Chapter 7
Recommendations of Fertilizer Formulas for the Production of the EVDT 97 Maize Variety in Northern Benin

A.M. Igué, I. Balogoun, A. Saidou, A.C. Oga, G. Ezui, S. Youl, G. Kpagbin, A. Mando, and J.M. Sogbedji

Abstract An experimental program was carried out in the year 2012 on tree main soil types: ferric Luvisols, gleyic Luvisols and eutric Gleysols in two agroecolological zones of Northern Benin. The global objective was to update the mineral fertilizer formulas recommended for maize production in these zones. The experimental design was a randomized completed bloc with four replicates, installed in farmers' fields with the specific objective to validate five N, P, K based fertilizer formulas. The maize variety EVDT-97 STRW was used. Biophysical and economic analyses completed using the seasonal stool of the DSSAT model allowed to identify a series of efficient options. The results of variance analyses relating to the effect of different fertilizer formulas on maize grain yields showed that the rate simulated by the DSSAT model (115-30-75) produced the highest grain yields regardless of the soil types and agro-ecological zones. The ratio of observed-to-simulated values are close to 1 and the mean standard prediction

A.M. Igué (✉) · A.C. Oga · G. Kpagbin
Laboratory for Soil Science, Water and Environment, Agricultural Research Centre of Agonkanmey, National Institute for Agronomic Research of Benin, 01 BP 988 RP Cotonou, Benin
e-mail: igue_attanda@yahoo.fr

I. Balogoun · A. Saidou
Integrated Soil and Crop Management Research Unit, Laboratory of Soil Sciences, Department of Crop Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 BP 526 RP Cotonou, Benin

G. Ezui
International Plant Nutrition Institute (IPNI), c/o IITA-Ibadan, Ibadan, Nigeria

S. Youl
IFDC Burkina Faso, 11BP 82 CMS Ouagadougou, Burkina Faso

A. Mando
GRAD Consulting Group, 01BP 6799 Ouagadougou, Burkina Faso

J.M. Sogbedji
School of Agronomy, University of Lomé, Lomé, Togo

error (NRMSE) between the observed and the simulated yields was comprised between 11% and 20% for gleyic Luvisols but between 21% and 30% for the other soil types. The results of the biophysical and economic analysis showed that the $N_{115}P_{30}K_{75}$ was the most efficient fertilizer formula for sustainable maize production in Northern Benin.

Keywords Agro-ecological zone · DSSAT · Fertilizer recommendation · Maize · Northern Benin

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7.1   Introduction

Agriculture in Sub-Saharan Africa is characterized by low productivity due to a steady decline in soil fertility (Worou 1998; Saïdou et al. 2012). According to Douthwaite et al. (2002), one of the major constraints for agriculture in sub-Saharan Africa is the steady decline in soil fertility. In developing countries, particularly in sub-Saharan Africa, the environment is not subject to excessive use of mineral fertilizers, but rather to very low or even non-use of fertilizers to compensate for crop exports. This has led to a decrease in soil fertility and therefore to a decrease in agricultural potential (Dudal 2002). According to Kanté (2001), the solution to the widespread depreciation of the "natural capital" and the decline in the production capacity of African lands south of the Sahara necessarily involves investments in soil fertility. According to the author, to be sustainable, actions to improve soil fertility must be multifaceted, to take into account the existing diversity between concrete agro-ecological and socio-economic situations. Serpentié and Ouattara (2001) emphasize the notion of sustainability relating to soil fertility. Thus, mineral fertilization is one of the soil improvement solutions proposed to compensate for nutrient losses and nutritional deficiencies observed in production systems. In Benin, low crop yields are often due to unfavorable rainfall conditions, inherent soil nutrient deficiency and low use of external inputs (Mrabet and Moussadek 2012). Climate variability and land degradation are the main constraints limiting maize production in Benin (Saïdou et al. 2012; Balogoun et al. 2013; Igué et al. 2013). This land degradation is due to overexploitation resulting in low availability of soil organic matter and poor soil management practices (Saïdou et al. 2012; Balogoun et al. 2013). This is reflected in the negative nutrient balances observed on soils (Saïdou et al. 2003).

Indeed, excessive and inappropriate use of tillage equipment at farm level, export of crop residues and the shortening of fallow periods have created the conditions leading to the decrease in soil organic matter content and the degradation of their structure (Robert 1996) and as a result to the decline of their fertility (Lal 2002; Mrabet et al. 2001). The tropical ferruginous soils (Luvisol hahlique, Luvisol gleyique, Plutthosol eutrique, Arenosol haplique) which occupy 60% of the total surface area of Benin (Agossou 1983) and to a lesser extent the hydromorphic soils of the depressed zones are clearly affected by this. These soils are known to be low in nitrogen and phosphorus (Sanchez and Jama 2002).

Any strategy aiming at correcting this situation requires a sound management of agricultural lands. This involves the application of mineral and organic fertilizers to restore the stock of organic matter and ensure nutrient supply to the soils. The role of organic matter in improving soil quality is widely recognized. Indeed, organic matter represents the main indicator and plays a determining role in biological activity (Lal 2002). It has a major influence on soils' physical and chemical properties. (Robert 1996).

In Benin, the fertilizer rates and formulas currently used by extension services (150 kg/ha NPK 14–23-14 and 50 kg/ha urea) for maize are mostly obsolete and generalized (Igué et al. 2013); they do not take into account the current levels of soil degradation and crop exports (Dugué 2010). Moreover, this fertilizer formula uniformly applied in all the agro-ecological zones of Benin does not take into account the climatic variability which can considerably affect the level of nutrient leaching and nutrient losses caused by erosion (Saïdou et al. 2012). Maize being a nutrient-intensive crop, it requires an update of the N-P-K fertilizer formulas used to improve soil productivity.

Therefore, in order to improve not only land productivity, but also maize productivity through the optimization of fertilizer use in North Benin, new site specific fertilizer recommendations (adapted to the soil potential and optimal sowing dates related to climate potential) are necessary.

This study aims (1) to characterize the inherent fertility status of concretioned tropical ferruginous soils (Luvisol ferrique), modal ferruginous soils (Luvisol haplique) and hydromorphic soils (Gleysol eutrique), in the communes of Tanguiéta and Banikoara; (2) to determine on-farm the fertilizer rate recommended to achieve the best maize grain yields depending on soil types and agro-ecological zones, (3) to evaluate the added value of a combined application of mineral and organic fertilizers on the three types of soil studied.

7.2 Materials and Methods

7.2.1 Study Environment

Trials for validating the recommended options using the DSSAT model were performed in two villages, one in Atacora and one in Alibori. Producers were selected from two soil units per village. These villages are located in two different agro-ecological zones: Zone 2 (Cotton Zone of North Benin) and Zone 4 (West Zone of Atacora) in Benin (Fig. 7.1).

The cotton zone of North Benin is a Sudanian zone with two contrasting seasons (a rainy season from June to October and a dry season from November to May). Rainfall varies between 800 and 1200 mm/year. The food crops grown are maize, sorghum, yam, cowpea; cotton is the industrial crop while perennial crops are mango and cashew nuts. Plant growth period is between 140 and 180 days. Relative humidity varies during the year according to temperatures maxima. Rains are heavier at the beginning of the season because of their stormy character and especially the absence of vegetal cover. The relief is a vast peneplain slightly developed and hardly undulating (slope between 1% to 4%) integrating mounds in a tabular form, increasingly high and in increasing numbers moving towards the Niger River.

A trial was carried out in northeastern Benin, in the village of Arbonga, Banikoara district located between 10° 50′ and 11° 30′ north latitude and between 2° and 2° 40′ longitude east. The study area is characterized by a Sudano-Guinean climate with a long dry period and a single rainy season. The monthly averages vary between 2 mm (Mars) and 280 mm (August) of rain. Rainfall varies widely from one year to another and during the vegetative period. The average temperature during the year is 27.4 °C. The relative humidity varies according to the temperatures maximum (33.9 °C). This study area is dominated by modal tropical ferruginous soils and concretionned ferruginous soils (Igué 2012a). The pedological study of the Banikoara district in the Banikoara commune allowed, using the toposequential method, to distinguish eight (8) soil types according to the French classification (CPCS 1967) and FAO (1998).

Agro-ecological zone 4 (zone West-Atacora) is characterized by a climatic variation of Sudano-Sahelian to Sudano-Guinean with an annual rainfall of 1000 to 1300 mm. Soils are also ferruginous, often deep, but with low water reserve. The vegetative period is between 160 and 220 days. In zone 4 the climate is very contrasted: in the west the dry season is 5 months in Natitingou and can reach 7 months in Porga, in the central area the dry season also lasts 7 months and the rainy season from June to September. In the eastern part, the two seasons are roughly equivalent.

The area studied is located approximately 10 km from Tanguiéta which is about 592 km from Cotonou. It is between 10° 40′ and 10° 45′ north latitude and between 1° 20′ and 1° 22′ east longitude. The climate is of the Sudano-Guinean type with a long dry season and a single rainy season. The soils of the Nanébou region in the
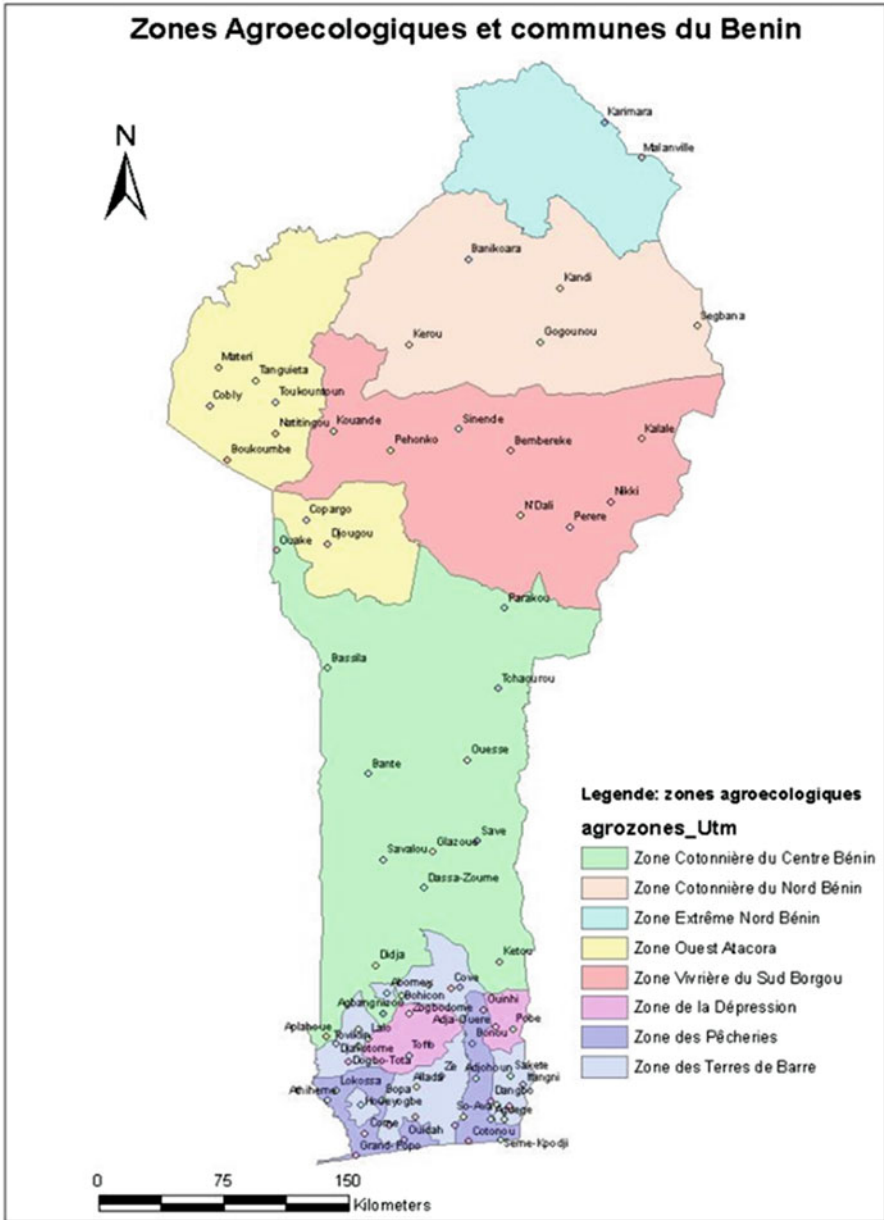
Fig. 7.1 Map of agro-ecological zones of Benin

Tanguiéta commune have very variable morphological and agronomic characteristics. This variability resulting from the heterogeneity of the parent rock, the diversity of the topographic positions and the pedological differentiation along

the toposequences, is reflected at the scale of the site mapping by the existence of combinations of soils rather than homogeneous units. The soil survey performed at Nanébou in north-west Benin allowed, using the toposequential method, to distinguish seven types of soils according to the French classification (CPCS) and FAO.

These two agro-ecological zones of the study area correspond to the sub-humid agro-ecological zone of West Africa (IFDC and AFAP 2016).

The results of soil fertility evaluation (Igué 2012a) showed that half of the soils in the study area are deficient in phosphorus and potassium, while one third is deficient in organic matter and nitrogen. In all soils, the cation exchange capacity (CEC) is the major constraint. The use of organic matter raises this CEC in the soil. It also increases soils' nitrogen content. To correct soil phosphorus and potassium deficiencies, the use of phosphate and potash fertilizers as nutrient supplements is required.

The assessment of fertility status and class indicates that all soils require phosphate and potash fertilizers except hydromorphic leached tropical ferruginous soils (Gleyic Luvisols) which are not prevalent in the area studied. These soils have generally high to moderate levels of nitrogen and organic matter. The lower slopes and lowlands have the highest nutrient contents. It should be noted that almost all soils have severe to very severe limitations in terms of the sum of exchangeable bases and cation exchange capacity. This is probably due to the nature of the rocks on which these soils were formed. All soils belong to the low to very low fertility class except the concretionned ferruginous soils (Ferric Luvisols) which are of the medium fertility class.

Table 7.1 presents the locations of the validation sites for the options and the types of soil on which the trials were carried out.

7.2.2 Plant Material

The plant material used in this study is the EVDT 97 STRW, which is a 90-day open-pollinated (composite) maize variety. The ear coverage is good enough. The grains are white, half-toothed, half-starchy and half-vitreous. Yields in the farming environment vary between 2 and 4 t/h, while the potential yield is 6 t/ha. This maize variety is highly appreciated by producers in Benin (Yallou et al. 2010).

Table 7.1 Sites and soil types in the communes where the trials were carried out

Department	Commune	District	Village	Types of soil considered in this study
ATACORA	Tanguiéta	Tanguiéta	Nanébou	Concretionned tropical ferruginous soils
				Hydromorphic pseudogley soils
ALIBORI	Banikoara	Arbonga	Arbonga	Hydromorphic tropical ferruginous soils
				Concretionned tropical ferruginous soils

7.2.3 Simulation of Maize Growth and Development

The simulation model used for cereal growth and development is the DSSAT 4.5. This model requires a minimum of input data that can be grouped into three categories: daily climatic data (maximum temperature, minimum temperature, precipitation, insolation), site information (latitude, longitude, altitude, physico-chemical properties of soils, previous cropping) and information on crop management (type of tillage, seeding rates, types of sowing, number of plants per square meter, depth of sowing, fertilizers application and genetic coefficients of cultivars determined on the basis of their physiological parameters and grain yields). Daily climate data for 32 years (1980–2011) were collected from ASECNA for the synoptic stations of Natitingou and Kandi.

The calibration of the variety used (EVDT-97 STRW) was based on the database of soils, climate, crop characteristics and crop management practice in the study areas. The genetic coefficients were determined through the GLUE program, a utility for estimating the genetic coefficients incorporated in DSSAT (He et al. 2010). To perform plant growth and development simulations, the maize CSM-CERES used six eco-physiological coefficients.

Biophysical and economic analyzes using the seasonal analysis tool of the DSSAT model identified a series of efficient options. Graphic analyzes were finally carried out to evaluate the dispersion of the various formulations in order to select only those which give the best yields with a low variance (a minimum of risk).

The seasonal analysis has two components. The first is the biophysical analysis that determines the minimum and maximum yields and their variance for the different treatments. The second category is the strategic and financial analysis that requires economic data. These analyses lead to the choice of the most efficient treatment using the coefficient of the Gini average. 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.

7.2.4 Statistical Evaluation of the DSSAT Model

The evaluation of the performance of the DSSAT CERES-Maize model in the prediction of plant growth and development consists in validating the values simulated by the model for the 2011 season based on data observed during on-farm experiments. To do so, a number of tools were used such as: correlation coefficient (Singh and Wilkens 2001), actual deviations separating simulated values from values observed, mean prediction errors RMSE (Du Toit et al. 2001) and the mean standard prediction error NRMSE (Loague and Green 1991; Jamieson et al. 1991).

Table 7.2 Characteristics of different fertilizer combinations

	Treatments	Nutrient rates (kg/ha)		
		N	P	K
T1	Rate simulated by DSSAT	115	30	75
T2	Adaptability rate to N and K	88	30	35
T3	Adaptability rate to N-P-K	74	20	23
T4	National extension	51	20	23
T5	Control	0	0	0

7.2.5 On-Farm Experimentation

The experimental design used for the trials is a four-replicate complete random block with 8 m x 5.6 m elementary plots. This design includes five treatments characterized by different combinations of fertilizers (Table 7.2). The vulgarized rate (T4) represents 200 kg/ha of NPK and 50 kg/ha of urea. The simulated rates (T1) represent the optimal levels of N, P and K simulated by DSSAT. The adaptability rates were determined for the validation of the optimal rates of N, P and K and their comparison with the vulgarized rate.

The method of soil preparation was flat plowing. The sowings were made on the elementary plots with spacings of 80 cm between two rows and 40 cm on the rows (a seeding density of 62,500 plants/ha with two plants per pocket). Two weedings were carried out, the first between the 11th and 14th day after sowing (DAS) and the second between the 40th and 44th DAS.

For the experimental plots, simple fertilizers were used such as urea (46% N), super triple phosphate (46% P_2O_5) and KCl (60% K_2O). Thus, the total amounts of TSP and KCl and half of the urea were applied 2 weeks after sowing at the first weeding, and the remainder of the urea 1 month later. The harvest was made at physiological maturity following the perfect drying of maize cobs on the useful area of each elementary plot after removal of the edges.

The GLM procedure of the Statistical Analysis System version 9.2 software (SAS v. 9.2) was used for statistical analyzes of data from on-farm trials. These consisted mainly of two-factor (soil type and fertilizer formula) analyses of variance by agro-ecological zone. The mean values were then compared with each other using the Student Newman Keuls test at the 5% threshold (the probability level used to refer to a significant effect).

7.3 Results and Discussion

7.3.1 Soils Chemical Properties

The results relating to the chemical parameters of the different soil types prior to the establishment of the trials are given in Tables 7.3 and 7.4. The analysis of these

Table 7.3 Soils chemical properties before trial installation at Nanébou

Soil types	Organic matter (%)	Nitrogen (%)	Base Saturation (%)	pH	CEC (%)	Available P (ppm)	Ca/Mg (%)	Mg/K (%)
Concretionned	2.28	0.092	90.50	5.7*	6.75	12.00	3,25	4,0.7
Ferruginous								
Hydromorphic	1.79	0.067	81.50	5.4*	5.15	6.93	2.50	4.58

Significant at 5%. Without (*) means no significant difference at 5%

Table 7.4 Soil chemical properties before trial installation at Arbonga

Horizons 0–20 cm								
Soil types	OM (%)	Nitrogen (%)	Base satu-ration (%)	pH	CEC (meq/100 g de sol)	Available P (ppm)	Ca/Mg	Mg/K
Concretionned Ferruginous	3.55	0.087	95	6.2	8.68	11.5	3	5
Hydromorphic	1.30	0.040	69.5	5.2	–	7	3.5	4.5

tables shows that organic matter contents were lower in concretionned tropical ferruginous soils than in hydromorphic soils (Nanébou) and hydromorphic tropical ferruginous soils (Arbonga). This low level of organic matter as well as that of total nitrogen observed in hydromorphic soils and hydromorphic tropical ferruginous soils reflects repeated use of these soils, with little or no return of nutrients either by burial of harvest residues, or directly by mineral fertilization (Igué 2012a). These results support that of Igué (2009) and Yallou et al. (2010), which showed that the cultivation of lands decreases their organic matter contents. (Igué et al. 2008) showed that the organic matter content of cultivated soils decreases according to the cropping systems. In the unbalanced system (poor farmer), organic matter is a very severe limitation compared to other systems (medium and balanced) or the limitation is average. Igué (2009) also indicated that organic matter in the topsoil (0–20 cm) decreases from 0.05 to 0.08% per year depending on the type of soil.

According to Worou (1998), the low organic matter content of hydromorphic soils on the study site can be explained by a rather dry soil climate. Fikri et al. (2004) stated that organic matter has a major influence on the physical and soils chemical properties and therefore on crop yields. Concretionned tropical ferruginous soils have higher levels of phosphorus than hydromorphic soils and hydromorphic tropical ferruginous soils. It was found that in the Department des Collines, the phosphorus content can increase by 10% after 10 to 25 years of continuous cultivation of maize/cotton (Igué 2009). This may be due to the regular application of phosphate fertilizers. On the other hand, the Ca/Mg and Mg/K ratios in the three soil types showed good cationic balance without any significant difference ($P > 0.05$) in the different soil types. It remains slightly higher in concretionned tropical ferruginous soils compared to hydromorphic soils and hydromorphic tropical ferruginous soils which are slightly more acidic.

7.3.2 Effect of Different Fertilizer Formulas on Maize Grain Yield According to Soil Type and Area

The results of the analysis of variance relating to the effect of various fertilizer formulas on maize grain yields showed that fertilizer formulas have a highly significant influence ($P < 0.01$ to $P < 0.001$) on maize grain yield regardless of

the areas and types of soil. Figures 7.2 and 7.3 show maize grain yields by area and soil type according to fertilizer formulas. The analysis of these figures reveals that maize grain yields increase with increasing rates of nitrogen. Nitrogen is therefore the major limiting factor to maize yield in Northern Benin. The rate simulated by the DSSAT model (115–30-75) leads to significantly higher grain yield, regardless of soil types and agro-ecological zones (Figs. 7.2 and 7.3).
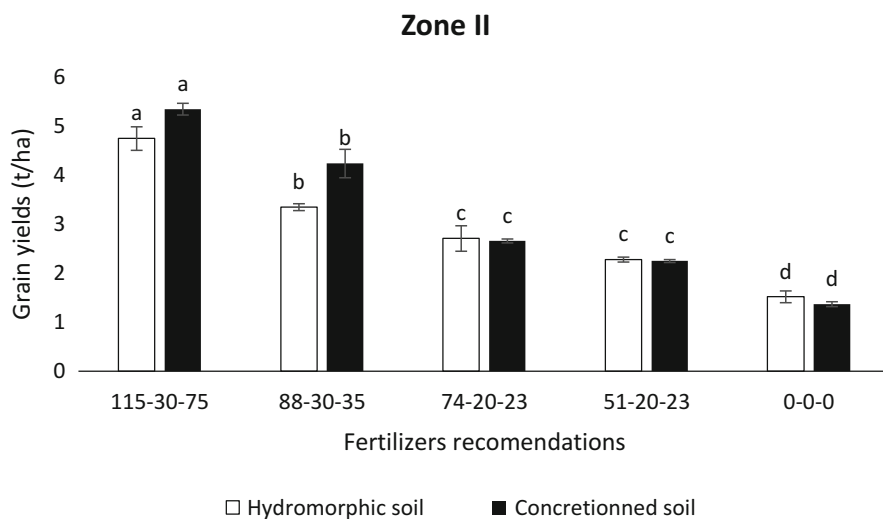

Fig. 7.2 Effect of different combinations of fertilizers on maize grain yields according to soil types in Arbonga (Banikoara)
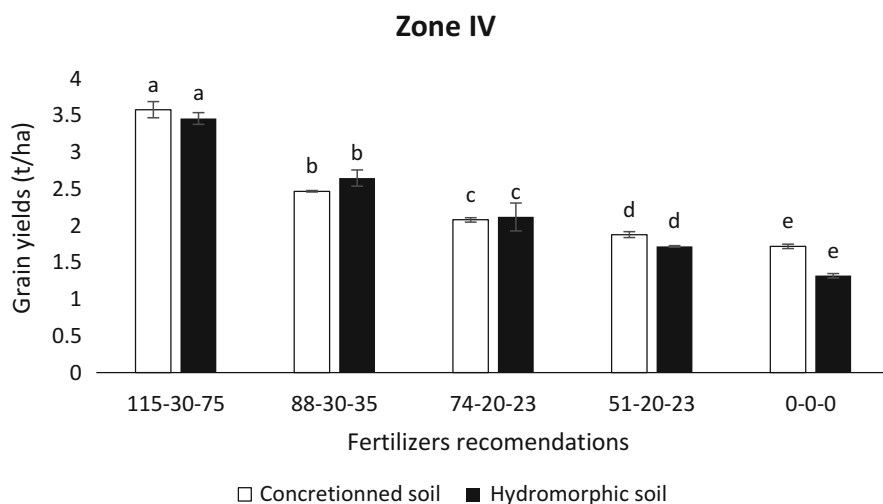

Fig. 7.3 Effect of different combinations of fertilizers on maize grain yield according to soil types in Nanébou (Tanguiéta)

These results are in line with those of Saïdou et al. (2012) who showed that nitrogen is the main limiting factor to cereal crop yields. These observations show the crucial role played by nitrogen fertilizers in improving cereal yields (Balogoun et al. 2013). Moreover, the application of mineral fertilizers without any organic restitution further affects soil chemical characteristics with the number of years of cultivation (Koulibaly et al. 2010). Ultimately, achieving good yields depends not only on the nature of the soils but also on the amount of nitrogen available for plant nutrition. Igué et al. (2015), showed that with the fertilizer formula $N_{42}P_{30}K_{35}$ combined with manure the highest yields were 2940.25 ± 383.60 and 2923.60 ± 653.26 kg/ha respectively for concretionned soils and hydromorphic soils. Without external nutrient supply, the productive capacity of the plots shows drastic deficiencies in the major nutrients (NPK); yield levels are 1246.88 ± 359.39 and 1327.60 ± 165.05 kg/ha respectively for concretionned ferruginous soils and hydromorphic soils with the absolute control ($N_0P_0K_0$).

In Arbonga (Banikoara), the difference in average yields varied significantly with the different types of soils under maize cropping. Grain yields on the concretionned soils increased by 600 kg/ha compared to the hydromorphic tropical ferruginous soils. Atacora et al. (2014) showed in a study in Ghana, that the differences in maize grain yields were more related to differences in soil fertility level. Igué et al. (2015) also showed that the treatment $N_{88}P_{30}K_{35}$ plus manure gave the highest yields on tropical ferruginous soils. On the other hand, on hydromorphic ferruginous soils, the treatment $N_{74}P_{20}K_{23}$ plus manure gave the highest yields. These observations support the works of (Balogoun et al. 2013) which showed that to achieve high maize yield in the South and Center Benin, a rate of 80.5 kg N/ha would be required. Indeed, achieving good yields depends not only on the nature of the soil but also on the amount of nitrogen available for plant nutrition.

In the agroecological zone II, the soils have a good productive potential for the cultivation of the maize variety EVDT ETR 97 whose yield, without external inputs, is around 1.5 t/ha. However, soil fertility decline is a major cause of low productivity in tropical soils. (Kanté 2001; Douthwaite et al. 2002; Saïdou et al. 2012). To redress this situation, the use of organic fertilizers was promoted all the more because mineral fertilization without any organic fertilizer negatively affects the chemical characteristics of the soils; which shows the limits of mineral fertilization. According to Viennot (1969), acidic soils have a negative impact on maize yields and are considered to be moderately suitable for this crop. On the other hand, the hydromorphic soils of the study area were subjected to heavy pressure characterized by overutilization associated with inappropriate agricultural practices. The low productivity of these types of soils without the use of fertilizers is also linked to their topographical position in the landscape, which causes the stagnation of water on the surface of the plots and, in turn, contributes to the asphyxiation of plant root system (Igué 2012a, b).

Table 7.5 Statistics for the comparison of observed and simulated grain yield values for the fertilization trials

Zones	Soils	Observed averages	Simulated averages	Ratio	R-Square	RMSE	NRMSE
II	Ferruginous hydromorphic	2922	2788	0.6	0.74	576.40	19.73
	Ferruginous concretionned	3174	3086	1.09	0.74	914.91	28.82
IV	Ferruginous concretionned	2346	2572	1.15	0.26	616.56	26.28
	Hydromorphic pseudogley	2254	2273	1.03	0.49	543.58	24.12

7.3.3 Evaluation of the Performance of the DSSAT Model

Table 7.5 shows the comparison between observed grain yields and those simulated by DSSAT taking into account fertilizer formulas according to the area and the type of soil. Grain yields simulated by the DSSAT model are slightly underestimated in zone II whereas they are slightly over estimated in zone IV. The values of the ratio observed-to-simulated values are very close to 1. Simulated values are therefore very close to observed values. The mean standard prediction error NRMSE between observed and simulated yields is between 11% and 20% for hydromorphic ferruginous soils whereas it is between 21% and 30% for the other soil types.

Tetteh and Nurudeen (2015) reported that the mean standard prediction error (NRMSE) between simulated and observed grain yields over 2 years (2010 and 2011) in Ghana was 26.13% and 18.24%, respectively. This supports our results. According to Wilmott et al. (1985) and Wallach and Goffinet (1987), any R^2 value between observed and simulated results close to 100% indicates a good performance of the simulation model. NRSME values between observed and simulated results of 21–30% are acceptable according to Jamieson et al. (1991) and Loague and Green (1991).

7.3.4 Application of the Model to the Multi-year Assessment of Fertilizer Formulas

Figure 7.4 presents the results of the biophysical analysis of grain yields by fertilizer formula in zone II according to soil types for the period 1980 to 2012. From this figure it appears that, in general, simulated grain yields are based on fertilizer rates. Thus, the formula 115-30-75 gave the highest average grain yields during the 33 years on the two soil types. Nevertheless, the formula 88-30-35 shows acceptable grain yields with less risk during the 33 years on the two types of soil.

Figure 7.5 presents the results of the biophysical analysis of grain yields by fertilizer formula in zone IV according to soil types for the period 1980 to 2012. It
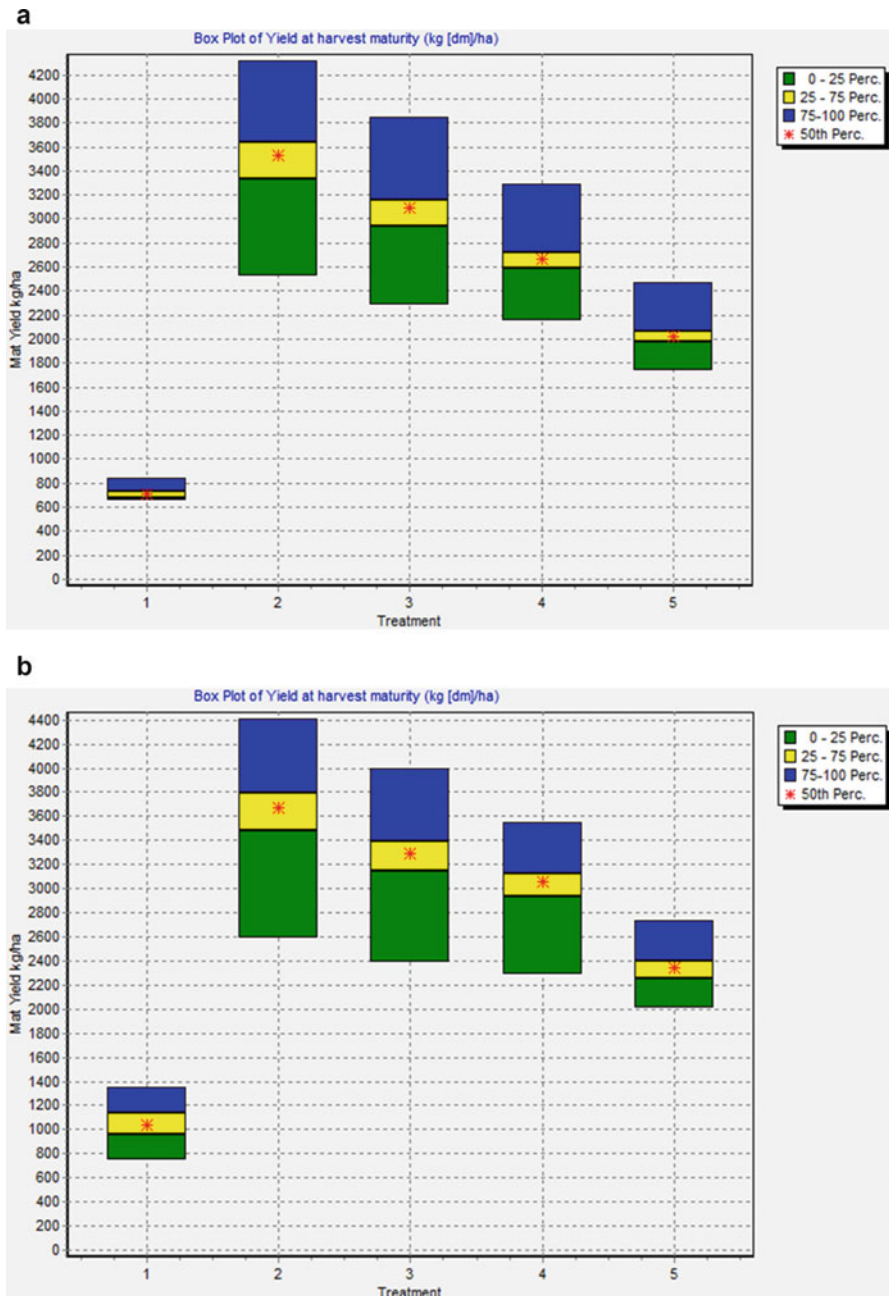
Fig. 7.4 Effect of different fertilizer formulas on grain yields (kg DM/ha) based on biophysical analysis covering the period 1980–2012 for hydromorphic ferruginous soils (**a**) and concretionned ferruginous soils (**b**) in zone II. (1 = 0-0-0; 2 = 115–30-75; 3 = 88-30-35; 4 = 74-20-23; 5 = 51-20-23)
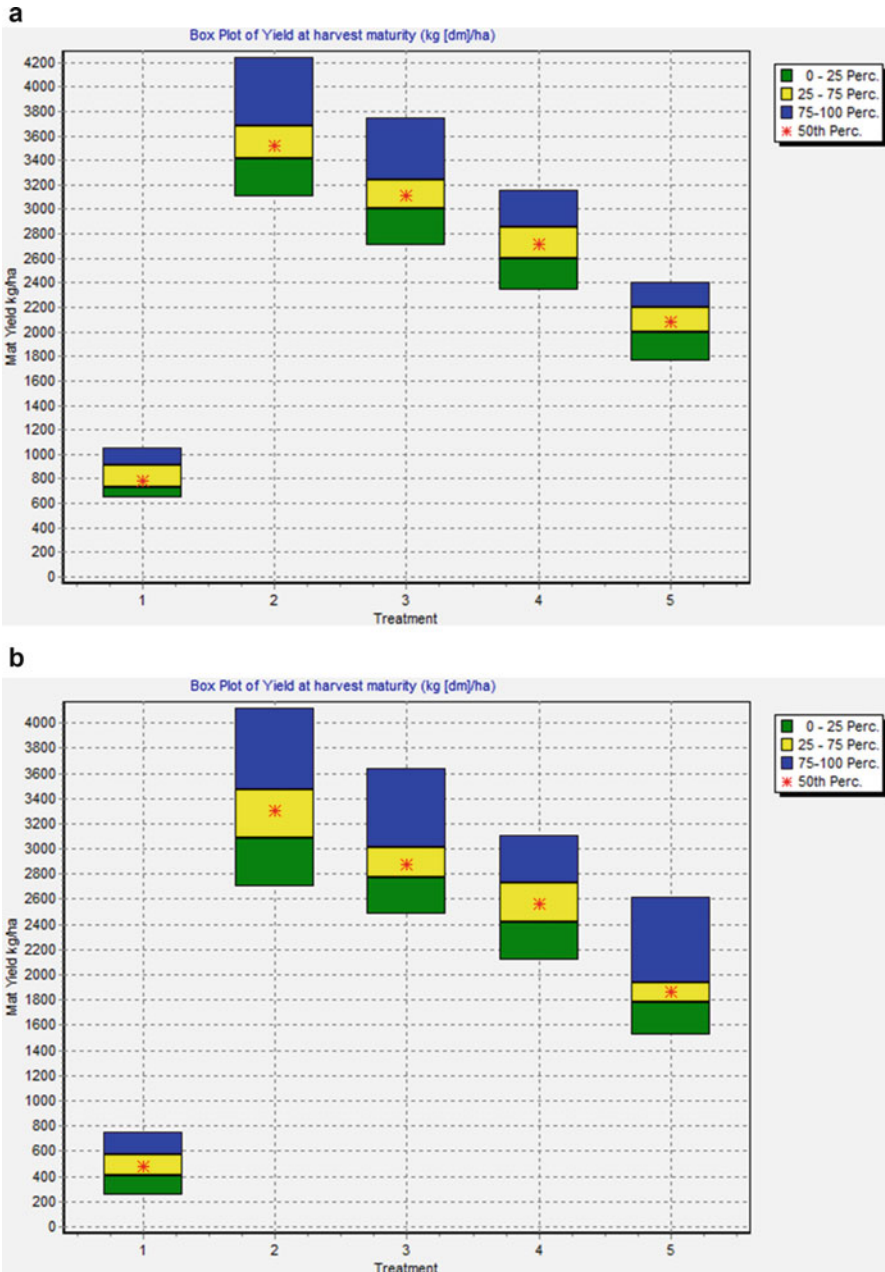
Fig. 7.5 Effect of different fertilizer formulas on grain yields (kg DM/ha) from biophysical analysis covering the period 1980–2012 for concretionned ferruginous soils (**a**) and hydromorphic soils (**b**) in zone IV. (1 = 0–0-0; 2 = 115–30-75; 3 = 88-30-35; 4 = 74-20-23; 5 = 51-20-23)

Table 7.6 Financial analysis of the different fertilizer formulas according to the communes of the study during 33 years (1980–2012)

Zones	Soils	Fertilizer formulas	E(x) (F CFA/ha)	E(x) – F(x) (F CFA/ha)	Efficient
III	Hydromorphic	0–0–0	142515.2	137462.1	No
		115-30-75	517846.3	485497.5	Yes
		88-30-35	483066.6	457741.2	No
		74-20-23	434676.6	414727.2	No
		51-20-23	323990.0	323990.0	No
	Concretionned	0-0-0	210600.0	194743.6	No
		115-30-75	550816.0	517989.5	Yes
		88-30-35	526559.9	497308.6	No
		74-20-23	507500.9	484590.3	No
		51-20-23	386062.8	369192.3	No
IV	Concretionned	0-0-0	163145.5	149549.6	No
		115-30-75	531422.1	504113.8	Yes
		88-30-35	494266.6	469563.2	No
		74-20-23	447100.9	425922.1	No
		51-20-23	335232.5	317777.5	No
	Hydromorphic	0-0-0	98054.5	82479.5	No
		115-30-75	477106.9	439383.5	Yes
		88-30-35	449054.5	422220.4	No
		74-20-23	417476.6	390215.3	No
		51-20-23	295171.8	276692.7	No

E (x) = Average monetary income calculated by the DSSAT model and F (x) = Gini coefficient

appears that, in general, simulated grain yields are based on nitrogen rates. Thus, the formula 115-30-75 gave the highest average grain yields during the 33 years on the two soil types. Nevertheless, the formula 88-30-35 shows acceptable grain yields and with less risk during the 33 years on the two types of soil.

The financial analysis of the monetary incomes from maize per hectare with the efficiency of the various fertilizer formulas during the period 1980 to 2012 by zone and soil type is presented in Table 7.6. The results show that the formula 115–30-75 yielded the best monetary income per hectare and the best efficiency whatever the type of soil and the agro-ecological zone. Nevertheless, incomes resulting from the 80–30-35 fertilizer formula are also better. Indeed, the monetary gains are about 20,000 to 35,000 FCFA between the 115-30-75 and the 80-30-35 formulas. This means that if a producer uses the 115-30-75 formula, he only earns between 20,000 and 35,000 FCFA more than the one using the 80-30-35 formula. This is not so much, given the additional expenses for the nutrients N and K. It can be concluded that the formula 80-30-35 is the best regardless of the soil types and agro-ecological zones.

Tetteh and Nurudeen (2015) showed that the formula 160-90-90 produced the highest monetary income in the Guinean savanna zone in Ghana followed by

formulas 120-0-90 and 120-45-90 respectively. They pointed out that this was due to the high monetary income per hectare and the Gini coefficient. However, they indicated that due to high prices of fertilizers, their availability on the market and low natural soil fertility, the 120-45-90 formula is the most economical for sustainable maize production on Lixisols in the agro-ecological zone of the Sudan Savanna zone of Ghana. The same arguments justify the choice of the formula 80-30-35 against the 115-30-75 for the production of maize in Northern Benin.

7.4 Conclusion

Generally, the DSSAT model was used to simulate maize yields in the agro-ecological zones II and IV of Benin. The grain yields simulated by the DSSAT model are slightly underestimated in zone II whereas they are slightly over estimated in zone IV. The values of the simulated and observed values ratio are very close to 1. Simulated values are therefore very close to observed values. The mean standard prediction error NRMSE between observed yields and simulated yields is between 11% and 20% for hydromorphic ferruginous soils whereas it is between 21% and 30% for the other soil types. Formulas 115-30-75 and 80-30-35 gave the best yields on-farm. Moreover, the seasonal analyzes with the DSSAT model over 33 years showed that the same formulas 115-30-75 and 80-30-35 gave the best yields and the best monetary incomes. The study recommended the formula 80-30-35 kg/ha of NPK as the most economically and strategically efficient fertilizer formula that gave optimum yields with less risk during the 33 years in the two agro-ecological zones of Northern Benin.

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