to the field results. In the case of intensive maize cultivation, N-P-K options 80-30-25 and 80-15-40 (for Acrisols) and 80.5-22.5-20 (for Ferric and Plintic Luvisols) are the most economically and strategically efficient fertilizer rates that gave maximum return to investment for the farmers. The way forward for uniform fertilizer recommendation for maize cultivation in the different agroecological zones of West Africa is to rerun the model considering different maize cultivars with different growing cycle, combining organic manure with different rates of mineral fertilizer and strategies to improve crop water use efficiency.

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