Andre Bationo · Djimasbé Ngaradoum
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Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems

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Preface

The population in West Africa has quadrupled over the last 50 years, and this rapid growth has had a huge impact on the food demand and natural resources. Food production per capita has declined for the past several decades in West Africa, the only major region of the developing world where this has occurred. This trend is putting at stake the livelihoods of the poor in the region and poses a daunting challenge to rural communities and regional and national policy makers. Poor land use and management result in soil and water erosion, depleted soil fertility, desertification, and salinization, creating a spiraling decline in the productivity of the land for food and other ecosystem services. Nearly 3.3% of agriculture GDP is lost annually because of soil and nutrient losses. Soil fertility depletion is one of the major causes of declining per capita agricultural productivity and the consequent food insecurity in the region. Much research and extension effort in the past has been directed to promoting the adoption of improved crop varieties and fertilizers with an objective of generating technologies for the "African Green Revolution." However, adoption studies have shown limited uptake of external input-intensive technologies. In much of West Africa, the use of fertilizers and other purchased inputs is not sufficiently profitable to stimulate use by farmers in this market environment. Even where such inputs are profitable, they are often not used by farmers due to poorly developed markets, high production and market risks, cash and credit constraints, and other socioeconomic constraints

In 2016, two IFDC projects funded by USAID, the West Africa Fertilizer Program (WAFP) and C4CP, organized a West Africa regional workshop in response to the adoption of the regional fertilizer recommendation actions by ECOWAS in Lomé to review the state of the art of fertilizer recommendation in the region. It brought together over 100 participants from the public sector (technicians, researchers and academics, etc.), ECOWAS (Agricultural Department), key institutions in charge of soil fertility in West Africa, donor community (Islamic Development Bank (IsBD), ECOBANK, World Bank), farmers' organizations (ROPPA), and the private sector (fertilizer blenders, distributors, etc.). The objectives of the workshop were to capitalize on past and current fertilizer recommendations, validate an extrapolation methodology, and develop a roadmap for regional upscaling of updated fertilizer recommendations in West Africa.

Unfortunately, low productivity returns from unskilled use of fertilizer present a major impediment to their adoption by most small-scale farmers, and this requires an improvement in mineral fertilizer use efficiency. Past fertilizer recommendation was based on pan-territorial blanket recommendations. IFDC worked in West Africa in the past years with our national partners focused on improving the profitability, sustainability, and efficiency of nutrients through site-specific fertilizer recommendations. Our research activities on fertilizer recommendations were on looking for means to improve the agronomic efficiency of fertilizer (agronomic efficiency (AE) is defined as a ratio describing the increase in crop yield per unit of applied nutrients) within the framework of integrated soil fertility management (ISFM). The role of ISFM as a means to increase the efficiency of fertilizer nutrients by generating higher yield per unit of fertilizer added will accelerate farmers' adoption of fertilizers. Topics discussed in this workshop to increase fertilizer use efficiency include (1) the usefulness of organic soil amendment, (2) the use of improved crop cultivars, (3) the urea deep placement for paddy rice, (4) the strategic application of small quantities of fertilizers known in the West Africa region as the microdose technology that has the potential to transform the Sahel from gray to green, (5) balanced crop nutrition consisting of applying not only the macronutrients but also secondary and micronutrients where needed, and (6) water harvesting technologies to improve the nutrient use efficiency in the drylands.

The diversity of West African soils and climates limits the extrapolation of experimental results to wide geographic areas, and it is practically impossible to do experiments everywhere. In West Africa, climate change is widely expected to result in major changes in crop productivity and affect adversely the livelihoods of millions of people unless appropriate measures are taken. The use of soil and extrapolation models can enhance our understanding of environmental (climate, soils, and management) influences on the productivity of crops and inform the key decision-makers at local, national, and regional levels in order to put the appropriate measures in place. Models offer a cheaper means of understanding crop responses to management in different environments. We need to move away from the "trial-and-error" approach in agricultural research for evaluating management practices. We need a system approach in which (1) experiments are conducted over a range of environments, (2) a minimum set of data is collected in each experiment, (3) cropping system models are developed and evaluated, and (4) models are used to simulate production technologies under different weather and soil conditions so as to provide a broad range of potential solutions for farmers. The use of decision support systems such as the Decision Support System for Agrotechnology Transfer (DSSAT) is gaining momentum in the region, and its wider use with improved IT knowledge will improve the site-specific fertilizer recommendations for more efficient and profitable fertilizers.

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Chapter 1
Combining the DSSAT Model with Experimentation to Update Recommendations of Fertilizer Rates for Rice and Maize in Burkina Faso

J. Ouedraogo, S. Youl, and A. Mando

Abstract Maize (*Zea mays* L.) and rice (*Oryza sativa* L.) are major commodities in Burkina Faso. However, yields remain low despite the creation of improved varieties. These low yields are mainly due to low soil fertility and inadequate fertilization, which require new fertilizer formulas. For this purpose, the Decision Support System for Agro Technology Transfer (DSSAT 4.5) model was combined with on-farm experimentation to determine optimal fertilizer rates (NPK) for maize production using a Fisher type experimental design. Response curves were used to develop options for the intensification of rice production.

Results of the experiments combined with those of the DSSAT model showed that the T5 treatment (80 N-30P-40 K) represents the best combination for intensive maize production with less risk from climatic variability in the eastern and western zones of Burkina Faso. Regarding rice, nitrogen and phosphorus were the limiting nutrients. An analysis of the results by quadratic regression, using two fertilizer cost scenarios, showed that optimal rates varied between 119 kgN.ha^{-1} and 136 kgN.ha^{-1} for nitrogen and 24 kgP.ha^{-1} and 32 kgP. ha^{-1} for phosphorus. The rates thus determined provide an opportunity for farmers to intensify agricultural production and substantially improve their monetary income.

Keywords Optimal rate · DSSAT · Agricultural intensification · Maizeβ · Rice · Burkina Faso

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Contents

1.1 Introduction

Maize and rice are major crops in sub-Saharan African countries. Rice imports rose from 0.5 million tons in 1961 to 6 million tons in 2003 (Balasubramanian et al. 2007). In Burkina Faso, maize and rice are respectively the third and fourth most widely grown cereal crops. According to the results of the continuous crop survey, 334,518 tons of rice were produced in 2015 while demand was around 485,000 tons. This leads to greater dependence of the country on rice imports, which is a drain of foreign exchange and a source of vulnerability in terms of food security. Moreover, demand for maize is increasingly strong due to changed eating habits of the populations, urban population growth and the development of intensive and semi-intensive livestock farming.

In this context, intensification of agricultural production is required to meet the growing needs of the populations. However, despite efforts to popularize seeds of improved varieties, yields remain low. This situation can be explained by low and irregular rainfall, but especially by low soil fertility (Sedogo 1993; Piéri 1989; Pallo et al. 2008; Bationo et al. 2012). Recommendations of fertilizer rates for cereal crops are outdated, and inappropriate, given the evolution of soil characteristics and climatic variability (Nziguheba et al. 2009). Indeed, updating works have been attempted, especially on food crop fertilizers (sorghum, millet, corn) (Hien et al. 1992). A number of fertilizer formulas were tested in farmers' fields in various agro-climatic zones between 1986 and 1991.

Moreover, sub-Saharan Africa, of which Burkina Faso, has the lowest mineral fertilizers consumption level, around 10 kg of nutrients (N, P205, K20) per hectare per year compared to an average of 90 kg worldwide, 60 kg in the Near East and 130 kg in Asia (FAO 2003). Cereal production is hampered by inadequate fertilizer rates (mineral or organic fertilizers) which greatly limits yields. Improving soil fertility through appropriate fertilization could be the key to reversing negative trends in agricultural production.

Therefore, updating fertilizer formulas is a prerequisite to meet this requirement. This can be achieved through conventional experiments, but also through the use of agronomic models. Matthews et al. (2000) stress the need to integrate modeling as a complementary tool in conventional agronomic research programs. Consequently, an approach combining the Agronomic Decision Support System (DSSAT 4.5) model used by several authors (Doztsi 2002; Nurudeen 2011; Bambara 2012; Balogoun et al. 2013 with experiments, helped to develop new recommendations of fertilizer rates for intensive and sustainable production of maize and rice in Burkina Faso.

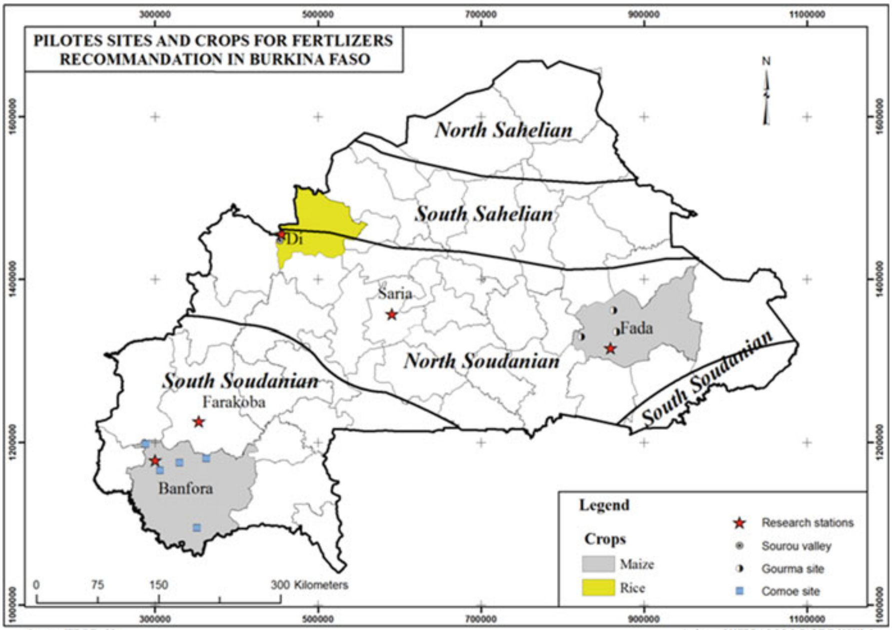
The underlying assumption of this study is that the fertilizer rates currently used are low and do not allow the expression of the potential of the varieties. The overall objective of this study was to develop site-specific and economically profitable fertilizer recommendations for intensive maize and rice production.

1.2 Materials and Methods

1.2.1 Site Description

Research on rice has been conducted in the Sourou valley, which is located in the northwestern part of Burkina Faso in the province of Sourou, about 270 km from Ouagadougou (03° 20′W and 13° 00′N). This valley has irrigable potential of approximately 57,000 ha. It has a semi-arid climate of the north- Sudanian type. According to the phytogeographical zoning (Fontes and Guinko 1995), the Sourou valley is situated between two main sectors, namely the sub-Sahelian sector characterized by a rainfall between 550 and 750 mm per year and the north-Sudanian sector with a rainfall between 700 and 900 mm per year. Average temperatures are stable between 17 °C and 22 °C for the cool months (November–February) and 35 °C and 41 °C for the hot months (March–May). Irrigated rice is produced mainly on tropical eutrophic brown vertic soils, and tropical ferruginous eutrophic brown soils.

Research on maize was carried out at the eastern agronomic research stations of Fada N'Gourma and Banfora in the western part of Burkina Faso. These areas are most suitable for maize production. The eastern research station is located in parallel between 12° 05′N and 11° 55′S and in meridian between 0° 10′ and 0° 25′E. The climate is of the north-Sudanian type with an average annual rainfall of about 800 mm. The average annual temperatures vary from 24 °C to 33 °C. The most frequently encountered soils are endoferric lixisol. They have a silty-sandy texture with organic matter contents of about 0.47% in the 0–20 cm horizon. The western research station is located at Banfora (4° 45′W and 10° 36′N). The climate is of Sudanian type in general (Fontes and Guinko 1995) with a Sudano-Guinean tendency towards the extreme south. Located between the isohyetes 1000 mm and 1200 mm, it is one of the wettest areas of Burkina Faso. Average monthly temperatures fluctuate between 25.9 °C and 31.6 °C. Soils are predominantly of the ferric lixisol type with a sandy-loamy texture. They are poor in clay, with organic matter contents between 0.4 and 0.6% (Fig. 1.1).



Source : IFDC Burkina

Authors : OUEDRAOGO J. PARE T. YOUL S.

Fig. 1.1 Presentation of the study sites

Table 1.1 Treatments for soil fertility diagnosis

	Amounts (kg) per hectare		
Treatments	Urea	TSP	KCL
T1 = 0N 0P 0K	0	0	0
T2 = 0N 30P 40K	0	148	149
T3 = 120N 0P 40K	261	0	80
T4 = 120N 30P 0K	261	149	0
T5 = 120N 30P 40K	261	149	80

1.2.2 Methodology for Updating Recommendations of Fertilizer Rates for Rice Production

1.2.2.1 Experimental Design for Nutrient Omission Trials

The diagnosis of soil fertility was carried out on farmers' plots. A total of 36 trials were conducted, including 11 in the dry season and 25 in the wet season. The field trials were conducted on the basis of 5 treatments with 11 replicates in the dry season (each farmer representing a replicate) and 25 replicates in the wet season. The elementary plots had an area of 25 m^2 (5 m × 5 m). The treatments are shown in Table 1.1.

Table 1.2 Amount of mineral fertilizers to be applied based on N, P and K rates

Treatments	Fertilizer units N, P et K	Amounts of fertilizers kg.ha^{-1}		
		Urea	TSP	KCl
T0	0-0-0	0	0	0
T1	69-30-40	150	149	80
T2	69-40-40	150	199	80
T3	69-50-40	150	249	80
T4	92-30-40	200	149	80
T5	92-40-40	200	199	80
T6	92-50-40	200	249	80
T7	120-30-40	261	149	80
T8	120-40-40	261	199	80
T9	120-50-40	261	249	80

1.2.2.2 Experimental Device for Studying the Response of Rice to Nitrogen and Phosphorus

The fertility diagnosis showed that nitrogen and phosphorus are the limiting nutrients to rice productivity in the Sourou Valley. Since potassium is not a limiting nutrient in irrigated rice farming in the Sourou valley, the results of the NP trial were used to formulate optimal recommendations for nitrogen and phosphorus. To this end, a trial consisting of a combination of increasing rates of nitrogen and phosphorus was then installed. The experimental design used was a Fisher block with three replicates. Three levels of nitrogen, 69, 92 and 120 kg.ha^{-1} and three levels of phosphorus, 30, 40 and 50 kg.ha^{-1} were studied. The level of K to be applied was fixed at 40 units to remain in the same dynamic as the nutrient omission trials. The experimental design consisted of 10 treatments including an absolute control (Table 1.2). The basic area of each treatment was 20 m^2 (5 m × 4 m).

1.2.2.3 Farming Operations

Soil preparation first consisted of flat plowing followed by mudding and then leveling. The FKR 62N variety was used. This rice variety has a seed-maturity cycle of 118 days with a potential yield of 5 to 7 t.ha^{-1}. The rice transplanting was done using three (3) to five (5) week seedlings from previously established nurseries. It was made at the spacing of 20 × 20 cm with two plants per pocket. Furrow irrigation was used and maintaining the water level in the rice field was in line with the water needs of the plant at its various phenological stages. The elementary plots were separated and irrigated individually. Two weeding operations were carried out. Paddy and straw yields were evaluated over the entire elementary plot. Urea (46% nitrogen), triple super phosphate (TSP with 46% P2O5) and potassium chloride (KCl containing 60% K_2O) were used. TSP and

KCl were applied as basal dressing while urea was applied in two fractions: the first fraction 15 days after transplanting (DAT) and the second fraction on the 40th day after transplanting.

1.2.2.4 Data Analysis

The data were submitted to an analysis of variance (ANOVA) using the Genstat 9.2 software. Separation of the averages was made using the Student-Newman and Keuls test at the 5% threshold.

A quadratic regression was performed to evaluate the response of rice to increasing doses of nitrogen and phosphorus. At the end of the quadratic regression, curves of responses to nitrogen and phosphorus have been developed. These curves are in the form:

$$Y = ax^2 + bx + c$$

Where: Y is the yield; X is the quantity of fertilizer and a, b and c are constants.

The method used by Dhuyvetter et al. (2000) served to determine optimum rates of nitrogen and phosphorus. For this purpose, two scenarios were considered for each variable (fertilizer prices, and the cost of paddy at collection). Concerning fertilizer prices, two situations were considered: the situation in which fertilizers are subsidized (CFAF 13,500 for a bag of 50 kg of DAP and NPK and CFAF 12500 for a bag of 50 kg of urea) and the situation where fertilizers are paid on the market without subsidy (CFAF 18,500 a bag of 50 kg of DAP and NPK, 17,500 FCFA for a bag of 50 kg of urea). The binary fertilizer DAP 18-46, higher in phosphorus and the NPK 14-23-14 used in rice growing were selected as fertilizer supply sources in the research scenarios. The price of collecting paddy from producers by agricultural cooperatives varies between CFAF 125 and CFAF 175.

1.3 Methodology for Updating Recommendations of Fertilizer Rates for Maize Production

1.3.1 Conduct of Validation Trials

A Fisher Block Experimental Design was used for carrying out validation trials. It consisted of four replicates separated by 2 m aisles. The treatments were established on 25 m^2 (5 m × 5 m) elementary plots, separated by 0.5 m aisles. Nine (09) treatments included combinations of N, P, K elements (Table 1.3).

The seeding was preceded by plowing to a depth of about 20 cm. The varieties Massongo and SR 21 were used in the western part while the varieties Barka and SR 21 were used in the eastern part. The characteristics of these varieties have been

Table 1.3 Definition of treatments for validation trials on maize

Treatments	Formulas
T1 (absolute control)	0N-0P-0K
T2 (conventional recommendation)	60N-10P-12K
T3 (semi-intensive recommendation)	97N-20P-48K
T4 (intensive recommendation)	111N-30P-60K
T5 (option 1 simulated with DSSAT)	80N-30P-40K
T6 (option 2 simulated with DSSAT)	90-30P-40K
T7 (option 3 simulated with DSSAT)	100N-30P-40K
T8 (option 4 simulated with DSSAT)	110N-30P-40K
T9 (option 5 simulated with DSSAT)	120N-30P-40K

Table 1.4 Characteristics of maize varieties

Number	Varieties	Seeding-male flowering DAS	Seeding-maturity DAS	Potential yield t/ha
1	SR 21	59	95	5,1
2	Barka	42	80	5,5
3	Massongo	58	100	5,6

described in Table 1.4. The seeding was done manually with a spacing of 80 cm between the rows and 40 cm on the rows. Three to four grains were sown per pocket. A thinning operation was carried out to adjust the number of plants to two per pocket. Two weeding operations were carried out: the first weeding 2 weeks after sowing and the second one at 6 weeks after sowing.

The basal dressings (NPK) were made on the 15th day after sowing (DAS), while urea applications were made in two (02) fractions: 2/3 on the 15th DAS and 1/3 on the 45th DAS except for the rate recommended by extension, where urea was applied at once, on the 15th DAS.

Maize grain and straw yields were evaluated on a utility plot of 19.32 m^2 delineated inside each elementary plot. The data collected were subjected to ANOVA, with the software Genstat 9.2. Separation of the averages was performed by the Student Newman Keuls test at the 5% threshold.

1.3.2 Determination of the Optimal Fertilizer Rate

Two maize varieties were used for the simulations. These include the Massongo variety in the western part and the Barka variety in the eastern part of Burkina Faso. These varieties were first calibrated using the DSSAT Glue Utility program. The results of calibration of the genetic coefficients of the variety used for model evaluation are presented in Table 1.5.

Table 1.5 Genetic coefficients calculated for the Massongo and Barka varieties using the GLUE program

Variety	P1	P2	P5	G2	G3	Phint
Massongo	210	0.600	750	650	10.10	40.00
Barka	180	0.600	700	458	10.20	37

P1: cumulative heat from emergence to the end of the juvenile phase (expressed in degree-days above a base temperature of 8 °C) where the plant is not sensitive to photoperiod variations

P2: developmental shift (expressed in days) for each 1 h increase in photoperiod over the longest photoperiod where development occurs at the maximum rate (assumed to be 12.5 h)

P5: cumulative heat from female flowering to physiological maturity (expressed in degree-days above a base temperature of 8 °C)

G2: maximum number of grains per plant

G3: the filling rate of grains during the linear grain filling phase and under optimum conditions (mg/day)

PHINT: Phylochron Interval; cumulative heat (expressed in degree-days) between the appearance of the tip of two successive leaves

Table 1.6 Price of fertilizer unit for nitrogen, phosphorus, potassium and of seeds

Input Costs (F CFA/kg)	East	West
Seeds (F CFA/kg)	600	750
Values of N (F CFA/kg) at 18,500 FCFA/bag of 50 kg	804	804
Values of P (F CFA/kg) at 17,000 FCFA/bag of 50 kg	739	739
Values of K (F CFA/kg) at 37,500 FCFA/bag of 50 kg	1250	1250

The determination of the optimal dose for maize production in the western part of Burkina Faso was based on the seasonal biophysical and strategic analysis of DSSAT, which was previously calibrated. In this type of analysis, only climate variations are taken into account, the other data remaining unchanged. The analysis was carried out over a period of 32 years from 1980 to 2011 for the western zone and over a period of 35 years (1977–2011) for the eastern zone of Burkina Faso. For strategic analysis, the context of family farming was taken into account. Fixed production costs were considered identical for all treatments. Crop management works were carried out using family labor. Only fertilizers and seeds were paid. Table 1.6 presents the input costs and the selling prices of maize. The selling price of maize was evaluated from the harvest in June at 158 CFAF in the western zone and 180 CFAF in the eastern zone. The biophysical analysis enables to choose the best treatment on the basis of the yields obtained whereas the economic analysis leads to the choice of the best efficient treatment using the coefficient of the average of Gini (an economic decision-making tool integrated in the DSSAT system).

1.4 Results

1.4.1 Diagnosis of Soil Fertility in Irrigated Rice Farming

The results showed that the best grain and straw yields were obtained with NPK and NP treatments (Table 1.7) in the dry season. The yields of these treatments differ significantly from those of other treatments. The lowest yields were obtained on the control followed by the NK and PK treatments, which were statistically identical. Omission of nitrogen or phosphorus resulted in a decline in paddy yield compared to the complete NPK formula. Therefore, N and P are the most limiting nutrients to rice production in the irrigated areas of the Sourou valley in the dry season, in an equivalent manner. Potassium is therefore not a limiting nutrient in rice production.

The results achieved in the wet season are in the same order of magnitude as those obtained in the dry season. Indeed, the best yields were achieved with the NP and NPK treatments. NP and NPK treatments did not differ significantly at the 5% threshold, in contrast with other treatments. The ANOVA did not reveal any significant difference between the NK and PK treatments. The lowest paddy and straw yields were obtained on the control. Therefore N and P are the most limiting nutrients of wetland rice production in an equivalent manner.

The results showed that fertilizer applications significantly improved paddy and straw yields. The highest paddy and straw yields, of 5333.3 kg.ha^{-1} and 8000 kg.ha^{-1} respectively, were achieved with treatment T9 (120N-40P-40K). This treatment improved paddy yield by 68%, and straw yield by 73% compared to the control. However, this treatment differs only from the control. The results also showed that the treatments had no significant effect on the number of panicles/m^2 (Table 1.8).

Table 1.7 Nutrients limiting rice yields in the Sourou valley

	Dry season planting		Wet season planting	
Treatment	Paddy yields (kg. ha^{-1})	Straw yields (kg. ha^{-1})	Paddy yields(kg. ha^{-1})	Straw yields (kg. ha^{-1})
Control	3577^b	4930^b	2771^c	2928^e
PK	4007^b	5867^b	3795^b	3874^d
NK	3960^b	6097^b	3798^b	4464^c
NP	5143^a	7223^a	4728^a	5018^b
NPK	5337^a	7600^a	4956^a	5618^a
CV (%)	17,3	20,8	16,5	17,7
Probability F (5%)	<0,001	<0,001	<0,001	<0,001
Significance	VHS	VHS	VHS	VHS

Values affected by the same letter in the same column are not significantly different at the 5% threshold, according to the Student Newman Keuls test

VHS very highly significant, *CV* coefficient of variation

Table 1.8 Effects of combined rates of nitrogen and phosphorus on paddy and straw yields

Treatments	Paddy yields (kg.ha^{-1})	Straw yields (kg.ha^{-1})	Panicle.m^{-2}
T1 (0N-0P-0K)	3166.7^{b}	4633.3^{b}	215.67^{a}
T2 (69N-30P-40K)	4783.3^{a}	7266.7^{a}	287^{a}
T3 (69N-40P-40K)	4316.7^{ab}	6555.6^{ab}	294.67^{a}
T4 (69N-50P-40K)	4233.3^{ab}	6544.4^{ab}	261a
T5 (92N-30P-40K)	4 950^{a}	7266.7^{a}	285.33^{a}
T6 (92N-40P-40K)	5116,7^{a}	7744.4^{a}	278.67^{a}
T7 (92N-50P-40K)	4816.7^{a}	7522.2^{a}	301.67^{a}
T8 (120N-30P-40K)	5066.7^{a}	7733.3^{a}	274^{a}
T9 (120N-40P-40K)	5333.3^{a}	8 000^{a}	262.67^{a}
T10 (120N-50P-40K)	5 000^{a}	7333,3^{a}	262.67^{a}
CV (%)	10.62	9,68	11,9
Probability	0.0033	0,0009	0.1962
Significance	HS	VHS	NS

Values affected by the same letter in the same column are not significantly different at the 5% threshold, according to the Student Newman Keuls test

VHS very highly significant ($P < 0.001$), *HS* highly significant ($P < 0.01$), *NS* non significant, *CV* coefficient of variation

1.4.2 Rice Response to Increasing Rates of N and P

The response of rice to increasing rates of nitrogen and phosphorus using quadratic regression with or without the use of organic matter is presented in Figs. 1.2 and 1.3. The results showed a significantly positive correlation between the rates of applied mineral fertilizers and the yields achieved.

The correlation coefficients are 0.99 for nitrogen and 0.99 for phosphorus, respectively. Furthermore, the derivatives of equations yn and yp are canceled respectively for the values of 155 and 34 indicating the respective biophysical recommendations of N and P.

1.4.3 Economic Evaluation of Nitrogen and Phosphorus Recommendations

The evaluation of fertilizer agronomic and financial performance is a decision-making tool that enables the producer to choose the optimal dose according to the cost of fertilizers and the value of the produce. These recommendations were determined on the basis of paddy prices and fertilizer costs (depending on the type of fertilizers) in order to improve the economic profitability of rice production.

The results presented in Table 1.9 showed that the economically profitable rates of nitrogen in the Sourou valley vary between 129 kg.ha^{-1} and 136 kg.ha^{-1} when

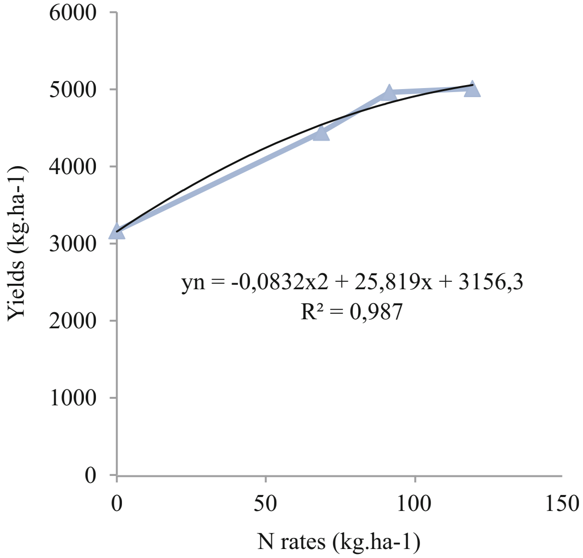


Fig. 1.2 Rice response curves with increasing rates of nitrogen

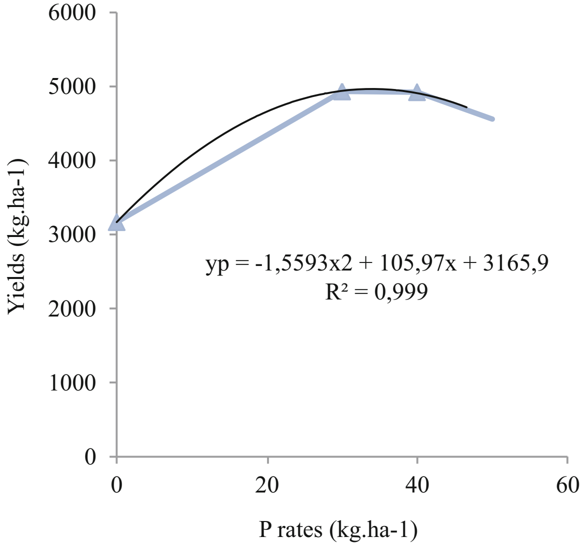


Fig. 1.3 Rice response curves with increasing rates of phosphorus

the fertilizer is subsidized. On the other hand, if the producer must acquire the fertilizer at market price, the optimum rate varies between 119 kg/ha and 129 kg/ha.

For phosphorus, the optimum rate varies according to the type of fertilizer used. Recommendations vary from 24 units to 32 units of phosphorus depending on the type of fertilizer complex used and paddy price. In addition, it was noted that recommendations with DAP were higher than with NPK complex (Table 1.9).

Table 1.9 Optimum rates of nitrogen and phosphorus according to fertilizer and paddy prices (kgN.ha^{-1})

	Nitrogen (N) rate		Phosphorus (P) ratefrom DAP 18-46		Phosphorus (P) rate from NPK 14-23-14	
Paddy price	Subsidizedfertilizer	Fertilizer at market price	Subsidizedfertilizer	Fertilizer at market price	Subsidizedfertilizer	Fertilizer at market price
Min paddy price (125f)	129	31	29	27	24	119
Max paddy price (175f)	136	32	31	29	27	129

Table 1.10 Effects of treatments on grain and straw yields for the maize varieties Massongo and SR 21 in western Burkina Faso

Treatments	Formulas	Massongo variety		SR 21variety	
		Grain yield (kg.ha^{-1})	Straw yield (kg.ha^{-1})	Grain yield (kg.ha^{-1})	Straw yield (kg.ha^{-1})
T1 (absolute control)	0N-0P-0K	1152^{c}	2006^{b}	1036^{c}	596^{b}
T2 (conventional recommendation)	60N-10P-12K	2769^{b}	4464^{a}	2981^{b}	1927^{a}
T3 (semi-intensive recommendation)	97N-20P-48K	4015^{ab}	5732^{a}	2925^{b}	1661^{a}
T4 (intensive recommendation)	111N-30P-60K	3715^{ab}	5280^{a}	2886^{b}	2068^{a}
T5 (option 1 simulated with DSSAT)	80N-30P-40K	3863^{ab}	5137^{a}	2852^{b}	1519^{a}
T6 (option 2 simulated with DSSAT)	90N-30P-40K	3830^{ab}	5098^{a}	2990^{b}	1550^{a}
T7 (option 3 simulated with DSSAT)	100N-30P-40K	4027^{ab}	5344^{a}	2894^{b}	1806^{a}
T8 (option 4 simulated with DSSAT)	110N-30P-40K	4661^{a}	6069^{a}	3614^{a}	2020^{a}
T9 (option 5 simulated with DSSAT)	120N-30P-40K	4574^{a}	5409^{ab}	3740^{a}	1870^{a}
CV (%)		20,9	21,3	12,1	16,2
Probability F (5%)		<0,001	<0,001	<0,001	0,005
Significance		THS	THS	THS	HS

Values affected by the same letter in the same column are not significantly different at the 5% threshold, according to the Student Newman Keuls test

VHS very highly significant ($p < 0.001$), *HS* highly significant, *CV* coefficient of variation

1.4.4 Effects of Fertilizer Rates on Maize Yields in Western Burkina Faso

The effects of fertilizer rates on the yields of Massongo and SR 21 maize varieties in the western part of Burkina Faso are shown in Table 1.10. The results showed that the best grain yield for the Massongo variety was observed on T9 treatment with a yield of 4661 kg.ha^{-1}; followed by T8 treatment with 4574 kg.ha^{-1}. These treatments differ significantly from T2 and T1 treatments. The T3, T4, T5, T6, T7, T8 and T9 treatments did not differ significantly and resulted in grain yield increases for the Massongo maize variety of 249%, 222%, 235%, 232%, 250%, 305%, and 297% respectively, compared to the control. Compared to the national extension recommendation, they led to grain yield increases between 34% and 68%. For the SR 21 variety, the best grain yields were observed with treatment T9 (3740 kg.ha^{-1}) and T8 (3614 kg.ha^{-1}), respectively. These two treatments do not differ significantly between themselves, but are contrasted with the other treatments. However, compared to the national extension recommendation, they resulted in grain yield increases of 25% for T9 and 21% for T8.

The highest straw yield for the Massongo variety (6069 kg.ha^{-1}) was achieved with the T8 treatment; followed by the T3 with 5732 kg.ha^{-1}. These treatments differ significantly from T1 treatment (Table 1.10). However, they differ only from the control. Compared to the control and the national recommendation, T8 treatment resulted in straw yield increases for the Massongo variety of 203% and 36%, respectively. Regarding the SR 21 variety, the straw yields observed were low, ranging from 596 kg.ha^{-1} for the control to 2068 kg/ha for T4 treatment. The ANOVA revealed that only the control differ significantly from the other treatments.

1.4.5 Effects of Fertilizer Rates on Maize Yields in Eastern Burkina Faso

The results showed that the best grain yield for the Barka variety was observed on the T7 treatment with a yield of 3443 kg.ha^{-1}; followed by T4 treatment with 3210 kg.ha^{-1}. These treatments differ significantly from the control (Table 1.11); but do not differ significantly from the national extension recommendation or other treatment. However, compared to the control, they increased grain yield by 228% for T7 and 206% for T4, respectively. Compared to the national extension recommendation, they increased grain yields by 40% and 31%. Concerning the SR 21 variety, the best grain yield was observed with the T4 treatment (3326 kg.ha^{-1}). This treatment differs significantly from the control only. Compared to the control and the national extension recommendation, it resulted in a yield increase of 63%.

The highest straw yield for the Barka variety was observed on the T7 treatment (7703 kg.ha^{-1}). It differs significantly only from the control and the national extension recommendation (Table 1.11). Compared to the control and national extension recommendation, T7 treatment increased Barka straw yields by 203% and 63%, respectively. Concerning the SR 21 variety, the highest straw yield was observed on the T4 treatment (4960 kg.ha^{-1}). This treatment differs from both the control and the national extension recommendation; but does not differ from other treatments. Compared to the control and the national extension recommendation, it resulted in straw yield increases of 204% and 93%, respectively.

1.4.6 Optimal Fertilizer Rate for Western Burkina Faso using the DSSAT Model

The DSSAT seasonal analysis program was used to determine the optimal fertilizer rate. For this purpose, the simulations have been extended to 32 years in order to

Table 1.11 Effects of treatments on grain and straw yields for Barka and SR 21 maize varieties in eastern Burkina Faso

Treatments	Formulas	Barka		SR21	
		Grain yields (kg.ha^{-1})	Straw yields (kg.ha^{-1})	Grain yields (kg.ha^{-1})	Straw yields (kg.ha^{-1})
T1 (Absolute control)	0N-0P-0K	1050^{b}	2539^{c}	1109^{b}	1634^{c}
T2 (Conventional recommendation)	60N-10P-12K	2451^{a}	4727^{b}	2043^{ab}	2568^{bc}
T3 (Semi-intensive recommendation)	97N-20P-48K	2626^{a}	5707^{ab}	2801^{ab}	4027^{ab}
T4 (Intensive recommendation)	111N-30P-60K	3210^{a}	7411^{a}	3326^{a}	4960^{a}
T5 (Option 1 simulated with DSSAT)	80N-30P-40K	2918^{a}	6945^{ab}	2218^{ab}	3618^{ab}
T6 (Option 2 simulated with DSSAT)	90N-30P-40K	2859^{a}	6361^{ab}	1809^{ab}	3151^{ab}
T7 (Option 3 simulated with DSSAT)	100N-30P-40K	3443^{a}	7703^{a}	2626^{ab}	4027^{ab}
T8 (Option 4 simulated with DSSAT)	110N-30P-40K	2918^{a}	6653^{ab}	2043^{ab}	3618^{ab}
T9 (Option 5 simulated with DSSAT)	120N-30P-40K	2363^{a}	5777^{ab}	2264^{ab}	4143^{ab}
CV (%)		19,1	15,3	28,6	19,9
Probability F (5%)		0,002	<0,001	0,03	0,001
Significance		HS	VHS	S	HS

Values affected by the same letter in the same column are not significantly different at the 5% threshold, according to the Student Newman Keuls test

VHS very highly significant ($p < 0.001$), *HS* highly significant; *S* significant

examine the behavior of the different treatments in an environment that changes from 1 year to another. The results show that yields vary according to fertilizer rates from 1 year to the next (Fig. 1.4). Indeed, the control and the rate recommended by the national extension have yields lower than 2 t/ha. For other options; T5, T6, T7, T8 and T9, which have better yields, T5 treatment has the lowest variability. From a biophysical point of view, T5 treatment is therefore the best rate for maize fertilization in the western part of the country. Also, strategic analysis has shown that T5 (80N-30P-40K) is the most efficient option for maize production in western Burkina Faso through the Gini coefficient (Table 1.12).

1.4.7 Optimal Rate for Eastern Burkina Faso

The results of the biophysical analysis showed that without fertilizers, maize yield is very low (about 1 t.ha^{-1}); it increases with the use of fertilizers. Indeed, the rate recommended by the extension allows to obtain a grain yield of approximately 3 t.

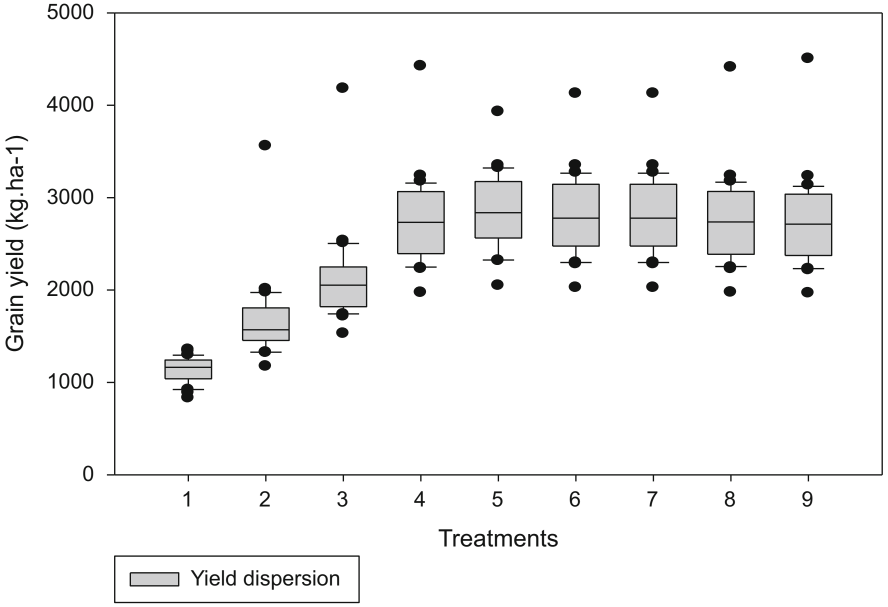


Fig. 1.4 Representation of variability in grain yields according to treatments over a period of 32 years
1 = N0P0K0; 2 = N60P10K12; 3 = N97P20K48; 4 = N111P30K60; 5 = N80P30K40; 6 = N90P30K40; 7 = N100P30K40; 8 = N110P30K40; 9 = N120 P30K40

Table 1.12 Financial analysis of the different treatments over 32 years

Treatments	Formulas	E(x)	F(x)E(x)-F (x)	Efficient
T1 (Absolute control)	0N-0P-0K	180480.9	145513.1	Non
T2 (Conventional recommendation)	60N-10P-12K	212097.3	148141.4	Non
T3 (Semi-intensive recommandation)	97N-20P-48K	210989.7	132706.6	Non
T4 (Intensive recommandation)	111N-30P-60K	280008.8	185415.2	Non
T5 (**Option 1 simulated with DSSAT)**	**80N-30P-40K**	**337731.7**	**245318.4**	**Oui**
T6 (Option 2 simulated with DSSAT)	90N-30P-40K	326567.6	233497.2	Non
T7 (Option 3 simulated with DSSAT)	100N-30P-40K	315916.9	221761.1	Non
T8 (Option 4 simulated with DSSAT)	110N-30P-40K	306163.6	211663.1	Non
T9 (Option 5 simulated with DSSAT)	120N-30P-40K	296673.0	201814.0	Non

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

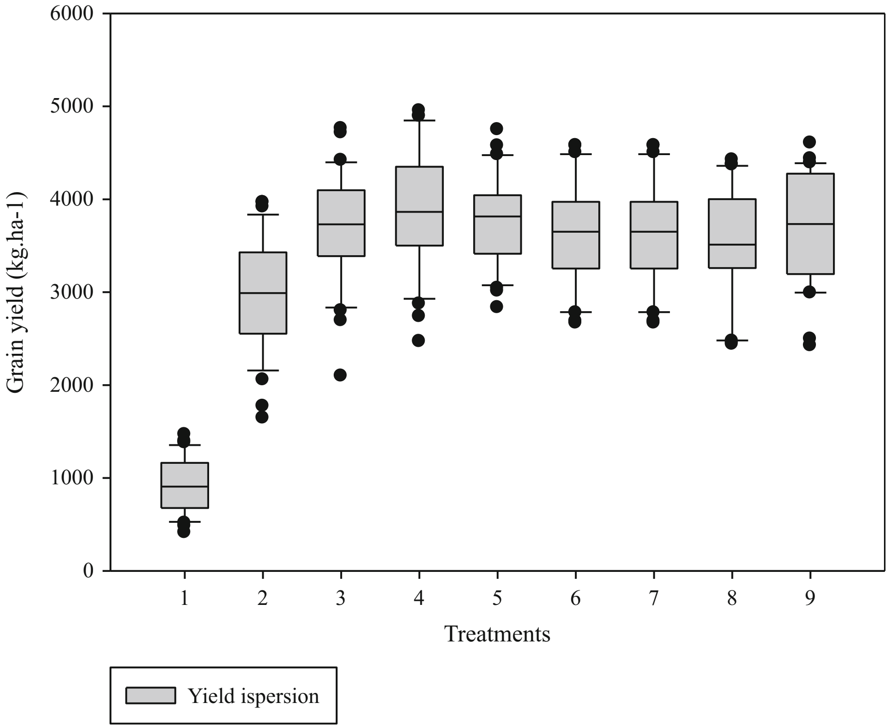


Fig. 1.5 Representation of variability in grain yields for the Barka variety in eastern Burkina Faso according to treatments over a period of 35 years
1 = N0P0K0; 2 = N60P10K12; 3 = N97P20K48; 4 = N111P30K60; 5 = N80P30K40; 6 = N90P30K40; 7 = N100P30K40; 8 = N110P30K40; 9 = N120 P30K40

ha^{-1}. Moreover, the best grain yield was achieved with treatment T4 (111N-30P-60K) with about 4 t/ha (Fig. 1.5). From a biophysical point of view, T4 treatment is the best option for maize fertilization in eastern Burkina Faso.

In contrast, strategic analysis showed that T5 treatment (80N-30P-40K) is the most efficient for maize production in the eastern zone (Table 1.13). Thus, this treatment could be recommended for a sustainable and profitable maize production in this area.

1.5 Discussion

1.5.1 Limiting Nutrients

The results obtained with the nutrient omission trials showed that there is a hierarchy in the supply of the nutrients N, P and K by the soil. In fact, nitrogen and phosphorus are, in an equivalent manner, the two limiting nutrients to rice

Table 1.13 Financial analysis of the different treatments over 36 years

Treatments	Formulas	E(x)	F(x)E(x)-F (x)	Efficient
T1 (Absolute control)	0N-0P-0K	1465362	1077498	Non
T2 (Conventional recommandation)	60N-10P-12K	3750545	2730332	Non
T3 (Semi-intensive recommandation)	97N-20P-48K	4531390	3330148	Non
T4 (Intensive recommandation)	111N-30P-60K	4492926	3233749	Non
T5 (Option 1 simulated with DSSAT)	**80N-30P-40K**	**4780510**	**3610770**	**Oui**
T6 (Option 2 simulated with DSSAT)	90N-30P-40K	4472626	3317714	Non
T7 (Option 3 simulated with DSSAT)	100N-30P-40K	4175273	3033969	Non
T8 (Option 4 simulated with DSSAT)	110N-30P-40K	4240526	3086908	Non
T9 (Option 5 simulated with DSSAT)	120N-30P-40K	4419537	3219446	Non

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

production in the Sourou valley. These results are in line with those of FAO (2003); IFDC (2008); Bandaogo (2010). According to these authors, nitrogen and phosphorus are the major limiting factors to cereal production. Already, Piéri (1989) showed that soils in West Africa are deficient in nitrogen and phosphorus (Pieri 1989). According to Segda (2006), nitrogen is one of the key nutrients that can be limiting to the growth and development of rice under conditions as varied as those in which this crop is grown in general.

Soil nutrients deficiency is a major constraint to the intensification of agricultural production (Sinaj et al. 2001; Lompo et al. 2009), especially as these nutrients determine soil productivity. The results showed that potassium is not limiting to rice production in the Sourou valley. These results are in line with those that Wopereis et al. (1999), Haefele (2001) and Haefele et al. (2003) observed on several irrigated areas in Sudano-Sahelian Africa. This is mainly due to high levels of potassium in the soils of several floodplains in the Sudano-Sahelian savannas of West Africa (Buri et al. 1999) and potassium supplies from other sources such as irrigation water, rainwater, and atmospheric deposition. Haefele (2001) has evaluated potassium from atmospheric deposition at 40 kg ha^{-1} year^{-1}. In addition, as nearly 80% of potassium is contained in rice straws (Witt et al. 1999), it can be easily returned to the soils.

1.5.2 Optimal Rates of Nitrogen and Phosphorus for Rice Production

The results showed a strong positive correlation between increasing levels of nitrogen and phosphorus and increasing paddy and straw yields, respectively.

These results confirm the results of the nutrient omission trials which have identified nitrogen and phosphorus as the key nutrients in irrigated rice production systems. Nitrogen is the most deficient nutrient; its management is therefore the main factor in improving productivity. The biophysical nitrogen recommendation for irrigated rice in the Sourou Valley is 150 kgN.ha^{-1}. By contrast, through quadratic regression, phosphorus gives a maximum response for the 34 kgP.ha^{-1} level.

Economic analysis determined the optimum level of nitrogen and phosphorus for rice production. The recommended rates are based on the purchase price of fertilizers and selling price of paddy at collection. Recommendations of fertilizer levels are all the more significant that fertilizer prices are low and paddy prices are high. This is to ensure better profitability in rice production for farmers according to the type of fertilizer complex. The binary fertilizer (DAP) has high phosphorus content compared to the NPK complex. Its use would be even more advantageous in terms of nitrogen supply due to its relatively high N content compared to NPK. However, optimal nitrogen recommendations in the valley range between 119 and 136 kgN ha^{-1}. These fertilizer recommendations are higher than the national extension recommendation (97 kgN.ha^{-1}). The deep placement of urea, in its granulated form, allows a better control of nitrogen use, thus contributing to reduce nitrogen rates. According to Yaméogo et al. (2013), only 1/3 of the nitrogen from simple urea usually broadcasted in rice production areas is effectively used by the crop. As for phosphorus, its optimal level according to paddy prices is between 24 and 32 kgP.ha^{-1}. These recommendations are also slightly higher than the extension recommendation (20 kgP.ha^{-1}), which is close to that obtained by Segda (2006) in the Bagré Plain (21 kgP.ha^{-1}) through modeling. These results can be explained by the difference in the level of phosphorus supply from the soil on the various sites.

1.5.3 Effects of Fertilizer Rates on Maize Yields

Les résultats ont montré que les doses d'engrais ont eu un effet sur les rendements des trois variétés de maïs. De faibles rendements ont été observés sur les parcelles témoins. En outre, la vulgarisation nationale a conduit à de très faibles productions par rapport aux autres options. Ces résultats s'expliquent principalement par la fertilité des sols. En effet, la déficience du sol en éléments majeurs (N, P et K) est. une contrainte majeure à la production du maïs. Ces résultats corroborent les observations faites par Pallo et al. (2008) ainsi que Bationo et al. (2012) et confirment la nécessité d'apport des engrais pour la production du maïs. L'apport de forte dose de fertilisants a donc conduit dans la plupart des cas, à l'obtention des meilleurs rendements. Ces résultats corroborent ceux de Nyembo et al. (2012), de Kidinda et al. (2015) qui ont montré d'autres agro-écologies que les rendements augmentaient avec l'apport de doses croissantes de fertilisants.

The results showed that fertilizer rates had positive effects on the yields of the three maize varieties. Low yields were observed on the control plots. Moreover, the national extension recommendation has led to very low production compared to the other options. These results are mainly due to low soil fertility. Indeed, soil deficiency in the three key elements (N, P and K) is a major constraint to maize production. These results are in line with the observations made by Pallo et al. (2008) as well as Bationo et al. (2012) and confirm the need for fertilizer use in maize production. High fertilizer rates have led, in most cases, to the highest crop yields. These results confirm those of Nyembo et al. (2012), Kidinda et al. (2015) which showed that, in other agro-ecologies, yields also increased with increasing rates of fertilizers.

Maize yield increases with fertilizer use are explained by the fact that the nutrient requirements of the crop are adequately met. Treatment T3 with a high nitrogen level compared to T5 treatment gave lower yields. This result highlights soil deficiency in phosphorus. Lompo, et al. (2009) showed that soil phosphorus deficiency is a major constraint to the intensification of soil productivity. With the DSSAT model, T5 treatment (80N-30P-40K) was shown to be the most efficient for maize production in western and eastern Burkina Faso. This rate is also most economically profitable under the conditions of production of these areas.

1.6 Conclusion

Food self-sufficiency is a great challenge for countries in sub-Saharan Africa in general and Burkina Faso in particular. It involves soil fertility improvement, a key factor for agricultural intensification. The results of this agronomic research show that the fertilizer rate recommended by extension for maize production does not allow the expression of the potential of the varieties Massongo, Barka and SR 21. This fertilization led to grain yields lower than the rates developed by the DSSAT model. The use of increasing fertilizer rates increases yields. The results of the multiannual and strategic analysis showed that the fertilizer option 80N-30P-40K is the best for intensive maize production in the eastern and western areas of Burkina Faso, the country's main maize – producing areas.

The diagnosis of soil fertility in the Sourou Valley revealed that phosphorus and nitrogen constitute the limiting nutrient to rice production. Significant responses to the application of increasing rates of nitrogen and phosphorus were observed with correlation coefficients greater than 98%. The optimum level of nitrogen in rice growing in the Sourou valley ranges between 119 kgN.ha^{-1} and 136 kgN.ha^{-1}, respectively. As for phosphorus, its optimum level is between 24 kgP.ha^{-1} and 32 kgP.ha^{-1}. The study also revealed that DAP binary fertilizer is more appropriate for rice growing in the Sourou valley compared to the NPK complex (14-23-14) currently being popularized and used. This option combined with good management of crop residues will help to better manage the potassium level, which is very high in biomass, to ensure the sustainability of the cropping system.

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Chapter 2
Participatory Evaluation of Productivity, Fertility Management, and Dissemination of Irrigated Exotic Vegetables in the Sahel, West Africa

A.K. Saidou, Hide Omae, Kimio Osuga, Boukary Absatou, and Satoshi Tobita

Abstract On-farm participatory experiments and activities were carried out for 3 years at three sites in the Fakara district of western Niger to demonstrate, verify, and evaluate crop productivity due to fertilizer application, economic benefits, and the dissemination of crop technology. We tested combinations of manure and mineral fertilizer on 13 exotic vegetables: bell pepper, cabbage, carrot, chili, eggplant, lettuce, melon, onion, potato, pumpkin, sweet potato, tomato, and zucchini. Farmers' selectivity was evaluated as the number of plots that farmers selected to carry out their own trials. The application of 110 kg N ha^{-1} manure plus 13.7 kg N ha^{-1} mineral fertilizer increased overall vegetable yields by 161% ($P < 0.01$). The improvement of soil fertility increased the yield of subsequent rainfed millet by 124% ($P < 0.05$). Less-experienced female farmers could afford to grow cabbage, onion, lettuce, potato, and pumpkin, which yielded 4.8–11.4 t ha^{-1} fresh weight. Daily management by women in the vegetable gardens gave regular opportunities to chat and thus disseminate the technology.

Keywords Integrated soil fertility management · Participatory approach · Irrigated vegetable production · Sahel · Niger · West Africa

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Contents

2.1 Introduction

The poor productivity of agro-pastoral systems in the Sahel, West Africa, has prompted numerous research and development projects concerned with soil fertility, land degradation, and desertification(Schlecht and Hiernaux (2004) Between 80% and 90% of the population in the Sahel lives by rainfed agriculture, producing a limited number of staple crops (millet, sorghum, groundnuts, and cowpeas) in the rainy season (June–September). Because of population growth (around 3% per year), there is a need to identify innovative alternatives for increasing productivity and for managing soil fertility such as the effective use of water resources and fertilizer (Sander and Shapiro 2003) in the off-season. Demand for exotic vegetables has been rising with increasing consumption of fruits and vegetables due to urbanization, and vegetable production contributes to poverty reduction (Weinberger and Lumpkin 2007; Drechsel and Keraita 2014). Despite the economic advantage of exotic vegetable production, little has been published on productivity and fertilizer application in the Sahel. In addition, there are few reports on the effective use of vegetable gardens in improving regional land productivity. Dry-season vegetable production offers an additional advantage of employing women (Grieco and Apt 2008; Quisumbing and Pandolffeli 2010). Women are challenged as much as men by diminished agricultural yields (IFAD 2001). The situation has increased male migration to cities to find work, making women's roles in production essential to household and community survival (Ward et al. 2004). Attempting to ensure food sufficiency, women supplement family earnings through small-scale income-generating activities such as the production of charcoal, the processing of sheep butter, and market gardening. Yet the transfer of new technologies and extension services seldom involve women farmers (IFAD 2000). As a solution, the "mother–baby trial" approach offers an on-farm participatory means to introduce and test a range of technology options suited to heterogeneous communities (Snapp 2002). It generates data on the performance of alternative technologies, creates the basis for dialogue between farmers and researchers, and encourages subsequent experimentation by farmers (Reddy et al. 2010).

The objective of this study were (1) to evaluate the productivity of exotic vegetables due to fertilizer application and the economic benefit for female farmers in the production of irrigated exotic vegetables; (2) to identify land productivity by the multiple-use cultivation of vegetable gardens; and (3) to evaluate methods for the dissemination of irrigated vegetable production by women in the Sahel.

2.2 Materials and Methods

2.2.1 Site Description

On-farm experiments and trials were conducted as mother–baby trials (Snapp 2002) in irrigated conditions during 2008–09, 2009–10, and 2010–11 in three villages (Maourey Kouara Zeno: 13°35.61′N, 2°39.03′E; Yerimadey: 13°29.11′N, 2°41.30′E; Bokossay: 13°25.72′N, 2°47.32′E) in the Fakara district, Dantiandou commune, Tillabery region, Western Niger, about 50 km North-East of Niamey, the capital (Fig. 2.1). The villages comprised 61 households in Maourey Kouara Zeno, 90 in Yerimadey, and 51 in Bokossay. The Zarma, the principal ethnic group of this area, are farmers engaged mainly in the rainfed production of grains such as millet (*Pennisetum glaucum* (L.) R.Br.) and cowpea (*Vigna unguiculata* (L.) Walp.). The prevailing soil type in the Fakara district is Psammentic Paleutalfs with a high sand fraction and typical characteristics of an infertile soil (Hiernaux and Ayantunde 2004; Oudwater and Martin 2003). Rainfalls from June until September, with a peak in August and total of about 550 mm (Hiernaux and Ayantunde 2004). From 2001 to 2008, the mean rainfall was 75.5 mm in September and 7.9 mm in October, little to none (<0.5 mm) to March, and 7.4 mm in April. The mean daily

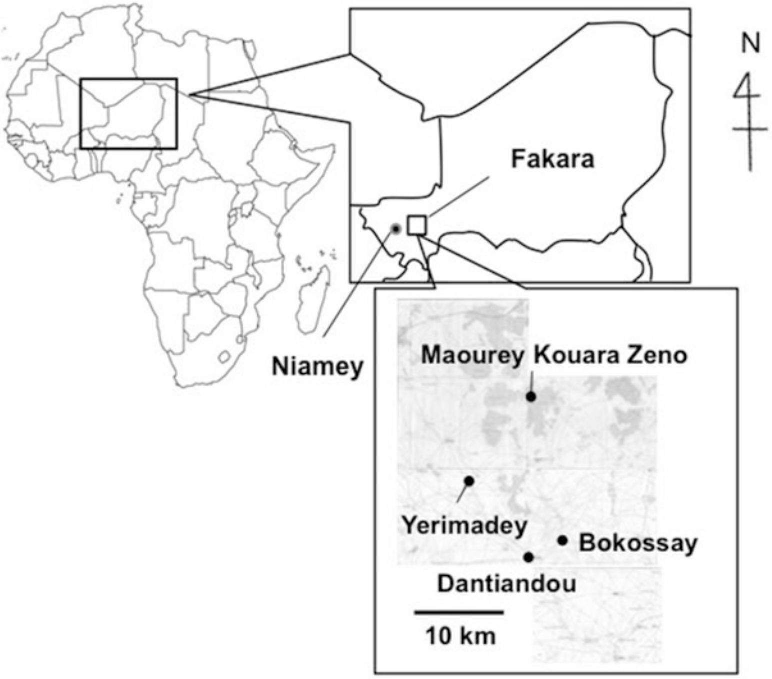

Fig. 2.1 Location of the experiments and demonstration sites

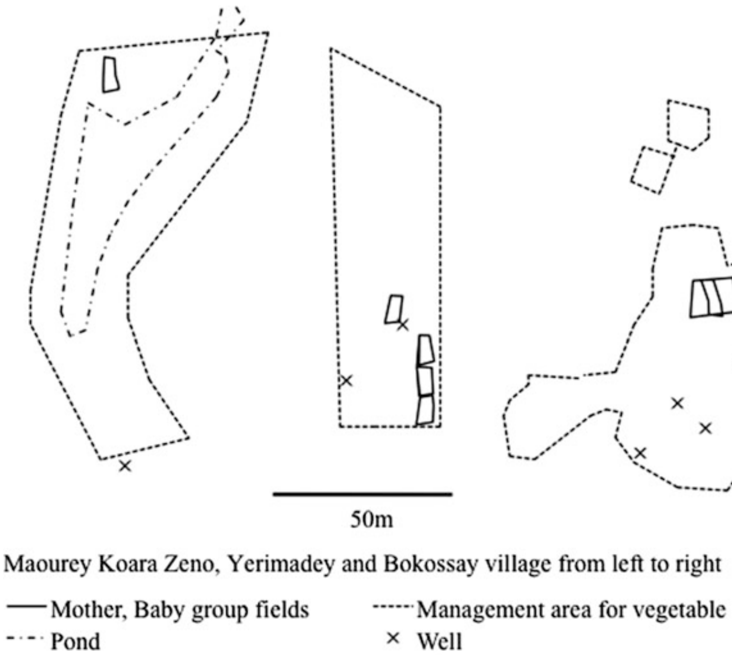

Fig. 2.2 Location of dry-season-vegetable production in Maourey Koara Zeno, Yerimadey and Bokossay, Fakara, Niger

temperature ranged from 23.9 to 30.2 °C from September to February, 31.2 °C in March, and 33.9 °C in April.

Irrigated vegetable production starts in late September and ends in early April. Because of the location of available water resources and the need for daily management, especially irrigation, vegetables are grown on farms adjacent to each village (Fig. 2.2). Wells are located at village center and used both for drinking and for irrigation. Metal fences protected the crops from animals at Mourey Koara Zeno and Yerimadey.

2.2.2 Participatory Approach to Experiments, Demonstration, and Practices

We used mother–baby trials to evaluate farmers' selectivity of the technologies. We set up experiments and demonstrations at one site in each village, which we regarded as the mother trial. Before setting up the mother fields, we conducted 1 to 3 days of farmer training in each village in March and April of 2008, 2009, and 2010. We presented the types and effects of organic and inorganic fertilizers, microdosing techniques (ICRISAT 2001; Tabo et al. 2006) for the application of mineral fertilizer, differences between traditional and advanced composts, characters of the exotic vegetables, sowing or planting methods for each crop, and preparation and management of seedlings. About 25 men and 25 women attended each meeting. After the training, we encouraged the farmers to practice the technologies of their choice on their farms, what was regarded as baby trials. Groups of some farmers elected to conduct our trials exactly; we regarded these group baby trials as separate, and encouraged the farmers to apply fertilizer at half or quarter doses to avoid repetition and to test the effect of dose. Farmers who did not attend the training also conducted trials with reference of the activities of the baby-trial farmers; we regarded those as non-baby trials, and recorded them as well. The results of the mother trial in each year were presented to the farmers at a field day at the mother field in October to November in 2008 and 2009. The results of the baby trials were reviewed by the farmers at meetings in February 2009 and April 2010.

2.2.3 Design of Field Experiments for Irrigated Vegetable Production

In each mother field, three mid-sized plots (3 m × 4 m) and ten small plots (3 m × 1 m) were established in 2008. Plots received one of four fertilizer treatments: manure, mineral fertilizer, both or neither. Thirteen vegetables were grown: bell pepper (*Capsicum annuum* L. var. angulosum), cabbage (*Brassica oleracea* L. var. capitata), carrot (*Daucus carota* L.), chili (*Capsicum annuum* 'Acuminoum'), eggplant (*Solanum melongena* L.), lettuce (L*actuca sativa* L.), melon (*Cucumis melo* L.), onion (*Allium cepa* L.), potato (*Solanum tuberosum* L.), pumpkin (*Cucurbita maxima* Duch.), sweet potato (*Ipomoea batatas* Poir), tomato (*Solanum lycopersicum* L.), and zucchini (*Cucurbita pepo* L.). The manure treatment comprised 9 tha^{-1} of cow dung manure (1.9% N, 1.5% P_2O_5 and 3% K_2O). The mineral fertilizer treatment comprised 3 g of compound mineral fertilizer (N: P: K = 15:15:15) at sowing and 2 g of urea (13.7 kg N ha^{-1}) per hill after 1 month of sowing by micro-dosing technique ICRISAT (2001) (Tabo et al. 2006). The experiments were conducted in a split-plot design with three replications (one per village). Seedlings of bell pepper, cabbage, chili, eggplant, lettuce, onion, and tomato were transplanted into the small plots at 0.3-m × 0.3-m spacing about 2 weeks after sowing. Tubers or seedlings of potato and sweet potato were planted directly into the small plots at 0.3-m × 0.3-m spacing, and those of melon, zucchini, and pumpkin into the mid-sized plots at 1.0-m × 1.0-m spacing, and thinned to one plant per hill after 2 weeks. Seeds of carrot were sown in line in small plots. Crops (between 12–33 depending on the density and crop except for carrot which seed were either spread or sown in line) were planted in September, were irrigated twice a day in morning and evening with a 24 l of watering can from pond (Maourey Koara Zeno) or pumping wells and harvested at physiological maturity from February to April. The fresh biomass and yield were recorded.

In the group baby trials, in which we encouraged the farmers to apply fertilizers at half or quarter doses, all other details were the same as in the mother trials. The crops were sown and harvested with reference to the mother trials. For the baby trials, we encouraged the farmers to apply fertilizers at the same dose in the mother trials.

The differences between treatments were determined by ANOVA followed by Student's t-test in JMP version 9.0.0 software (SAS Institute, Cary, NC, USA).

2.2.4 Design of Field Experiments for Subsequent Rain Fed Millet Production

Following the first season of irrigated vegetable production, we combined all plots into one big plot (3 m × 24 m) in the mother fields. Each village had four such plots. In addition, we established another four such plots in fields with a history of rain fed grain cultivation. Each mother vegetable field and each mother rain fed grain field received one of the four fertilizer treatments, and a crop of millet ('Haini Kirey', a local landrace; 120 days to harvest) was sown in each. The fertilizers were applied as in the vegetable experiments. The experiment was conducted in a split-plot design with three replicates (one per village). Millet was sown at 1.0 m × 1.0 m in June 2009, thinned to three plants per hill after 2 weeks, and harvested at physiological maturity in October 2009. Millet plants were harvested and partitioned into ears and stalks. After drying, the ears were threshed and the total biomass was determined. All aboveground crop residues were removed from the plots at the end of the cropping season.

2.2.5 Farmer Survey

After training and before the baby trials in 2008, we interviewed the baby-trial and non-baby-trial farmers about them, their families, and their farms. After establishing the baby trials, we divided the data between the two groups.

To gauge the economic situation of the women, we visited an average of 24OK female farmers in each village in 2008 and interviewed them about source of income and money in their possession. Additional farmers were interviewed if numbers were low.

2.2.6 *Soil Sampling and Analysis*

Soil sampling and analysis were done according to Omae et al. (2014). And the analysis of manure was done according to ICRISAT routine analysis method.

2.3 Results

2.3.1 *Results of Mother and Group Baby Trial*s

Both fertilizer application and vegetable type were similar between the mother and group baby trials (Table 2.1). The effects of both were significantly different when all results were averaged over seasons 1 and 2. Manure plus mineral fertilizer increased vegetable yields by 161% ($P < 0.01$), followed by mineral fertilizer at 119% ($P < 0.01$). The yields of cabbage (11.4 t ha^{-1}) and onion (8.4 t ha^{-1}) were highest, followed by lettuce, carrot, potato, and melon. The Yields of cabbage, potato and onion were highest than those of pumpkin, eggplant, tomato, sweet potato, zucchini, chili, and bell pepper first because of the type of crop and secondly due to fertilizer application.

Manure plus mineral fertilizer applied to mother vegetable fields increased millet biomass by 115% ($P < 0.01$) and yield by 118% ($P < 0.01$) relative to no fertilizer (Table 2.2). Manure plus mineral fertilizer applied at half rate to group baby vegetable fields produced a similar increase in millet biomass (n.s.) and increased millet yield by 195% ($P < 0.05$). Mineral fertilizer applied to mother vegetable fields increased millet biomass by 213% ($P < 0.01$) and yield by 160% ($P < 0.05$) relative to that applied to mother rainfed grain fields. Similarly, manure plus mineral fertilizer applied to mother vegetable fields increased millet biomass by 112% ($P < 0.01$) and yield by 124% ($P < 0.05$) relative to that applied to mother rain fed grain fields. In the group baby fields, millet biomass and yields showed increasing trends with increasing fertilizer dose from quarter to full (Table 2.2).

Values followed by the same letters in the same column are not significantly different at $P = 0.05$ by Student's *t*-test.

"Veg." indicates mother rainfed vegetable fields. "Grain" indicates mother rainfed grain fields.

The no-fertilizer treatment significantly increased pH compared with fertilizers in season 1 (Table 2.3). Manure increased total N by 137% ($P < 0.01$) relative to no fertilizer in season 1. It also increased total N by 83% relative to mineral fertilizer alone in season 1, and by 55% ($P < 0.05$) in season 2. It increased organic C by 150% ($P < 0.01$) relative to no application and mineral fertilizer alone in season 1. Manure plus mineral fertilizer increased Bray I P by 53%–829% ($P < 0.001$) relative to the other treatments, and increased total P by 18%–32% ($P < 0.05$) relative to no fertilizer and mineral fertilizer alone.

Table 2.1 Effects of fertilizer and vegetable type on yield in mother and group baby fields

	Control		Mineral fertilizer (MF)		Manure		Manure + MF	
Crops	S1	S2	S2	S2	S2	S2	S2	S2
Bell pepper								
Cabbage								
Carrot								
Chili								
Egg plant								
Lettuce								
Melon								
Onion								
Potato								
Pumpkin								
Sweet potato								
Tomato								
Zucchini								
Bell pepper								
F Test								
Fertilizer								
Varieties								
F × V								

Table 2.2 Effect of fertilizer application on vegetable production (mean of two seasons)

	Control	MF (t ha^{-1})	Manure	Manure + MF	Mean
Bell pepper	2.3	2.9	2.8	3.0	2.8
Chili	4.5	4.0	5.6	5.7	5.0
Sweet potato	2.6	7.8	4.4	6.0	5.2
Tomato	0.9	3.7	5.1	6.2	4.0
Egg plant	3.4	4.3	7.6	7.7	5.8
Zuccini	2.8	5.2	1.5	8.9	4.6
Carrot	2.4	5.0	11.2	12.2	7.7
Onion	4.3	11.6	6.8	12.6	8.8
Lettuce	3.7	7.0	10.0	12.9	8.4
Pumpkin	1.7	3.8	4.5	13.4	5.9
Potato	2.2	7.0	13.1	13.8	9.0
Cabbage	1.7	22.9	20.7	31.9	19.3
Melon	nd	nd	nd	nd	nd

Values followed by the same letter in the same column are not significantly different at $P = 0.05$ by Student's *t*-test.

Table 2.3 Residual effect of fertilizer on millet production in in the rainy season, 2009

Site	Fertilizer (F)	Biomass (kg ha^{-1})	Yield (kg ha^{-1})
Mother (veg.)	No application	4319 cde	559 bcdef
Mother (veg.)	Mineral	8535 ab	1036 abc
Mother (veg.)	Manure	6738 abc	758 abcde
Mother (veg.)	Manure + mineral	9307 a	1221 a
Group baby (veg.)	No application	3764 cde	393 def
Group baby (veg.)	1/2 mineral	6875 abc	1036 abc
Group baby (veg.)	1/2 manure	4932 bcde	668 abcdef
Group baby (veg.)	1/2 manure +1/2 mineral	7286 abc	1161 ab
Group baby (veg.)	No application	4290 cde	492 cdef
Group baby (veg.)	1/4 mineral	6763 abc	914 abcde
Group baby (veg.)	1/4 manure	5546 bcd	595 bcdef
Group baby (veg.)	1/4 manure + 1/4 mineral	7188 abc	768 abcde
Mother (grain)	No application	1379 e	154 f
Mother (grain)	Mineral	2725 de	399 ef
Mother (grain)	Manure	5057 cd	829 abcde
Mother (grain)	Manure + mineral	4380 cde	546 cdef
F		**	*

$^{**}P < 0.05$, $^{*}P < 0.01$

2.3.2 Results of Individual Baby Trials

There were no significant differences between baby-trial and non-baby-trial farmers in percentage of women, farmer age, cultivation area, numbers of plots, number of vegetable types, number of plants, fertilizer application, percentage of area cultivated, or years of experience (Table 2.4). In contrast, 74.8% of baby-trial farmers belonged to a farmers' group, versus only 13.3% of non-baby-trial farmers ($P < 0.01$). In both groups, about 75% of farmers were women. Both groups grew 3 to 4 vegetable types on 200–235 m^2. Around 40% of both groups applied manure plus mineral fertilizer, while 33.7–49.1% applied none. Both groups preferentially grew pumpkin (38.2–57.5%), followed by cabbage, onion, lettuce, and watermelon (Table 4-2). Both groups had the longest experience with pumpkin (2.4–5.8 years), followed by watermelon, tomato and eggplant, zucchini, lettuce, onion, potato, and cabbage (Table 4-3).

Table 2.4 Effects of fertilizers on soil chemical properties in mother vegetable fields

	pH (H_2O)		Total N (mg kg^{-1})		Organic C (%CO)		Bray I P (mg kg^{-1})	Total P (mg kg^{-1})
Application (A)	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
No application (control)	8.1 a	6.2	161.3 b	178.7 ab	0.2 b	0.2	4.9 c	118.0 bc
Mineral fertilizer	6.8 b	6.4	208.7 b	137.6 b	0.2 b	0.2	29.7 b	105.3 c
Manure	7.2 b	6.1	382.0 a	213.9 a	0.5 a	0.2	15.1 c	134.0 ab
Manure + mineral fert.	7.3 ab	6.2	371.0 a	199.6 a	0.4 a	0.2	45.5 a	139.3 a
A	*	n.s.	**	*	**	n.s.	***	*

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, n.s. not significantly different

2.4 Discussion

2.4.1 *Productivity of Exotic Vegetables with Fertilizer Application*

Yields of cabbage and onion were highest, and yields of pumpkin, eggplant, tomato, sweet potato, zucchini, chili, and bell pepper were lowest, regardless of fertilizer application. It is OK with the new Table 2.1. Manure plus mineral fertilizer increased overall vegetable yields by 161%, followed by mineral fertilizer at 119%. The biggest vegetable crop in Africa in 2013 was potato (30,499 kt), followed by sweet potato (20,131 kt), tomato (18,649 kt), onion (9650 kt by dry weight), cabbage (4114 kt), green chilies and bell peppers (2874 kt), melons (2068 kt), and pumpkin (1990 kt) (FAOSTAT). The production potential of potato, onion, cabbage, and melon in our trials is thus parallels vegetable production in Africa, but that of lettuce and carrot does not because lettuce and carrot can be grown more easily and harvested sooner than potato, onion, cabbage, and melon, they may offer an advantage in increasing yields by increasing plantings. Carrot, in particular, can be harvested early by thinning. This may be compatible with the minimal experience of the farmers with those crops (Table 4-3).

The fresh biomass and yields of vegetables tended to increase as the rate of fertilizer increased (Table 2.2). This means that an upper limit on application rates was not reached. Excessive application of fertilizer has led to annual positive nutrient balances of 843 kg N ha^{-1}, 70 kg P ha^{-1}, and 200 kg K ha^{-1} in urban and periurban agricultural systems in Niamey (Diogo et al. 2010). Similarly, annual surpluses of 85–882 kg N ha^{-1}, 109–196 kg P ha^{-1}, and 20–306 kg K ha^{-1} were applied in small-scale periurban vegetable farming in Hanoi, Vietnam (Khai et al. 2007). These rates pose high risks of soil pollution (Sangare et al. 2007). The rates applied in our study (110 kg N ha^{-1} as manure and 13.7 kg N ha^{-1} as mineral fertilizer) are less than the above reports. Further study will be needed to investigate the effects of fertilizer application and rates on soil pollution, and to determine ways to take up excess fertilizer such as through continuous cropping.

2.4.2 *Land Productivity in Vegetable Cultivation*

Around 40% of farmers, both baby-trial and non-baby-trial, were already familiar with applying manure plus mineral fertilizers (Table 4-1). This practice improved soil fertility (Table 2.3) and grain production in the following rainy season (Table 2.2). In mother vegetable fields also, manure plus mineral fertilizer increased millet biomass and millet yields.

In contrast to the low nutrient inputs and the negative NPK balances that generally prevail in West Africa (Stoorvogel et al. 1993; Lesschen et al. 2007), some farmers apply very high rates of nutrients, leading to large nutrient surpluses; (Khai et al. 2007; Zhu et al. 2005; Thompson et al. 2007) high inputs of irrigation water and fertilizer have been recorded in Benin, Ghana, and Niger, in West Africa (Diogo et al. 2010; Drechsel et al. 2004; Graefe et al. 2008). Continuous cropping is thus beneficial for the management of total soil fertility in the region, and can give women farmers, who lack access to sources of income in West Africa, as in Benin (Kinkingninboun-Medagbe et al. 2010), more chance to earn incomes.

2.5 Conclusions

(1) Manure plus mineral fertilizer increased the yields of all vegetables. (2) The improvement of soil fertility improved rainfed grain production. (3) Cabbage, onion, lettuce, potato, and pumpkin, which promise high yields, are affordable for the less-experienced women farmers to cultivate. (4) Daily management gives the women regular opportunities to chat and exchange information, and thus for dissemination of the technology.

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Chapter 3

Recommendation of a New Fertilizer Rate for Rice in the Irrigated Areas of the Niger River Valley

Sido Amir, Addam Kiari Saidou, Ichaou Aboubacar, and Salou Moussa

Abstract Rice is a major crop in the irrigated areas of the valley of the River Niger. Rice growers use urea and NPK on this crop. To help improve knowledge on soil fertility, fertilizer quality, and practices related to their use, a study was conducted in the irrigated areas of Saga, Karma, Sébery and Gaya. Thus, the variety of rice Kogoni 91-1 (Gambiaka) was used on hydromorphic to pseudo-gley soils in the rainy season 2014 and the dry season 2015. The experimental design was a randomized complete block with five treatments: T0 = N122P30K30 (peasant Practice); T1 = N138P90K60; T2 = N175 P112 K60; T3 = N100P120K50S20Zn2; T4 = N122P30K30S20Zn2. The comparison of averages shows that the highest average yield was achieved with the formula T4 (N122P30K30S20Zn2). Yields vary from 3.6 t/ha at Sébery to 7.2 t/ha in Gaya during the rainy season of 2014. The same trend was observed in the dry season of 2015 when the T4 yielded about 11 t/ha in Sébery.

Keywords Rice · Soil · Fertilizing · Fertilizer rate · Formula · Yield · Niger

Contents

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3.1 Introduction

Rice is a major crop in the irrigated areas along the Niger River. The old recommendations relating to fertilizer application on rice no longer meet the needs of the soils subjected to an increasingly demanding monoculture. This has led to drastic yield reductions in rice growing areas.

(GUERO 1987) has found that the amount of nitrogen released by mineralization increases with the amount of organic matter present in the soil. By comparing infrastructures of various ages, (Maazou 1986) and (Moussa 1996) deduced that their organic matter content was low and below 1% for the former and 0.7% for the latter (Toujan 1980) considers that soil nitrogen content in the hydro-agricultural infrastructures is low. Rice yield is inversely proportional to the rate of nitrification; between 0.015% and 0.01%, rice yields are substantially proportional to nitrogen levels.

For the production of 10 quintals of grain, rice consumes approximately 25 kg of nitrogen, 16 kg of P_2O_5 and 25 kg of K_2O (Smirnov et al. 1981). To help improve knowledge on soil fertility, fertilizer quality, and practices related to their use, this study was carried out (Toujan 1980) in four rice growing areas of the Niger River valley. This included: (1) assessing the current level of soil fertility in these areas after several years of exploitation; (2) proposing fertilizer rates and formulas adapted to current fertility status and able to meet the requirements of new rice varieties.

3.2 Materials and Methods

3.2.1 Materials

3.2.1.1 Experimental Site

This study was carried out in the irrigated areas of Saga, Karma, Sébery and Gaya, whose geographical coordinates are given in Table 3.1.

3.2.1.2 Biological Material

The plant material used in the 2014 rainy season and 2015 dry season was the Kogoni91-1 variety called Gambiaka (Table 3.2).

Table 3.1 Geographical coordinates of the sites

Locations	Longitude	Latitude
Saga	1°36′47,977	14°3′20,304
Karma	1°48′52,135	13°40′24,672
Gaya	3°26′52,944	11°53′3336
Sébéry	2°20′49,225	13°17′36,816

Table 3.2 Variety pedigree and origin

Genotypes	Crossing	Origin
KOGONI 91-1 (GAMBIAKA)	GAMBIAKA//IR36	Mali

3.2.2 Methods

The working method used in this study combined:

1. A diagnostic survey of farmers
2. Analyzes of the physical and chemical characteristics of soils in the selected plots
3. The conduct of agronomic trials

3.2.2.1 Choice of Farmers and Investigation Process

Through a concise questionnaire, a diagnostic survey among farmers of the study sites allowed to collect data on soils’ agro-pedological characteristics, fertilizer types and applications, and supply sources, etc. In total, 30 randomly selected farmers were interviewed at each site, i.e. 120 farmers for the four rice growing areas. The sampling carried out by the Groupement Mutualiste de Production (GMP) at the level of each cooperative allowed to reach practically all farmers’ fields with different agro-pedological characteristics.

3.2.2.2 Sampling and Analysis of Soil Samples

To carry out the soil survey, three voluntary farmers were selected at each site during a meeting of members of the cooperatives of the concerned areas. At the beginning of the season soil samples were taken on their plots with an auger and to the depths of 0–20 and 20–40 cm. The objective was to assess the initial fertility status of the plots through the evaluation of the following physico-chemical parameters: contents in available phosphorus, total nitrogen, exchangeable sodium, exchangeable potassium, organic matter, total sulphates and zinc, pH and texture.

3.2.2.3 Agronomic Trial

An agronomic trial was conducted on the plots of voluntary farmers during both seasons.

The experimental design used was a complete randomized bloc with three replicates. The elementary plots had an area of 15 m^2 with spacing of 20 × 20 cm.

The treatments were:

- T0 = N122P30K30
- T1 = N138P90K60
- T2 = N175 P112 K60
- T3 = N100P120K50S20Zn2
- T4 = N122P30K30S20Zn2
- Treatment T0: It is the farmer's practice; the formula used by farmers on irrigated areas in Niger in general and in particular on the study sites.
- Treatments T1 and T2 are formulas tested without micronutrients but with a gradual variation (increase) of N and P.
- Treatments T3 and T4 are formulas to which have been added micronutrients Sulphur and Zinc.

The main parameter being measured was paddy yield. The statistical analysis of the results was carried out using the MINITAB software version 16. The analysis of variance (ANOVA) was supplemented with the Tukey test at the 5% threshold whenever a significant difference was detected between averages.

3.3 Results and Discussions

3.3.1 Results

3.3.1.1 Soil Physico-chemical Characteristics in the Four Irrigated Areas of the Study

The physico-chemical characteristics of soils in the four irrigated areas of the study are shown in Table 3.3.

An analysis of Table 3.3 shows that:

- Soils in Karma are extremely acidic ($pH < 4.5$). Available phosphorus content is very low as is the total nitrogen content. Sodium levels are three to four times higher than for potassium.
- In the Saga area, soils are slightly acidic to neutral with low level of phosphorus. Their nitrogen content is low. In some places the sodium level is a source of serious concern (1 mq/100 g of soil) which deserves particular attention. The potassium content is low and sulfates are found at trace levels.

Table 3.3 Physico-chemical characteristics of soils in the four irrigated areas studied

Depth (cm)	pH	N %	P ppm	K méq/100 g	M.O. %	Na méq/100 g
Karma area						
0–20	4.3	0.100	2.38	0.09	1.43	0.33
20–40	5.5	0.063	1.26	0.09	0.73	0.31
Saga area						
0–20	6.2	0.073	9.80	0.10	1.21	0.62
20–40	7.3	0.044	2.0	0.07	0.39	0.65
0–20	5.0	0.062	7.63	0.11	0.83	0.41
20–40	6.5	0.044	1.00	0.09	0.32	0.55
Sébéry area						
0–20	4.0	0.064	19.52	0.39	0.59	2.50
20–40	5.2	0.022	10.01	0.30	0.38	2.70
Gaya area						
0–20	4.3	0.113	0.10	0.10	2.24	0.25
20–40	5.2	0.122	0.35	0.06	1.47	0.19

- In Sébéry, soils are extremely acidic ($pH < 4.5$). They are rich in phosphorus in the upper part and moderately rich in depth. Nitrogen and organic matter contents are relatively low.
- In Gaya (Sakongui) soil pH varies from extremely acidic at the surface to strongly acidic in depth. These soils have very low level of phosphorus, nitrogen and organic matter.

The soils studied are exploited for rice monoculture. They are predominantly low in available phosphorus (less than 4 ppm), organic matter and nitrogen. These soils have extremely low nutrient contents. The determination of their sulfate content shows the presence of sulphur at trace levels in all the areas studied.

3.3.1.2 Fertilizer Use by Farmers

Results from the surveys carried out on fertilizer applications in the four areas show that 100% of rice growers use urea and NPK (15-15-15) to fertilize their plots both during the rainy season (RS) and the dry season (DS). The rates applied vary from one farmer to another and two to three applications are made.

Figure 3.1 shows the average percentage of fertilizer applications during the rainy season and the dry season.

On average in the rainy season and the dry seasons 30% of rice growers make only two fertilizer applications, and 70% make three applications.

Figure 3.2 shows the rate in (50 kg) bags of urea and NPK for 0.25 ha, in the rainy season.

In the rainy season, fertilizer rates vary from 1.5 bag (75 kg) to 6 bags (300 kg) for NPK and 0.5 bag (25 kg) to 4 bags (200 kg) for urea.

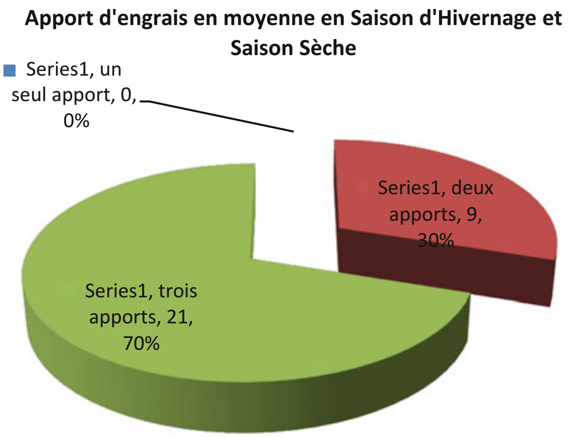

Fig. 3.1 Percentage of fertilizer applications in the rainy season and in the dry season

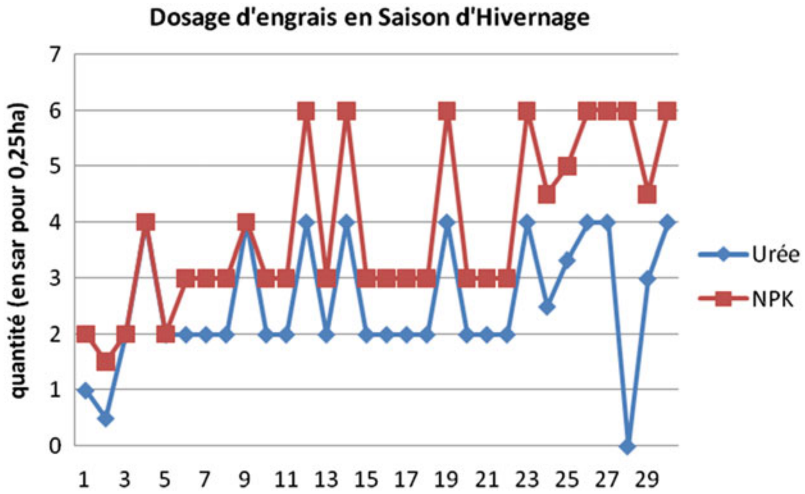

Fig. 3.2 Fertilizer rates (50 kg bag/0.25 ha) in the rainy season

The results of the survey show that rice growers limit their fertilization to 2 bags, 100 kg/0.25 ha for urea and 3 bags, or 150 kg/0.25 ha for NPK.

In the dry season, the rates vary from 1 bag (50 kg) to 4 bags (200 kg) for urea and 2 bags (100 kg) to 8 bags (400 kg) for NPK as shown in Fig. 3.3.

The survey shows that rice growers use rates of 2 bags (100 kg) of urea and 3 bags (150 kg) to 4 bags (200 kg) of NPK in this season.

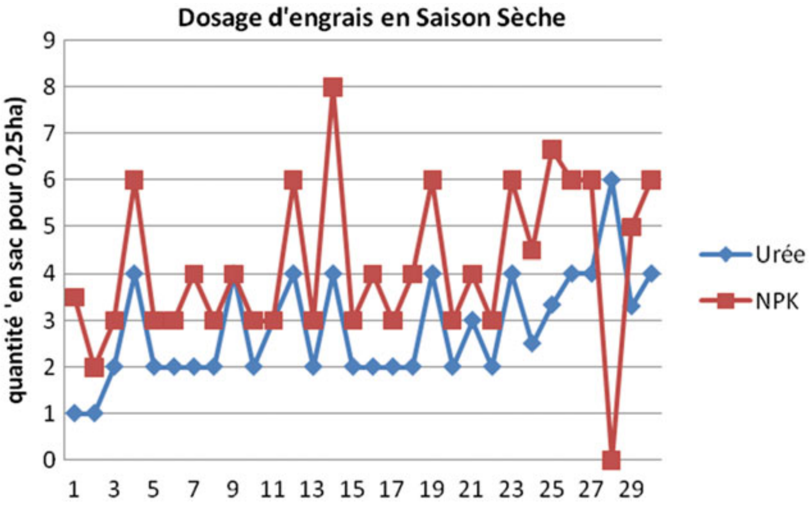

Fig. 3.3 Fertilizer rate (50 kg bag/0.25 ha) in dry season

3.3.1.3 Effect of Treatments on Rice Yields

The yields achieved on the Saga site are recorded in Table 3.4.

Table 3.4 shows significant differences between treatments in the dry season during which yields ranged from 2.48 to 8.98 t/ha respectively for T0 and T4, unlike in the rainy season during which no difference was noted between treatments. It was also observed that yields vary according to the seasons: T3 and T4 have a greater effect on yields in the dry season (DS) whereas T0, T1 and T2 gave higher yields in the rainy season (RS).

Table 3.5 shows the results of the two seasons RS 2015 and DS 2015 in Sébéry.

Table 3.5 shows a very significant difference in yields, especially between T0 and T4, with 3.68 t/ha and 6.29 t/ha in the rainy season, respectively, and 3.99 t/ha and 10.68 t/ha in the dry season. On this site, the analysis of variance showed significant differences between treatments in both the rainy season and the dry season. The highest yields were achieved with T3 and T4 treatments in the dry season with 9.28 t/ha for T3 and up to 10.68 t/ha with T4.

Table 3.6 shows the results achieved on the Karma site during the rainy season 2014 and the dry season 2015.

The results show that on this site the T4 treatment gave the best yield with 10.98 t/ha against 3.24 t/ha for the T0 in the dry season. A yield increase was also observed in DS compared to RS with the 4 treatments T1, T2, T3, T4.

For the Gaya site, the results obtained are given in Table 3.7.

Results in Table 3.7 show that in the Gaya area there was no significant differences between treatments during the rainy season. In the dry season, yields ranged from 4.5 t/ha for the T0 to 6.06 t/ha for the T4 treatment.

Table 3.4 Average yields of paddy rice per treatment in the rainy season (RS) 2014 and dry season (DS) 2015 on the irrigated areas of Saga

Treatments	Yields (t/ha)	
	WS 2014	DS 2015
T0	6.983	2.483 d
T1	6.516	4.453 c
T2	6.853	6.333b
T3	6.753	7.766 ab
T4	7.033	8.983a
P	0.815	<0001
Standard deviation	0.5749	0.5748

NB means that do not share a letter are significantly different, *RS* rainy season *DS* dry season, *t*/*ha* ton per hectare

Table 3.5 Average yields of paddy rice per treatment in the rainy season (RS) 2014 and the dry season (DS) 2015 in the irrigated area of Sébéry

Treatments	Yields (t/ha)	
	SH 2014	SS 2015
T0	3.683b	3.990d
T1	5.200ab	7.930bc
T2	4.720ab	7.190c
T3	5.396a	9.287b
T4	6.290a	10.683a
P	0006	<0001
Standard deviation	0.6292	0.506

NB means that do not share a letter are significantly different, *RS* rainy season, *DS* dry season, *t*/*ha* ton per hectare

Table 3.6 Average yields of paddy rice per treatment in the rainy season (RS) 2014 and the dry season (DS) 2015 in Karma irrigated area

Treatments	Yields (t/ha)	
	SH 2014	SS 2015
T0	5.856	3.243e
T1	6.036	6.113d
T2	5.900	7.433c
T3	5.230	8.887b
T4	6.376	10.987a
P	0.271	<0001
Standard deviation	0.5868	0.335

NB means that do not share a letter are significantly different, *RS* rainy season, *SS* dry season, *t*/*ha* ton per hectare

The average yields for the two seasons RS 2014 and DS 2015 are shown in Table 3.8.

Table 3.8 shows that yields achieved with T4 are higher than with other formulas on all sites and with significant differences between treatments. During the 2 years of experimentation, yields ranged from 3.8 t/ha in Sébery with the control (T0) to 8.68 t/to Karma with T4.

Figure 3.4 shows the average yields for both seasons, RS 2014 and DS 2015 per treatment.

Table 3.7 Average yields of paddy rice per treatment for the rainy season (RS) 2014 and the dry season (DS) 2015 in the irrigated area of Gaya

Treatments	Yields (t/ha)	
	SH 2014	SS 2015
T0	4.187	4.566c
T1	5.497	5.000bc
T2	5.730	5.300b
T3	6.343	5.566ab
T4	7.243	6.066a
P	0.081	<0001
Standard deviation	1.155	0.2530

NB means that do not share a letter are significantly different, *RS* rainy season, *DS* dry season, *t*/*ha* ton per hectare

Table 3.8 Average yields for the two seasons RS 2014 and Dry Season 2015 for Saga, Sébéry, Karma and Gaya (t/ha)

Treatments	Saga	Sébéry	Karma	Gaya
T0	4.733c	3.837b	4.550b	4.376b
T1	5.485bc	6.565ab	6.075ab	5.248ab
T2	6.593abc	5.955ab	6.667ab	5.515ab
T3	7.260ab	7.342a	7.058ab	5.955a
T4	8.008a	8.487a	8.682a	6.655a
P	0.004	0.002	0.005	0.002
Standard deviation	1.429	1.774	1.677	0.8444

NB means that do not share a letter are significantly different, *RS* rainy season, *DS* dry season, *t*/*ha* ton per hectare

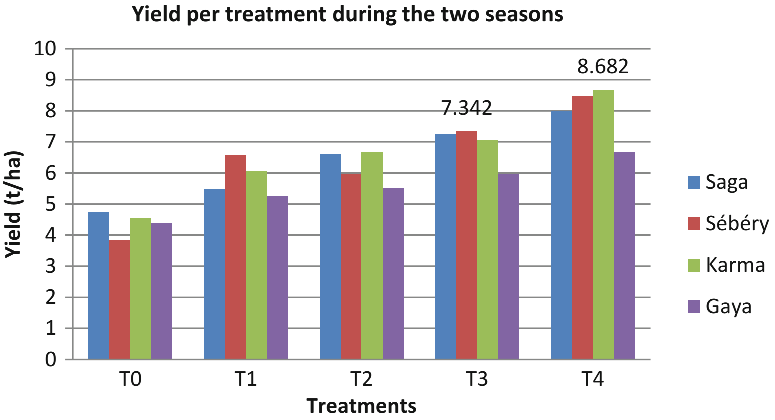

Fig. 3.4 Average of overall yields in the rainy season 2014 and the dry season 2015

Figure 3.4 clearly shows the yield increases achieved with the T4 treatment on the four sites, with yields of over 8 t/ha at the Saga, Sébéry and Karma sites. The T3 treatment gave yields of 7 t/ha on these same sites.

3.3.2 Discussions

Rice needs only the optimal fertilizer rate to express its potential in paddy yield, compared to farmer's practice that needs to maximize fertilizer rate to achieve its best yield.

Statistical analyzes per site and for all areas combined showed that the T4 treatment (N122P30K30S20Zn2) was the best for both seasons (rainy and dry season) with an average yield exceeding 8 t/ha on the four sites. Rice best responses to moderate mineral fertilizers rates are consistent with research results (Dupuy et al. 1990) which showed that split applications including an application at panicle initiation allows better utilization of the fertilizers applied. These trends had already been observed by (Akintayo et al. 2008) and (Lacharme 2001), who highlighted the fact that grain filling is a decisive stage in yield development.

Starting from a quarter of the recommended fertilizer rate, any rate increase is expressed as a yield reduction which is estimated to average 0.37 kg of paddy and 6.03 kg of paddy per unit of fertilizer (1 kg/ha). Thus, (Lafitte et al. 2004) suggested that the very limited number of fertilizer applications could improve drought tolerance. Moreover, high mineral fertilizers rates could leave in the soil certain nutrients that can disturb crop mineral nutrition. This is the case of H + ions, acidifying agents, which can be released by the decomposition of urea. However, the decrease in pH could lead to the unavailability of phosphorus and the disruption of several other reactions favoring the absorption of nutrients by the crops (Dicko 2005). This stresses the need to further study the economic rate that can optimize mineral fertilizer use (Vilain 1997).

3.4 Conclusion

This study indicates that the T4 treatment (N122P30K30S20Zn2) which is the farmer's practice (N122P30K30) with the addition of sulphur (20 kg/ha) and zinc (2 kg/ha) achieved the best average yields. The results show that any proposal relating to a new fertilizer formula for improved rice yields must necessarily include trace elements such as sulphur and zinc. Thus, T4 treatment can be introduced as a new formula for rice fertilization in the irrigated areas of the Niger River valley in particular and in Niger in general. In this respect, it is proposed to replace tertiary fertilizers (NPK) by complexes containing more nutrients in their composition (NPKSZn) and to further study the economic aspects of the T4 formula.

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Chapter 4
The Interactive Effect of Residue Quality, Quantity, Soil Texture and N Management on Maize Crop Yield in Ghana

E. Yeboah, M.K. Abekoe, G.N.N. Dowuona, B. Vanlauwe, S.P. Sohi, and J.W. Six

Abstract Food insecurity and declining soil fertility across much of sub-Saharan Africa in recent decades have led to pursuit of alternative nutrient management strategies for both improving crop yields and the restoration of degraded soils. In this respect, a 3-year field based studies involving two sites (Ayuom and Kwadaso) of contrasting soils (Suko and Nzima series) in the semi-deciduous forest zone of Ghana was initiated in year 2003. The treatments involved 5 organic resources of different qualities (in terms of N, lignin and polyphenol) with and without inorganic N application. The organic resources were applied at two application rates; 1.2 t C ha^{-1} year.$^{-1}$ and 4 t C ha^{-1} year.$^{-1}$ in the major season and the residual effect evaluated in the ensuing minor season. Cumulative maize grain yield (3 years) at Ayuom on the Suko series for the major season showed that 1.2 t C ha^{-1} *L. leucocephala*+120 kg N ha^{-1} proved to be the most effective treatment with yield of almost 18,000 kg ha^{-1}. At Kwadaso on the Nzima series however, 4 t C ha^{-1} Cattle manure+120 kg N ha^{-1} for the minor season was the most effective. At both sites, major season grain yields were generally higher than minor season. Furthermore, between cropping seasons, maize yields were superior on the Suko series than the Nzima series. To improve food security in the semi-deciduous forest zone of Ghana,

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soil nutrient management to restore soil fertility should take into consideration: soil type, cropping season, organic resource quality and quantity as well as their interaction with inorganic N.

Keywords Soil texture · Residue quality · Residue quantity · N management · Cropping season

Contents

4.1 Introduction

The livelihoods of millions of people are threatened by food insecurity and climate change issues in many developing countries. The need to improve food security is important in most developing countries particularly in sub-Saharan Africa. The food insecurity and declining soil fertility coupled with growing population have led to pursuit of new and innovative nutrient management strategies for both improving crop yields and the restoration of degraded soils (Sanchez 2002).

These new strategies need to address the limited availability of inorganic fertilizer inputs and rely more upon the management of organic resources that are available to farmers (Palm et al. 2001). Additionally, there is a need for technologies and practices to sustainably increase the productivity, stability and resilience of the production systems to confront the growing challenges of climate change.

The combined use of inorganic and organic nutrient sources in particular has been put forth as a means to improve crop yields (Kramer et al. 2002; Vanlauwe et al. 2001) through improved synchronization of nutrient availability and plant uptake and to increase soil carbon stocks. As a key component of agricultural sustainability, soil organic matter (SOM) contributes greatly to improving soil structure, fertility and water relations and plays a central role in greenhouse gas mitigation efforts.

Land users often lack the information needed to choose the most suitable soil management strategies that enhance or protect SOC and therefore increase sustainability. To make informed decisions, land users need the ability to quantify the effects of soil management strategies in a given soil type. Without being armed with this information, land users can only guess at the long-term implications of soil management strategies on SOC and sustainability which may lead to inappropriate decisions with consequencies for land degradation. An assessment of the various soil management practices in different soil types is therefore needed at the local scale to fill in this knowledge gap. This study addresses an important component necessary to achieve a sustainable Green Revolution in Africa. One of the goals of the Alliance for the Green Revolution in Africa (AGRA), chaired by the former Secretary-General of the United Nations, Kofi Anan, is to increase soil health. The soil health component of AGRA, launched in early January 2008, aims at promoting integrated soil fertility management (ISFM) as a basis for maximizing the N use efficiency of organic resources (OR) and mineral inputs. In this context, a good soil organic carbon (SOC) status will be a prerequisite for sustainable implementation of ISFM. The objective of the study is to assess the influence of organic resource quality and quantity, soil type, inorganic N management and their interactions on miaze crop yield in the semi-deciduous forest zone of Ghana.

4.2 Materials and Methods

4.2.1 Site Description

The experiment was established in year 2003 in the semi-deciduous forest zone of Ghana. Table 4.1 highlights the site characteristics and description of the experimental sites. The mean annual rainfall of the experimental site is about 1200 mm but it is characterised by high intensity and seasonal annual variability. The bimodal rainfall pattern, typical of the semi-deciduous forest zone of West Africa, results in two growing seasons each lasting for about 4 months. The major season spans from April to July with a short dry spell in August intervening the major and minor season which runs from September to December.

4.3 Organic Resources

The organic resources used in the study were selected following the Decision tree on the use of organic resource for integrated nutrient management (Palm et al. 2001). Five organic resources of different quality were evaluated alongside a control that received no organic resource application. The organic resources used in the study as well as their classes are described in Table 4.2. Two application rates, 1.2 t C ha^{-1} and 4 t C ha^{-1} for each organic resource were considered.

Table 4.1 Site characterisation and description

Soil series	Suko (Ayuom site)	Nzima (Kwadaso site)
Geographic coordinates	06° 63.95′N;15° 34.69′W	06° 67.85′N;16° 57.38′W
Altitude	287 m	278 m
Soil classification		
WRB	Humi-Plinthic Lixisol (Chromic)	Ferri-Plinthic Acrisol (Episkeletic)
Soil Taxonomy	Typic Plinthustalf	Typic Plinthustult
Local name	Suko series	Nzima series
Parent material	Granite	Phyllite
Slope	3%	5%
Vegetation	semi-deciduous forest	semi-deciduous forest
Precipitation	1200 mm a^{-1}	1200 mm a^{-1}

Table 4.2 Description of treatments used for the study

No.	Treatment	Organic resource class
1	Control + P_{30} K_{60} kg ha^{-1}	–
2	Control + N_{120} P_{30} K_{60} kg ha^{-1}	–
3	*C. juncea* 1.2 t C ha^{-1} + P_{30} K_{60} kg ha^{-1}	I
4	*C. juncea* 1.2 t C ha^{-1} + N_{120} P_{30} K_{60} kg ha^{-1}	I
5	*C. juncea* 4 t C ha^{-1} + P_{30} K_{60} kg ha^{-1}	I
6	*C. juncea* 4 t C ha^{-1} + N_{120} P_{30} K_{60} kg ha^{-1}	I
7	*L. leucocephala* 1.2 t C ha^{-1} + P_{30} K_{60} kg ha^{-1}	II
8	*L. leucocephala* 1.2 t C ha^{-1} + N_{120} P_{30} K_{60} kg ha^{-1}	II
9	*L. leucocephala* 4 t C ha^{-1} P_{30} K_{60} kg ha^{-1}	II
10	*L. leucocephala* 4 t C ha^{-1} + N_{120} P_{30} K_{60} kg ha^{-1}	II
11	Maize stover +P_{30} K_{60} kg ha^{-1}	III
12	Maize stover + N_{120} P_{30} K_{60} kg ha^{-1}	III
13	Maize stover + P_{30} K_{60} kg ha^{-1}	III
14	Maize stover + N_{120} P_{30} K_{60} kg ha^{-1}	III
15	*Afzelia africana* (sawdust) + P_{30} K_{60} kg ha^{-1}	IV
16	*Afzelia africana* (sawdust) + N_{120} P_{30} K_{60} kg ha^{-1}	IV
17	*Afzelia africana* (sawdust) + P_{30} K_{60} kg ha^{-1}	IV
18	*Afzelia africana* (sawdust) + N_{120} P_{30} K_{60} kg ha^{-1}	IV
19	Cattle manure + P_{30} K_{60} kg ha^{-1}	Unclassified
20	Cattle manure + N_{120} P_{30} K_{60} kg ha^{-1}	Unclassified
21	Cattle manure + P_{30} K_{60} kg ha^{-1}	Unclassified
22	Cattle manure + N_{120} P_{30} K_{60} kg ha^{-1}	Unclassified

4.4 Land Preparation, Experimental Design and Field Management

The experimental fields were hand cleared of biomass and all above ground biomass removed. There was no burning on the experimental fields. The experimental design was a split-split plot with three replicates. The main plot measured 12.8 m by 6 m and was split into sub-plots of 6.4 m by 6 m. In each sub-plot, a sub-subplot of 3.2 m by 3 m was left bare. There were 33 main plots with 66 sub-plots and 132 sub-subplots.

The organic resources were applied yearly in the major season and the residual effects evaluated in the minor season. A hybrid maize variety "mamaba" was planted at 80 cm x 40 cm. Three weeding regimes were carried out before harvesting of the maize. At harvest, the above ground maize biomass was completely removed from the field to avoid confounding effect of decomposition of maize residue on the organic resource applied.

4.5 Fertilizer Application

In the major season, triple super phosphate and muriate of potash fertilizers was applied to each main plot at the rate of 30 kg P ha^{-1} and 60 kg K ha^{-1} respectively in a single dose at planting. This was to ensure that N was the sole nutrient limiting maize production. N-fertilizer was applied as urea at 120 kg N ha^{-1}. Split application of nitrogen was employed; a third was applied at planting and two-thirds was applied 6 weeks after planting. The fertilizers were broadcast and buried in order to reduce N losses through volatilization. Table 4.3 shows the organic resources, inorganic and organic N, P and K additions of the treatments.

4.5.1 *Statistical Analysis*

The effects of treatments on maize yield indices and soil nutrients were determined using GenStat® (2007) and an ANOVA procedure (Payne et al. 2006). The model used for the ANOVA was:

$$\text{Treatment structure}: \quad (\text{Control}/(\text{Material}+\text{Rate}))^{*}\ \text{N management} \qquad (4.1)$$

where 'Control' is treatment with no organic amendment, 'Material' denotes the five ORs, 'Rate' refers to the application rate of the ORs (either 1.2 t C ha^{-1} or 4 t C ha^{-1}) and 'N management' denotes fertiliser application rates (either 0 or 120 kg N ha^{-1}),

Table 4.3 Initial soil characteristics of the experimental sites

	Soil type	
Soil parameter	Suko series (Ayuom)	Nzima series (Kwadaso)
pH (1:1 H_2O)	6.6	5.4
Org C (%)	1.55	1.29
Total N (%)	0.16	0.12
C/N	9.7	10.8
Available P (mg kg^{-1})	3.93	5.75
Available K (mg kg^{-1})	109.83	75.0
Exchangeable Ca cmol(+)/kg	7.76	4.32
Exchangeable Mg cmol(+)/kg	0.83	0.48
Exchangeable K cmol(+)/kg	0.36	0.19
Exchangeable Na cmol(+)/kg	0.07	0.13
Total exchangeable bases (+)/kg soil	9.02	5.12
Exchangeable acidity (Al+H)	0.10	0.20
ECEC cmol(+)/kg	9.12	5.32
% Base saturation	98.9	96.2

ECEC = Exchangeable cation capacity

$$\text{Block structure}: \quad \text{Block}/(\text{Hplot}^{*}\text{Vplot})/\text{subplot} \tag{4.2}$$

where ‘H_{plot}’ is the material and ‘V_{plot}’ is the quantity of application of ORs. Treatment means that were found to be significantly different from each other were separated by least significant differences (LSD) at $p < 0.05$.

4.6 Results and Discussion

4.6.1 Initial Soil Characteristics

The soils were taxonomically different and showed variable soil nutrients. Soils of the Suko series showed higher soil nutrients compared to the Nzima series reflecting the long fallow period of the site prior to the experiment (Figs. 4.1, 4.2, 4.3 and 4.4).

4.6.2 Maize Grain Yield

4.6.2.1 Suko Series Major Season

The cumulative yield of maize as influenced by continuous addition of organic resources and inorganic N management on the Suko series during the major season

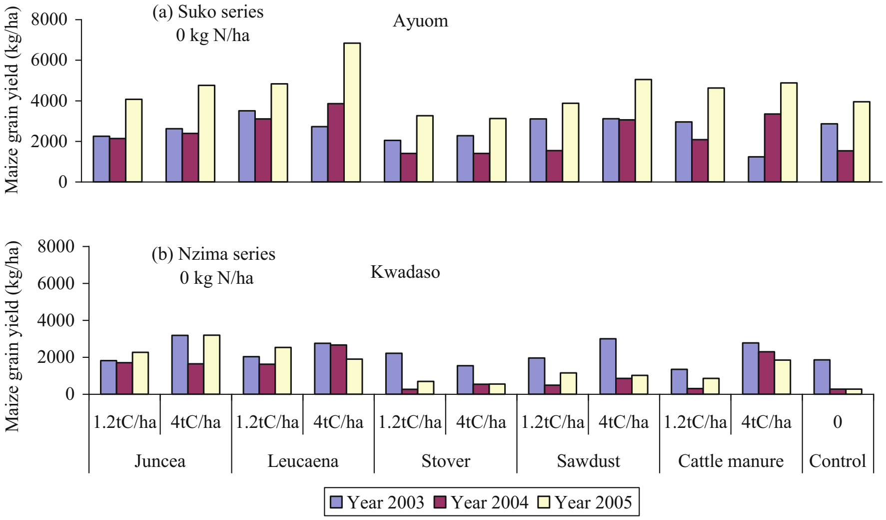

Fig. 4.1 Effect of organic resource quality and quantiy with 0 kg N/ha application on (**a**) Suko series and (**b**) Nzima series during major season cropping from 2003 to 2005

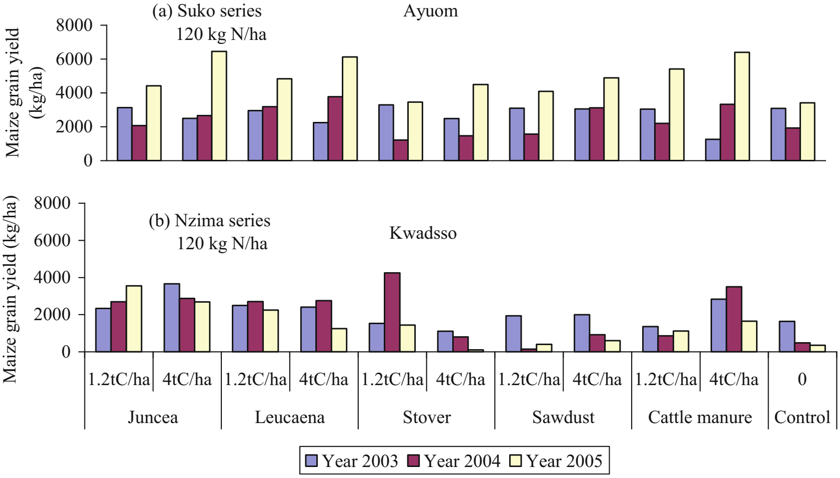

Fig. 4.2 Effect of organic resource quality and quantiy with 120 kg N/ha application on (**a**) Suko series and (**b**) Nzima series during major season cropping from 2003 to 2005

is shown in Fig. 4.5. Maize grain yield increased linearly with organic inputs at both 1.2 and 4 t C ha^{-1} with and without inorganic N supplementation. *L.leucocephala* showed superior maize grain yield across years with the highest at 3.6 t C ha^{-1} at 1.2 t C ha^{-1} with 120 kg N ha^{-1}. The results show that to maximize main grain yield production on the Suko series, combined application of *L.leucocephala* at 1.2 t C ha^{-1} with 120 kg Nha^{-1} will be a better soil fertility management option than 4 t C ha^{-1}

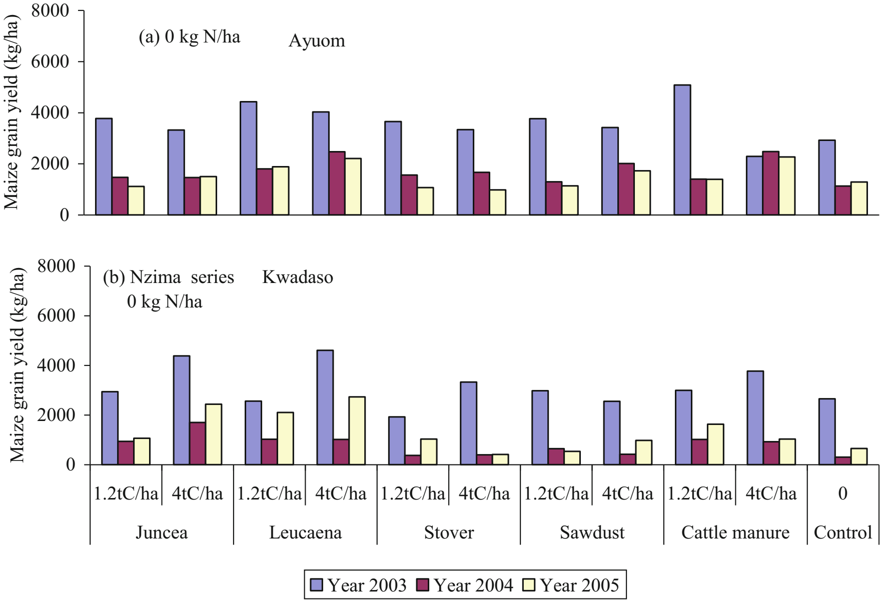

Fig. 4.3 Effect of organic resource quality and quantiy with 0 kg N/ha application on (**a**) Suko series and (**b**) Nzima series during major season cropping from 2003 to 2005

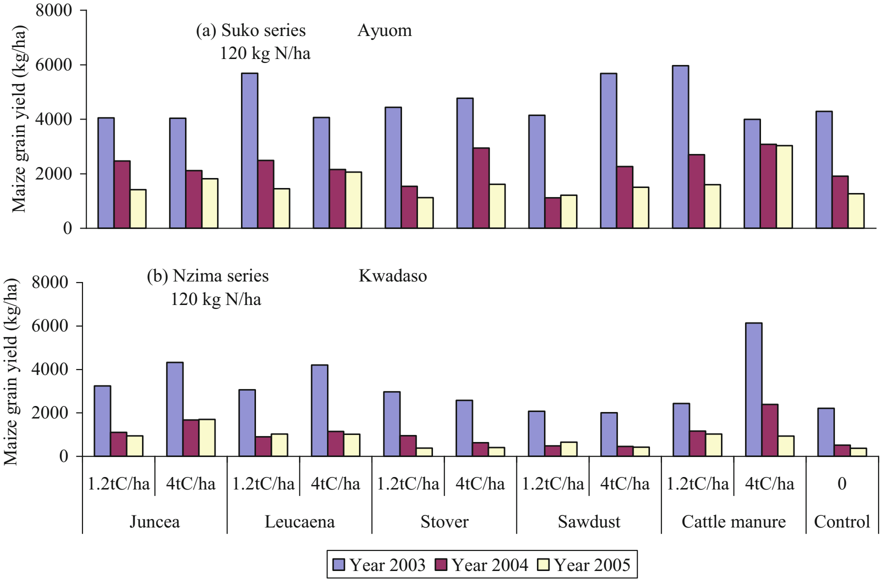

Fig. 4.4 Effect of organic resource quality and quantiy with 120 kg N/ha application on (**a**) Suko series and (**b**) Nzima series during major season cropping from 2003 to 2005

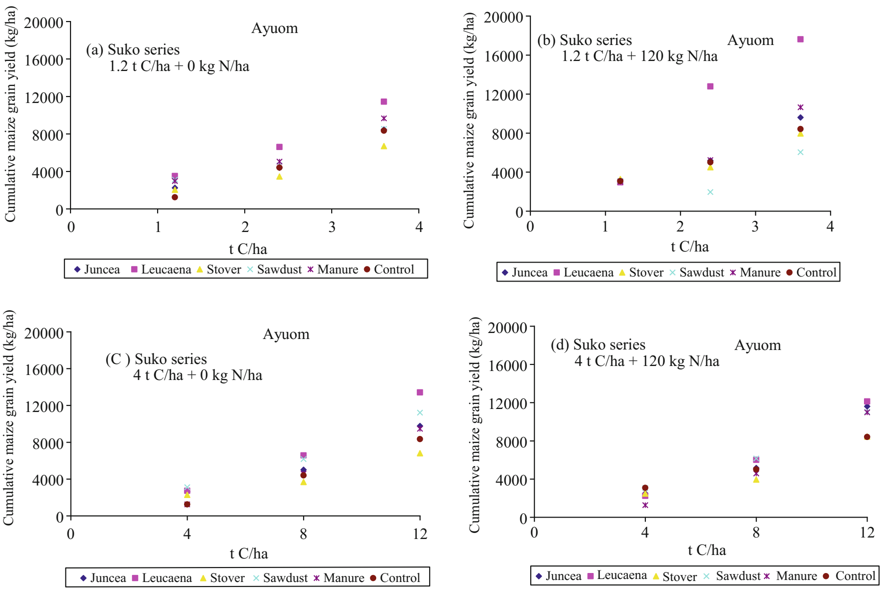

Fig. 4.5 Cumulative major season maize grian yield on Suko series as influenced organic resource quality, N management and season of cultivation

plus 120 kg N ha^{-1}. The results further show that at 4 t C ha^{-1} application of organic resources, the benefits of supplementary inorganic N is minimal (Fig. 4.5c, d).

4.6.2.2 Suko Series Minor Season

The continuous application of organic resources and maize cumulative yield on the Suko series during the minor season is shown in Fig. 4.6a, b, c and d. In general, continuous application of organic inputs showed corresponding maize yield increases during the period of the study. Combined application of organic resources and inorganic N at both 1.2 t C ha^{-1} and 4 t C ha^{-1} showed net benefit of inorganic N supplementation. The net benefit however, was higher at the 1.2 t C ha^{-1} (Fig. 4.6b) application rate than 4 t C ha^{-1} (Fig. 4.6d) quantity of application.

The order of maize grain yield at 1.2 t C ha^{-1} with 0 kg N ha^{-1} at the end of the third year (3.6 t C ha^{-1}) was: *L.leucocephala*>Cattle manure>*C.juncea*>Maize stover>sawdust>control. At the same application rate with 120 kg N ha^{-1}, the order of maize grain yield benefit was: Cattle manure>*L. leucocephala*>*C. junea*>control>maize stover>sawdust. Cattle manure and *L. leucocpehala* showed higher maize grain yield across years than the rest of the treatments at 1.2 t C ha^{-1} with and without inorganic N amendments.

At 4 t C ha^{-1} with 0 kg N ha^{-1} (Fig. 4.6c) at year 3, the trend in decreasing order of maize grain yield was: *L.leucocpehala*>sawdust>cattle manure>*C. juncea*>maize stover>control. Addition of inorganic N (Fig. 4.6d) at the end of

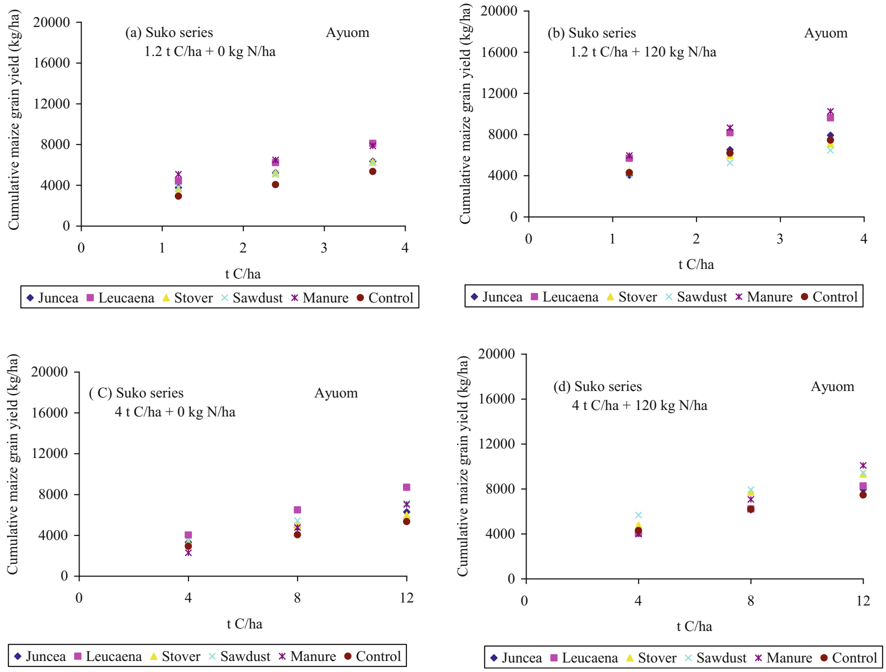

Fig. 4.6 Cumulative minor season maize grian yield on Suko series as influenced by organic resource quality, N management and season of cultivation

the study on the other hand showed the trend: Cattle manure>sawdust>maize stover>*L.leucocephala*>*C.juncea*>control. This trend again emphasize the fact that inorganic N influences high quality materials (*C.juncea* and *L.leucocphala*) least while low quality materials (maize stover, sawdust and cattel manure) benefit substantially from inorganic N in supporting maize growth. The results of the study have important implications for sustainable maize crop production in the tropics. Depending on the resource endowment of the smallholder farmer and availability of organic resources, a number of options for increasing maize grain yields are available. In situations where access to inorganic fertilizers are a major constraint to soil fertility improvement, cattle.

4.6.2.3 Nzima Series Major Season

The variation in major season maize cumulative yield as influenced by organic resource quality, N management and season of cultivation on the Nzima series is shown in Fig. 4.7a, b, c and d. Similar to major and minor season in Suko series, maize grain yield increased linearly with organic inputs with and without inorganic N supplementation.

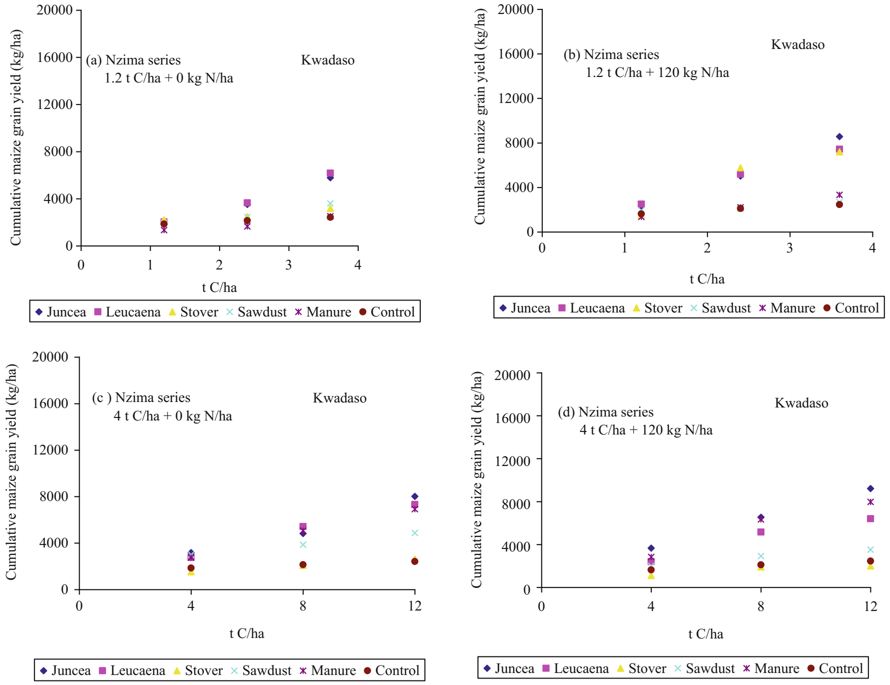

Fig. 4.7 Cumulative major season maize grian yield on Nzima series as influenced by organic resource quality, N management and season of cultivation

At 1.2 t C ha^{-1} plus 0 kg N′ha^{-1} (Fig. 4.7a) while *C.juncea*, *L.leucocephala* and the sawdust organic inputs showed cumulative maize yield increases, maize stover and control treatments increased marginally. In combination with inorganic N however, maize stover showed response to inorganic N supplementation and compared in cumulative yield to *C.juncea* and *L.leucocephala* (Fig. 4.7b). The control plus inorganic N showed marginal increases across the years. This suggests that sole application of inorganic nutrients may not be able to sustain maize grain yields in the Nzima series. Application of 4 t C ha^{-1} organic inputs plus 0 kg N ha^{-1} (Fig. 4.7c) clearly showed added benefits of higher application rates compared to lower application rate (Fig. 4.7a). At 4 t C ha^{-1} with and without inorganic N addition, *C.juncea* showed the highest cumulative maize yield of 8013 kg ha^{-1} and 9215 kg ha^{-1} respectively after 3 years of continuous application of organic inputs. Unlike the Suko series where *L.leucocephala* appears to be the best material for increased maize yield, *C.juncea* seems to be the best bet for Nzima series.

4.6.2.4 Nzima Series Minor Season

The cumulative minor season maize grain yield on the Nzima series is shown in Fig. 4.8. The response of maize grain yield to continuous addition of organic inputs

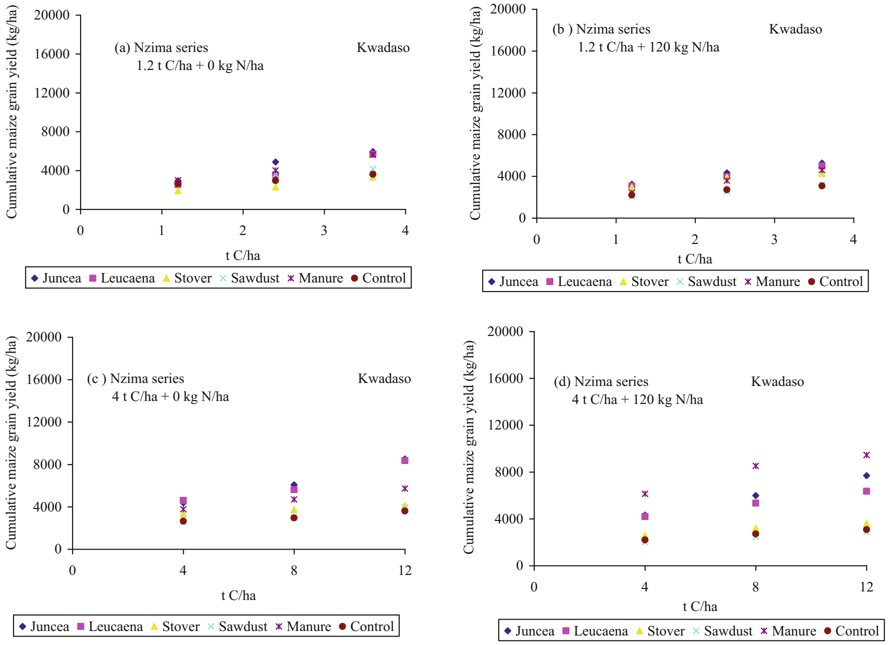

Fig. 4.8 Cumulative minor season maize grian yield on Nzima series as influenced organic resource quality, N management and season of cultivation

were observed with 1.2 t C ha^{-1} plus 0 kg N ha^{-1} (Fig. 4.8a) and 1.2 t C ha^{-1} plus 120 kg N ha^{-1} (Fig. 4.8b) management options. The combined application of 4 t C ha^{-1} with 120 kg N ha^{-1} (Fig. 4.8d) showed the highest cumulative maize yield (almost 9500 kg ha^{-1}) followed closely by sole application of organic inputs at 4 t C ha^{-1} (Fig. 4.8c). Cattle manure consistently showed superior maize grain yield at 4 t C ha^{-1} plus inorganic N amendment (Fig. 4.8d) with cumulative maize grain yield of almost 9500 kg ha^{-1} at 3.6 t C ha^{-1} cumulative organic C inputs.

The results in general show that soil management options to sustain maize grain yield decreased in the following order: organic inputs+120 kg N ha^{-1}>sole application of organic inputs>control+120 kg N ha^{-1}>control+0 kg N ha^{-1}. These results show that external inputs are definitely needed for sustainable maize crop production in the study sites. Major emphasis however, must be given to integrated systems of nutrient management using organic and inorganic inputs.

4.7 Conclusion

Maize grain yield was consistently higher on the Suko series than the Nzima series during the period of the experiment. The highest maize grain yield for the major season was observed in year 2005 and for the minor season, the highest was observed in 2003. The production variability index during the major season on the Suko series was 36% while that of the minor season was 34%. Maize grain production on the Suko series was therefore stable in the minor season than in the major season. Unlike the Suko series, the production variability in the minor season (82%) was higher than that of the major season (72%) on the Nzima series indicating better maize yield stability in the major season. In both seasons, the production variability was higher on the Nzima series than on the Suko series.

Application of organic inputs at 4 t C ha^{-1} generally yielded more maize grain than 1.2 t C ha^{-1}. The added benefit of inorganic N addition to organic resources was higher at 1.2 t C ha^{-1} than 4 t C ha^{-1} particularly with the high quality materials such as *C.juncea* and *L.leucocephala*. Inorganic N influenced high quality materials (*C.juncea* and *L.leucocphala*) least while low quality materials (maize stover, sawdust and Cattle manure) showed added benefit of grain yield when combined with inorganic N. Technological options to sustain maize grain yield decreased in the order: organic resources+120 kg N ha^{-1}>sole organic resources>control +120 kg N ha^{-1}>control+0 kg N ha^{-1}. Cumulative maize grain yield showed linear relation with organic C inputs. The application of organic materials is needed not only to replenish soil nutrients but also to improve soil physical, chemical and biological properties.

The maintenance of soil fertility in small farm systems in sub-Saharan Africa has become a major issue as a consequence of continued land degradation and rapid population growth. Agricultural development efforts therefore must be directed towards the improvement of productivity and sustainability of small-holder production systems. This study has provided a number of soil fertility management interventions for sustaining maize crop yield depending on the socioeconomic constraints of the small holder farmer and the availability of organic resources. While external inputs are essential to improve and sustain crop production on these soils, major emphasis must be given to integrated systems of nutrient management using both organic and inorganic inputs. Rainfall appears to be a major climatic factor in sustaining maize crop production. The results of the study have important implications for food security in developing countries and provide options for reducing poverty particularly sub-Saharan Africa.

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Chapter 5
Efficient Use of Nutrients and Water Through Hill-Placed Combination of Manure and Mineral Fertilizer in Maize Farming System in Northern Benin

Pierre G. Tovihoudji, P.B. Irénikatché Akponikpè, André Adjogboto, Jonas A. Djenontin, Euloge K. Agbossou, and Charles L. Bielders

Abstract Maize, a major staple food in many farming systems in sub-Saharan Africa, is characterized by low productivity due to the scarce availability and use of external inputs and recurrent droughts exacerbated by climate variability. Within the integrated soil fertility management framework, there is thus a need for optimizing the use of fertilizers and manure for the efficient use of limited nutrient resources and rainfall, and to increase crop yield and farmer income. On-station experiments were conducted in Northern Benin over a 4-year period using a split-plot design with three replications to evaluate the effect of hill-placed mineral fertilizer and manure on yields and soil chemical properties. The treatments

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consisted of the combination of: (i) three rates of manure (main plot): 0, 3 (3M) and 6 (6M) t ha^{-1}; and (ii) three levels of fertilizer (sub-plot): 0%(NF), 50% (50F) and 100% (100F) of the recommended rate (76 kg N + 13.1 kg P + 24.9 K ha^{-1}). Hill-placement of manure and/or fertilizer significantly improved soil organic carbon content, available P and exchangeable K in the vicinity of the planting hills. As a result, yields increased steadily over time for all manure and fertilizer combinations, with yields up to 5 times higher than the control for the 6M-100F treatment. Value-cost ratios and benefit-cost ratios were >2 and generally as good or even better for treatments involving 50F compared to NF or 100F. Although applying half the recommended rate of fertilizer is performed by many farmers and appears to make economic sense, this practice is unlikely to be sustainable in the long run. Substituting 50F for 3M or complementing 50F with 3M are two possible strategies that are compatible with the precepts of ISFM and provide returns on investment at least as good as the current practice. However, this will require greater manure production, made possible by the increased stover yields, and access to means of transportation to deliver the manure to the fields.

Keywords Manure · Fertilizer · Maize yields · Water and nutrient use efficiency · Profitability

Contents

5.1 Introduction

In Sub-Saharan Africa (SSA), agriculture plays an important function in the economic growth and rural livelihoods. However, the low inherent soil fertility and loss of soil fertility through nutrient and organic matter depletion negatively affect agricultural productivity (Bationo and Waswa 2011; Tittonell and Giller 2013). According to Henao and Baanante (2006), “the declining fertility of African soils because of soil nutrient mining is a major cause of decreased crop yields and per capita food production and, in the mid to long term, a key source of land degradation and environmental damage”. These soil fertility constraints have been aggravated in recent years by climate variability and change, and mismanagement of agricultural land (Traoré et al. 2013; Yegbemey et al. 2014). The combination of these constraints has resulted in low yields for food crops. In the case of maize for instance, which is a major food crop across much of SSA (Smale et al. 2011), grain yields seldom surpass 1 t ha^{-1} in the majority of the smallholder farms, compared with a potential yield of 3–5 t ha^{-1} (http://faostat3.fao.org).

Traditionally, unproductive fields were regenerated mainly through medium or long-duration fallows, but this practice is no longer feasible due to the increased population leading to land pressure and competing land-use demands (Samaké et al. 2005; Pascual and Barbier 2006). Consequently, organic amendments such as farmyard manure (FYM) or compost are, more than ever, essential components of soil fertility maintenance strategies (Zingore et al. 2008; Nezomba et al. 2015). Besides their nutrient supply function, the addition of organic amendments is crucial for sustaining soil organic carbon and biological activity levels as well as soil physical and chemical quality (Mando et al. 2005; Zingore et al. 2008). However, the application rates required to achieve sustainable crop production are generally much higher than what is available to smallholder farmers because of limitations in fodder supply, cattle or labor (Mapfumo and Giller 2001). Besides improvements in the recycling of organic resources through, for instance, a better integration of crop-livestock activities (Vanlauwe et al. 2010), it is thus necessary to develop approaches that enhance the efficiency of use of the organic amendments. One example of such approach is the zaï system developed in the Sahelian zone, in which small quantities of manure or compost are concentrated in small planting pits. The technique greatly enhances the use efficiency of organic amendments compared to broadcast application (Fatondji et al. 2006). In the zaï system, the hill-placed application of organic amendments is combined with water harvesting, both of which contribute to the greater productivity of zaï compared to conventional tillage with a broadcast application of organic amendments. However, other studies have demonstrated that hill-placement of organic amendments in the absence of planting pits also leads to increased efficiency and yields (Otinga et al. 2013; Ibrahim et al. 2015). In the more humid tropics, where droughts are a lesser constraint and hence water harvesting is less crucial to achieve a decent harvest, hill-placement of organic amendments without having to dig planting pits offers a serious advantage over the zaï as this considerably reduces the labor requirements.

Nevertheless, it has long been recognized that organic resources cannot ensure by themselves the closure of the nutrient balance since they are merely a form of imperfect nutrient recycling (Valbuena et al. 2014). In addition, the livestock-mediated fertility transfers from grazing land to cropland, which traditionally greatly contributed to sustain crop production, breaks down when the pasture-cropland ratio drops below a certain threshold as a result of increasing population pressure (Andrieu et al. 2014). Finally, because the availability of organic amendments is already limiting simply to sustain current yields, these resources cannot by themselves lead to the large-scale crop intensification that must be achieved to feed the fast growing population. In response, the use of mineral fertilizers has been strongly encouraged in many places in SSA for increasing agricultural production.

Fertilizer application rates have generally been developed with a view to maximize yields. However, these recommended rates are not affordable to most smallholder farmers and imply a high financial risk (Chianu et al. 2012). Consequently, adoption of mineral fertilization for food crops has been minimal. In places where fertilizers have been adopted, farmers have often reduced the quantity applied. For example, actual mineral fertilizer application rates in Northern Benin are generally equal or less than half of the recommended rate (Kormawa et al. 2003). Given this situation, as for organic amendments, strategies have been developed to enhance the use efficiency and economic return from mineral fertilizers. One such successful technology is fertilizer microdosing. In this technique, a few grams of mineral fertilizer are hill-placed at sowing and/or within a few weeks after sowing. The technique has been shown to result in large yield increases with higher fertilizer use efficiencies and higher value-cost ratios than previous fertilizer recommendations (Sime and Aune 2014).

However, although inorganic fertilizer is a key factor for agricultural intensification (Vanlauwe et al. 2014), mineral fertilizer-based systems alone cannot solve the problem of declining soil fertility and loss of productivity because fertilizers do not compensate for the many other environmental functions of organic amendments (Vanlauwe et al. 2011). In addition, the sole use of some mineral fertilizers can enhance soil acidification and therefore the decline in productivity. This has led to the integrated soil fertility paradigm, which advocates the combined use of organic and inorganic amendments for crop intensification purposes (Akponikpe et al. 2008; Vanlauwe et al. 2010). Numerous studies report substantial positive effects of the combined application of organic amendments and mineral fertilizers in addressing soil fertility depletion in the short and in the long-term by preventing soil acidification and improving soil functioning (Kihara et al. 2011; Bedada et al. 2014; Wei et al. 2016). A meta-analysis by Chivenge et al. (2011) concluded that, across SSA, the combined use of organic inputs and nitrogen fertilizers leads to a greater yield response than either input on its own.

Maize is the main food crop and a staple food in Benin. Maize production has increased remarkably over the last decades, in part due to demand from neighboring countries, including Nigeria and Niger. The volume of production was 788,320 tons in 2003 and reached to 1,354,344 tons in 2014 (http://faostat3.fao.org). In the past, maize production and consumption were confined to the southern parts of the country, but it has extended to the northern regions, gradually replacing cotton as a cash crop in the cropping systems. Increasing maize productivity would be strategically interesting by increasing export revenues, improving domestic food security, and rural livelihoods. In Benin, agronomic researchers have long advocated a soil fertility management approach that combines mineral fertilizer with organic inputs (Vanlauwe et al. 2001; Dagbénonbakin 2005). Despite the fact that research trials demonstrated yield benefits from the combined nutrient sources in the short term, integrated soil fertility management (ISFM) adoption is currently low, because of the above-mentioned constraints regarding the use of organic amendments and inorganic fertilizers at the rates recommended by extension services. Hill-placement of organic amendments and fertilizers may thus constitute an interesting option because the increased resource use efficiency that results from hill-placement may lead to substantial yield increases even for application rates that more closely match the reality of farmer’s practices. Using the results from a 4-year maize cropping trial combining hill-placed manure and mineral fertilizer under rain-fed conditions in northern Benin, the present study therefore aimed at identifying locally-relevant ISFM practices on the basis of their productivity, resource use efficiency and economic viability.

5.2 Materials and Methods

5.2.1 Experimental Site Description

In 2012, a long-term field experiment was started at the Agricultural Research Centre of Northern Benin (CRA-Nord) of the National Institute of Agricultural Research in Benin. The station is located at Ina village (Ina district, municipality of Bembèrèkè), Northern Benin (9°57′N and 2°42E, 365 m a.s.l), 70 km northeast of Parakou. The average annual rainfall for the last 30 years at Ina was 1148 ± 184 mm (±SD) and the average temperature was 27.5 °C (CRA-Nord Climate Database, 1982–2015). The climate is tropical sub-humid characterized by a single rainy season that occurs between May and October. July and August are the wettest months. The soil is classified as the ferruginous tropical soil in the French soil classification system and as Lixisols according to the FAO soil classification system. The soil is a loamy-sand with approx. 5% clay in the top 0.2 m, acidic with low organic carbon and total nitrogen and medium phosphorus content (Table 5.1). The experimental site was previously under continuous maize-sorghum rotation cultivation with manual tillage and without mineral fertilizer application. Maize residues were harvested each year for animal feeding as commonly practiced in the study area.

Table 5.1 Initial soil chemical and physical properties of the experimental field

Parameters	0–20 cm
Soil texture	
Sand (%)	77.5
Silt (%)	17.2
Clay (%)	5.3
Texture	Loamy-sand
Soil chemical properties	
pH-$_{H2O}$	5.6
pH-$_{KCl}$	5.3
Organic C (g kg^{-1})	4.5
Total N (mg kg^{-1})	320
P bray-1 (mg kg^{-1})	9.3
Exch. K (cmol + kg^{-1})	0.2

5.2.2 Experimental Design and Treatments

Twenty-seven experimental plots of added (4 × 5 m) were arranged in a split-plot design in three blocks (replicates) with different combinations of FYM (main plot) and mineral fertilizer (sub-plot). The three levels of FYM were: no manure (NM) and an annual application of air dried FYM at a rate of 3 t ha^{-1} (3M) and 6 t ha^{-1} (6M). The three levels of mineral fertilizer were: no fertilizer (NF), 50% (50F) and 100% of the recommended rate (100F). The recommended rate is 200 kg ha^{-1} of NPK (15-15-15) at 15 days after sowing and 100 kg ha^{-1} of urea at 45 days after sowing, equivalent to 76 kg N ha^{-1} + 13.1 kg P ha^{-1} + 24.9 kg K ha^{-1}. The 6M and 100F treatments are the rates recommended by the National Agricultural Research System. The 50F treatment was selected because it more closely matches farmer's practice (Kormawa et al. 2003). The organic amendments were hill-placed 10 days after sowing in the upper 10 cm of the soil. Mineral fertilizer was spot-applied without incorporation (for NPK), while the urea application was immediately followed by weeding-ridging according to the method used by most farmers in the study area. FYM and fertilizer rates were applied annually in the same plots during 2 years (2012 and 2013) for the 3M treatment and 4 years (2012, 2013, 2014 and 2015) for the 6M treatment.

Each year, a representative sample of the FYM was dried in the oven at 40 °C, ground to pass through a 1 mm sieve, and analyzed for organic carbon, total nitrogen, total phosphorus and total potassium. The farmyard manure was a mixture of cattle manure, residues, and soil, and was composed on average of 14.8 ± 5.6% C, 1.4 ± 0.5% N, 0.3 ± 0.2% P, and 0.9 ± 0.4% K. The corresponding mean annual application rates for the 6M treatment were 885 ± 336 kg C, 84 ± 30 kg N, 18 ± 12 kg P and 54 ± 24 kg K ha^{-1}, and half of that for the 3M treatment.

5.2.3 Crop Management

The experimental sites were prepared for sowing using standard cultivation practices. At the onset of the experiment, land preparation was done uniformly across all plots by tractor disk-plowing to a 20 cm depth. At the time of planting, the experimental plots were leveled manually using rakes. The experimental plots were sown with maize, variety DMR-ESR (90 day-maturity). Sowing took place at the onset of rainfall after a major rain greater than 20 mm on the 26th of June 2012, 28th of June 2013, 4th July 2014 and 20th July 2015. The planting hills were spaced 0.8 m × 0.4 m. Maize seedlings were thinned to two plants per hill 2 weeks after planting, giving a density of 62,500 plant ha^{-1}. Plots were weeded twice (15 days and 30 days after sowing) and ridged 45 days after sowing in each cropping year with a hand hoe. Harvesting took place on 18 October in 2012, 25 October in 2013, 20 October in 2014 and 5 November in 2015.

5.2.4 Data Collection and Calculation

Daily rainfall data was recorded each year with a rain gauge located at the experimental field.

To measure total above-ground biomass and grain yields, the three middle rows of each plot were harvested at soil level. Grain, core, and stover sub-samples were oven-dried to a constant mass at 65 °C for 48 h to determine moisture content. Total biomass and grain yields were expressed on a dry matter basis.

In order to establish how much productivity could be gained by mineral fertilizer and/or FYM applications, the partial factor productivity (PFP-X) of each nutrient X ($X = N$, P or K) was calculated as proxy of nutrient use efficiency following Dobermann (2007):

$$\text{PFP-}X\left(\text{kg } grain \text{ kg}^{-1}X\right) = Y/R_X \tag{5.1}$$

where Y is the maize grain yield (kg ha^{-1}) and Rx is the application rate of nutrient X (kg ha^{-1}). The quantity of nutrient applied was the sum of the mineral fertilizer and FYM nutrient contents of the treatment.

To assess the effects of the different treatment on changes in soil properties, soil samples were collected at harvest in 2013, 2014 and 2015 using an auger (0–20 cm depth) from 9 to 12 randomly selected points close to plant holes in each plot. All the visible organic residues were removed by hand and then replicate samples from each plot were thoroughly mixed before sub-sampling for analysis. Each sample was analyzed for pH (H_2O) (soil/water ratio of 1:2.5), organic carbon (van Reeuwijk 1993), available phosphorus Bray-1 (Van Reeuwijk 1993) and exchangeable K (van Reeuwijk 1993). All analyses were carried out at the soil and plant analysis laboratory of International Crop Research Institute for the Semi-Arid Tropics (ICRISAT, Sadoré, Niger).

Economic profitability of the different treatments was analyzed based on gross margin, benefit/cost ratio and value/cost ratio. Fixed costs included the cost of seed and most labor charges (field preparation, seeding, weeding, ridging, harvesting, and threshing), whereas variable costs included fertilizer and FYM as well as labor charges for application of the different fertilizer and manure rates. Input and output prices were taken as the averages of the four cropping seasons (2012–2015; Table 5.2). The price of seeds and fertilizers fixed by the Beninese government through the "Société Nationale pour la Promotion Agricole (SONAPRA)" were used. Since there is no market for manure in the study area and farmers consider it a free input, the value of FYM was estimated as the cost required for collecting manure from kraals, transporting and applying it to fields as reported by Nezomba et al. (2015). Labor costs for land preparation, planting, manure/fertilizer application, weeding and harvesting were collected during the experiments through farm diaries. For the maize grain price, we used the official price of the "Office National pour la Sécurité Alimentaire du Bénin (ONASA)" database (http://www.onasa-benin.org/). Values fluctuate between a minimum of 120 FCFA kg^{-1} in September–

Table 5.2 Input and output prices used in the economic analysis

	Unit	Cost (US$)
Inputs		
Maize seed	US$ kg^{-1}	0.70
NPK fertilizer	US$ kg^{-1}	0.50
Urea fertilizer	US$ kg^{-1}	0.50
Manure	US$ t^{-1}	4.00
Labour for maize cultivation		
Tillage	US$ ha^{-1}	60.00
Seeding	US$ ha^{-1}	14.00
Manure application	US$ ha^{-1}	36.00
Mineral fertilizer application	US$ ha^{-1}	12.00
Weeding	US$ ha^{-1}	56.00
Harvesting	US$ ha^{-1}	28.00
Output		
Maize grain	US$ t^{-1}	300.00

October and a maximum of 200 FCFA kg^{-1} in June–July with an average of 150 FCFA kg^{-1} (1US$ = 500 FCFA). Total revenue was calculated by multiplying grain yield with the average price of grain. The gross margin (GM) was calculated by subtracting variable costs from total revenue. The gross return (GR) was calculated by subtracting fixed and variable costs from the revenue. The benefit/cost ratio (BCR) was obtained by dividing the gross return by the total cost of cultivation (fixed and variable costs), whereas the value-cost ratio (VCR) was computed as the difference in grain yield between the fertilized and/or manured plots and the control plot multiplied by the unit market price of grain, divided by the cost of applied fertilizer and/or manure. Some simulations were carried out to see how the VCR was affected by fluctuations (−50% to +50%) in the price of fertilizer and maize grains.

5.2.5 *Data Analysis*

Prior to the analysis, data were carefully checked for normal distribution using the Kolmogorov–Smirnoff test and homogeneity of variance was assessed using Levene's test. A log transformation was applied to the partial productivity and water use efficiency data because of non-normality. Firstly, a combined analysis of variance (ANOVA) across years was used to test the effect of the year. Because year effects were significant for all parameters, the ANOVA was then performed on a year-by-year basis for easier interpretation using a General Treatment Structure (in split-plot design). All analyses were done with GENSTAT for Windows, Discovery Edition 12 (Lawes Agricultural Trust 2009). Mean separations were performed using the honestly significant difference (HSD)/Tukey's test at an error probability <0.05.

5.3 Results

5.3.1 Rainfall Distribution During the Cropping Periods

Rainfall patterns differed across the four maize growing seasons (July–October). The rains were more evenly distributed in 2013 and 2014 compared to 2012 and 2015, despite the greater number of dry spells and the lower rainfall amount recorded in those 2 years (Fig. 5.1). The amount of rainfall was the highest in 2012 (885 mm) followed by 2015 (797 mm), whereas the 2014 and 2013 growing seasons received the lowest rainfall of 694 mm and 650 mm, respectively. Of the total rainfall received in 2012, 52% occurred between the emergence and flowering stages with a total of 50 rainfall events (6 of which exceeded 40 mm), while in 2013 most of the rains (57%) occurred from 48 till 90 DAS (flowering to maturity stage) with a total of 47 rainfall events. In 2012 one dry spell of 8–10 days was recorded from 26 to 36 DAS (DAS; juvenile stage), whereas in 2013 six dry spells of 4–10 days were observed between 15 and 52 DAS (juvenile-flowering stage). In 2014, most of the rains occurred from 63 to 80 DAS, accounting for 38% of the total rainfall recorded during the cropping period with three dry spells of 8–10 days at the beginning of the growing season (0–10 DAS, and 20–27 DAS) and at flowering period (54–63 DAS). Most of the rains in 2015 were concentrated between 15 and 40 DAS (the vegetative period), accounting for 55% of the total rainfall recorded during the cropping period. There were two dry spells of about 7 days from 0 to

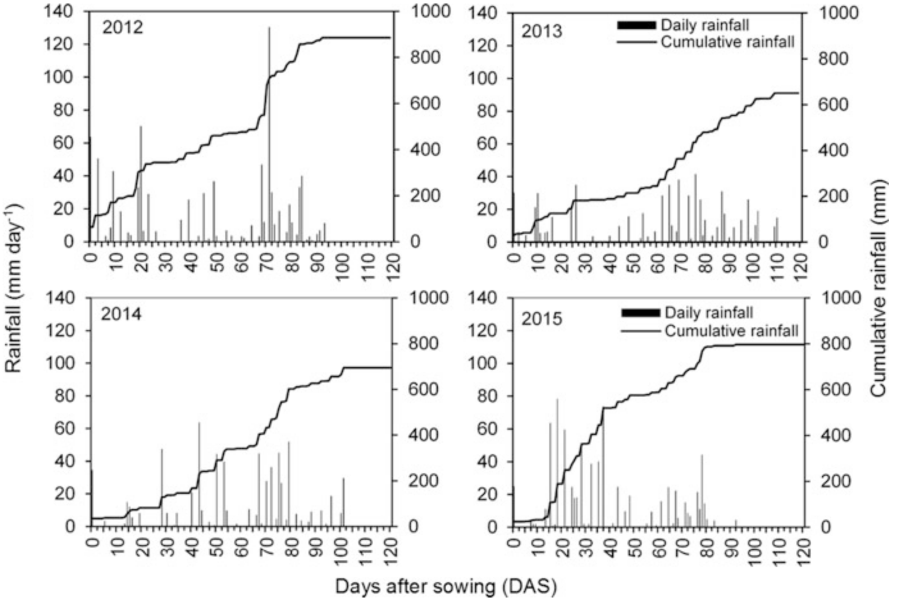
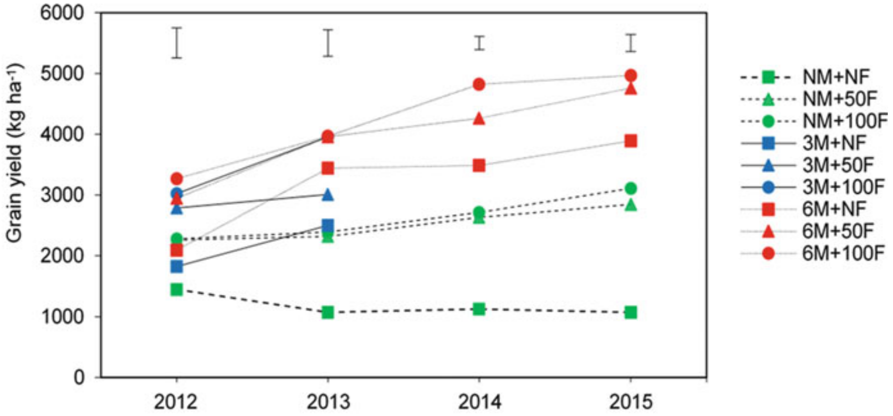


Fig. 5.1 Rainfall distribution in 2012, 2013, 2014 and 2015. The sowing date corresponds to 0 DAS



P-values				
Manure (M)	0.002	<0.001	<0.001	<0.001
Fertilizer (F)	<0.001	<0.001	<0.001	<0.001
M x F	0.798	0.026	0.021	0.015

Fig. 5.2 Maize grain yield following the application of 0 (NM), 3 (3M) or 6 (6M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons. Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3M treatments are missing in 2014 and 2015

7 DAS and from 50 to 57 DAS (flowering stage) and four heavy rainfall events $\geq$60 mm per day.

5.3.2 *Maize Grain Yield*

Overall, grain yields tended to increase over the 4-year period for all fertilized or manured treatments (Fig. 5.2). Depending on the treatment combinations, yields increased at an average rate comprised between 195 kg ha^{-1} year^{-1} for NM+50F and 604 kg ha^{-1} year^{-1} for 6M+50F. Only the NM+NF treatment showed a decreasing trend, from 1449 kg ha^{-1} in 2012 to 1073 kg ha^{-1} in 2015. Based on the combined analysis, there was a strong year effect on the treatment responses ($p < 0.001$), hence the results will hereafter be discussed on a year by year basis.

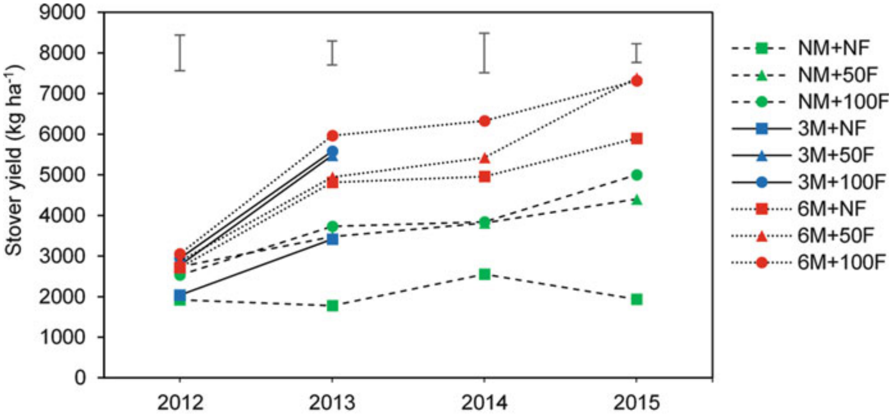
The addition of manure significantly increased maize grain yield in all years ($p < 0.01$; Fig. 5.2). In 2012, grain yield was improved by 28% for 3M compared to NM, on average over all fertilizer application rates, but the application of 6M resulted in only a minor additional increase. On the contrary, in 2013 grain yield was improved on average by 64% and 97%, respectively, for 3M and 6M compared to NM. The response to manure in 2014 and 2015 was rather similar to 2013. Grain yields increased by 94% on average for 6M compared to NM.

There was a significant fertilizer effect for maize grain yield in all years as well as a significant manure x fertilizer interaction in all years ($p < 0.05$) except in 2012 for which the effects of manure and fertilizer were additive (Fig. 5.2). In all years, the NM treatments responded well to the addition of 50F but adding 100F provided little additional gain compared to 50F. The response to fertilizer in the absence of manure tended to increase over time (from +821 kg ha^{-1} in 2012 to +1905 kg ha^{-1} in 2015), both as a result of decreasing yields in the NM+NF treatment and increasing yields in the fertilized treatments. In 2012, all manure treatments (3M and 6M) responded well to the addition of 50F, with an average yield increase of 878 kg ha^{-1} compared to NF. 100F provided only little additional gain in grain yield compared to 50F. In 2013, compared to NF the addition of 50F and 100F to the 3M treatment increased grain yield by 510 and 1458 kg ha^{-1}, respectively, whereas the response to 50F and 100F was similar (on average 521 kg ha^{-1}) in the presence of 6M. In 2014 and 2015, grain yields in the 6M treatment increased by 775 and 865 kg ha^{-1}, respectively, after adding 50F (Fig. 5.2). Adding 100F to 6M further increased yields by 561 kg ha^{-1} in 2014 compared to 50F, but no significant increase was observed in 2015.

5.3.3 Maize Stover Yield

As for grain yield, there was a significant year effect on stover yield ($P < 0.001$). Stover yields tended to increase over time for all treatments except for the NM-NF treatment for which yields remained fairly stable (Fig. 5.3). Significant effects of manure application were observed in all years except in 2012 (Fig. 5.3). Compared to NM, stover yield in 2013 was improved by 61% and 75% for 3M and 6M, respectively, on average over all fertilizer treatments. In 2014 and 2015, stover yields increased by 60% and 74%, respectively, for 6M compared to NM.

Significant effects of fertilizer application were observed in all years except in 2012 (Fig. 5.3). On average over all manure treatments, adding fertilizer improved stover yields in the 50F and 100F by 39% and 53% in 2013, by 23% and 31% in 2014 and by 69% and 77% in 2015, compared to NF (Fig. 5.3). There was no interaction between any of the treatments in all years, except for 2013. In 2013, compared to NF the addition of 50F increased stover yield by 1697 and 2062 kg ha^{-1} in the NM and 3M treatment, respectively, while the addition of 100F provided only little additional gain in stover yield compared to 50F. Conversely, no significant increase in stover yield was observed after the addition of 50F in the 6M treatment, but adding 100F increased stover yields by 1147 kg ha^{-1} compared to NF (Fig. 5.3).



P-values				
Manure (M)	0.217	<0.001	0.002	<0.001
Fertilizer	0.074	0.002	0.060	<0.001
M x F	0.770	0.003	0.550	0.137

Fig. 5.3 Maize stover yield following the application of 0 (NM), 3 (3M) or 6 (6M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons. Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3M treatments are missing in 2014 and 2015

5.3.4 Yield Response to Nutrient Application

Maize grain yield was significantly correlated ($p < 0.001$) with the N, P and K application rates from the combined manure and fertilizer amendments in all years. Although there was some indication of a non-linear response for N in 2013 and 2015 and K in 2013, the nutrient response could in general be fairly well approximated by a linear regression (R^2 between 0.54 and 0.95). The slope of the relationship was year-dependent (Fig. 5.4). For N and K, the response was lowest in 2012 and highest in 2015 (Fig. 5.4). For P, the response was lowest in 2014 and similar for the other 3 years. Maximum grain yields of the order of 4800 kg ha^{-1} were achieved in 2015 and 2014, albeit with significantly lower inputs in 2015 (110 kg N, 30 kg P, 50 kg K ha^{-1}) compared to 2014 (200 kg N, 50 kg P, 95 kg K ha^{-1}) (Fig. 5.4).

5.3.5 Partial Factor Productivity (PFP) of N, P and K

There was a highly significant effect of year on the PFP of N, P, and K on a grain basis. For each growing season, manure and fertilizer applications had a significant effect on the PFP of N, P and K ($p < 0.001$). There was also a highly significant

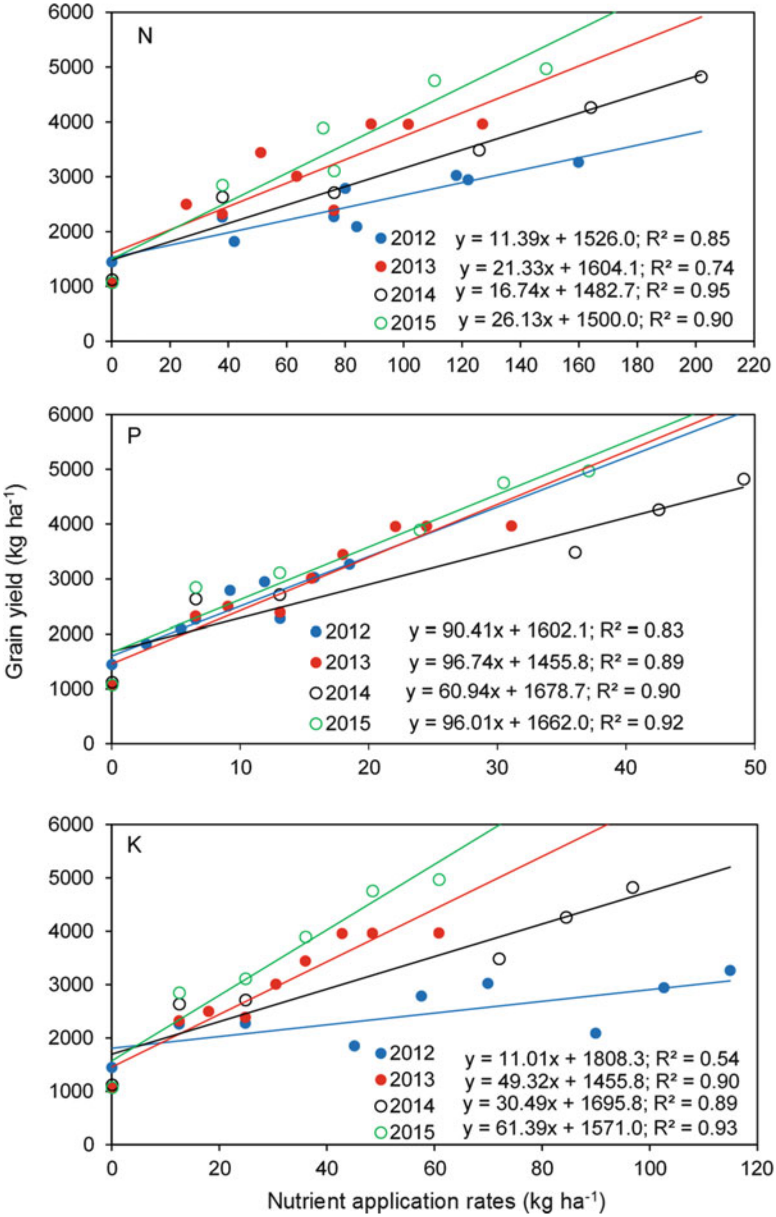


Fig. 5.4 Maize grain yield response to N, P and K as a result from the combined nutrient input from fertilizer and manure over four seasons (2012–2015)

manure x fertilizer interaction in all growing seasons ($p < 0.01$; Fig. 5.5). In general, the PFP of N and P decreased with increasing rates of fertilizer, for each level of manure. However, this rate of decrease tended to be highest for the NM

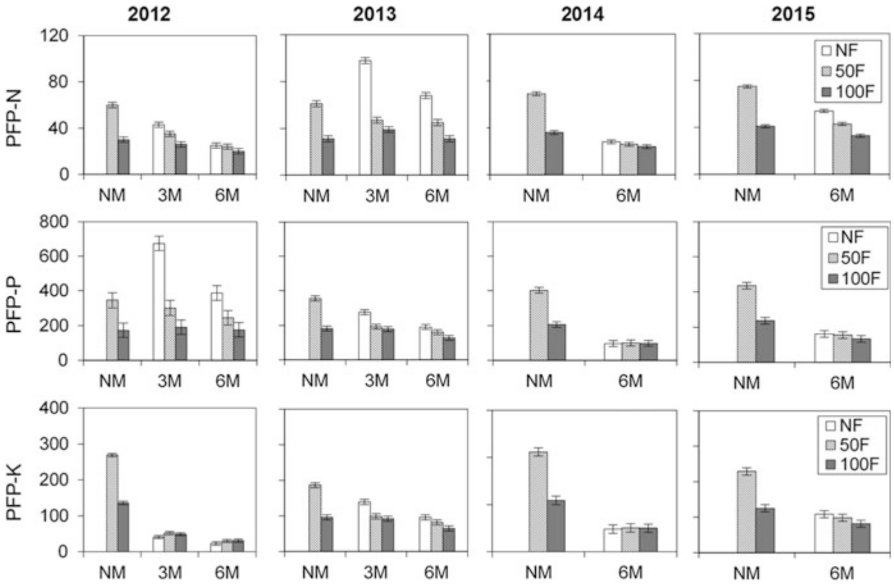


Fig. 5.5 Partial factor productivity (PFP) of N, P and K (in kg grain kg^{-1} N, P or K) following the application of 0 (NM), 3 (3M) or 6 (6M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons (2012–2015). Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3M treatments are missing in 2014 and 2015

treatments and lowest for the 6M treatments. For K, the PFP decreased with increasing rates of fertilizer application in the NM treatment only, while it remained nearly stable for the different fertilizer rates in the 3M and 6M treatments.

5.3.6 Post-harvest Soil Status

SOC content showed upward trends in all manured treatments (3M and 6M). For 6M, SOC increased from 4.5 g C kg^{-1} in 2012 to approximately 10 g C kg^{-1} in 2015 on average over the fertilizer rates (Fig. 5.6a). For a given level of manure, there was a tendency for SOC contents to increase with increasing levels of fertilizer (Fig. 5.6a). However, application of mineral fertilizer on the NM treatment did not significantly increase SOC content. Overall, the SOC was significantly related to grain yield ($p < 0.01$; $R^2 = 0.71$).

As for SOC, available P tended to increase over time for the 3M and 6M treatments (Fig. 5.6b). For NM, available P increased for 50F and 100F but decreased for NF. On average over 50F and 100F, the rate of increase in available P was higher for 6M than NM. The annual increase in available P ranged from 1 to 5 mg kg^{-1} $year^{-1}$ in manured plots compared to 2 mg kg^{-1} $year^{-1}$ on average in the

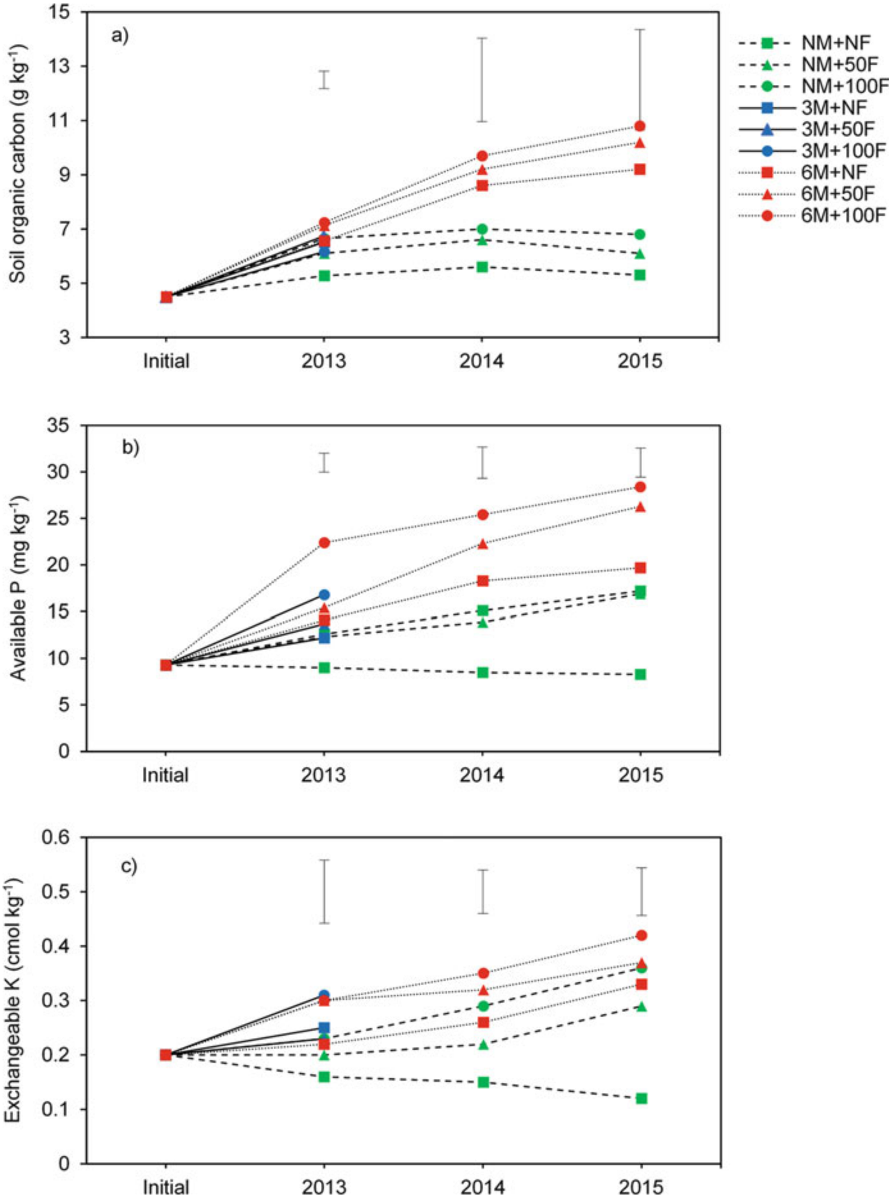


Fig. 5.6 Changes in soil organic carbon (**a**), available P (**b**) and exchangeable K (**c**) in the 0–20 cm soil layer following the application of 0 (NM), 3 (3M) or 6 (6M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate after two (2013), three (2014) and four (2015) cropping seasons. Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3M treatments are missing in 2014 and 2015

no manure treatment. At the end of the experiment, available P was significantly higher ($p < 0.05$) in the 100F and 50F treatments compared with the NF control treatment whether combined with 6M or NM. Available P was significantly correlated to grain yield ($p < 0.001$; $R^2 = 0.86$) and to SOC ($p < 0.01$; $R^2 = 0.83$).

Compared with the initial values, soil exchangeable K was significantly increased over the four growing seasons in all treatments except for the NM-NF treatment in which it declined (Fig. 5.6c). On average over the 50F and 100F treatments, exchangeable K tended to increase more rapidly for 6M compared to NM. The manure and fertilizer management showed a significant interaction effect on soil exchangeable K in 2013 and 2015 but their main effects were not significant, except for fertilizer application in 2013 (Fig. 5.6c). There was a general tendency for exchangeable K to increase with increasing rates of fertilizer for a given level of manure.

5.3.7 Economic Performance Indicators

Overall, there was a highly significant effect of year on the gross margin ($p < 0.001$). As for yields, the highest gross margin was observed in 2015 and the lowest in 2012 (Fig. 5.7). In all years, increasing application rates of fertilizer ($p < 0.05$) and manure ($p < 0.01$) significantly increased gross margins (GM). On average, manure increased the GM by 26% and 32% in 2012, and by 67% and 99% in 2013 for the 3M and 6M treatments, respectively, compared to NM. The GM increased by 96% in 2014 and by 95% in 2015 for 6M, compared to NM (Fig. 5.7). There was no significant interaction between any of the treatments in all years. In 2012, similar GMs were achieved for 50F and 100F in combination with 3M or 6M (Fig. 5.7). In 2013, the 3M+100F treatment was again comparable to the 6M+50F and 6M+100F treatments. In 2014 and 2015, the 6M+50F and 6M+100F achieved comparable GMs.

Overall, benefit cost-ratio (BCR) tended to increase with increasing application rates of farmyard manure. The BCR was generally highest for the 50F treatments irrespective of the manure application rate ($p < 0.01$; Fig. 5.8). BCR values <1 were observed for the NM + NF treatment in all years except 2012. BCR of the 50F treatments were close to two or higher, reaching almost 4 in 2015 in combination with 6M (Fig. 5.8).

Unlike the BCR, the value cost-ration (VCR) generally and significantly ($p < 0.01$) increased with increasing application rates of manure and with decreasing application rates of fertilizer, except in 2012 where the manure effect was not significant and where NF had lower VCR than 50F and 100F (Fig. 5.9). VCR values of the 50F treatments were 1.5–1.6 times greater than those of the 100F treatment, irrespective to the years. In 2014 and 2015, NF and 50F had comparable VCR when combined with 6M.

As expected, VCR values are sensitive to fluctuations in fertilizer and maize grain prices. If the cost of fertilizers were increased by 50%, the VCR values of all the treatments combining the 100F treatment drop under the threshold line of 4 and even below 2 in the case of NM + 100F (all other things remaining equal). For the

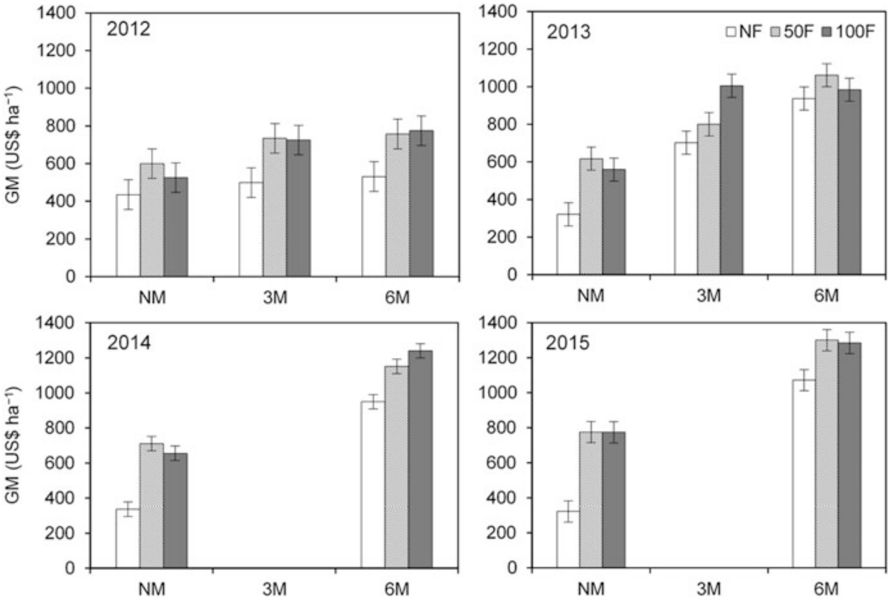


Fig. 5.7 Gross margins (GM) following the application of 0 (NM), 3 (3M) or 6 (6M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons (2012–2015). Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3M treatments are missing in 2014 and 2015

treatments that include 50F the VCR values always remain >2 and even >4 in the presence of 3M and 6M (Fig. 5.10a). A rise in maize price by 25% would result in all treatments having a VCR > 4 except for the NM + 100F treatment (Fig. 5.10b).

5.4 Discussion

5.4.1 Soil Fertility Improvement

The continuous application of manure alone or in combination with mineral fertilizer increased the soil organic carbon content in the top 20 cm of the soil. This may be attributed to the direct additions of organic C through the manure, or indirectly through enhanced root biomass in the manured and fertilized treatments. Although the manured and fertilized treatments both enhanced maize above ground biomass production (Fig. 5.3), the increased C content in soils could not have resulted from crop residue additions since these were exported from the fields at the end of each cropping season, in accordance with farmers' current practices.

Several studies have indicated that an increase in soil carbon can be observed only if the dose of organic manure is sufficiently high (up to 25 t of manure ha^{-1}) and

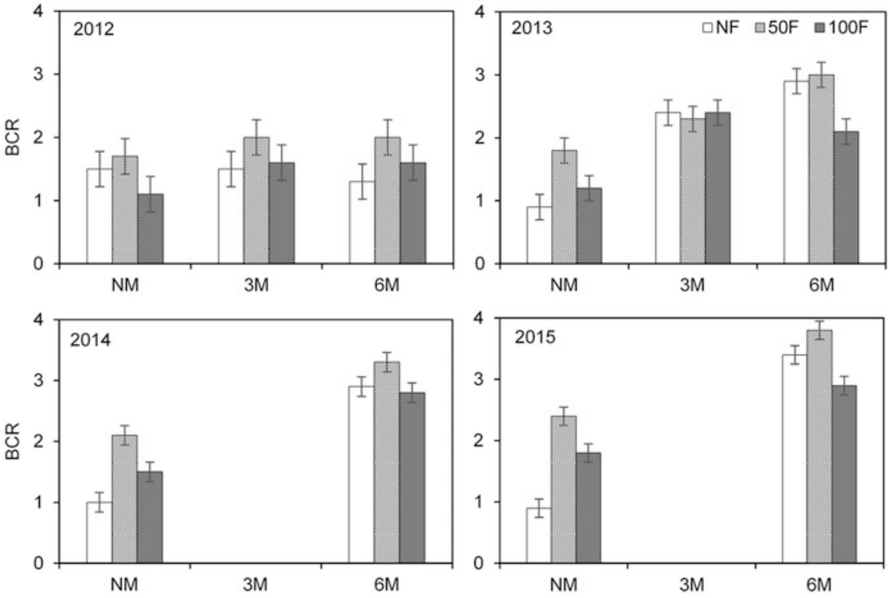


Fig. 5.8 Benefit cost-ratio (BCR) following the application of 0 (NM), 3 (3 M) or 6 (6 M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons (2012–2015). Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3 M treatments are missing in 2014 and 2015

applied for several years (Liu et al. 2010; Rusinamhodzi et al. 2013). In this study, the application rates were much smaller than these recommended rates, yet significant improvements in SOC content were observed. This can be explained by the fact that both the manure application and soil sampling were performed near the plants. By concentrating the manure in pits around the planting hills, substantial soil improvement can be achieved within a few years. In addition, the hill-placement of manure and fertilizer may have favored root development near the plant, which may explain the increase in SOC content in the no manure, fertilized treatments (Fig. 5.6).

A marked improvement of available P and exchangeable K contents in the surface soil (0–20 cm) was observed on the plots that received manure compared with the NM plots (Fig. 5.6). Others studies have reported strong effects of manure on available P and exchangeable K (Zingore et al. 2008). The higher available P may be attributable to P released during manure decomposition as well as the higher pH on the manured plots than no manured plots, due mainly to the high content in basic cations (K, Ca, Mg) of manure. The cations improve the base saturation of the soil solution and induce the release of hydroxide ions (OH^{-}) during manure decomposition (Zhang et al. 2015).

Mineral fertilization strongly increased available P and to a lesser extent exchangeable K (Fig. 5.6). Nevertheless, continuous application of mineral fertilizer alone can lead to acidification on the loamy sand soils which dominate in the study zone and to a depletion of available P despite the addition of P, due to

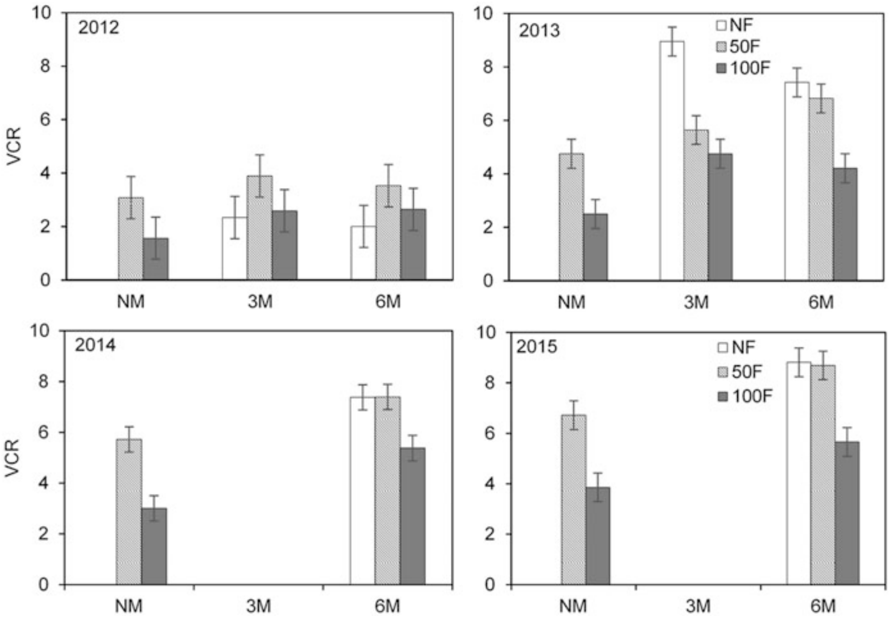


Fig. 5.9 Value-cost ratio (VCR) following the application of 0 (NM), 3 (3 M) or 6 (6 M) t ha^{-1} of manure and 0 (NF), 50 (50F) or 100% (100F) of the recommended mineral fertilization rate over four seasons (2012–2015). Error bar represents standard error of the difference between the means for interaction. Note: Data from the 3 M treatments are missing in 2014 and 2015

increased removal of P or reduced P availability to crops. Moreover, the soil acidification under sole application of fertilizer may result in significant decline in microbial biomass content and enzyme activities (Liu et al. 2010). Although detrimental effects were not observed on the sole fertilizer plots, this practice should thus be avoided if at all possible.

5.4.2 *Maize Productivity and Resource Use Efficiency*

Overall, there was a trend of increasing maize yields over the 4-year period for all fertilized or manured treatments (Fig. 5.2). In SSA, numerous studies reported that the rainfall quantity and distribution is one of the most critical factors affecting growth and yield of rain-fed crops (Rusinamhodzi et al. 2013; Traore et al. 2013; Eyshi Rezaei et al. 2014; Ripoche et al. 2015). However, rainfall records during the present experiment do not provide a clear indication of improving conditions over the years, neither in terms of intra-annual rainfall distribution nor in terms of total seasonal rainfall (Fig. 5.1). For example, in 2012 where the rainfall was relatively high and evenly distributed, the grain yield response to fertilizer and manure applications was low. Early sowing and a longer growing season may favor yields.

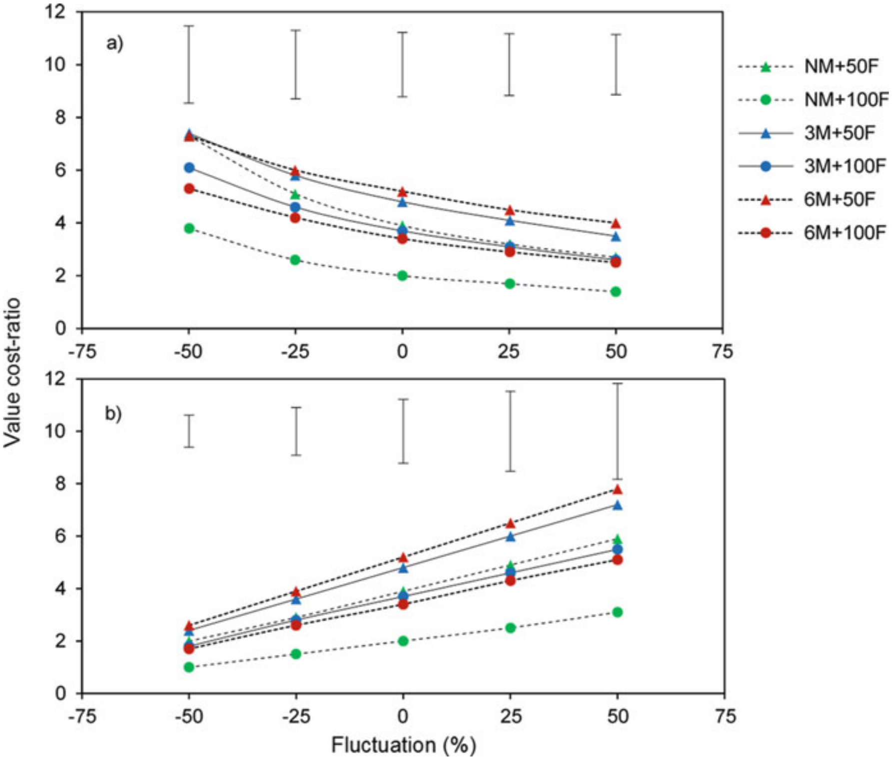


Fig. 5.10 Sensitivity analysis of the value cost-ratio (VCR) under fluctuation of fertilizer cost (**a**) and maize grain price (**b**) following the application of 3 (3 M) or 6 (6 M) t ha^{-1} of manure and 50 (50F) or 100% (100F) of the recommended mineral fertilization rate. Error bar represents standard error of the difference between the means for interaction. Note: due to the absence of the 3 M treatment in 2014 and 2015, the first 2 years (2012 and 2013) data only were used for the sensitivity analysis

However, sowing dates tended to be increasingly delayed over the years (from 26 June in 2012 to 20 July in 2015), and the length of growing period was shorter in 2014–2015 (108 days) than in 2012 (114 days) and 2013 (119 days). Finally, despite the occurrence of short dry periods, there was no indication of serious water stress for maize during the experiment, as plant available water in soil did not reach critically low levels (data not shown). Hence, it seems likely that the increasing yields largely resulted from improved soil fertility (Fig. 5.6) as a result of the beneficial cumulative effects of the manure on soil quality and the residual effects of the mineral and organic amendments. As discussed earlier, the hill-placement of manure resulted in a significant increase in SOC content near the maize plants. Both manure and fertilizer additions also had a positive impact on the available P and exchangeable K levels in soil (Fig. 5.6). The role of soil fertility is further supported by the significant correlations between SOC ($p < 0.01$) or available P ($p < 0.001$) and maize grain yields. Furthermore, in the NM+NF treatment the declining grain yields were accompanied by a decline in available P and exchangeable K contents, further emphasizing the strong link between yield and soil fertility. All this points to soil fertility as the main driver of maize grain yield during the experiment and certainly as the main determinant of the observed yield variations over time. Biotic constraints such as weeds, stem-borer, disease etc. were not assessed specifically but there was no indication that these constraints decreased over time and could have resulted in the observed yield trend.

Maize responded positively to manure application rates (Fig. 5.2). Maize yields were significantly larger for 3M and 6M compared to the NM plot. The lower response in 2012, despite the high seasonal rainfall, may have resulted from the post-emergence application of the manure. The latter most likely resulted in a delayed release of nutrients and possibly in an incomplete decomposition during the growing season. This also applies to subsequent years, except that the maize may then have benefited from the residual effects of the amendments applied in the previous year(s). In the present study, the overall response to manure application may have been enhanced as a result of the hill-placement as compared to the usual broadcast application. Fatondji et al. (2009), Otinga et al. (2013) and Ibrahim et al. (2015) reported benefits from manure hill-placement vs. broadcast application. This positive effect of hill-placement of manure may result a better uptake of the limited amount of nutrients by the roots due to the early roots proliferation favored by this method. In addition, the hill-placed manure may favor moisture retention which would enhance microbial decomposition and nutrient release.

Mineral fertilizer application significantly increased maize yields compared to the unfertilized control. On average across years and manure treatments, fertilizer application increased grain yields by 760–1320 kg ha^{-1} and 1069–1557 kg ha^{-1} for 50F and 100F, respectively, compared to the unfertilized control (NF). Likewise, stover yields increased by 568–2410 kg ha^{-1} and 616–2676 kg ha^{-1} for 50F and 100F, respectively, compared to the unfertilized control (NF). Since rainfall is identical in all treatments for a given year, these yield increases following mineral fertilization result in higher rainfall water productivity (not shown). In only a few instances (3M treatment in 2013, or 6M treatment in 2014) did the 100F substantially increase grain yields as compared to 50F (Fig. 5.2). Overall, the 100F treatment performed only marginally better than the 50F treatment. Consequently, the partial factor productivity of the 50F treatment is higher on average than the 100F recommended rate (Fig. 5.5). Similar trends have been reported by Fatondji et al. (2006), Liu et al. (2010) and Kihara and Njoroge (2013).

There was a significant interaction between manure and fertilizer for grain yield in all years except 2012 (Fig. 5.2). Although synergetic effects have sometimes been reported (Chivenge et al. 2011), this was not observed in the present study. On the contrary, the response to fertilizer additions tended to be lower in the 6M treatments than in the NM treatments between 2013 and 2015, indicating a greater benefit from fertilizers in the absence of manure. In view of the low initial SOC contents at the experimental site (Fig. 5.6), this appears to contradict earlier findings in SSA that showed the positive response of crops to mineral fertilizer in soils rich in organic matter whereas the application of fertilizers in soils poor in organic matter led to no significant crop response (Wopereis et al. 2006; Rusinamhodzi et al. 2013; Kurwakumire et al. 2014).

When combining the nutrient inputs from manure and fertilizer, a rather linear relationship between grain yield and total N, P or K input was observed in most years (Fig. 5.4). Strictly speaking, the response lines of Fig. 5.4 do not reflect the response to single elements, as all three nutrients are present in both the fertilizer and the manure. They should therefore be interpreted as the response of maize to N, P or K inputs in the presence of proportional inputs of P + K, N + K and N + P, respectively. The observed linearity emphasizes the strong dependence of yields on nutrient inputs and hence that soil fertility rather than rainfall was the main factor controlling yields in the present experiment. However, the slopes of the linear regressions are different across years, indicating that some seasonal factors affected maize yield response to nutrient inputs. Most of the seasonal effects can be attributed to the cumulative effects of the nutrient inputs as discussed earlier. Indeed, the slope of the regressions tends to increase from 2012 till 2015. In any given year, the response to the amendments therefore reflects the direct effect of the amendments as well as the residual effects of previously applied amendments, which includes residual soil nutrients (e.g. K, Fig. 5.6), previously undecomposed manure as well as improvements in soil properties (e.g., SOC; Fig. 5.6). Nevertheless, one observes that the response was on average better in 2013 than 2014, despite less favorable climatic conditions in 2013 (Fig. 5.1). The reason for this discrepancy is unclear. Finally, in the case of P, with the exception of 2014 for which the yield response is clearly lower, the seasonal effects are absent. This appears to indicate that plant available P achieved non-limiting levels as from the 1st year.

5.4.3 Implications for Nutrient Management by Farmers of Different Resource Endowments

From an economic viewpoint, the VCR of 100F was always lower than that of 50F (Fig. 5.9). This is because the application of 100F generally resulted in only marginal yield increases compared to 50F (Fig. 5.2). In addition, except for 3M in 2013, the VCRs of NF plots were lower or similar to the VCRs of 50F. Hence applying half the recommended rate appears to be an optimal choice in terms of value-cost ratio. A similar conclusion can be drawn from the BCR calculations, which indicate that 50F treatments always perform as well or better than NF and 100F treatments (Fig. 5.8). Finally, the VCRs of the 50F treatments were always >2, which is often considered to be a minimal condition for technology adoption in risky environments (Kihara et al. 2015). Consequently, any treatment relying on 50F sole or in combination with manure would appear to be an economically sensible choice. This is consistent with the current practice of many farmers who are using half the recommended rate for economic reasons (Kormawa et al. 2003).

In practice, many farmers apply 50F without any manure because of limited access to organic resources. Although this is not advisable for reasons explained below, it remains an economically sensible choice since NM+50F treatment had BCR values close to 2 or higher, whereas NM+NF had BCR values of the order of 1 in the last three experimental years, i.e., no net benefit.

In the study area, farmers (80%) have few cattle and would have access to 2765 ± 1827 kg ha^{-1} of manure (mean ± standard deviation; data not shown) if all manure could be returned to the fields. In practice, incomplete collection of the manure and lack of means of transportation (carts) implies that many fields are left unmanured or insufficiently manured. In any case, the recommended rate of 6 t manure ha^{-1} seems highly unrealistic at present.

Applying 50F without manure, though economically viable, should not be recommended in the long term. Indeed, ccontinuous cultivation of maize without organic amendment has been shown to lead to an increase of soil acidification and an overall decline in soil organic matter and in the availability of other nutrients (Amoah et al. 2012). Organic additions are essential for maintaining soil quality in the long run and are an integral part of ISFM. Besides supplying micronutrients, organic amendments are also essential to sustain soil life (Vanlauwe et al. 2011; Opala et al. 2010; Chivenge et al. 2011; Kihara et al. 2011; Otinga et al. 2013; Agegnehu et al. 2016). However, the broadcast application of 3 t manure ha^{-1} is unlikely to substantially ameliorate soil quality. Hence hill-placement of the manure appears to be a good alternative since it allows to substantially improve soil properties where it matters most, i.e., close to the plants.

Given that most smallholder farmers cannot generate large quantities of manure due to the low number of livestock, relying on fertilizer to achieve acceptable yields ($>$ 2000 kg/ha) seems sensible. However, farmers should be encouraged to value the added biomass (Fig. 5.3) in order to produce more manure and gradually either substitute fertilizer by manure or complement the fertilizer with manure. As can be seen from Figs. 5.8 and 5.9, the 3M+NF treatment provides returns on investments at least as good as the NM+50F treatment. The gross margin is, however, even better for the 3M+50F treatment than for the 3M+NF, such that the former may be a suitable alternative in situations where labor is not a constraint.

Given that the grain yields in the NM+NF treatment were fairly stable across the 4 years, it appears that the actual VCR values will strongly depend on the yield of the fertilized plots and on the fertilizer or grain prices. As expected, the VCR increases as fertilizer prices decrease or as maize prices increase (Fig. 5.10). All treatments remain financially attractive (VCR $>$ 2) even in case of large fertilizer price increases (+50%) or a substantial drop in maize price (−25%), except for the NM + 100F treatment. Hence, the results of the economic analysis will remain valid over a fairly broad range of fertilizer and maize prices. Nevertheless, supporting policies will be particularly required to keep mineral fertilizer affordable and support the internal maize market.

The hill-application of low quantities of manure and fertilizer thus appears to be an effective technology in terms of absolute yields, soil improvement and economic returns. However, hill-placement is labor intensive, which may constitute a limitation to its adoption. The main limitation is likely to be the manure application in pits. Because it is done after sowing, it does not interfere with sowing which is one of the bottlenecks in terms of labor requirement. Given the encouraging results of the on-station trial, large-scale testing of the technology in on-farm trials seems warranted.

5.5 Conclusions

The results of the current study show that soil quality can be significantly improved in the vicinity of the plants as a result of the hill-placement of limited quantities of manure and/or fertilizer. This increase in soil fertility resulted in an upward trend in maize grain and stover yields. From an economic standpoint, applying half the currently recommended rate of fertilizer (i.e 100 kg ha^{-1} NPK 15-15-15 and 50 kg ha^{-1} of urea) appears sensible and may explain why many farmers apply this treatment in practice. However, not applying organic amendments may prove unsustainable in the long run. The results of the experiment indicate clearly that applying 3 t ha^{-1} of manure without fertilizer, half of the currently recommended rate, is economically at least as interesting both in terms of gross margin and return on investment as off the second year. Hence farmers should be encouraged to gradually substitute fertilizer by manure by valuing the increased maize stover production. They could also complement the fertilizer with manure, which provides slightly higher gross margins than manure alone. However, measures have to be taken to provide farmers with more means of transportation of the manure from the homesteads to the fields. The economic results (BCR and VCR) of the present study remain valid over a rather wide range of fertilizer and maize prices. This warrants further testing of the technologies over a wider range of soil and climatic conditions through on-farm experiments.

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Conflict of Interest The authors declare that they have no conflict of interest.

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Chapter 6

Determining Soil Nutrient Capacity to Update Fertilizer Recommendations Under Soil and Water Conservation Techniques in the Zondoma Watershed of Burkina Faso

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Abstract The use of the model Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) was combined with on-farm experiments to evaluate soil nutrient status under soil and water conservation (SWC) techniques such as stone barriers and Zaï to update fertilizer formulae used in sorghum production in the northern part of Burkina Faso. Results from nutrient omission trials (NOT) carried out in farmers' fields show clearly that phosphorus (P) and nitrogen (N) are the most limiting nutrients to sorghum production. SWC techniques affect soil nutrient status, nutrient exports and nutrient use efficiency. The average initial nitrogen fertility of these farms was 23.16 kg.ha^{-1} and 21.10 kg ha^{-1} under stone barriers and zaï respectively. Nitrogen exports reached an average of 28.05 kg ha^{-1} under stone barriers and 21.14 kg ha^{-1} under zaï. The average use efficiency for 1 kg of N was 40.11 kg of grain under stone barriers and 26.20 kg of grain under zaï. The results also show that the use of organic matter lowers the amount of mineral

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fertilizers needed for the same targeted yields. A basket of recommendations combined or not with organic matter was developed and evaluated for sorghum production. As a result, the formula (N29P11K13) was identified as the best option for sorghum grain production in this area under soil and water conservation (SWC) techniques.

Keywords QUEFTS · Targeted yield · Nutrient status · Fertilizer recommendation · Soil and water conservation techniques

Contents

6.1 Introduction

Soil fertility decline is one of the main causes of falling crop yields in sub-Saharan Africa. It is partly due to farmers' failure to comply with good agricultural practices, the inefficiency of fertilizer use and the inadequacy of applied fertilizer rates. Most fertilizer recommendations are pan-territorial with the same fertilizer package irrespective of agro-ecological zones. Moreover, most of fertilizer formulas are obsolete dating back to the introduction of cash crops (cotton, groundnut, etc.). In some countries, there have been unsuccessful attempts to update fertilizer recommendations, particularly on sorghum, millet and maize (Hien et al. 1992).

In Burkina Faso, sorghum (bicolar sorghum) is a major crop due to its role in feeding the country's populations. Sorghum is also used in the local processing sector to produce a local beverage which is sold on more than half of the territory. Yet sorghum yields are low especially in the semi-arid zone, due to both biophysical and socio-economic factors. In addition to climatic and anthropogenic constraints another causal factor is low soil fertility. Moreover, several studies carried out in this area on soil and water conservation have shown that these techniques alone are insufficient to ensure increased yields. Therefore they must be combined with the use of fertilizers (Zougmoré 2003). Indeed, the integrated management of water and soil organic amendments enables efficient use of water (Zougmoré et al. 2004b), just as nutrients improve the efficiency of soil and water conservation techniques (Zougmoré et al. 2004c). Few, if any, studies carried out in this area have focused on the inherent nutrient capacity of these soils particularly in relation to soil and water conservation techniques. Yet, the knowledge of soil nutrient capacity is required to develop site-specific fertilizer recommendations. The need for updating and adapting fertilizer recommendations to crop requirements and to production area conditions has been repeatedly reaffirmed.

This study aims to develop fertilizer recommendations for sorghum production in the northern part of Burkina Faso. The overall objective is to develop optimal options for an intensive production of sorghum in Burkina Faso, particularly in the northern zone, taking into account the fertility of soils under soil and water conservation techniques. Specifically, it aims at determining the nutrient status of soils under SWC techniques (stone barriers and zaï) in the Zondoma watershed to formulate site-specific recommendations for the production of sorghum in the northern part of Burkina Faso.

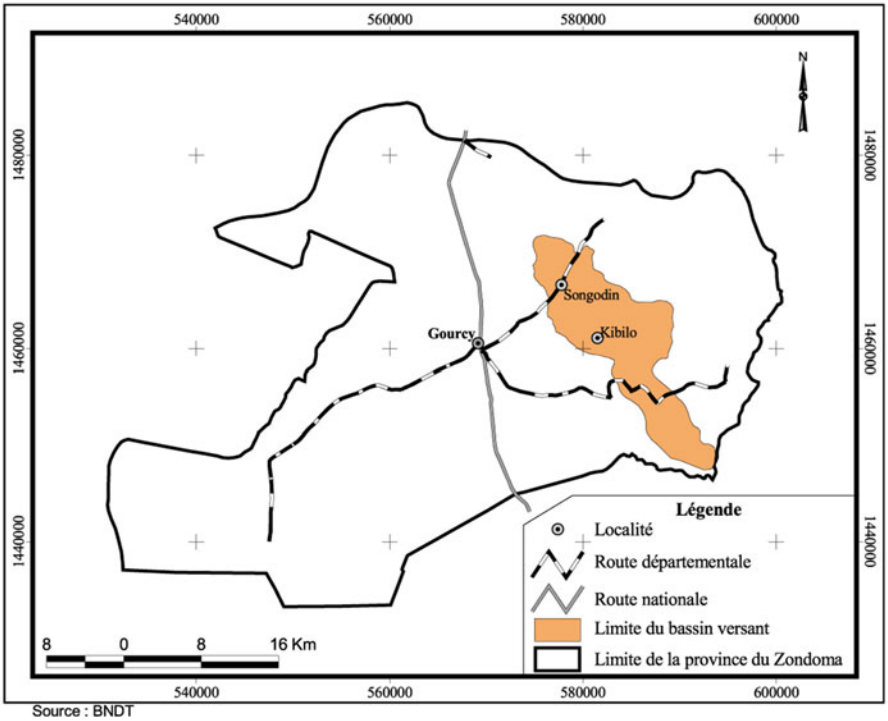
6.2 Materials and Methods

6.2.1 Characterization of the Study Sites

The study area (Fig. 6.1) is located in the province of Zondoma in the northern part of Burkina Faso (13 ° and 15 ° north latitude, 1° 45 and 3° west longitude) belonging to the semi-arid zone (Jalloh et al. 2011). Yougbaré (2008) and Drabo (2009) described the watershed from a biophysical and socio-economic point of view. The province of Zondoma has a dry continental soudano Sahelian climate characterized by two seasons: a dry season from November to April and a rainy season from May to October. The province is located between isohyets 500 mm and 750 mm. Rainfall is sparse, irregular and unevenly distributed over time and space. A total rainfall of 742.8 mm was measured for the year 2007 in 44 rainy days. In 2008, a total rainfall of 876 mm was measured in 50 rainy days.

The vegetation cover described by Zombré et al. (2008) quoted by Drabo (2009) includes some forest relics, plant formations characteristics of the plateau, the wooded savanna based on Khaya senegalensis Desr., Tamarindus indica L., Sclerocarya birrea (A. Rich.) Hochst and Parkia biglobosa (Jacq.) R.Br. in the lower-lying areas; of Parkia biglobosa (Jacq.) R.Br., Acacia albida (Delile) A. Chev., Sclerocarya birrea (A. Rich.) Hochst and Vitellaria paradoxa C.F.Gaertn on the most fertile parts. The upper slopes are covered by much degraded formations including shrubs (Combretum micranthum G. Don, Guiera senegalensis J.F. Gmel.), and a dense herb layer based on Loudetia togoensis (PILG.) C.E. HUBB.

The trials were carried out in the villages of Kibilo and Songodin in the Zondoma Watershed.



Source : BNDT

Fig. 6.1 Localisation of the Zondoma Watershed

6.2.2 Soils of the Study Site

The types of soils that can be found in the Zondoma watershed fall into three broad classes, but the soils rich in iron and manganese sesquioxydes with low fertility are the dominant soils. The average slope described in the zone is 1.5% and the average depth is 70 cm (Zougmoré et al. 2004a).

The chemical characteristics of the study soils in the Zondoma watershed are summarized in Table 6.1. The average organic matter content of these soils is 1%. These are slightly acidic (pH = 5.6) and nitrogen deficient soils.

6.2.3 Variety Used

The improved variety of sorghum Sariasso 11 was used as plant material for carrying out the study in 2008 and 2009. This variety has a production cycle of 100–105 days, with a potential yield between 3 and 4 tons/ha.

Table 6.1 Chemical characteristics of the study sites (2008)

Parameters	Values
Organic matter (%)	1,01
Total carbon (%)	0,58
Total nitrogen (%)	0,0422
Total phosphorus (ppm)	72,47
Available phosphorus bray I (ppm)	7,27
Available potassium (mEq/100 g)	0,30
Sodium (Na+) (mEq/100 g)	0,07
Calcium (Ca2+) (mEq/100 g)	2,35
Magnesium (Mg 2+) (mEq/100 g)	1,10
Exchangeable aluminium Al 3 + (mEq/100 g)	0,02
pH-H2O	5,61
pH-KCl	4,75

Source: Soil analysis

6.2.4 Experimental Design

The experimental design consisted of nutrient omission trials. The experimental plots were set up in farmers' fields on soils developed under stone barriers or zaï techniques. Farmers were selected according to the participatory approach during a village assembly. The most important selection criteria were availability of developed lands, labor and equipment, plot accessibility and open-mindedness.

The nutrient omission design for NPK was adopted. The defined treatments were as follows:

T0: 0 N:0P:0 K, absolute control without fertilizer [0 kg ha^{-1} N, 0 kg ha^{-1} P, 0 kg ha^{-1} K]
T1: 0 N, treatment without N, but with P and K [0 kg ha^{-1} N, 30 kg ha^{-1} P, 35 kg ha^{-1} K]
T2: 0P, treatment without P, but with N and K [100 kg ha^{-1} N, 0 kg ha^{-1} P, 35 kg ha^{-1} K]
T3: 0 K, treatment without K, but with N and P [100 kg ha^{-1} N, 30 kg ha^{-1} P, 0 kg ha^{-1} K]
T4: NPK, treatment with N, P and K [100 kg ha^{-1} N, 30 kg ha^{-1} P, 35 kg ha^{-1} K]
T5: NPK, treatment with N, P and K [100 kg ha^{-1} N, 30 kg ha^{-1} P, 35 kg ha^{-1} K] + micro nutrient pool (ZnO + MgO)

A balanced treatment with micronutrient applications was introduced to ensure non-limitation by these micronutrients.

6.2.5 *Evaluation of Mineral Fertilizer Options*

The classic QUEFTS version was used to develop fertilizer recommendations for sorghum. The input data are the yields observed on the nutrient omission trials of the first year. The other input data are the default values for sorghum (Janssen 2003). Recovery rates of 0.35; 0.15 and 0.35 were retained for N, P and K respectively. Formulas were developed for several targeted yields (1500, 2000, 2500, 3000, 3500 and 4000 kg per hectare). Formula validation trials were conducted and the results evaluated. A Fisher block design was used. The treatments consisted of the fertilizer options developed for the production of sorghum under stone barriers (combined or not with organic matter) and under zai (combined or not with organic matter).

The data collected were mainly grain yields and straw yields. Soil and plant samples were taken for the determination of N, P and K levels in soil and plants. This work was carried out by BUNASOLS according to standard methods.

6.3 QUEFTS Concepts

6.3.1 *Limiting Nutrient*

The Liebig law or the law of the minimum allows to define the notion of limiting nutrient. According to this law, the nutrient present in lower amount in the soil is the limiting nutrient. It is the element that determines crop production. Nutrient omission trials enable to determine the limiting nutrient. When a treatment where a nutrient has been omitted gives a yield that does not differ from the control, then the omitted nutrient is limiting.

6.3.2 *Potential Supply*

Soil nutrient supply was calculated on the basis of data from laboratory soil analysis to estimate initial soil fertility by QUEFTS formulas (Janssen 2003). Total exports of nutrients absorbed by grains and straws were calculated and then added up to obtain the total potential supply.

6.3.3 *Internal Efficiency*

Internal efficiency is the amount of product harvested (grain) (kg) per kg of nutrient absorbed.

It is calculated by making the ratio of grain yields to the total amount of nutrient absorbed.

$$EIx = \frac{\text{Rdt}}{\text{Upt totx}}$$

Where Yield (Rdt) = Grain yield at 12% moisture and Upt totx = Total amount of nutrient x absorbed.

6.3.4 *Data Analysis*

An Analysis of Variance (ANOVA) was carried out on grains and straw yield data using the GenStat 9.2 software. The measured data were used to assess the quality of the model prediction. For this purpose the average standard error (NRSME), (Jamieson et al. 1991, Loague and Green 1991) was used.

6.4 Results and Discussion

6.4.1 *Effect of Mineral Fertilizers on the Yield of Sorghum Under Different Soil and Water Conservation Techniques*

The trials were carried out in 2007/2008 and 2008/2009 under different soil and water conservation techniques (Table 6.2 and Table 6.3). The results of the 2 years showed a significant influence of the treatments on grain and straw yields with stone barriers and zaï.

Regarding stone barriers, grain yields ranged from 421.2 kg.ha^{-1} to 942.1 kg.ha^{-1} in 2008. In 2009, grain yields varied between 707 kg.ha^{-1} and 1553 kg.ha^{-1}. Results in terms of grain and straw yields observed in 2008 showed that NP treatment did not differ significantly from NPK treatment. However, it differs from the control. In addition, the NK treatment forms a homogeneous group with the control. Also, in 2009, the same trend was observed for grain. For example, in the Zondoma watershed, in areas developed with stone barriers, potassium is not a nutrient limiting the production of sorghum. However, nitrogen and phosphorus were the major nutrients limiting sorghum production.

With zaï, grain yields varied between 326.7 kg.ha^{-1} and 929.7 kg.ha^{-1} in 2008. No difference was observed between the NK, NP and PK treatments. However, treatments can be classified in the following order: NP > PK > NK. In 2009, yields ranged from 507.8 kg.ha^{-1} to 1326.2 kg.ha^{-1}. NP treatment differs significantly from NK and PK treatments. Thus, the N and P nutrients are the most limiting ones

Table 6.2 Grain and straw yields under different SWC techniques in 2008

Treatment	Stone barriers		Zaï	
	Grain yields (kg/ha)	Straw yields (kg/ha)	Grain yields (kg/ha)	Straw yields (kg/ha)
Control	421,20b	1108b	326,7b	1029b
NK	454,60b	1115b	490,8ab	1327ab
PK	608,10ab	1587ab	565ab	1436ab
NP	942,10a	2341a	710,1ab	1588ab
NPK	860,70a	2206a	858,1a	2040a
NPK + micronutrients	862,00a	2325a	929,7a	2066a
Sed	114	299,8	154	302,6
Probability	<0,001	<0,001	0,002	0,007
Significance	THS	THS	HS	HS

Table 6.3 Grain and straw yields under different SWC techniques in 2009

Treatments	Stone barriers		Zaï	
	Grain yields (kg/ha)	Straw yields (kg/ha)	Grain yields (kg/ha)	Straw yields (kg/ha)
Control	707b	1781b	714,8 cd	1572c
NK	1076ab	2639ab	507,8d	1943bc
PK	1016ab	2117ab	820,3bcd	2664abc
NP	1461a	3139ab	1029,3abc	2908abc
NPK	1225ab	3139ab	1326,2a	3832a
NPK+ micronutrients	1553a	3584a	1244,1ab	3484ab
Sed	240	533,4	184	634,7
Probability	0,015	0,016	<0,001	0,008
Significance	S	S	THS	HS

for the production of sorghum in the areas under zaï in the Zondoma watershed. On the other hand, potassium does not appear to be limiting.

6.4.2 Validation of QUEFTS Recommendations on Sorghum Sariasso 11

For plots with stone barriers (Table 6.4), observed yields are lower than the target yields, especially in the absence of organic matter. For options that combine organic matter with mineral fertilizers, the observed yields were quite close to the target yields.

On plots developed in zaï the observed yields were very close to the target yields with mineral fertilizers alone as well as in combination with organic matter.

Table 6.4 Targeted and observed grain yields of sorghum, Sariasso 11, (kg ha-1) in the northern area

SWC techniques	Organic matter	Treatment	Targeted grain yields (kg ha^{-1})	Observed grain yields (kg ha^{-1})
Stone barriers	No	$N_0P_0K_0$		165
Stone barriers	No	$N_{37}P_{10}K_{12}$		640
Stone barriers	No	$N_{24}P_5K_0$	1000	540
Stone barriers	No	$N_{57}P_{14}K_{26}$	1500	740
Stone barriers	No	$N_{91}P_{23}K_{56}$	2000	860
NRMSE %			27.85	
Stone barriers	Yes	$N_0P_0K_0$		810
Stone barriers	Yes	$N_{37}P_{10}K_{12}$		1180
Stone barriers	Yes	$N_6P_4K_0$	1000	905
Stone barriers	Yes	$N_{40}P_{13}K_{16}$	1500	1070
Stone barriers	Yes	$N_{73}P_{22}K_{46}$	2000	1200
NRMSE %			9.30	

The results (Table 6.5) show that the most promising options for sorghum production are: $N_{29}P_{11}K_{13}$; $N_{42}P_{10}K_{12}$; $N_{47}P_{11}K_{28}$; $N_{63}P_{21}K_{43}$. Options derived from these have been formulated and evaluated: N_{37}-P_{10}-K_{12}; N_{35}-P_{10}-K_{25}; N_{41}-P_{10}-K_{25}; N_{46}-P_{14}-K_{25}, N_{69}-P_{20}-K_{40}.

The Zai technique with or without organic matter as well as the technique of stone barriers with organic matter are three options for which the observed yields are closest to the simulated yields within the average standard error prediction NRMSE (NRMSE <10). This value indicates that the performance of the model is excellent (Jamieson et al. 1991; Loague and Green 1991).

6.5 Potential Soil Supply, Nutrient Exports and Fertilizer Use Efficiency

6.5.1 Soil Potential Supply in N, P and K

The results (Table 6.6) show that the potential supplies varied according to the type of development. Indeed, nitrogen potential supply was higher with zaï (17.78 kg/

Table 6.5 Targeted and observed grain yields of sorghum, Sariasso 11, (kg ha^{-1}) in the northern area

SWC Techniques	Organic matter	Treatment	Targeted grain yields (kg ha^{-1})	Observed grain yields (kg ha^{-1})
Zaï	No	$N_0P_0K_0$		633
Zaï	No	$N_{37}P_{10}K_{12}$		1154
Zaï	No	$N_{39}P_{13}K_{26}$	1000	1125
Zaï	No	$N_{72}P_{22}K_{56}$	1500	1452
Zaï	No	$N_{105}P_{31}K_{86}$	2000	1433
NRMSE %			2.24	
Zaï	Yes	$N_0P_0K_0$		1005
Zaï	Yes	$N_{37}P_{10}K_{12}$		1510
Zaï	Yes	$N_0P_2K_0$	1000	1146
Zaï	Yes	$N_{29}P_{11}K_{13}$	1500	1663
Zaï	Yes	$N_{63}P_{21}K_{43}$	2000	1420
NRMSE %			3.47	

Table 6.6 Average values of initial fertility, total exports and internal efficiency of N, P and K under the three types of soil and water conservation techniques in the two villages

	Potential supply (Kg ha^{-1})			Total exports (Kg ha^{-1})			Internal efficiency (Kg ha^{-1})		
Technology	ISN	ISP	ISK	UN	UP	UK	IEN	IEP	IEK
SB	14.32	9.86	58.18	31.23	7.05	51.85	44.19	198.20	28
Zaï	17.78	1.96	31.01	19.48	2.97	28.58	23.79	156.40	16.06

IS (N, P, K): Indigenous supply of N, P and K: Initial soil fertility estimated by QUEFTS
U (N, P, K): Total exports of N, P and K
IE (N, P, K): Internal efficiency of N, P and K

ha), compared to stone barriers. On the other hand, the highest supplies of P and K were observed with the stone barrier system.

6.5.2 N, P and K Nutrients Exports

Exports of N, P and K nutrients followed the same trends as potential supplies (Table 6.6). The highest N export level was observed with stone barriers developments with 31.23 kg. ha^{-1}. Regarding phosphorus and potassium, the highest export levels were observed in stone barrier developments with 7.05 kg.ha^{-1} and 51.85 kg. ha^{-1}, respectively. By comparing the exports of N, P and K to the respective potential supplies, N and P exports are higher than the soil potential supply in N and P, while exports of K are lower than the supply of this nutrient. This result shows the mining character of sorghum production regarding nitrogen and phosphorus in the Zondoma watershed.

6.5.3 Internal Efficiency of the Use of Nitrogen, Phosphorus and Potassium

Internal efficiency is the amount of dry matter produced per kilogram of nutrient absorbed by sorghum. When stone barriers were used, average values of internal efficiency were 44.19 kg of grain per kg of nitrogen absorbed, 198.2 kg of grain per kg of phosphorus absorbed and 28 kg of grain per kg of potassium absorbed (Table 6.6). The average internal efficiency values obtained under zai were respectively 23.79 kg of grain per kg of nitrogen absorbed, 156.4 kg of grain per kg of phosphorus absorbed and 16.06 kg per kg of potassium absorbed (Table 6.6). These results show that nutrient efficiency is high with stone barriers.

6.6 Discussions

6.6.1 Limiting Nutrients

The nutrient omission trials, in spite of their simplicity, are adapted to evaluate the limiting nutrients in a given soil (Janssen 2000; Nziguheba et al. 2009). Mineral fertilizers significantly increase sorghum yields in the Zondoma watershed. An important productivity gap remains to be filled due to the potential of the variety, which is 3–4 tons per hectare. Analysis of the results showed low yields with the NK and PK treatments, which are comparable to the yields of the control treatment. These results have consistently shown that phosphorus is the most limiting nutrient of sorghum production in the watershed, followed by nitrogen; while potassium did not appear to be limiting during the 2 years of the study. Nitrogen and phosphorus are often the nutrients that are lacking most in cultivated soils. These results corroborate those of Pieri (1989). It follows from the above that soil nutrient capacity in N and P does not appear to be sufficient to support a good sorghum production in the Zondoma watershed given the physico-chemical characteristics of the area and the results of the nutrient omission trials. The use of soil and water conservation techniques improves soil fertility, especially the physico-chemical and hydric properties of soils (Zougmoré et al. 2002).

6.6.2 Soil Nutrient Capacity, Internal Efficiency and Nutrient Exports

Internal efficiencies observed showed that stone barriers and half – moons differed significantly from zaï. This difference may be related to differences in crop management since it is the same variety that was grown with the same inputs. Internal efficiency values are somewhat lower than those calculated in Togo for sorghum, which are 38 grains per kg of nitrogen (N), 278 kg of grain per kg of phosphorus (P) and 42 kg of grain per kg of potassium (K) (Wopereis et al. 2008). According to Rao (2012), various factors lead to low internal efficiency (loss or inaccessibility of nutrients, interaction between nutrients, unbalanced fertilization, soil problems, diseases, weeds etc.). Good agricultural practices could improve the efficiency of nutrient use. These good practices include good plot maintenance and application of the right amount of fertilizers at the right time and in the right place.

The basic concept of good nutrient management practices is the right fertilizer, at the right rate, at the right time and in the right place (Roberts 2007). It is at this price that improving the efficiency of fertilizer use will be possible. This is also true when combined with water and soil conservation techniques. However, in their practices, farmers use fertilizers well below the recommended rates. This low fertilizer use leads to a decline in soil fertility and productivity. Total average nutrient exports vary according to water and soil conservation techniques. The highest potential supplies were obtained with stone barriers. Exports of nitrogen and phosphorus exceed soils nutrient capacity. This situation leads to the depletion of these soils (Bationo et al. 2012).

6.6.3 Fertilization Options

The performance of the QUEFFS model was excellent for predicting sorghum grain yields under stone barriers (SB) management with organic matter and under zai with or without organic matter. The model assumes a number of conditions are fulfilled including no water stress, controlling weeds, pests and diseases, and calculates yields based on the availability of soil nutrients and N, P and K fertilizers (Smaling and Janssen 1993). Moreover, in addition to the absence of water deficit or flooding, the use of QUEFTS requires good agricultural practices to ensure good root development and well drained and deep soils (Janssen et al. 1990). The stone barriers and zaï techniques would then offer the ideal conditions for the management of soil and water as well as organic matter and fertilizers applied.

6.7 Conclusions and Perspectives

The approaches used allow to identify the limiting nutrients in sorghum production and to measure the impact of soil and water conservation techniques on soil nutrient capacity and sorghum production. This enabled to develop optimal crop management recommendations that are specific to the production sites. Thus new fertilizer recommendations for sorghum have been developed and evaluated in a very short time.

The results obtained with the nutrient omission trials showed that phosphorus is the most limiting nutrient to sorghum production in the watershed, followed by nitrogen. This would explain the low nutrient capacity of soils in phosphorus and nitrogen. The results also showed that nutrient use efficiency varies depending on water and soil conservation techniques. It also clearly showed that these techniques affect soil initial fertility. The results of the nutrient omission trials allowed to derive specific recommendations for the production of sorghum in the North. The development of fertilizer rate recommendation based on the QUEFTS model shows that a $N_{29}P_{11}K_{13}$ formula combined with organic matter is optimal for sorghum production in the semi-arid zone. It should be appropriate to install demonstration plots to compare the $N_{29}P_{11}K_{13}$ formula with the conventional recommendation ($N_{37}P_{10}K_{12}$) in several environments with different water and soil conservation techniques associated or not with organic matter in order to facilitate the adoption of the optimal formula.

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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

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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

Contents

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

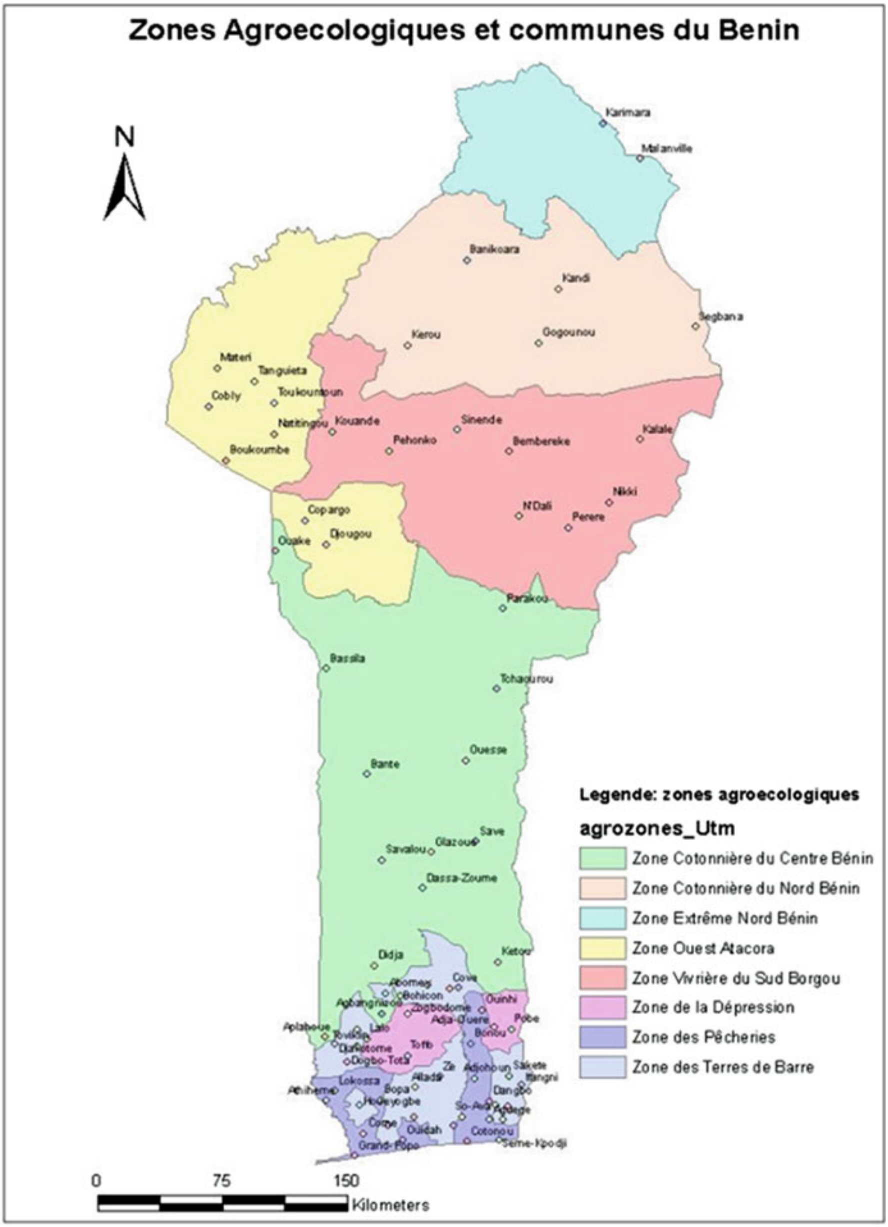

Fig. 7.1 Map of agro-ecological zones of Benin

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% P2O5) and KCl (60% K2O). 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 saturation (%)	pH	CEC (meq/100 g de sol)	Available P (ppm)	Ca/Mg	Mg/K
Concretionned	3.55	0.087	95	6.2	8.68	11.5	3	5
Ferruginous								
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).

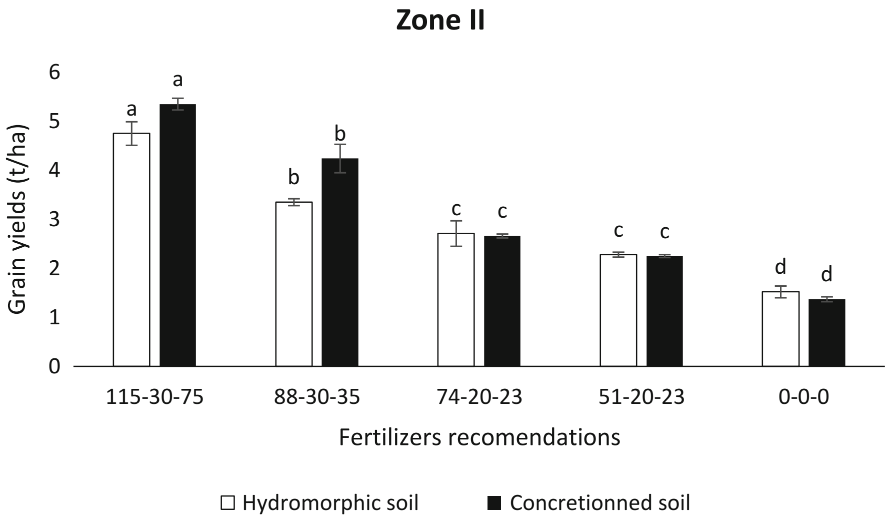

Fig. 7.2 Effect of different combinations of fertilizers on maize grain yields according to soil types in Arbonga (Banikoara)

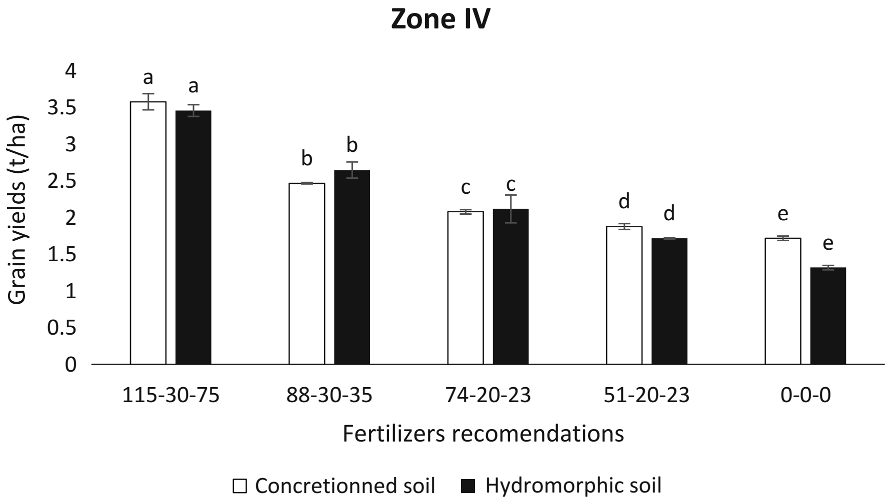

Fig. 7.3 Effect of different combinations of fertilizers on maize grain yield according to soil types in Nanébou (Tanguiéta)

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

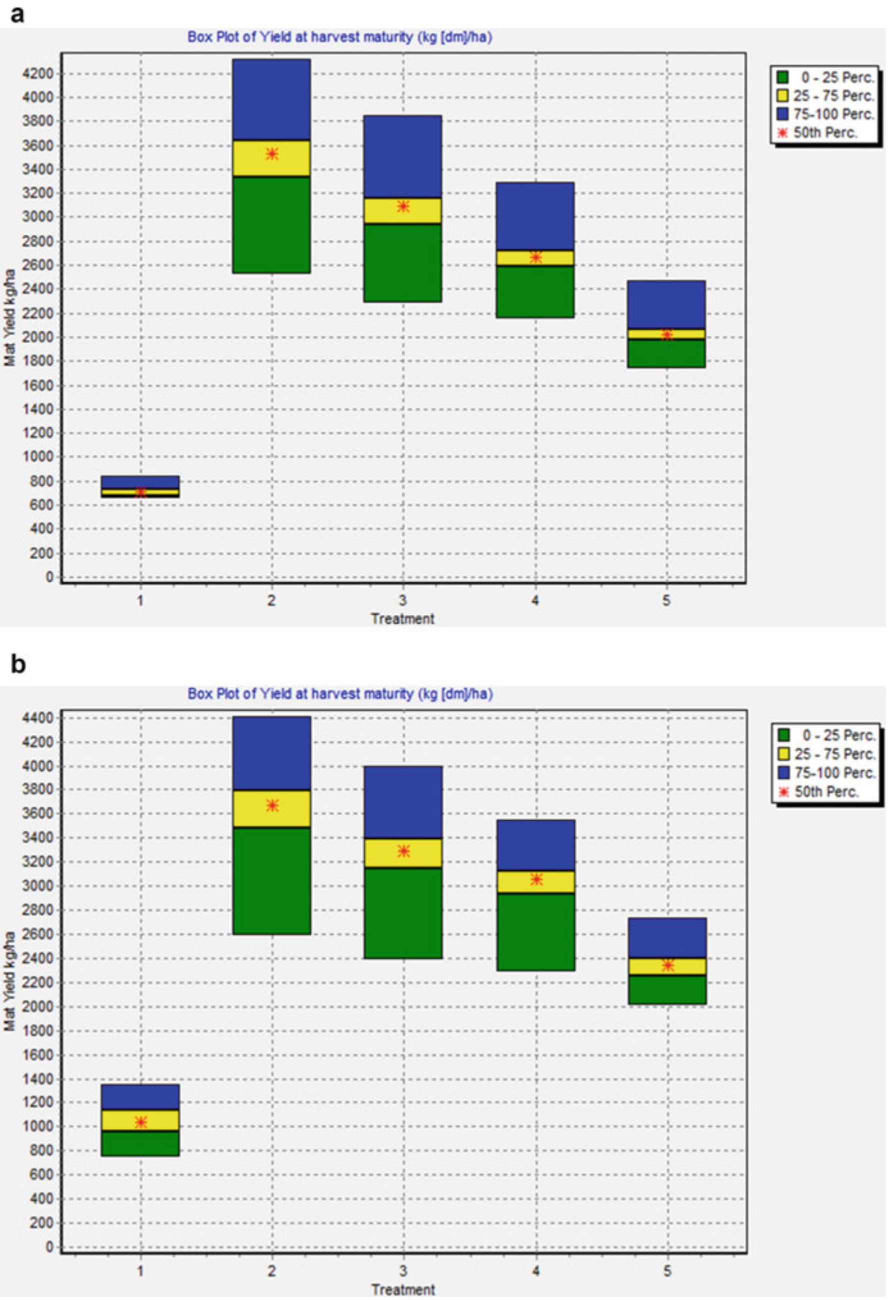

Fig. 7.4 Effect of different fertilizer formulas on grain yields (kg DM/ha) based on biophysical analysis covering the period 1980–2012 for hydromorphic ferruginous soils (**a**) and concretionned ferruginous soils (**b**) in zone II. (1 = 0-0-0; 2 = 115–30-75; 3 = 88-30-35; 4 = 74-20-23; 5 = 51-20-23)

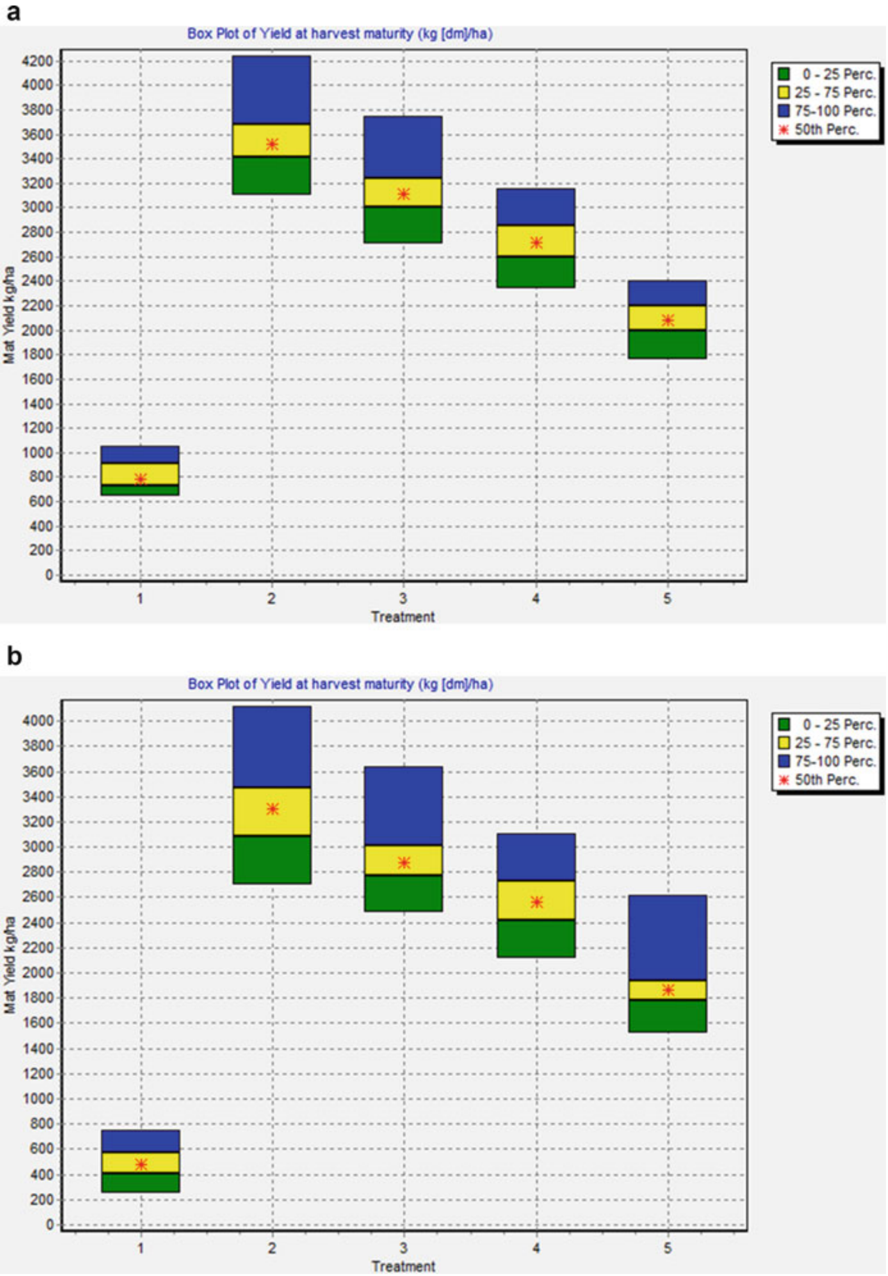

Fig. 7.5 Effect of different fertilizer formulas on grain yields (kg DM/ha) from biophysical analysis covering the period 1980–2012 for concretionned ferruginous soils (**a**) and hydromorphic soils (**b**) in zone IV. (1 = 0–0-0; 2 = 115–30-75; 3 = 88-30-35; 4 = 74-20-23; 5 = 51-20-23)

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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Chapter 8

Decision Support System for Site-Specific Fertilizer Recommendations in Cassava Production in Southern Togo

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Abstracts The Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model recommended as a decision support tool for deriving optimal site-specific fertilizer rates for cassava has limited ability to estimate water-limited yields. We assessed potential and water-limited yields based on the light interception and utilization (LINTUL) modelling approach in order to enhance the determination of fertilizer requirements for cassava production in Southern Togo. Data collected in 2 years field experiments in Sevekpota and Djakakope were used. Potential ranged from 12.2 to 17.6 Mg ha^{-1}, and water-limited yields from 10.4 to 14.5 Mg ha^{-1}. The simulated average fertilizer requirements were 121 kg N, 2 kg P and no K ha^{-1} for a target yield of 9.3 Mg ha^{-1} at Sevekpota, and 103 kg N, 6 kg P and 175 kg K ha^{-1} for a target yield of 9.7 Mg ha^{-1} at Djakakope. The variability of fertilizer requirements was attributed to differences in indigenous soil fertility and water-limited yields. The latter correlated well with rainfall variability over years and sites. Integrating LINTUL output with QUEFTS helped account for location-

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specific weather seasonal variability and enhanced assessment of fertilizer requirement for cassava production in Southern Togo.

Keywords LINTUL · Water-limited yield · Potential yield · QUEFTS · Togo

Contents

8.1 Introduction

Cassava, *Manihot esculenta*, Crantz, is an important staple crop that provides food for about 800 million people across the world. The global production of cassava of fresh storage roots has increased between 2000 and 2013 from 176 to 277 million Mg per year, with about 57% of this production coming from Africa (FAOSTAT 2014). This production increase was associated with expanded cassava cultivated lands and increased yields from 9.7 to 13.0 Mg ha^{-1} from 2000 to 2013 in West Africa. Within the same period, national average fresh storage root yields increased from 9.6 to 14.0 Mg ha^{-1} in Nigeria as against 5.6 to 6.6 Mg ha^{-1} in Togo. These yields remain relatively low, since 21 Mg ha^{-1} storage roots dry matter, equivalent to 55–58 Mg ha^{-1} fresh storage roots (about 36–38% dry matter content) has been achieved in researcher-managed field experiments in Kumasi and Davié in Togo (Ezui et al. 2016).

A key constraint to agriculture in Sub-Saharan Africa (SSA) is rainfall, which is generally erratic in amount and distribution. As a consequence, the crop suffers long droughts, which cause significant yield reduction. The occurrence of a long drought period can cause up to 60% yield losses within 1–5 months after planting (Alves 2002; Connor et al. 1981).

Another key constraint to crop production in Sub-Saharan Africa is declining soil fertility (Smaling et al. 1997). Cassava is cultivated with minimal or without external fertilizer application (Somana and Nkpenu 2008), whereas most harvest products are removed from the fields, thus decreasing soil fertility. Poor soil fertility is further aggravated by the lack of fertilizer recommendations for cassava in Togo. The rare applications of fertilizer in cassava production systems are often allocated to the intercrop, such as maize in Southern Togo. In that case, it is recommended to apply 300 kg NPK 15-15-15 plus 100 kg urea ha^{-1} (91 kg N, 19.6 kg P and 37.5 kg K ha^{-1}) for maize-cassava intercropping (Somana and Nkpenu 2008). In order to increase cassava productivity and profitability, the use of site-specific fertilizer rates is recommended (Ezui et al. 2016). For this purpose, a modelling approach based on the Quantitative Evaluation of the Fertility of Tropical Soil (QUEFTS) has been used to derive fertilizer requirements of cassava for Ghana and Togo by Ezui et al. (2016). However, this model requires a sound estimate of the water-limited potential yield, which is used as maximum yield that is an input data for the model.

A limited number of process-based models have been developed to assess cassava potential and water-limited yields. The GUMCAS model (GUMCAS derived from gumaya meaning "simulate" in Tagalog, the national language of the Philippines) by Matthews and Hunt (1994), also referred to as CROPSIM-Cassava in the decision support system for agro-technology transfer (DSSAT) framework (Jones et al. 2003; Singh et al. 1998) is cited among the most recommended process-based models for cassava. These models are very detailed and have not yet been adapted for the rainfed West African conditions. Moreover, the dormancy and the recovery from dormancy which commonly occur in Southern Togo as a consequence of a long drought period towards the end of the cropping season and their effects on cassava storage roots are not accounted for in GUMCAS.

In order to estimate water-limited yields with locally measured parameters within the rainfed conditions of West Africa, a light interception and utilization (LINTUL) approach (Spitters 1990) was used (Ezui 2017). LINTUL1 calculates potential crop growth, whereas LINTUL2 aims at assessing crop growth from daily intercepted photosynthetically active radiation (PAR) and light use efficiency under water-limited growth conditions (Spitters and Schapendonk 1990), was adapted for cassava (LINTUL-Cassava) (Ezui 2017). The model assumes that biomass growth rate is linearly correlated with the amount of light intercepted with a constant light or radiation use efficiency, following Monteith (1977).

The aim of this study is to assess water-limited yields of cassava using the LINTUL model and adjust site-specific fertilizer recommendations by using QUEFTS in Southern Togo.

8.2 Material and Methods

8.2.1 Description of LINTUL-Cassava

The LINTUL-Cassava simulates cassava growth and development under potential and water-limited conditions (Ezui 2017). Data requirements include daily weather data (solar radiation, minimum and maximum temperature, vapor pressure, wind speed and rainfall), soil data (rooting depth, hydraulic properties such as wilting point, field capacity, water content at saturation), and crop genetic characteristics. The model assumed three development phases as in CROPSIM-Cassava: (i) planting to emergence, (ii) emergence to first branching, (iii) first branching to maturity or harvest. The model describes nine main growth processes: the growth of (i) stem cuttings, (ii) leaf area index, (iii) biomass, (iv) leaf, stem, fibrous root and storage roots, then (v) senescence, (vi) dry matter partitioning, (vii) dormancy; (viii) biomass production upon the recovery from dormancy and, finally, (ix) the growth of rooting depth. Temperature was the key environmental factor affecting the growth processes. Cassava growth was inhibited below 15 °C and beyond 40 °C (Alves 2002). Considering as well, the optimal temperature range of cassava growth between 25 and 29 °C, four cardinal temperatures were used: base temperature (TBASE), optimum temperatures 1 & 2 (TOPT1 & TOPT2) and high temperature (THIGH). A full description of the model is provided by Ezui (2017).

Biomass production (GTOTAL) for the water-limited conditions was modelled as a function of light use efficiency (LUE), of the cumulative light interception (PARINT) and of the transpiration reduction factor (TRANRF). A TRANRF value of 1 (water content at field capacity, no water stress) was considered under potential conditions.

$$\mathrm{GTOTAL} = \mathrm{LUE} \times \mathrm{PARINT} \times \mathrm{TRANRF} \tag{8.1}$$

$$\mathrm{PARINT} = 0.5 \times \mathrm{DTR} \times (1. - \mathrm{EXP}(-\mathrm{K} \times \mathrm{LAI})) \tag{8.2}$$

$$\mathrm{LUE} = \mathrm{LUE\_OPT} \times f(\mathrm{TBASE}, \mathrm{TOPT1}, \mathrm{TOPT2}, \mathrm{THIGH}, \mathrm{DAVTMP}) \tag{8.3}$$

GTOTAL [g m^{-2} ground d^{-1}]; PARINT [MJ PAR m^{-2} ground d^{-1}] was defined as the amount of light intercepted by the canopy per day and per m^2, assuming an exponential light profile in the plant canopy from its top towards the soil; LUE [g MJ PAR^{-1}] was expressed as a function of LUE_OPT (LUE under optimal condition) that was a parameter, which value was null below TBASE and beyond THIGH, maximum between TOPT1 and TOPT2, and linearly increasing between TBASE and TOPT1, and decreasing between TOPT2 and THIGH; K was the light extinction coefficient; DTR [MJ m^{-2} d^{-1}] was the daily total radiation; 0.5 is the conversion factor from MJ DTR to MJ PAR. The growth of stems (RWST), green leaves (RWLVG), fibrous roots (RWRT) and storage roots (RWSO) were modelled based on fractions of the total biomass (Eqs. 8.4, 8.5, 8.6 and 8.7). The fractions were derived based on empirical data and literature.

$$RWST = (GTOTAL + |RWCUTTING|) \times FST \tag{8.4}$$

$$RWLVG = (GTOTAL + |RWCUTTING|) \times FLV - DLV \tag{8.5}$$

$$RWRT = (GTOTAL + |RWCUTTING|) \times FRT \tag{8.6}$$

$$RWSO = (GTOTAL + |RWCUTTING|) \times FSO \tag{8.7}$$

DLV is the rate of leaf death. *FST, FLV, FRT* and *FSO* are the fractions of the produced dry matter that were allocated to the stems, the leaves, the fibrous roots and the storage organs, respectively. The integration of *RWST*, *RWLVG*, *RWRT* and *RWSO* over time led to the amount of dry matter accumulated (g DM m^{-2}) for stem (*WST*), green leaves (*WLVG*), fibrous roots (*WRT*) and storage organs (*WSO*).

8.2.2 Field Experiments

8.2.2.1 Field Experiment for Model Calibration

The model was parameterized using a dataset collected in a field experiment in Sevekpota (6.437°N, 0.959°E, with an elevation of 121 m above sea level – masl) located in southern Togo. A bimodal rainfall regime covered the location with two growing seasons: from mid-March through July and from September through mid-November. The experiment was carried out on a ferruginous soil with a hard pan at about 40–80 cm depth. Healthy stem cuttings of the disease resistant and drought tolerant cultivar Gbazekoute (TME 419) grown across West Africa were planted on April 23, 2013. The experiment was laid out following a randomised complete block design with three replicates of 15 NPK combinations at the rates of 0, 50 and 100 kg N and K ha^{-1}, and 0, 20 and 40 kg P ha^{-1}. To ensure no nutrient limitations, only data from treatments with N, P and K rates above zero were used for model parameterisation between 75th to 95th percentiles of the variable of interest of the dataset. Crop parameters derived at different measurement times included: specific leaf area (SLA), light extinction coefficient (K), radiation or light use efficiency (RUE). More details on this experiment and method of determination of these parameters are described by Ezui et al. (2017).

8.2.2.2 Field Experiments for LINTUL-Cassava Testing

Experimental data collected at Djakakope (6.464°N, 1.597°E, 86 masl) between 2012 and 2014 (Year 1 from 2012 to 2013, Year 2 from 2013 to 2014), and at Sevekpota in Year 1 were used for model testing. The experimental design and the type of data collected were identical to the experiment at Sevekpota in Year 2. The experiments were laid out on different fields in Years 1 and 2 at each site. Rain gauges placed in-situ were used for rainfall measurement. Data on solar radiation were supplied by NASA Power (http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov), while minimum and maximum temperatures, air humidity, and wind speed data were provided by the nearest weather station which was in Lomé (6.167°N, 1.250°E, 19.6 masl) for Sevekpota site and in Tabligbo (6.583°N, 1.500°E, 40 masl) for Djakakope site. Simulation results and observations were compared to assess the robustness of the model using the Normalised Root Mean Squared Error ($NRMSE$) (Loague and Green 1991), the slope of the regression line between measured and simulated values, and the coefficient of determination R^2. Composite soil samples were collected at all sites before crop establishment, and analysed by ICRISAT laboratory in Niamey (Niger). Particle size was determined using the hydrometer method, pH (H2O, 1:2.5) with a glass electrode pH meter, organic carbon by Walkley-Black method, total N by Kjeldahl digestion method, and available P by Bray 1 method.

Table 8.1 Initial soil chemical and physical properties of the study sites at 0–20 cm depth

	Sevekpota		Djakakope	
Properties	2012, Field 1	2013, Field 2	2012, Field 1	2013, Field 2
SOC, g kg^{-1}	11.5	12.2	6.2	4.7
SON, g kg^{-1}	0.9	0.8	0.4	0.3
Na^+, mmol kg^{-1}	1.15	0.40	0.09	0.14
K^+, mmol kg^{-1}	3.52	1.35	0.38	0.66
Ca^{2+}, mmol kg^{-1}	18.1	13.6	18.2	17.3
Mg^{2+}, mmol kg^{-1}	5.32	4.47	7.1	7.0
Sand, g kg^{-1}	536	680	835	858
Silt, g kg^{-1}	163	150	52	45
Clay, g kg^{-1}	301	170	113	97
pH H_2O, 1:2.5	6.5	6.5	6.5	6.5
P-Bray-I, mg kg^{-1}	1.9	3.2	4.5	10.4
P-total, mg kg^{-1}	189	202	155	194

Exchangeable cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) were extracted using a single extraction with dilute Silver-Thiourea (AgTU) solution (0.01 M Ag+), measured using an atomic absorption spectrophotometer for Ca^{2+} and Mg^{2+}, and a flame spectrophotometer for Na^+ and K^+. The physical and chemical soil analysis results are presented in Table 8.1.

8.3 Site-specific Fertilizer Recommendation

After calibration and testing, LINTUL-Cassava was used to simulate potential and water-limited yields for the period of 2002–2015. Daily weather data comprising solar radiation, minimum and maximum temperature, wind speed and rainfall were downloaded online from NASA Power using the geographic coordinates of these sites. We thereafter estimated the target yield to be used for deriving fertilizer requirements by considering 75% and 50% of the water-limited yield. According to Ezui et al. (2016), nutrient use efficiency of cassava is maximized with target yields lower than 77–93% of the maximum attainable, which is the water-limited yield in the case of the current study.

Fertilizer requirements were obtained by dividing the additional nutrient uptake by the fertilizer recovery fraction of 0.50, 0.21 and 0.49 for N, P and K (Ezui et al. 2016). The additional uptake was derived by subtracting the value of the indigenous soil fertility from the value of the total nutrient requirement. Plant uptakes measured on non-fertilized fields were used as proxy for assessing the amounts of indigenous soil N, P and K. The total nutrient requirement was calculated by multiplying the target yield by the NPK requirement of 16.2 kg N, 2.7 kg P and 11.7 kg to produce 1 Mg storage roots DM at harvest index of 0.5 (Ezui et al. 2016).

The reciprocal NPK requirement was assessed based on the balanced nutrition approach of QUEFTS for cassava (Ezui et al. 2016).

8.4 Results

8.4.1 *Yield Prediction Performance of LINTUL-Cassava*

Simulated yields were in good agreement with the observed yields, as showed in the model testing (Fig. 8.1). The slope of the regression line was close to 1, with high R^2 value, and low *NRMSE* of 13% for the observed storage roots yields.

8.4.2 *Potential and Water-Limited Yields of Cassava in Djakakope and Sevekpota*

Simulated potential and water-limited yields are presented in Fig. 8.2. Potential yields ranged from 12.3 to 17.8 Mg ha^{-1}, and water-limited yields from 10.4 to

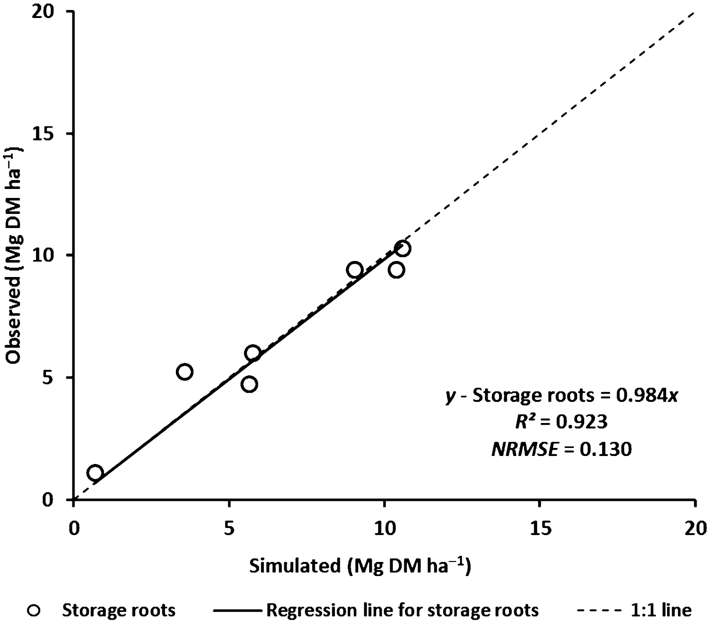

Fig. 8.1 Model performance in simulating storage roots yields in fields different from the field for which the model was calibrated. The model testing fields comprised Sevekpota Year 1 and Djakakope Years 1 and 2, and the observed yield data were measured in sequential harvests

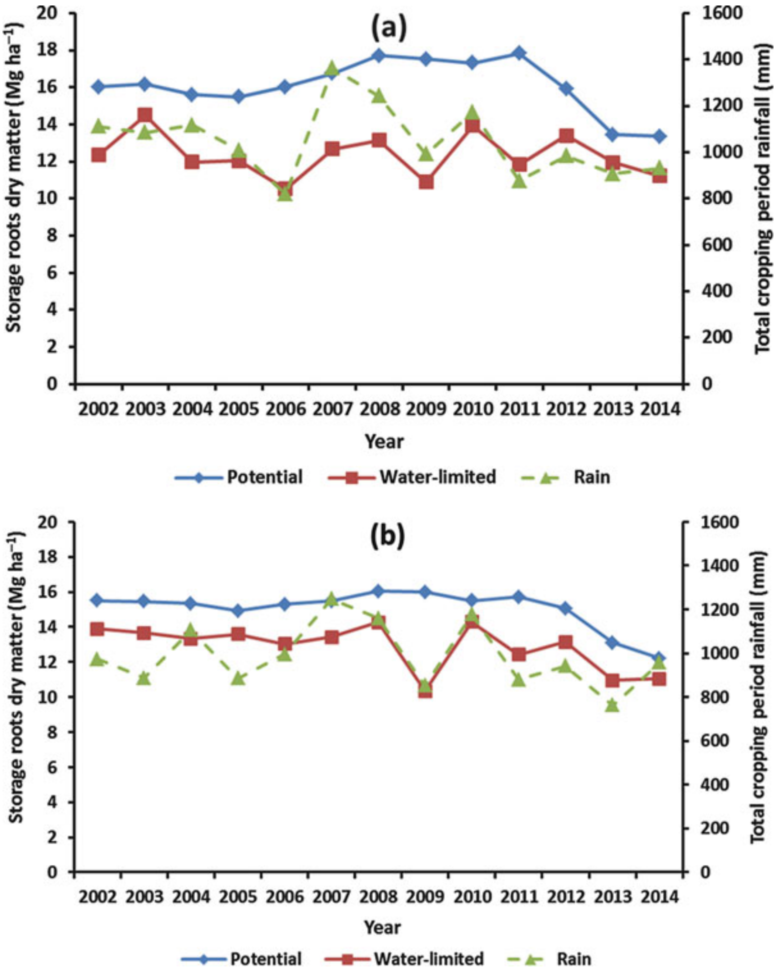

Fig. 8.2 Simulated yearly potential and water-limited storage roots yields and total rainfall from planting to harvest with planting years 2002–2014

14.5 Mg ha^{-1} across the two sites from 2002 through 2014. The lowest potential yields were obtained in the last 2 years due to relatively lower cumulative amount of intercepted light caused by smaller cumulative incident solar radiation compared to the other years (data not shown). The potential yields were less variable than the water-limited yields, which depended on rainfall. Water limited yield reflected variability in rainfall.

Table 8.2 Indigenous soil supply of N, P and K in Sevekpota and Djakakope in Years 1 and 2

Site/year	Indigenous soil supply (kg ha^{-1})		
	N	P	K
Sevekpota			
Year 1	81.7	14.6	126.9
Year 2	97.3	39.0	128.0
Average	*89.5*	*26.8*	*127.5*
Djakakope			
Year 1	110.8	24.9	16.6
Year 2	98.6	26.6	37.8
Average	*104.7*	*25.8*	*27.2*

8.4.3 Indigenous Soil Fertility Assessment

Indigenous soil fertility varied between fields, with each year and site having a unique experimental field (Table 8.2). Indigenous soil K supply was larger in Sevekpota than in Djakakope. Indigenous soil P supply was approximately similar in the two sites. Indigenous soil N was larger in Djakakope than in Sevekpota.

8.4.4 Site-Specific Fertilizer Requirements Per Target Yields of Cassava Storage Roots

Fertilizer requirements varied per target yield, which was a function of water-limited yield (Table 8.3). The total nutrient requirements (soil and fertilizer) to achieve target yields of 7.8–10.9 Mg ha^{-1} storage roots dry matter representing 75% of the location-specific water-limited yields were 126–176 kg N, 21–29 kg P and 91–127 kg K across the two zones, assuming a harvest index of 0.5 with a reciprocal nutrient requirement of 16.2 kg N, 2.7 kg P and 11.7 kg K to produce 1 Mg storage roots dry matter (Ezui et al. 2016). By considering the indigenous soil fertility of each site, fertilizer requirements estimated ranged from 77 to 173 kg N, 0 to 12 kg P and no K at Sevekpota, as against from 42 to 138 kg N, 0 to 15 kg P and 130 to 200 kg K ha^{-1} at Djakakope. These correspond to an average fertilizer requirement of 121 kg N, 2 kg P and no K ha^{-1} for a target yield of 9.3 Mg ha^{-1} at Sevekpota, and 103 kg N, 6 kg P and 175 kg K ha^{-1} for a target yield of 9.7 Mg ha^{-1} at Djakakope. At lower target yields of 5.2–7.2 Mg ha^{-1} storage roots dry matter representing 50% of the water-limited yields, lower fertilizer rates were required (Table 8.4): 0–56 kg N ha^{-1}, no P and no K at Sevekpota, and 0–22 kg N ha^{-1} and 68–115 kg K ha^{-1} at Djakakope.

Table 8.3 Fertilizer requirements for target yields set at 75% of the water-limited yields simulated for the period of 2002–2014

Site/ year	Potential	Water-limited	Target yield	Total requirement (kg ha^{-1})			Additional uptake (kg ha^{-1})			Fertilizer needs [a] (kg ha^{-1})		
	(Mg ha^{-1})			N	P	K	N	P	K	N	P	K
Sevekpota												
2002	16.0	12.3	9.2	149.9	25.0	108.3	60.4	0.0	0.0	121	0	0
2003	16.2	14.5	10.9	176.1	29.4	127.2	86.6	2.6	0.0	173	12	0
2004	15.6	12.0	9.0	145.5	24.2	105.1	56.0	0.0	0.0	112	0	0
2005	15.5	12.1	9.1	146.4	24.4	105.7	56.9	0.0	0.0	114	0	0
2006	16.0	10.5	7.9	127.8	21.3	92.3	38.3	0.0	0.0	77	0	0
2007	16.8	12.7	9.5	153.9	25.6	111.1	64.4	0.0	0.0	129	0	0
2008	17.7	13.1	9.8	159.7	26.6	115.4	70.3	0.0	0.0	141	0	0
2009	17.5	10.9	8.2	132.3	22.0	95.5	42.8	0.0	0.0	86	0	0
2010	17.3	13.9	10.4	169.4	28.2	122.4	79.9	1.4	0.0	160	7	0
2011	17.8	11.8	8.9	143.6	23.9	103.7	54.2	0.0	0.0	108	0	0
2012	15.9	13.4	10.1	162.8	27.1	117.6	73.3	0.3	0.0	147	2	0
2013	13.4	11.9	8.9	145.1	24.2	104.8	55.6	0.0	0.0	111	0	0
2014	13.4	11.2	8.4	136.5	22.7	98.6	47.0	0.0	0.0	94	0	0
Min	13.4	10.5	7.9	127.8	21.3	92.3	38.3	0.0	0.0	77	0	0
Max	17.8	14.5	10.9	176.1	29.4	127.2	86.6	2.6	0.0	173	12	0
Djakakope												
2002	15.5	13.9	10.4	168.8	28.1	121.9	64.1	2.4	94.7	128	11	193
2003	15.6	13.7	10.3	166.1	27.7	120.0	61.4	1.9	92.8	123	9	189
2004	15.4	13.3	10.0	161.9	27.0	117.0	57.2	1.2	89.8	114	6	183
2005	15.0	13.6	10.2	165.1	27.5	119.2	60.4	1.8	92.0	121	8	188
2006	15.3	13.0	9.8	158.3	26.4	114.3	53.6	0.6	87.1	107	3	178
2007	15.6	13.4	10.1	163.1	27.2	117.8	58.4	1.4	90.6	117	7	185
2008	16.1	14.3	10.7	173.4	28.9	125.2	68.7	3.1	98.0	137	15	200
2009	16.1	10.4	7.8	125.8	21.0	90.9	21.1	0.0	63.7	42	0	130
2010	15.7	14.3	10.7	173.7	28.9	125.4	69.0	3.2	98.2	138	15	200
2011	15.9	12.4	9.3	150.8	25.1	108.9	46.1	0.0	81.7	92	0	167
2012	15.2	13.1	9.8	159.6	26.6	115.3	54.9	0.8	88.1	110	4	180
2013	13.3	11.0	8.3	133.1	22.2	96.1	28.4	0.0	68.9	57	0	141
2014	12.3	11.0	8.3	134.2	22.4	97.0	29.5	0.0	69.8	59	0	142
Min	12.3	10.4	7.8	125.8	21.0	90.9	21.1	0.0	63.7	42	0	130
Max	16.1	14.3	10.7	173.7	28.9	125.4	69.0	3.2	98.2	138	15	200

[a] Fertilizer needs were using fertilizer recovery fractions of 0.50, 0.21 and 0.49 for N, P and K, respectively, indigenous soil fertility values of 89.5 kg N, 26.8 kg P and 127.5 kg K in Sevekpota, and 104.7 kg N, 25.8 kg P and 127.5 kg K in Djakakope, and based on NPK requirements of 16.2 kg N, 2.7 kg P and 11.7 kg to produce 1 Mg storage roots DM at harvest index of 0.5

Table 8.4 Fertilizer requirements for target yields set at 50% of the water-limited yields simulated for the period of 2002–2014

Site/year	Target yield	Total requirement (kg ha^{-1})			Additional uptake (kg ha^{-1})			Fertilizer needs (kg ha^{-1})		
		N	P	K	N	P	K	N	P	K
Sevekpota										
2002	6.2	99.9	16.7	72.2	10.4	0.0	0.0	21	0	0
2003	7.3	117.4	19.6	84.8	27.9	0.0	0.0	56	0	0
2004	6.0	97.0	16.2	70.0	7.5	0.0	0.0	15	0	0
2005	6.1	97.6	16.3	70.5	8.1	0.0	0.0	16	0	0
2006	5.3	85.2	14.2	61.5	0.0	0.0	0.0	0	0	0
2007	6.4	102.6	17.1	74.1	13.1	0.0	0.0	26	0	0
2008	6.6	106.5	17.7	76.9	17.0	0.0	0.0	34	0	0
2009	5.5	88.2	14.7	63.7	0.0	0.0	0.0	0	0	0
2010	7.0	112.9	18.8	81.6	23.5	0.0	0.0	47	0	0
2011	5.9	95.8	16.0	69.2	6.3	0.0	0.0	13	0	0
2012	6.7	108.5	18.1	78.4	19.0	0.0	0.0	38	0	0
2013	6.0	96.7	16.1	69.9	7.2	0.0	0.0	14	0	0
2014	5.6	91.0	15.2	65.7	1.5	0.0	0.0	3	0	0
min	5.3	85	14	62	0.0	0.0	0.0	0	0	0
max	7.3	117	20	85	27.9	0.0	0.0	56	0	0
Djakakope										
2002	7.0	112.6	18.8	81.3	7.9	0.0	54.1	16	0	110
2003	6.9	110.7	18.5	80.0	6.0	0.0	52.8	12	0	108
2004	6.7	108.0	18.0	78.0	3.2	0.0	50.8	6	0	104
2005	6.8	110.1	18.3	79.5	5.3	0.0	52.3	11	0	107
2006	6.5	105.5	17.6	76.2	0.8	0.0	49.0	2	0	100
2007	6.7	108.7	18.1	78.5	4.0	0.0	51.3	8	0	105
2008	7.2	115.6	19.3	83.5	10.9	0.0	56.3	22	0	115
2009	5.2	83.9	14.0	60.6	0.0	0.0	33.4	0	0	68
2010	7.2	115.8	19.3	83.6	11.1	0.0	56.4	22	0	115
2011	6.2	100.5	16.8	72.6	0.0	0.0	45.4	0	0	93
2012	6.6	106.4	17.7	76.8	1.7	0.0	49.6	3	0	101
2013	5.5	88.7	14.8	64.1	0.0	0.0	36.9	0	0	75
2014	5.5	89.5	14.9	64.6	0.0	0.0	37.4	0	0	76
Min	5.2	84	14	61	0.0	0.0	33.4	0	0	68
Max	7.2	116	19	84	11.1	0.0	56.4	22	0	115

8.5 Discussion

The present study showed how variable potential and water-limited yields of cassava can be and how they can affect the estimation of fertilizer requirements in Southern Togo. This stresses the usefulness of considering location-specific water-limited yield into QUEFTS modelling in order to provide fertilizer recommendations that account for weather seasonal variability and location-specific potential yields. Further assessment of the likelihood of occurrence of a given water-limited yield across historical weather data may lead to providing location-specific fertilizer recommendations derived based on that water-limited yield.

The difference between potential and water-limited yields provides an indication of the drought stress in the growing season. The bigger the gap between potential and water-limited yield, the more severe the drought stress, which can cause up to 60% yield losses when it occurs with the first 5 months after planting (Alves 2002; Ezui 2017).

The potential dry matter yields of 12.3 to 17.8 Mg ha^{-1}, equivalent to 34–49 Mg ha^{-1} fresh roots (assuming a dry matter content of 36%), are close to the attainable fresh yield of 40 Mg ha^{-1} reported for TME 419 (Gbazekoute) by the National Research System in Togo (Somana and Nkpenu 2008). However, up to 60 Mg ha^{-1} fresh storage roots of this cultivar was obtained in Nigeria (Odedina et al. 2009). Our study sites seem unsuitable for the cultivar to express this potential of 60 Mg ha^{-1}. However, achieving yields closer to the simulated water-limited yields than the actual national average yield of 5.6 to 6.6 Mg ha^{-1} fresh roots (2 Mg ha^{-1} dry matter storage roots) in Togo will be a major achievement towards improving smallholders' livelihood in Southern Togo.

Fertilizer requirements were different between the two sites, especially for K (Tables 8.3 and 8.4). Fertilizer K requirements were necessary only in Djakakope, because soil K was very low at Djakakope (Table 8.1). This low soil K characterizes Rhodic Ferralsols in West Africa (Carsky and Toukourou 2005). The ferruginous soils at Sevekpota supplied enough K to achieve the various target yields. Nitrogen requirements were variable across the two zones. Contrariwise, P requirements were in general low (Table 8.3), even nil with low target yields in the two zones (Table 8.4), despite the fact that soil available P was low at both sites (Table 8.1). Fertilizer P requirements of cassava were low at these sites likely due to enhancing effects of mycorrhizal P uptake efficiency of cassava (Sieverding and Howeler 1985). These results highlight the need for site-specific fertilizer recommendations for cassava production in Southern Togo, with the possibility to adjust the target yield to farmers' objectives.

The simulated N and K fertilizer requirements were meant to achieve high target yields of 7.8–10.9 Mg ha^{-1} (Table 8.3) and low target yields of 5.2–7.3 Mg ha^{-1} (Table 8.4) at balanced nutrition. Previous studies showed that fertilizer requirements determined using balanced nutrition approach of QUEFTS gave higher nutrient use efficiency and larger profitability compared to blanket fertilizer recommendations (Ezui et al. 2016). Lower target yields implying lower fertilizer requirements, could be chosen by the farmers, depending on his/her financial capacities. Nevertheless, further assessment of the current recommendations shall be carried out with more economic considerations to ensure wider usage.

The approach of combining in series LINTUL-Cassava results with QUEFTS for deriving fertilizer requirements will facilitate the extrapolation of the results. Since LINTUL-Cassava is a process-based model that assesses cassava growth as affected by daily weather data, the simulation of potential and water-limited yields can be extrapolated to other cassava growing environments. Hence, the total nutrient requirements can be assessed for a wider area. However, the determination of fertilizer rates will require a sound assessment of the indigenous soil nutrient supplies. The assessment of the indigenous soil nutrient supplied should be based on major soil types or agro-ecology to avoid having too many specific recommendations. Data may be collected from previous experiments to define relationships between nutrient uptake and soil chemical properties in various cassava production systems to achieve this goal.

This fertilizer recommendation framework should be further improved through data collected in farmer' field validation trials across large ranges of locations and agro-ecological zones in order to increase its effectiveness. These validation trials should consider also economic analyses, which may help integrate economic analysis component into this framework for assessing the profitability of the recommended rates. The current framework uses the two models in series. Further improvement should also consider integrating QUEFTS equations in LINTUL so that nutrient dynamics are captured directly in relation to water availability for better estimate of nutrient requirements for enhanced cassava production.

8.6 Conclusion

The current study provided a framework for site-specific fertilizer recommendation for cassava production in Southern Togo. The assessment of potential and water-limited yields helped the determination of the maximum target yield values at balanced nutrition, and made more location-specific the QUEFTS assessment of fertilizer requirements based on climate seasonal variabilities. Testing these model outputs through validation trials is recommended to improve this decision support system framework for enhanced cassava production in Southern Togo.

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Chapter 9
Effects of Split Mineral Fertilizer Applications on the Growth and Productivity of Three Tomato Varieties (*Lycopersicon esculentum Mill.*) in Rainy Season Cropping

Ouango Koala and Jérôme Bélem

Abstract The objective of this study was to evaluate the effects of three frequencies of mineral fertilizer applications (NPK and Urea) on the growth and productivity of tomato produced in the rainy season. Three varieties of tomato: Padma, Thorgal and Tomy were used for a trial set up at the Kamboinsé Research Station under shelter "insect proof" to evaluate their response to three types of mineral fertilizer applications (NPK and Urea). The experimental design used was a split-plot with 4 replicates. Fertilizer use frequency (F1: splitting in 6 applications with an application frequency of 2 weeks; F2: splitting in 4 applications with an application frequency of 3 weeks; and F3: a single application for NPK and two applications for urea) was the main factor while the variety was the secondary factor. Observations and measures focused, among others, on seedling raising date, flowering date, plant height, height of insertion of the first floral bouquet, fruit setting date, harvest date, number of floral bouquets per plant, number of clustered fruits per plant, number of fruits per plant, total weight of fruit per plant, average weight of a fruit, output, firmness and soluble dry matter content of the fruits.

The results achieved highlighted the positive effect of the application every 3 weeks of NPK and urea (F2) on plant height. Results also showed that the application of NPK and urea every other week (F1) increased yields by 51% and soluble dry matter content by 19% compared to conventional application (F3). On the other hand, regarding fruit firmness, the single application of NPK and urea (F3) gave the best results in comparison with split applications (F1 and F2). Results also showed that the Thorgal variety was the best in terms of growth under the F2 application type. The Padma and Tomy varieties gave higher yields and higher

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soluble dry matter content with F1 fertilizer application. The Tomy variety produced the firmest fruits with the single fertilizer application F3.

Thus results achieved indicate that high frequency of fertilizer applications (F1) improves the rain-fed tomato productivity in terms of quantity and quality. This method can be exploited not only to reduce tomato shortages during the rainy season but also to improve diet quality for the Burkinabè population.

Keywords Split application · Single application · Mineral fertilizer · Tomato · Variety · Rainy season crop

Contents

9.1 Introduction

In sub-Saharan Africa, soils have low inherent fertility due to natural constraints that are specific to each agro-ecological zone (Nyembo et al. 2013). According to Bado et al. (1991), agriculture in these countries is characterized by low productivity. In Burkina Faso, low crop yields are largely due to low rainfall (Bado et al. 1991; Sedego et al. 1997) and poor soils (Bado 1994; Sedego et al. 1997). Moreover, nutrients exported by harvests on already poor soils are not adequately replenished.

The low inherent soil nutrient content explains the efficiency of mineral fertilizers in raising crop yields (Kabrahy et al. 1996; Sedego et al. 1997). Improving soil fertility through the use of nutrients in mineral or organic forms, increases water efficiency and crop yields (Sedego et al. 1997). Under these conditions, mineral fertilizer becomes a determining production factor.

However, the use of mineral fertilizers on food crops in rural areas remains insignificant due to farmers' low purchasing power (Nyembo et al. 2013). Nevertheless, Burkinabè farmers strive to increase the use of mineral fertilizers on vegetable crops given the financial contribution of these crops to the improvement of their incomes. Indeed, since the 1990s, the fruit and vegetable sector has emerged as an important source of agricultural growth and poverty reduction (Mahrh 2008).

Tomato is the most important vegetable crop in Burkina Faso. It ranks first in terms of quantity produced (INERA/CREAF 2010) and monetary incomes (Masa 2012). However, for decades, tomato crops have been grown mainly during the dry season due to the lack of or inaccessibility of varieties adapted to the rainy season. The amounts of fertilizers applied to this dry season crop are 450 kg/ha of NPK and

200 kg/ha of urea. These amounts are brought in a single application for NPK and in two applications for urea.

In recent years, scientific research has focused on evaluating new imported varieties of tomato under our rain-fed based agro-ecological conditions and breeding new varieties (FBT1, FBT2 and FBT3, etc.) in order to increase the availability of this vegetable during the rainy period. At farmers' level, the mineral fertilization of this rainy season production is done in the same way as for the dry season production. However, if during the dry season water supplies are controlled, which limits mineral nutrient losses through leaching; this is not the case in the rainy season. Indeed, the use of the single application of mineral fertilizers to the crop in the rainy season, as is the case in dry season, increases nutrient losses. Rainfall, which is heavier and not controlled like irrigation in the dry season, accelerates nitrogen nitrification and increases losses through leaching. According to Pieri (1982), the amount of nitrogen lost during the rainy season in sandy soils varies between 10 kg/ha and 50 kg/ha. The leaching process is all the more accentuated as the water height at the ground surface is high (Ganry 1990). In leached ferruginous tropical soils, 1 mm of rain causes nitrates to leach to the lower layers of the soil, which can be as low as 70 mm (Ganry 1990). These high leaching levels are combined with losses through runoff. Gigou and Chabalier (1987) observed nitrogen losses through water erosion of about 11 kg/ha under maize crop. The nitrate ion is the main lost nutrient. These ions carry with them calcium and magnesium (Gigou and Chabalier 1987). These losses may also be due to wind erosion (Falisse et al. 1994).

Furthermore, even in dry season, the availability of the nutrients applied at the beginning of the growing season does not always coincide with the periods when the needs of the tomato are greatest. In the soil, nitrogen, which plays a pivotal role in the fertilization process, is extremely mobile, its efficiency and loss depend on the composition of the fertilizers used and their application periods (Nyembo et al. 2013). In general, ammonia from urea is fixed as NH_4+on clay fractions and on soil organic matter (MO) (FAO 2003). This also applies to phosphorus and potassium. However, as soils in Burkina Faso are very poor in organic matter (Sedogo 1981), irrigation and / or rainfall lead to clay dispersing, causing nutrient losses through leaching. In addition, low soil organic matter content greatly reduces cation exchange capacity (CEC). This limits the capacity for the sequestration of K^+, Ca^{2+} and Mg^{2+}. According to Charbeau (2013) CEC characterizes the size of soil "pantry" and indicates whether it can be emptied and filled up rapidly or over a long period of time. Phosphorus fixation is also limited by the weak captions, particularly Ca^{2+}, on the absorbing complex. These result in low tomato yields in Burkina Faso compared to world data. In 2005, tomato yields were estimated at 24 tons/ha and 26.2 tons/ha in 2012 (Masa 2012), while international yields reached 40–80 tons per ha (Marques and Moreau 2007).

These conditions pose technical problems especially to small-scale, low-income farmers as they must manage with efficiency small fertilizer amounts to achieve higher profits. **Split fertilizer applications could be a key to this efficient management.**

The aim of this study is to evaluate the effect of split applications of mineral fertilizers on the growth and productivity of the tomato produced in the rainy season in Burkina Faso.

9.2 Study Objectives and Assumptions

The overall objective of this study is to improve tomato production in the rainy season.

Specifically, it aims to determine the effect of the correct frequency of mineral fertilizer applications on the growth and productivity of three tomato varieties as rainy season crops;

The study was based on the following assumptions:

- Split mineral fertilizer applications increase yields compared to conventional application;
- Tomato response to split mineral fertilizer applications varies according to the variety.

Three improved tomato varieties were used in the study. These are the varieties Padma (V1), Thorgal (V2) and Tomy (V3).

The trial was conducted in pots under shelter "insect proof". The pots used were 6 liter plastic buckets. On average, 4.5 kg of soil was put into each pot for carrying out the trial.

The mineral fertilizers used in this study were NPK (14-23-14-6S) and Urea (46% N).

9.2.1 Experimental Design

The trial used a split-splot design with four replicates. The treatments (fertilizer input frequencies) were placed in main plots and the varieties (three) in secondary plots.

The applied rates of NPK and urea were 450 kg/ha and 200 kg/ha, respectively:

- F1: Application of 3 grams of NPK and 1.33 grams of urea per pot every two (02) weeks from 14 days after plant emergence.
- F2: Application of 4.5 grams of NPK and 2 grams of urea per pot every three (03) weeks from 14 days after plant emergence.
- F3: Single application of 18 grams of NPK per pot 14 days after emergence and 8 grams of urea per pot in two applications (three weeks after emergence and six weeks after emergence).

In each replicate, interactions between factors gave 9 elementary plots; resulting in 36 elementary plots for the 4 replicates which constitute the trial. Each elementary plot consists of 8 pots, leading to 72 pots for each replicate and 288 pots for the whole trial. In each replicate, the main treatments (application frequencies) were randomized and within each main treatment, the secondary treatments (varieties) were also randomized giving the final layout below.

The trial was carried out from May to August 2014

9.2.2 Mineral Fertilizers Application (NPK and Urea)

Fertilizers were applied on the basis of the rates disseminated in farming areas, that is 450 kg of NPK/ha and 200 kg of urea/ha. One hectare carries 25,000 tomato plants; this assumes that each plant receives 18 grams of NPK and 8 grams of urea. The tomato crop requires mineral fertilization until fruit production. It requires more nitrogen during this period (Pip and Coleacp 2011). To achieve this, we phased out the different application frequencies up to 90 days after plant emergence. The Table 9.1 indicates the number of fertilizer applications and the amounts supplied per treatment.

9.3 Results and Discussions

9.3.1 Effect of Fertilizer Application Frequency on Growth

9.3.1.1 Effect of Fertilizer Application Frequency on Plant Height

Figure 9.1 shows the developments of the height of tomato plants according to the frequency of fertilizer applications. It shows that plants under NPK and urea applications every three weeks (F2) grew faster than those under F1 and F3. This difference in plant height under F2 was more visible from 40 Days After Emergence (DAE). Plant heights under F1 (application every two weeks) and F3 (single application) were almost similar all along from plant emergence to the end of crop growth.

Figures 9.2a, b and c show the evolution of plant height for each variety depending on application frequencies.

For the Padma variety (Fig. 9.2a), plants that received fertilizers every three weeks (F2) achieved faster growth. They are followed by plants that received a single application (F3). Under F1, the plant height limit was reached at 50 DAEs whereas under F2 and F3, the height limit was reached approximately 10 days later.

For the Thorgal variety (Fig. 9.2b), plants that received fertilizers every three weeks (F2) also achieved faster growth. They are followed by plants fertilized every two weeks (F1). Under F1 and F3, the height limit was nearly reached at

Table 9.1 Number of fertilizer applications and amounts per application

Treatment	Type of fertilizers	Number of applications	Amounts per application
F1 (Application every two weeks)	NPK	90/14 = 6 times	18/6 = 3 g
	Urea	90/14 = 6 times	8/6 = 1,33 g
F2 (Application every three weeks)	NPK	90/21 = 4 times	18/4 = 4,5 g
	Urea	90/21 = 4 times	8/4 = 2 g
F3 Single application	NPK	1 time	18 g
	Urea	2 times	8/2 = 4 g

The measurement of the amounts applied was done with an electronic scale. The application started two weeks after plant emergence i.e. on June 04, 2014

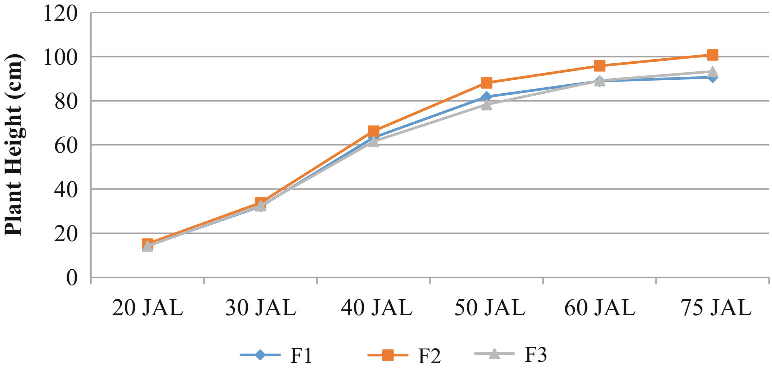

Fig. 9.1 Effect of fertilizer application frequencies on plant height

50 DAEs while under F2, growth continued up to 75 DAEs. Regarding the Tomy variety (Fig. 9.2c), plants under F1 and F2 showed similar growth. Their growth was faster than for plants under single application (F3) up to 60 DAEs.

9.3.2 *Effect of Fertilizer Application Frequencies on Main Stem Diameters*

Figure 9.3a shows the developments of the main stem diameters according to the frequency of mineral fertilization. The results indicate a similarity for all three frequencies of fertilizer applications from plant emergence up to 75 DAE. The maximum average diameters were 9.3 mm for the application frequency F1, 9.2 mm for the application frequency F2 and 9.1 mm for the application frequency F3. The maximum diameter of the stem was reached from the 60th DAE.

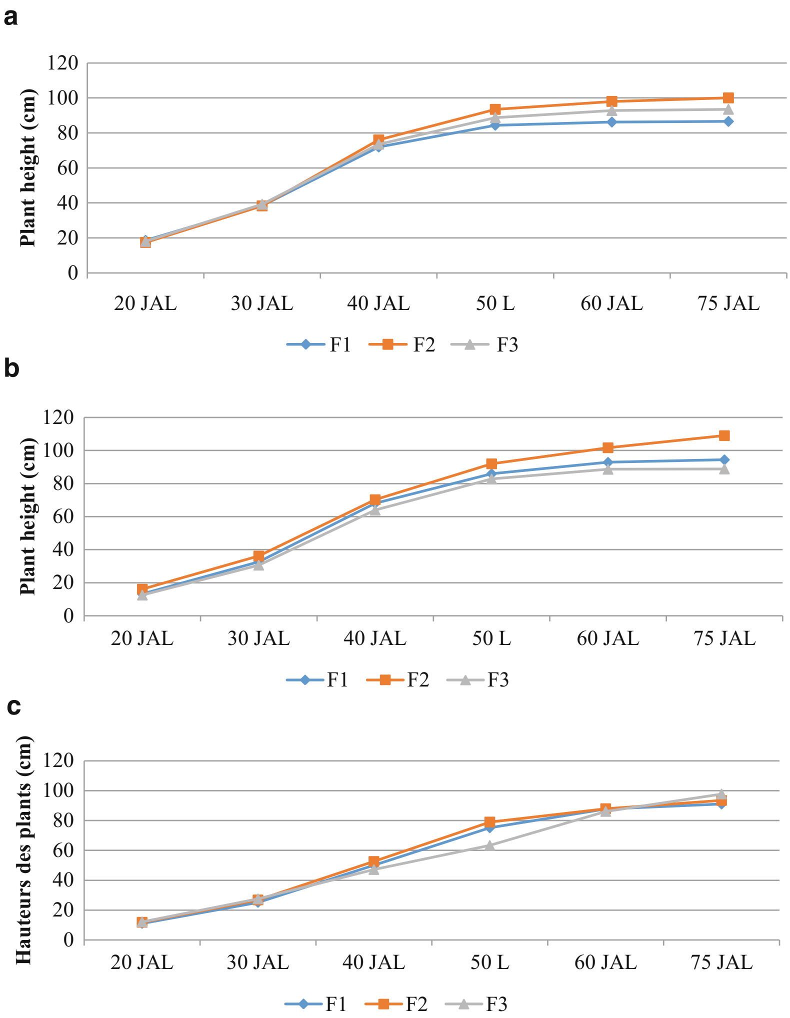

Fig. 9.2 (**a**) Effect of application frequencies on plant height for the Padma variety (**b**) Effect of application frequencies on plant height for the Thorgal variety (**c**) Effect of Application Frequencies on Plant Height for the Tomy Variety

Figures 9.3b, c and d show the developments of main stem diameters, per variety, under the three fertilization frequencies. They show a similarity of main stem diameters under the three application frequencies for each variety. For the Padma and Thorgal varieties, the maximum diameter was reached approximately at 50 DAEs whereas for the Tomy variety, growth continued up to 75 DAEs.

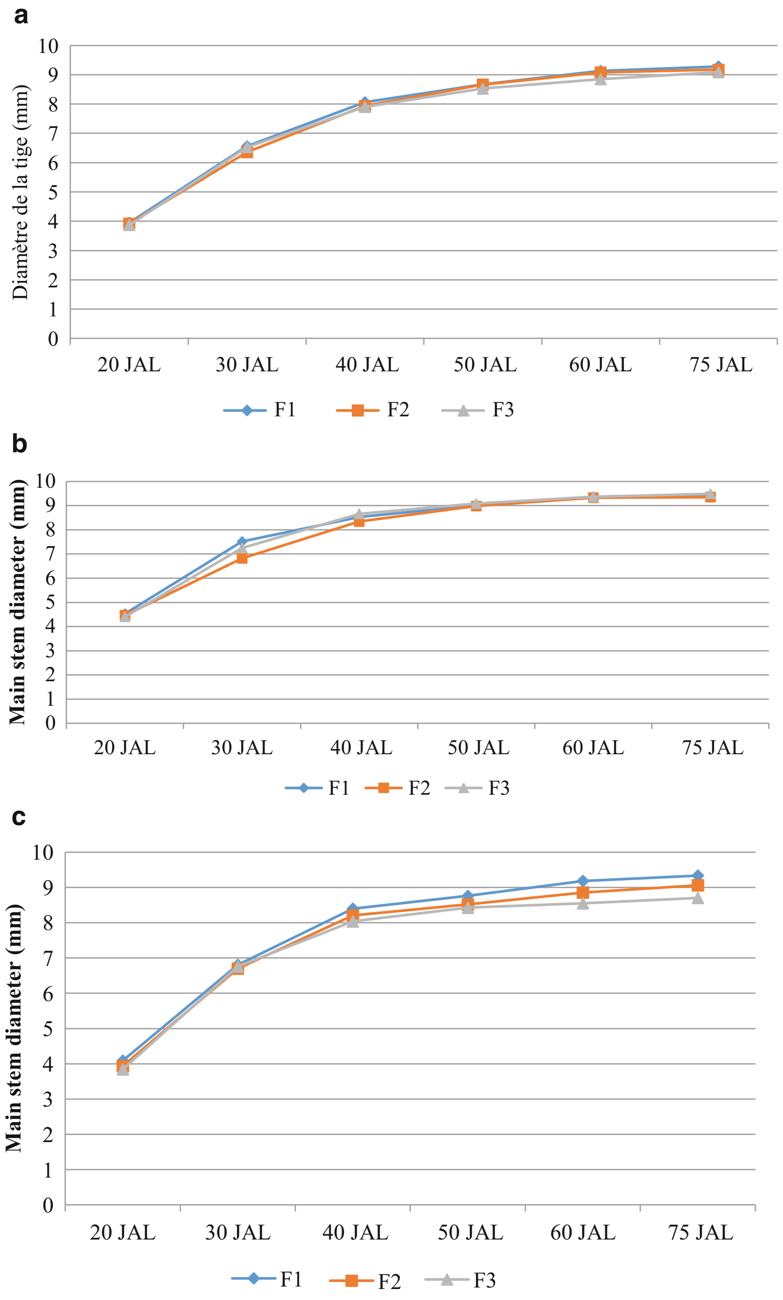

Fig. 9.3 (**a**) Effect of fertilizer application frequencies on tomato stem diameters (**b**) Effect of application frequencies on Padma stem diameter (**c**) Effect of application frequencies on Thorgal stem diameter (**d**) Effect of application frequencies on Tomy stem diameter

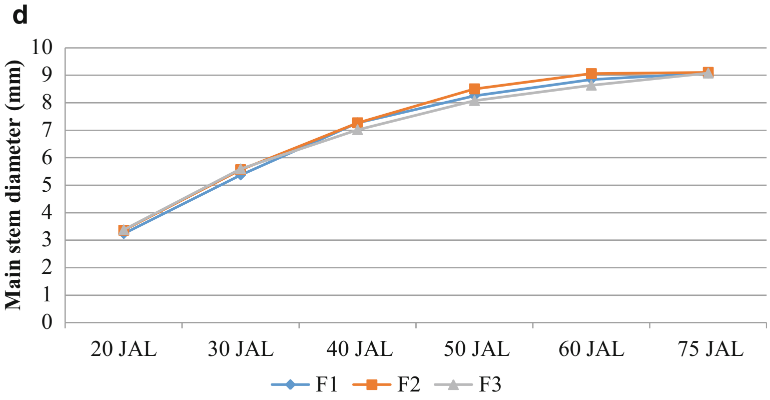

Fig. 9.3 (continued)

9.3.3 Effect of Fertilizer Application Frequencies on Development Variables for Tomato

9.3.3.1 Effect of Application Frequencies on Flowering

Table 9.2 shows tomato plant flowering (beginning and 50%) under the three fertilization frequencies. With treatment F3 (conventional fertilizer application), the beginning of the flowering phase was delayed by 1 day compared to plants under F1 and F2. But all treatments had the same number of days for flowering at 50%.

The Padma and Thorgal varieties flowered sooner than the Tomy variety with all application frequencies (Table 9.2). They also reached 50% flowering for all fertilizer application frequencies before the Tomy variety.

9.3.3.2 Effect of Fertilizer Application Frequencies on the Height of Insertion of 1st Floral Bouquet

Figure 9.4 shows the height of insertion of the first floral bouquet on tomato plants under the three fertilizer application frequencies. The height of insertion of the first floral bouquet was lower on the plants under conventional application (F3) compared to the other application frequencies F1 and F2 (Fig. 9.4). The 1st floral bouquet under F1 was also lower than that appearing under F2.

Figure 9.5 shows that irrespective of the application frequencies, the height of insertion of the first floral bouquet was higher in the Padma variety than in the other two varieties. For all varieties, a fertilizer application every three weeks resulted in a higher insertion height (Fig. 9.5).

Table 9.2 Effect of fertilizer application frequencies on early flowering (number of DAEs)

Treatments		Beginning of flowering			50% flowering		
		Padma	Thorgal	Tomy	Padma	Thorgal	Tomy
F1		32^b	32^b	38^a	35^b	36^b	40^a
F2		33^b	33^b	37^a	36^b	36^b	41^a
F3		33^b	33^b	38^a	35^b	36^b	40^a
Source of variation (test F)	Replicate	NS			NS		
	Fertilizer	NS			NS		
	Variety	***			***		
	Fertilizer*Variety	NS			NS		

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test
NS: Non Significant; ***significant at $p < 0, 001$; *significant at $p < 0, 05$

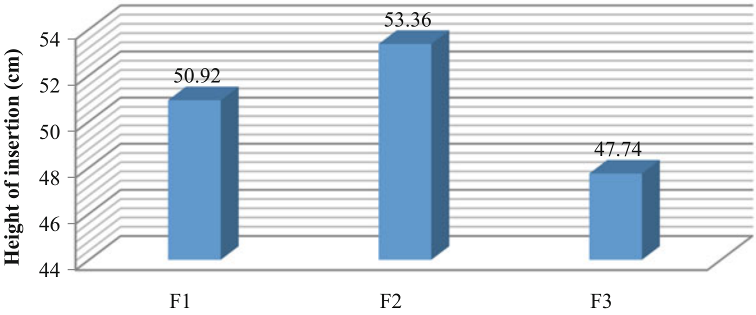

Fig. 9.4 Effect of fertilizer application frequencies on the insertion height of the 1st floral bouquet

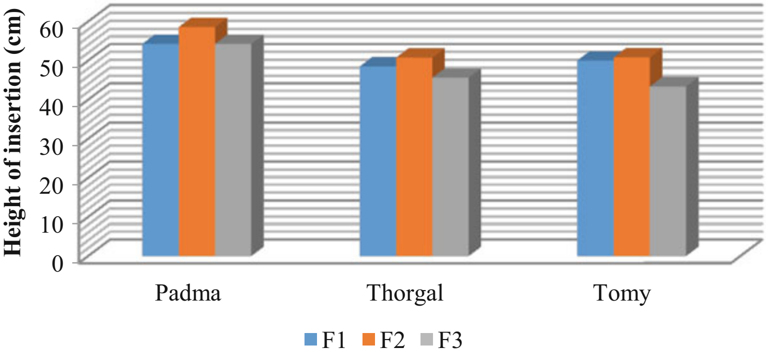

Fig. 9.5 Effect of fertilizer application frequencies on the insertion height of the 1st floral bouquet depending on the variety

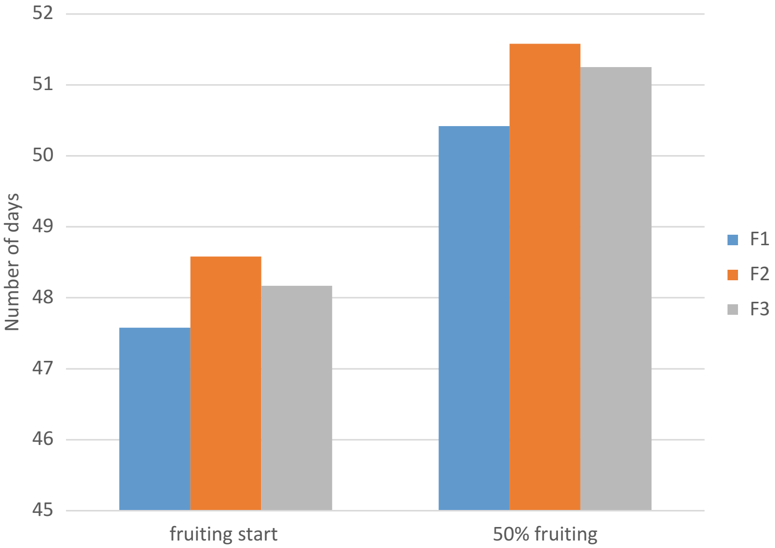

Fig. 9.6 Effect of fertilizer application frequencies on fruit setting

Table 9.3 Effect of fertilizer application frequencies on early fruit setting (Number of DAEs)

		Beginning of fruit setting			50% of fruit setting		
Treatments		Padma	Thorgal	Tomy	Padma	Thorgal	Tomy
F1		39^{b}	39^{b}	50^{a}	41^{b}	43^{b}	53^{a}
F2		40^{b}	40^{b}	52^{a}	42^{b}	43^{b}	55^{a}
F3		39^{b}	40^{b}	51^{a}	41^{b}	43^{b}	55^{a}
Source of variation (test F)	Replic	NS			NS		
	Ferti	NS			NS		
	Variety	***			***		
	Fert*V	NS			NS		

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test

NS = Non Significant; ***Significant at $p < 0.001$

9.3.3.3 Effect of Fertilizer Application Frequencies on Fruit Setting

Figure 9.6 shows the effect of fertilizer application frequencies on the beginning and 50% of tomato fruit setting. The results show that under the single application (F3) and application every two weeks (F1) of NPK fertilizers and urea, fruit setting started a little earlier than under application every three weeks.

Fruit setting started earlier for the Padma and Thorgal varieties with all application frequencies (Table 9.3). Fruit setting started late for the Tomy variety. Plants

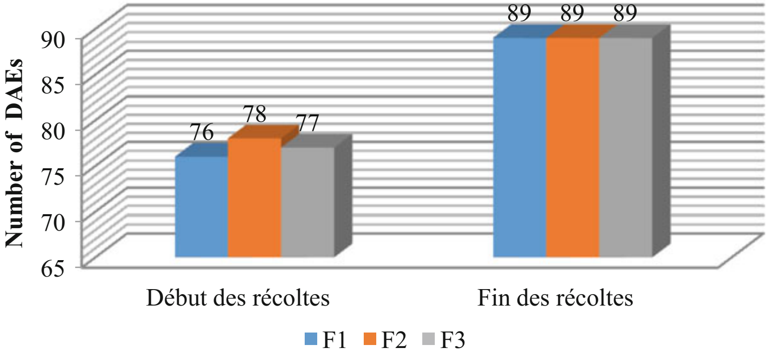

Fig. 9.7 Effect of fertilizer application frequencies on the beginning and end of harvests

Table 9.4 Effect of application frequencies on the beginning and end of harvests (Number of DAEs)

Treatments		Beginning of harvests			End of harvests		
		Padma	Thorgal	Tomy	Padma	Thorgal	Tomy
F1		73^b	72^b	83^a	86^b	86^b	96^a
F2		76^b	73^b	84^a	86^b	86^b	94^a
F3		73^b	73^b	86^a	86^b	86^b	96^a
Source of variation (test F)	Replicate	NS			NS		
	Fertilization	*			NS		
	Variety	***			***		
	Fertilization*Variety	***			NS		

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test

NS = Non Significant; ***Significant at p <0.001; * = significant at p <to 0,05

of the Tomy variety under application frequency F1 started fruit setting earlier than plants under application frequencies F2 and F3.

9.3.3.4 Effect of Fertilizer Application Frequencies on Harvests

Figure 9.7 presents the harvesting dates (start and end) of the tomato plants under the three fertilization frequencies. The results show that plant harvesting under F1 started one to two days earlier than under F3 and F2, respectively. However, at the end of the harvest period, all treatments produced the same result.

The Padma and Thorgal varieties had earlier harvests irrespective of application frequencies. The Tomy variety, on the other hand, had later harvest (Table 9.4). Fertilization did not influence the end of harvests.

Table 9.5 Effect of fertilizer application frequencies on the production of floral bouquets and fruit clusters

Treatment	Number of floral bouquets per plant	Number of fruit clusters per plant
F1	9^{a}	5^{a}
F2	9^{a}	6^{a}
F3	10^{a}	5^{a}

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test

Table 9.6 Effect of application frequencies on the production of floral bouquets and fruit clusters

		Number of floral bouquets per plant			Number of fruit clusters per plant		
Treatments		Padma	Thorgal	Tomy	Padma	Thorgal	Tomy
F1		8^{b}	10^{a}	9^{a}	6^{a}	5^{b}	6^{a}
F2		8^{b}	11^{a}	9^{a}	6^{a}	5^{b}	6^{a}
F3		8^{b}	10^{a}	10^{a}	6^{a}	5^{b}	5^{b}
Source of variation (test F)	Replicate	NS			NS		
	Fertilization	NS			NS		
	Variety	**			*		
	Fertilization*Variety	NS			NS		

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test
NS: Non Significant; *significant at $p < 0, 0.05$; **significant at $p < 0, 0.01$

9.3.4 Effect of Application Frequencies on Tomato Productivity

9.3.4.1 Effect of Application Frequencies on the Number of Floral Bouquets and Fruit Clusters

There were no significant differences between the three treatments regarding the number of floral bouquets and the number of fruit clusters (Table 9.5).

Table 9.6 shows the number of floral bouquets and fruit clusters per plant. It was found that under all application frequencies, 75% of the floral bouquets of the Padma variety were transformed into fruit clusters. For the Thorgal variety, 46–50% of the floral bouquets have become fruit clusters under all fertilization types. For the Tomy variety 67% of the floral bouquets under F1 and F2 were transformed into fruit clusters, whereas under F3 only 50% of the floral bouquets were transformed into fruit clusters.

Table 9.7 Effect of fertilizer application frequencies on the total number of fruits harvested, marketable fruits and nonmarketable fruits

Treatment		Total number of fruits harvested	Number of marketable fruits	Number of non-marketable fruits
F1		20^a	14^a	6^a
F2		22^a	18^a	3^b
F3		22^a	18^a	4^b
Source of variation (test F)	Replicate	NS	NS	NS
	Fertilization	NS	NS	NS
	Variety	***	**	**
	Fertilization*Variety	NS	NS	NS

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test

NS: Non Significant; ** Significant at $p < 0.01$; *** Significant at $p < 0.001$

9.3.4.2 Effect of Application Frequencies on the Total Number of Harvested Fruits, Salable Fruits and Non-salable Fruits

Table 9.7 shows the total number of fruits harvested, the number of salable fruits and the number of non-salable fruits with the three fertilization frequencies. Of the fruits harvested under F1, 30% were non-salable while under F2 and F3, the rate was respectively 14% and 18%.

Depending on the varieties, Padma produced more fruits harvested than the two other varieties with all application frequencies (Fig. 9.8a). Plants under F2 and F3 produced more salable fruits in the Padma and Thorgal varieties (Fig. 9.8b). Plants under F1 and F3 of the Padma variety produced more non-salable fruits than plants under F2 (Fig. 9.8c). For the Tomy variety, fertilization frequency F1 produced more non-salable fruits (Fig. 9.8c).

9.3.5 Effect of Application Frequencies on the Number of Rotten and Cracked Fruits

Table 9.8 shows the percentage of rotten and cracked fruits according to the types of fertilizer application. The application frequency F3 caused more rotting and cracking of fruits.

Figures 9.8a, b show the percentages of rotting and cracking per variety. The Tomy variety had the highest percentage of rotten fruits under the F1 and F3 application frequencies. Under the frequency F2, the Thorgal variety recorded more rotting (Fig. 9.8a).

Regarding cracking, fruits under F3 fertilization frequency (conventional fertilization) had the highest percentage (%) for all three varieties (Fig. 9.8b).

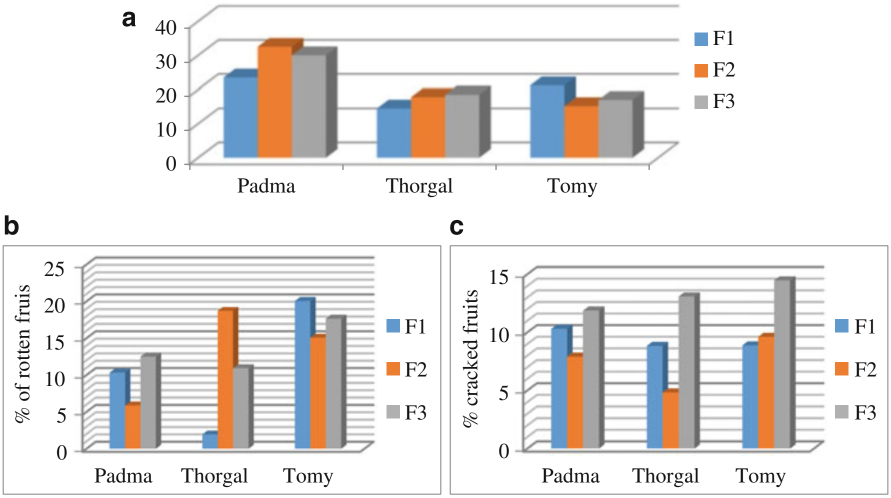

Fig. 9.8 (**a**) Effect of application frequencies on the number of fruits harvested (**b**) Effect of application frequencies on the percentage of rotten fruits (**c**) Effect of application frequencies on the percentage of cracked fruits

Table 9.8 Effect of fertilizer application frequencies on the percentage of rotten and cracked fruits

Treatment	Total number of fruits harvested	Number of marketable fruits	% of rotten fruits	% of cracked fruits
F1	20[a]	14[a]	11,72	9,39
F2	22[a]	18[a]	11,51	7,48
F3	22[a]	18[a]	13,39	12,89

9.3.5.1 Effect of Application Frequencies on Fruit Firmness

Figure 9.9 shows the percentage of fruit firmness according to fertilizer application frequencies. The application frequency F3 gave the firmest fruits compared to the other two forms of fertilization.

Table 9.9 shows the percentage of fruit firmness per variety. All varieties produced firmer fruits with the application frequency F3 compared to the two other frequencies. The variety Thorgal gave the least firm fruits under the application frequency F1 whereas under the application frequency F2, the variety Tomy gave the least firm fruits.

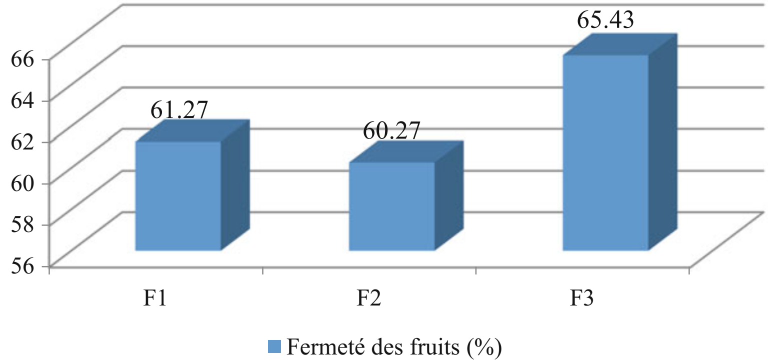

Fig. 9.9 Effect of application frequencies on fruit firmness

Table 9.9 Effect of application frequencies on fruit firmness

Treatment		Padma	Thorgal	Tomy
F1		62,60^{b}	58,00^{c}	63,20^{b}
F2		60,00^{c}	62,40^{b}	58,40^{c}
F3		63,80^{b}	66,00^{a}	66,50^{a}
Source of variation (test F)	Replication	NS	NS	NS
	Fertilization	**	**	**
	Variety	NS	NS	NS
	Fertilization*Variety	*	*	*

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test

NS: Non Significant ; * Significant at $p < 0,05$; ** Significant at $p < 0,01$

9.3.5.2 Effect of Application Frequencies on Soluble Dry Matter Content

Figure 9.10 shows the rates of soluble dry matter content depending on the fertilization frequencies. The application of NPK and urea fertilizers every two weeks (F1) yielded fruits with highest soluble dry matter content.

Table 9.10 shows the effect of application frequencies on soluble dry matter content per variety. Under F1, the Tomy and Padma varieties produced fruits that had the highest soluble dry matter content. Under F2, the fruits of the Tomy variety had the highest soluble dry matter content. Under the F3 application frequency, the Padma variety produced fruits with highest soluble dry matter content.

9.3.5.3 Effect of Application Frequencies on Yields

Production yield under application frequency F1 was 44% and 51% higher than under F2 and F3, respectively (Fig. 9.11).

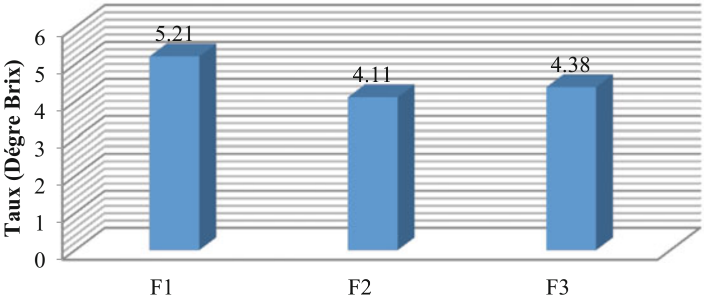

Fig. 9.10 Effect of application frequencies on soluble dry matter content

Table 9.10 Effect of application frequencies on soluble dry matter content

Treatment		Padma	Thorgal	Tomy
F1		570^a	407^b	588^a
F2		364^b	332^b	538^a
F3		529^a	441^b	344^b
Source of variation (test F)	Replicate	NS		
	Fertilization	*		
	Variety	*		
	Fertilization^{a}Variety	**		

NB: Values affected by the same letter in the same column are not significantly different at the 5% threshold according to the LSD test
NS: Non Significant ; * Significant at $p < 0{,}05$; ** Significant at $p < 0{,}01$

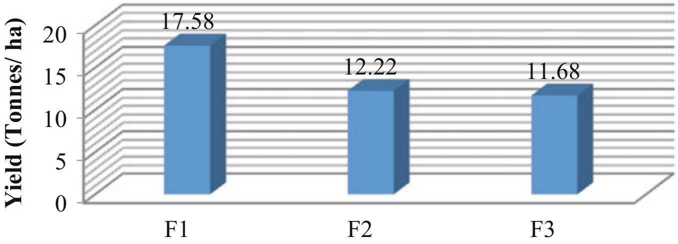

Fig. 9.11 Effect of application frequencies on yields

Yields of the Padma variety under F1 were 26% and 16% higher than yield under F2 and F3, respectively. For the Thorgal variety, yields under F1 were higher than under F2 and F3 respectively by 15% and 48%. For the Tomy variety, yields under F1 exceeded that of F2 and F3 by 103% and 102%, respectively.

9.4 Conclusion– Recommendations and Prospects

This study consisted of verifying the effects of split mineral fertilizer applications on the growth and productivity of tomatoes in rainy season cultivation. In order to achieve this objective, a confined field trial was carried out. The results achieved led to draw the following conclusions:

- The application of NPK and urea every 2 weeks (F1) gave a greater total weight of fruits per plant (422 g) compared to F2 (293 g) and F3 (280 g). It also produced fruits with the highest soluble dry matter content (5.21%) compared to F2 (4.11%) and F3 (4.38%). The greater number of splits inducing high frequency applications increases the agronomic efficiency of fertilizers in production in terms of quantity and quality.
- Splitting NPK and urea in 4 equal fractions with an application frequency of every 3 weeks (F2) fostered growth in tomato plants.
- A single application of NPK (450 kg / ha) and urea in two fractions (100 kg/ha/ application) produced firmer fruits (65.43%) compared to F1 (61.27%) and F2 (60.27%). Fertilizer splitting reduced the firmness of tomato fruits.
- The Padma variety responded better to the F1 application frequency in terms of fruit production (416 g of fruit / plant), and soluble dry matter production (5.21%). The Tomy variety also responded well to the F1 application frequency in terms of fruit production (496 g of fruit / plant), and soluble dry matter production (5.88%). These two varieties responded better to the every two weeks application in terms of production quantity and quality. The Thorgal variety responded better to the F2 application frequency in terms of plant height. The Thorgal and Tomy varieties responded better to the F3 application frequency in terms of fruit firmness with respectively 66% and 66.5% of firmness.

In view of these findings, we recommend raising farmers' awareness on the importance of splitting fertilizers in 6 applications with a frequency of every 2 weeks in order to take full advantage of the contribution of these fertilizers to productivity. Also we suggest the dissemination of the Padma variety in the northern part of the country where the rainy season is short with low rainfall. The Tomy variety can be recommended to farmers in the center and the western part of the country. Moreover, this study is a contribution to reasoned fertilization in tomato production in a context where efficient fertilizer use is required given the high costs of mineral fertilizers.

However, it would be necessary to further this study by setting up a trial in farmers' fields to better take into account the effect of application frequencies on the phytosanitary evolution (fungal, bacterial, viral diseases), cracking and especially fruit blossom-end rot. Blossom-end rot results from calcium deficiency, whereas splitting, which allows the presence of mineral salts around the roots at the time of fruiting and reduces the flow of water to the fruit for a better concentration of soluble dry matter, also may limit the transport of calcium to the fruit. In addition, a study should be carried out to evaluate the economic profitability of fertilizer application frequencies because splitting requires additional expenditures in crop management, which should normally be compensated for by the crop surplus resulting from the splitting.

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Chapter 10
Fertilizer Recommendation for Maize and Cassava Within the Breadbasket Zone of Ghana

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Abstract This study was to review and update fertilizer recommendation for maize and cassava to improve yields and incomes of food crop producers as well as sustain the environment. The trials covered part of the semi-deciduous forest, forest savanna transition and the Guinea savanna agro-ecological zones which form the breadbasket area of Ghana. Five on-station and 200 on-farm fertilizer trials were conducted on maize and cassava. Random complete block design in four replications was used on station. The on-station research treatments were 15, with various combinations of N, P_2O_5 and K_2O and the on-farm trails had 5 N rates; 0, 45, 90, 135, and 160 kg N ha^{-1} with 60 kg ha^{-1} P_2O_5 and 70 kg ha^{-1} K_2O as basal application except on the zero fertilizer plots. Maximum yields obtained across the three ecological zones ranged from about 2000 to 9000 kg ha^{-1}. Yields followed quadratic trends in most locations and years, with a clear optimum application rate of 90 kg N ha^{-1}. In some districts, yields continued to increase steadily up to 135 kg N ha^{-1}, after which yields could not increase with additional N application. In some situations the economic optimum rate was lower than the biological optimum rate. Cassava root yields followed a distinct quadratic trends across the Forest savanna transition agro-ecological zone with yields increasing with application of N up to 60 kg N per hectare. Optimum N rate for cassava production was 60 kg N ha^{-1}. The full treatment is therefore 60–45-90 kg ha^{-1} N-P_2O_5-K_2O which gave an average yield of about 50 T ha^{-1}.

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Keywords Benchmark soil · NPK fertilizer · Cassava · Maize · Fertilizer recommendation · Agro-ecological zone

Contents

10.1 Introduction

Ghana's agriculture is characterized by low crop yields due to low soil fertility, soil degradation and low fertilizer use, estimated at 12 kg/ha as compared to world-wide average of 107 kg/ha. The soils are poor and cannot adequately satisfy the food demands of about 28 million Ghanaians. Area expansion-based crop production can no longer meet the food requirements of our growing population. Sustainable intensification is the way only if farmers can access high quality and affordable fertilizer with efficient recommendations that will maximize yields and profits for the small holder farmer. Fertilizers hold the key to good yields when it is applied properly. Current fertilizer recommendations were developed over 30 years ago with no serious review/update. There are two major reasons for low productivity in maize and other food crops, and these are low soil fertility and low application of external inputs. The soils of the major maize growing areas are low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 ppm) and available phosphorus (<10 ppm) (Adu 1995; Benneh et al. 1990). A large proportion of the soils are also shallow with iron and magnesium concretions (Adu 1969). Despite these shortcomings, soil fertility management is low. Fertilizer nutrient application in Ghana is approximately 12 kg ha^{-1} (FAO 2005) while depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK) ha^{-1} year^{-1} (FAO 2005) and among the highest in Africa. FAO estimates show negative nutrient balance for all crops in Ghana. The escalating rates of soil nutrient mining are a serious threat to sustainability of agriculture and poverty reduction.

The low to moderate rates of recommended nutrient levels in Ghana were due to the practice of long fallow periods and less intensive agriculture. With increasing population and infrastructural development, good agricultural lands are dwindling in size. Agriculture is developing into sedentary farming system with improved crop varieties with high nutrient demand. Fertilizers are expensive and beyond the purchasing power of the smallholder farmer and yet he cannot do without these inputs to farm his holdings. Farmers who do apply nutrients to crops below the recommended rates do not realize high economic returns. By investing in nutrient application rates that are economically and scientifically sound, farmers will derive benefits, keep the soil resources productive, and ensure their conservation for sound environment.

Crop varieties introduced to farmers by Scientists are high yielding (*Obatanpa*, *Mamaba*, *Tech-bankye* etc) with concomitant high nutrient demand which leads to nutrient mining and soil degradation if not replenished. To increase yields and realize the full yield potentials of the new crop varieties as well as sustain crop production, there is the need to update fertilizer recommendation for major crops and make farmers appreciate the effect of fertilizers on crop production.

Maize is an important cereal crop in most part of West Africa (Fosu et al. 2004). In Ghana it is the major staple especially in the northern part where it is even replacing sorghum and millet which were the major staples some years ago. Average yield of maize in Ghana is 1.7 t/ha (MoFA 2011) compared to world average of 4.9 t/ha (Edgerton, 2009).

The production of cassava (*Manihot esculenta* Crantz) increased tremendously between 2000 and 2013 with world production of fresh storage roots rising from 176 to 277 million Mg (FAOSTAT 2014). West Africa produces 28% of the world's cassava and the rest of Africa a further 26% (FAOSTAT 2014). The increase in production resulted both from expansion of the cultivated area and enhanced yields of cassava. Although average yields in West Africa increased between 2000 and 2013 from 9.7 to 13 Mg ha^{-1} of fresh storage roots (FAOSTAT 2014), a large yield gap remains given that yields close to 60 Mg ha^{-1} have been attained in researcher managed fields in the region (Odedina et al. 2009).

Plausible reasons for this yield gap are nutrient limitations due to poor soil fertility. Fertiliser use onroots and tuber crops in Sub-Saharan Africa are negligible. However, nutrient removal for cassava production is on average 4.5 kg nitrogen (N) – 0.83 kg phosphorus (P) – 6.6 kg potassium (K) per 1000 kg dry matter of storage roots (Howeler 2001). The insufficient use of external nutrients leads to soil nutrients depletion. Moreover, the use of blanket fertiliser recommendations across large areas generates unbalanced crop nutrition since soils on farmers' fields are highly heterogeneous (Adjei-Nsiah, 2007).

The overall goal of the study was to come out with fertilizer recommendation for maize and cassava in the Semi-deciduous forest, Forest savanna transition and Guinea savanna zones of Ghana. The specific objectives were to develop fertilizer response curves through on-station and on-farm NPK fertilizer trial.

10.2 Materials and Methods

10.2.1 Study Area

The trials were conducted on farmers' fields in 20 districts of Ghana; 11 districts in the Forest-savanna transition zone –FSTZ and nine districts in the Guinea savanna-GSZ. These areas form the major part of the breadbasket area of Ghana. The area lies within 10°48′26.227″ N, 2°53′ 40. 794″W, 10° 14′ 35.542″N, 0° 20′ 51.505″E, 5° 35′ 1.593″, 0″ 47′ 53.47″ E., 6° 43′ 48.959″N, 13′ 32.737″W, 13′32.737″W,. The study consisted of on-station research at 6 sites: Nyankpala, Damongo (in the Guinea savanna zone), Berekum, Kwadaso, and Mampong (in the Semi-deciduous forest zone) Wenchi, Nkoranza and Forifori (in the Forest savanna transition zone) and on-farm research in 12 districts, namely Atebubu, Nkoranza, Wenchi, Berekum, Sunyani, Krachi, Sekyere West, Sekyere East, Ejura-Sekyedumase, and Nyankpala. In the transitional zone rainfall ranges 1200–1500 mm with the highest amounts recorded in June and October (Fig. 10.2). Annual rainfall for the Guinea savanna zones (e.g. Nyankpala site) ranges 1000–1365 mm with the highest amount recorded in August (Fig. 10.2).

The mean annual minimum and maximum temperatures are 22.3 and 34.3 °C, respectively. The mean annual relative humidity for a day is about 40 to 50% (Adu 1969; Nyarko et al. 2008) (Fig. 10.1).

10.2.2 Soil Sampling and Chemical Analysis

A composite soil sample was taken randomly across each site to determine the initial fertility status of the soil. Sieved air-dried soil samples were analyzed for pH (1:1, soil:H_2O), total N by Kjeldahl digestion and distillation method (Bremmer and Mulvaney 1982), available P by Bray 1 extraction solution procedure (Bray & Kurtz, 1945). Exchangeable bases (Ca, Mg, K, and Na) content in the soils were determined in 1.0 M ammonium acetate extract (Thomas 1982) and organic carbon by modified Walkley and Black procedure as described by Nelson and Sommers (1982).

10.2.2.1 Study 1-Maize

The on-station research treatments were 15, with various combinations of N, P_2O_5 and K_2O and the on-farm trails had 5 N rates; 0, 45, 90, 135, and 160 kg N ha^{-1} with 60 kg ha^{-1} P_2O_5 and 70 kg ha^{-1} K_2O as basal application except on the zero fertilizer plots. Urea, TSP and MOP were the fertilizers, split banded at both sides of the plant at 2 and 6 weeks after sowing. The test crop was maize variety 'Obatanpa', an open pollinated medium maturing maize variety. A randomized

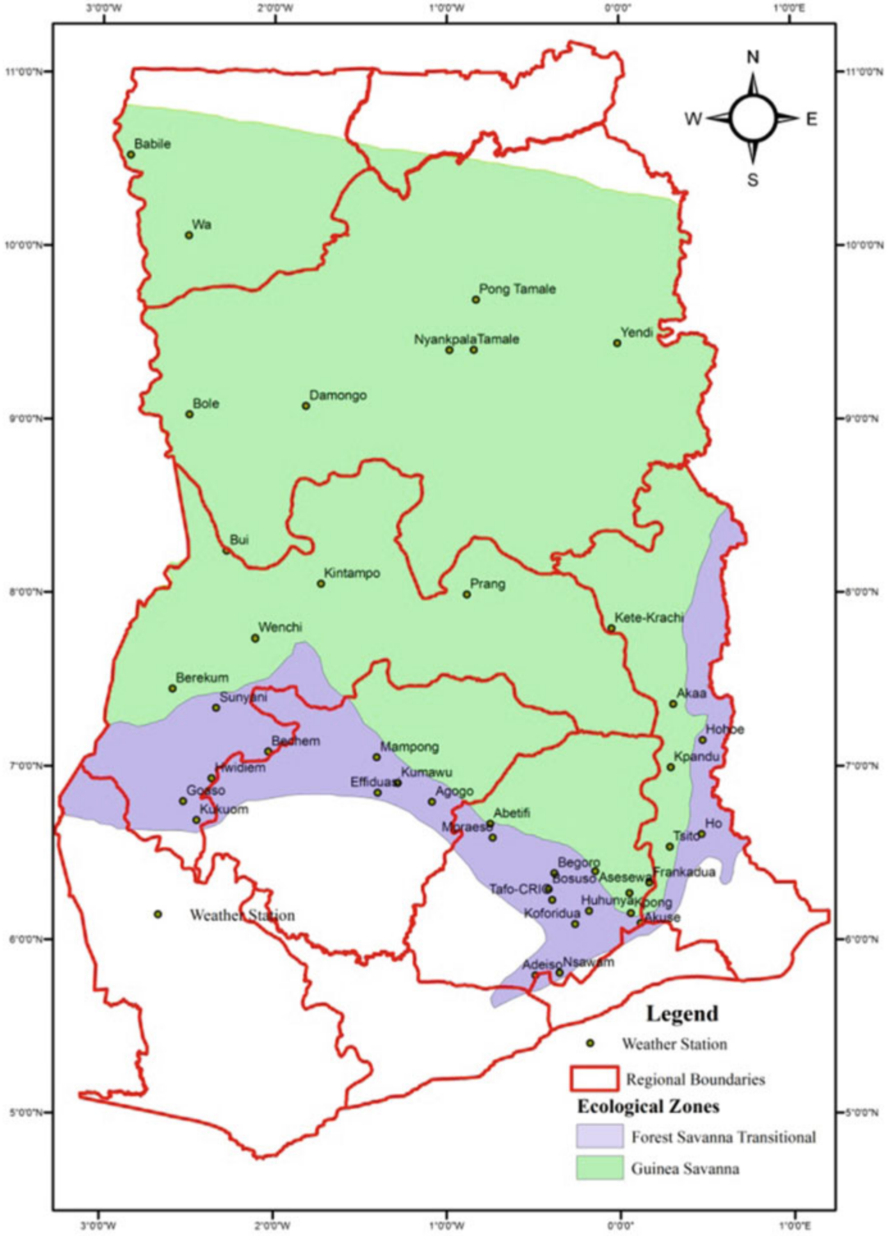

Fig. 10.1 Project sites within Semi-deciduous forest, Forest savanna transition and Guinea savanna zones of Ghana

complete block design was used on-station in 4 replications. On-farm, each farmer constituted a replicate. Ten farmers per district were selected. The plot size was 6.0 m × 4.8 m and the spacing was 80 cm × 40 cm. Targeted plant population was 62,500 plants ha^{-1}.

10.2.3 Data Collection

At maturity, grain and stover dry weight data were collected. A known area of 12.8 m^2 was marked in the middle of each plot for data collection on grain yield. Benefit cost ratio and gross return were estimated from grain yield, cost of inputs and labor used for production and price of grain yield.

10.2.4 Statistical Analysis

The statistical software STATISTIX 8 was used to analyze field data. Least significant difference ($LSD_{0.5}$) was used to separate treatment means.

10.2.5 Evaluation of the DSSAT Model

Relevant crop data (soil parameter, initial soil conditions and agronomic information) collected at the experimental site were used in evaluating the DSSAT model using the two maize varieties Obatanpa and Mamaba. Statistical methods were used for assessing the performance of the crop simulation model in comparison with observed field measured data. The closeness of the relationship between observed (O) and simulated (P) crop yields were estimated using: 1. Coefficient of determination (R2) 2.Root mean square error (RMSE).

10.3 Results and Discussion

10.3.1 Soils

The dominant soils encountered were as follows: Soils of the Forest savanna transition zone – *Damongo series* (Ferric Lixisols), *Sutawa series* (Distric Nitisols), and *Bediesi series* (Rhodic Nitisols) and; Guinea savanna zone- *Kpelesawgaw series* (Eutric Plinthosols), *Nyankpala series* (Ferric Acrisol), *Varempere series* (Ferric Lixisols) and *Changnalili series* (Gleic Plinthosols). The soils are developed

Table 10.1 Chemical characteristics of soils at the various sites

		pH	TN	OM	Av. P	Av. K	CEC	Ca	Mg
Location		%				mg/kg	cmol +/kg		
Mampong	0–15 cm	7.3	0.13	2.41	13.0	247	18.3	8.5	8.3
	15–30 cm	5.8	0.05	1.16	5.8	159	20.9	10.4	9.3
Berekum	0–15 cm	6.5	0.20	4.00	6.1	152	7.5	5.9	1.1
	15–30 cm	6.4	0.09	1.60	3.5	105	6.1	3.7	1.9
Afram Plains	0–15 cm	6.1	0.09	1.80	7.8	65	8.1	6.2	1.8
	15–30 cm	5.8	0.07	1.38	3.9	55	8.6	5.3	2.5
Kpalesawgu	0–20 cm	5.6	0.05	1.33	3.4	80	5.0	5.88	0.6
	20–40 cm	5.8	0.08	1.17	3.9	72	5.1	3.7	1.0
Wenchi	0–20 cm	6.3	0.08	1.24	2.1	201	9.1	6.4	1.9
	20–40 cm	6.3	0.09	1.53	3.9	121	8.1	6.4	1.2

from weathering voltaian shale and sandstone. Soil of the Semi-deciduous forest zone are Nzima series (Dystric Nitosol), Kokofu series (Dystric Nitosol) Debibi series (Ferric Acrisol) and Bekwai series. These soils are developed from granite, Lower and Upper Birimian phyllite and sandstones.

10.3.2 Initial Soil Chemical Properties

Soil pH values across most districts were slightly acidic and desirable (5.7–6.8), soil organic matter was moderate (1.3–1.8%) in the semi-deciduous forest and forest savanna transition zone and very low (<1.0%) in the Guinea savanna zone soils, Effective cation exchange capacity values were low in most cases ($<10.0\ \mathrm{cmol_c\ kg^{-1}}$) except in Berekum where the value was moderate. Potassium was low in most cases ($<0.20\ \mathrm{cmolc\ kg^{-1}}$), calcium and magnesium ranged from low to moderate levels (from 5 to 10 cmolc $\mathrm{kg^{-1}}$.). Potassium was deficient in Sekyere West, Ejura Sekyidumase and Afram Plains. Response to potassium fertilization was therefore expected in these areas. Phosphorus was deficient in most districts (Tables 10.1 and 10.2).

10.4 Study 1–Maize On-Station and On–Farm Trials

10.4.1 On-Station Research

10.4.1.1 Grain Yields

It is worthwhile to note that rainfall amount and distribution in 2005 were not favorable for maize production as the major season was characterized by frequent

Table 10.2 Yield of maize grains in Nkoranza and Wenchi 2005 and 2006

Treatment	Maize grain yield (T/ha)			
	Nkoranza (2005)	Nkoranza (2006)	Wenchi (2005)	Wenchi (2006)
1. 0-0-0	1.06	0.37	3.17	3.52
2. 0-45-45	1.67	0.43	2.15	4.32
4. 45-45-0	1.82	1.10	3.91	3.71
5. 45-45-45	1.65	1.45	3.28	5.32
6. 0-90-90	1.71	1.11	2.84	4.17
7. 45-90-90	2.26	1.42	3.62	5.21
8. 90-45-90	1.71	2.37	4.38	4.69
9. 90-45-60	2.50	1.87	3.80	3.97
10. 90-90-90	2.63	1.69	3.88	4.91
11. 180-0-90	1.76	2.11	3.17	3.43
12. 180-45-90	1.97	2.23	4.49	4.97
13. 180-90-0	2.30	2.63	4.23	4.36
14. 180-90-45	2.54	1.91	4.34	5.50
15. 180-90-90	2.54	1.99	3.56	4.75
SED	0.37	0.38	0.37	0.370

drought spells which may not have allowed maximum benefit to be realized from the applied fertilizer. Consequently a large number of the established trials failed. There was a significant ($p \leq 0.05$) interaction between location and NPK fertilizer treatment on maize grain yields. Highest maize grain yields were achieved at different fertilizer rates at the different locations with 90-90-90, 180-45-90 and 45-45-0 kg N-P_2O_5-K_2O ha^{-1} at Nkoranza, Wenchi and Berekum, respectively. (Table 10.3). At Fori-Fori, Kwadaso, Kpelesawgu, a highest maize grain yield were obtained at 180-90-90, 180-0-90, 45-45-45, 45-90-90N-P_2O_5-K_2O ha^{-1} which were also not significantly different. Across the various sites maximum yields obtained ranged from about 2000 to 9000 kg ha^{-1}. Yields followed quadratic trends in most locations and years, with a clear optimum application rate of 90 kg N ha^{-1}. In some districts, yields continued to increase steadily up to 135 kg N ha^{-1}, after which yields could not increase with additional N application. In some situations the economic optimum rate was lower than the biological optimum rate (Tables 10.4 and 10.5).

10.5 Nutrient Omission Trial (NOT)

Results of the Nutrient Omission Trials are presented in Table 10.2. The results show that, for most of the soils across the project sites, Nitrogen (N) and phosphorus (P) were the most limiting of the three major nutrients. Nitrogen was the most deficient nutrient in Wenchi, Berekum, Kwadaso, Afram Plains, Damongo, and

Table 10.3 Yield of maize as affected by NPK applicaton at Kwadaso (2005&2006)

Kwadaso-2005		Kwadaso 2006	
$N\text{-}P_2O_5\text{-}K_2O$ kg/ha		$N\text{-}P_2O_5\text{-}K_2O$ kg/ha	
180-90-90	2008.5	180-90-90	2160
45-90-90	1802.9	180-90-0	2130
90-90-90	1798.6	180-90-45	2130
180-0-90	1771.9	90-45-90	1870
180-45-90	1763.2	90-45-60	1840
180-90-0	1664.5	45-45-45	1740
45-45-0	1655.8	180-45-90	1730
180-90-45	1647.8	90-90-90	1580
45-45-45	1528.4	180-0-90	1530
90-45-90	1496.9	45-45-0	1480
0-0-0	1370.5	45-0-45	1310
45-0-45	1187.1	45-90-90	1280
90-45-60	1176.6	0-45-45	1280
0-45-45	587.0	0-90-90	1240
0-90-90	516.7	0-0-0	810
$LSD_{0.05}$	*680.6*	*615*	

Table 10.4 On-station maize grain yield at Nkoranza and Wenchi in 2005 and 2006

	Maize grain yield (T/ha)			
Treatment	Nkoranza (2005)	Nkoranza (2006)	Wenchi (2005)	Wenchi (2006)
1. 0-0-0	1.06	0.37	3.17	3.52
2. 0-45-45	1.67	0.43	2.15	4.32
3. 45-0-45	1.65	1.67	3.43	5.17
4. 45-45-0	1.82	1.10	3.91	3.71
5. 45-45-45	1.65	1.45	3.28	5.32
6. 0-90-90	1.71	1.11	2.84	4.17
7. 45-90-90	2.26	1.42	3.62	5.21
8. 90-45-90	1.71	2.37	4.38	4.69
9. 90-45-60	2.50	1.87	3.80	3.97
10. 90-90-90	2.63	1.69	3.88	4.91
11. 180-0-90	1.76	2.11	3.17	3.43
12. 180-45-90	1.97	2.23	4.49	4.97
13. 180-90-0	2.30	2.63	4.23	4.36
14. 180-90-45	2.54	1.91	4.34	5.50
15. 180-90-90	2.54	1.99	3.56	4.75
SED	0.37	0.38	0.37	0.370

Nyankpala resulting in low yields especially in the second year of cropping. Phosphorus was most deficient in Nkoranza and Mampong. Potassium was the least limiting for maize production at all three locations. In 2006, Potassium, (not N and P), was found to be most limiting nutrient for maize grain production at Wenchi.

Table 10.5 Most Limiting Nutrient for maize production in 9 districts of the bread baslet zone of Ghana

	Nkoranza	Wenchi	Berekum	Mampong	Kwadaso	A. Plains	Damongo	Nyankpala
N-P_2O_5-K_2O	(Grain yield kg ha^{-1})							
0-0-0	1063	3168	1280	2632	1370.5	1285	2120	1240
0-45-45	1671	2148 (−)	1172 (−)	2692.4	587	1054	2670	1030
45-0-45	1649	3429	1324	1437	1187	2153	4400	2690
45-45-0	1823	3906	2625	2633	1656	2086	3840	3230
Limiting element	P	N	N	P	N	N	N	N

10.6 On-Farm Maize Trials

The results of the effect of increasing N fertilizer rates on maize yield grown on 6 soils from the 3 ecological zones (Semi-deciduous, forest savanna transition and Guinea savanna zones) are shown in Fig. 10.4. Maize grain yield significantly increased on the various soils and ecologies similarly as a result of N fertilizer application in increasing rates.

Even thought response to N followed the same trend, maize grain yields obtained from the Semi-deciduous forest zone were higher (about 6 Mt/ha) than those obtained from the transition zone and the guinea savanna zones (Fig. 10.4). There was a gradual decline in yield from the forest zone through the transition zone to Guinea savanna zone. It is important to note that the growing seasons were characterized by intermittent drought spells which could not have allowed the full benefit of the fertilizers to be realized. With the exception of Nkoranza in the transitional zone and West Gonja (Damongo) and Nyankpala districts in the Guinea savanna zone, grain yields in 2005 where higher than in 2006. Maximum yields ranged from 5.0 T ha^{-1} in Berekum district to 7.0 T ha^{-1} in Sunyani district in 2005 and from 1.5 T ha^{-1} in Berekum district (due to drought) to 6.6 T ha^{-1} in Atebubu district in 2006.The N response charts for some benchmark soils and ecological zones are shown in Figs. 10.4 and 10.5. Nitrogen response functions representing district averages are presented in Fig. 10.6. As evidenced by the nutrient omission trials that nitrogen deficiency exists across the three ecological zones, maize response to N application was positive and followed the same trends across the ecological zones and districts although the magnitudes differed

Generally maize showed response to fertilizer (especially N) application. This is shown in Figs. 10.2, 10.3, 10.4, 10.5, 10.6, from one farmer to the other, from

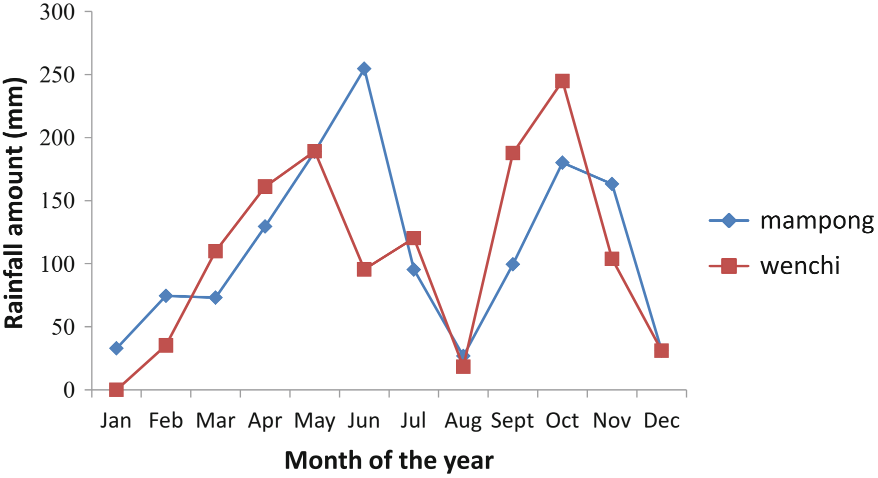

Fig. 10.2 Monthly rainfall distribution in the Guinea savanna zone of Ghana

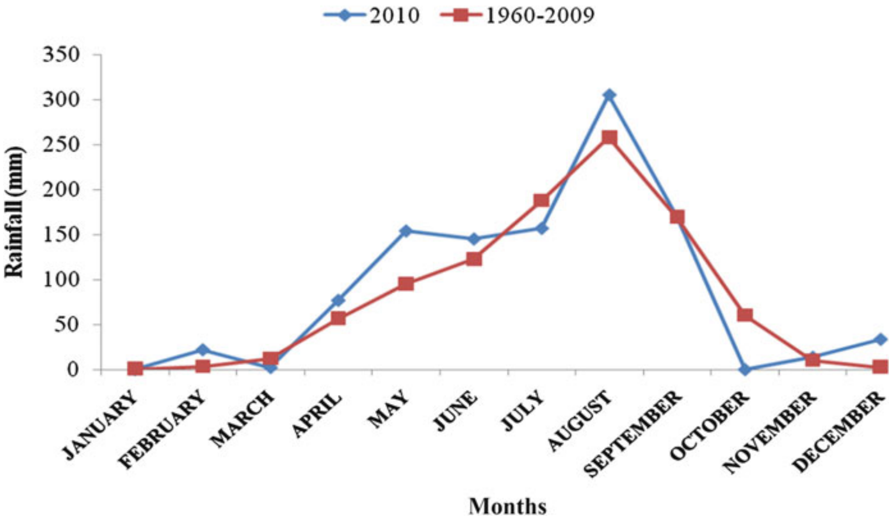

Fig. 10.3 Monthly rainfall distribution in the Guinea savanna zone of Ghana

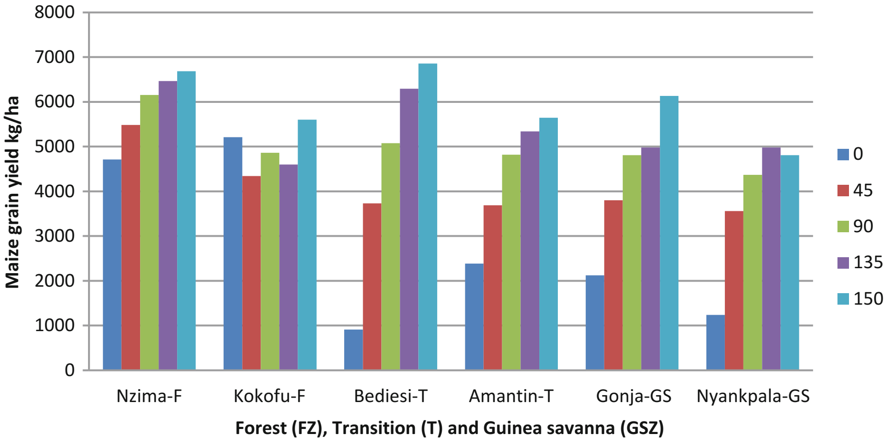

Fig. 10.4 On-farm maize fertilizer trials showing N response in the Forest zone (FZ), Transition zone (T) and Guinea savanna zone (GS)

district to district and from one benchmark soil to the other. Yields followed quadratic trends in all locations and years, with clear optimum N application rate ranging from 90 to 135 kg N per hectare. In some districts yields were increasing steadily even beyond 135 kg N ha^{-1}. It is evident therefore that the optimum N application rate has not been reached in these districts and grain yields may continue to increase with increasing N application rates beyond 150 kg N ha^{-1}.

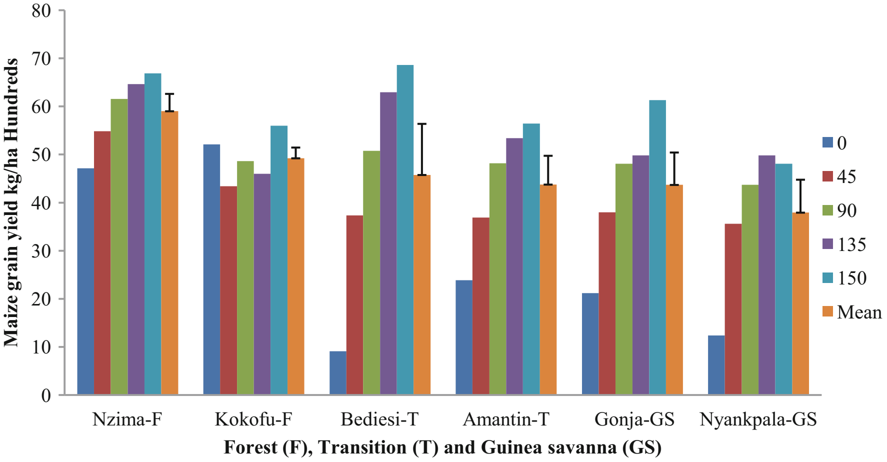

Fig. 10.5 On-farm maize fertilizer trials showing N response curves on the different benchmark soils (Nzima, Kokofu, Bediesi, Amantin, Debibi, Damongo, Techiman, Murugu and Nyankpala series)

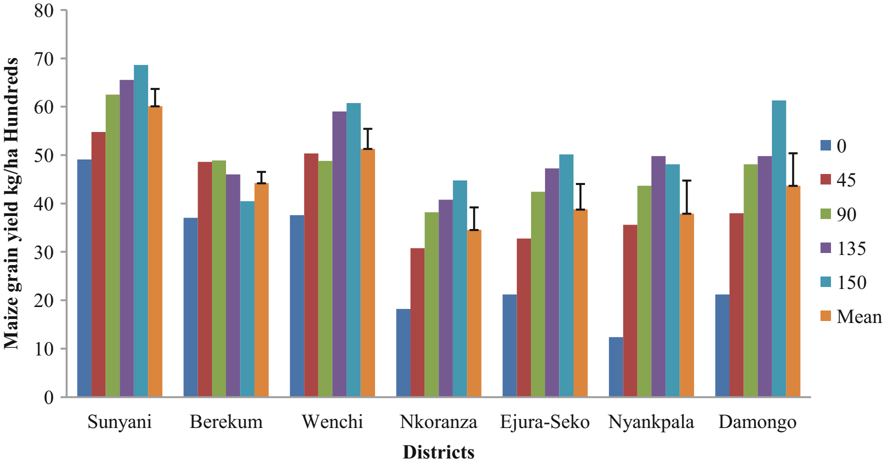

Fig. 10.6 On-farm maize fertilizer trials showing average N response across the districts

However any recommendations on rate of fertilizer application must take into consideration the economic optimum rate rather than the biological optimum

Quadratic equations relating average maize grain yields (Y) in some districts to applied nitrogen fertilizer (N) were as follows:

$$Y = 463 + 1573N - 157N^2 \quad \text{(at Nkoranza)}$$

$$Y = 2425 + 1643N - 267N^2 \quad \text{(at Berekum)}$$

$$Y = 2971 + 988N - 73N^2 \quad \text{(at Wenchi)}$$

$$Y = 4031 + 915N - 70N^2 \quad \text{(at Sunyani)}$$

High response was observe on *Bediesi*, *Techiman* and *Murugu* soil series. On some of the benchmark soils the response equations relating average maize grain yield (Y) to nitrogen fertilizer applied (N) were as follows:

$$Y = 3688 + 1122N - 105N^2 \quad \text{(on Nzima series)}$$

$$Y = -2082 + 3435N - 332N^2 \quad \text{(Bediesi series)}$$

$$Y = 834 + 1979N - 174N^2 \quad \text{(Techiman series)}$$

$$Y = 1686 + 1036N - 104N^2 \quad \text{(Damongo series)}$$

10.7 Study 4 Comparing Maize Performances with National Blanket and Research Recommendations

10.7.1 Methodology

With a clear optimum rate of 90–135 kg N ha^{-1}, the objective was to compare current blanket fertilizer recommendations with SFI optimum rates (90 and 135 kg ha^{-1}) in 15 sites (districts) in 6 regions of Ghana (Wenchi, Berekum, Ejura, Mampong, Effiduase, Apam, Swedru, Kade, Asamankese, Ho, Hohoe, Bole, Damongo, Kpando and Oda, Nkwanta, Adidwan,). The trials compared 60-40-40 –N-P_2O_5-K_2O with 90-60-70 and 135-60-70- N-P_2O_5-K_2O.

From Table 10.6 and Fig. 10.7), the Soil Fertility Initiative recommendation (SFI) performed better than the existing blanket fertilizer recommendation (Standard) at Manga (*Obatanpa*, major season), Kwadaso (*Mamaba* & *Obatanpa*, minor season) and Ejura (*Obatanpa*, minor season). Minor season maize grain yield at Kwadaso was very poor due to drought. However the SFI rates were superior to the blanket recommendation. The differences in yield between the SFI rates and the blanket recommendation become more pronounced under severe conditions of minimum moisture as experienced in the minor season in Ghana. Fig. 10.8 is comparing the SFI treatments and the blanket recommendation in the Sudan savanna zone (Manga), Guinea savanna (Bole) and the Forest savanna transition (Ejura) zones.

Table 10.6 Maize grain yield for the blanket (Standard) and Soil Fertility Initiative (SFI) recommendations at Kwadaso, Manga and Ejura

	Major season		Minor season		
Treatment	Kwadaso (Mamaba)	Manga (Obatanpa)	Kwadaso (Mamaba)	Ejura (Obatanpa)	Kwadaso (Obatanpa)
Control	1.19e	0.28e	1.15d	1.21e	1.37c
Standard	4.16cd	1.82d	1.26d	3.33c	1.11c
SFI 1	4.50c	2.54c	1.68b	4.41b	1.99b

NB: Mamaba and Obatampa are hybrid and OPV maize respectively

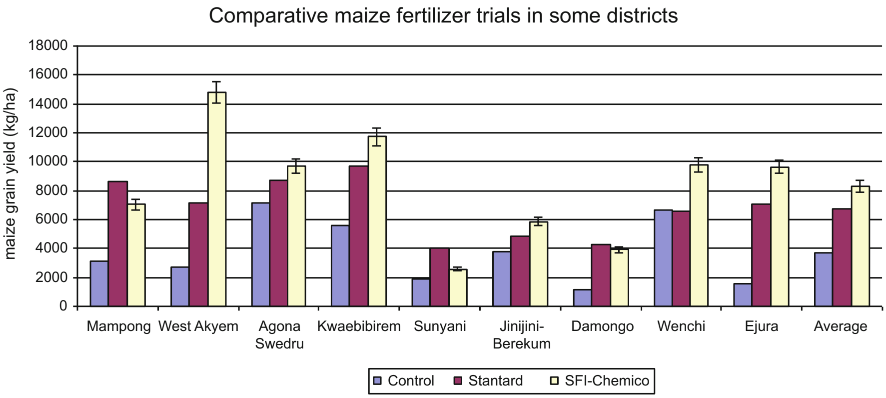

Fig. 10.7 Comparing blanket recommendation (standard) against SFI rates in 10 maize growing areas in Ghana

The results show the superiority of the SFI rates to the blanket recommendation across all the ecological zones.

10.8 Economic Analysis of Researcher Managed Trials

The SFI- 1 and 2 out-yielded the standard (64–38-38) which is the blanket fertilizer rate currently used by farmers as recommended by MOFA. Tables 10.7, 10.8, 10.9, 10.10, 10.11, 10.12, 10.13, 10.14 and 10.15 show the economic analysis (Value Cost ratio) on the maize fertilizer trial at Mampong and Adidwan. The Value Cost Ratio (VCR) was higher for the 90 kg N than the blanket (Standard) recommendation.

The fertilizer rate with the highest return was SFI-1 N-P_2O_5 -K_2O) 90–60-71.

On a fertile soil, with good fertilizer handling, and sowing at the right time, we expect good maize grain yields, at least between 5 to 8 t ha^{-1} with high financial returns if the SFI-1 (90–60-71 + B + S) fertilizer is applied to maize.

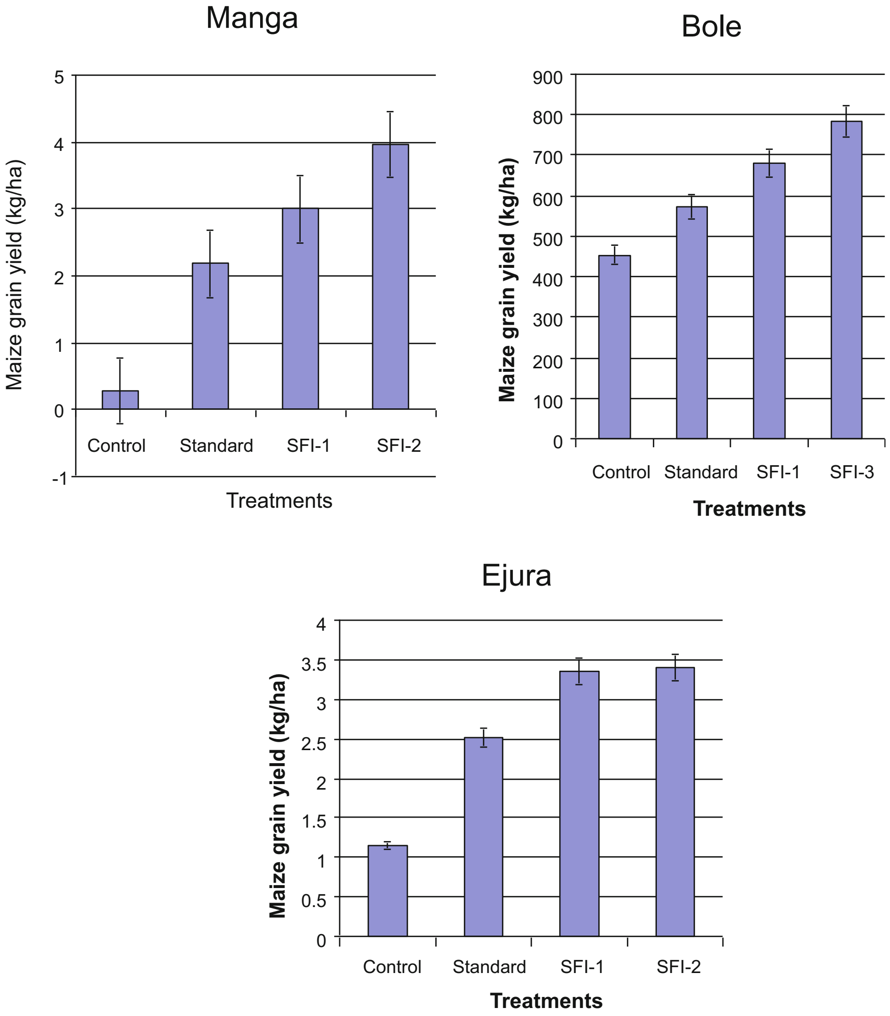

Fig. 10.8 Maize grain yield at Manga (Sudan savanna), Ejura (Forest Savanna Transition zone) and Bole (Guinea Savanna zones) as affected by standard blanket fertilizer recommendation and SFI recommendation

Table 10.7 Economic analysis of trial at Mampong (2007)

N	Yield (Y) (T/ha)	ΔY (T/ha)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
0	3.0	–	–	–	–	–
Standard	6.2	2.8	5.6	1.98 m	3.62	1.8
90	8.0	5.0	10.0 m	2.55 m	7.45	2.9
135	4.56	3.32	10.0 m	4.09 m	5.91 m	1.4

NB: A market price of ¢200,000 was used in the computation. March 2007 price is ¢140,000

Table 10.8 Economic Analysis of fertilizer trial at Adidwan (2007)

	Yield (Y)	ΔY	Gross Return	Fert.Cost	Net Return	
N	T/ha		(¢)			VCR
0	1.24	–	–	–	–	–
90	5.32	4.08	12.0 m	2.55 m	9.45 m	3.7
135	4.56	3.32	10.0 m	4.09 m	5.91 m	1.4

Table 10.9 Economic analysis of trial at Ejura (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	0.6	–	–	–		–
Standard	2.9	2.3	892	65	827	12.7
SFI	3.9	3.3	1320	94	1226	13.0

Table 10.10 Economic analysis of trial at Wenchi (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	2.7	–	–	–	–	–
Standard	2.6	−0.1	4	65	−69	−1.1
SFI	3.9	1.2	480	94	386	4.1

Table 10.11 Economic analysis of trial at Kwaebibirim (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	2.3	–	–	–	–	–
Standard	3.9	1.6	640	65	575	8.8
SFI	4.7	2.4	960	94	866	9.2

Table 10.12 Economic analysis of trial at Agona Swedru (2007) (100 kg = Gh¢40.00)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	2.9	–	–	–	–	–
Standard	3.5	0.6	240	65	175	2.6
SFI	3.9	1.0	400	94	306	3.2

Table 10.13 Economic analysis of trial at West Akyem (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	1.1	–	–	–	–	–
Standard	2.9	1.8	720	65	655	10.1
SFI	5.9	4.8	1920	94	1826	19.4

Table 10.14 Economic analysis of trial at Jinijini (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	1.5	–	–	–	–	–
Standard	1.9	0.4	160	65	95	1.5
SFI	2.3	0.8	320	94	226	2.4

Table 10.15 Economic analysis of trial at Sunyani (2007)

N	Yield (Y) (t/acre)	ΔY (t/acre)	Gross Return (¢)	Fert.Cost (¢)	Net Return (¢)	VCR
Control	0.8	–	–	–	–	–
Standard	1.6	0.8	320	65	255	3.9
SFI	1.0	0.2	80	94	−14	0.15

10.9 DSSAT Simulated Results

The CSM-CERES model was evaluated by comparing the observed field data with the simulated data for Nyankpala (Guinea savanna zone), Wenchi (forest savanna transition zone) and Mampong (semi-deciduous forest zone). Figs. 10.9 and 10.10a&b present box plots of yield outcomes under different N levels using 43 years historical data to know which of the N levels will be most appropriate to recommend to farmers at each site.

The DSSAT simulated results show that in the Guinea savanna (Tamale), forest savanna transition (Wenchi) and the Semi-deciduous forest (Mampong) zones of Ghana and the Sudan savanna zones, the optimum rate of nitrogen for maize is 120 kg ha^{-1}. Combined application of organic fertilizer (poultry manure) at 2.5 T ha^{-1} with 60 kg N ha^{-1} mineral fertilizer gave the same yield as application of sole 90 kg N ha^{-1}. Works done by Atakora et al. 2014 at Kpelesawgu and Nurudeen *et al.*, 2015 at Navrongo also obtained 120 kg ha^{-1} as the highest rate. These rates fall within the SFI rates (90–135 kg N ha^{-1}) obtained in the SFI on-station and on-farm trials.. The 90 N kg ha^{-1} obtained in the on-farm SFI trials is therefore appropriate. These results confirm results of on-farm trials conducted across all the maize growing districts under the SFI project which came out with 90–135 N kg ha^{-1}.

10.10 Conclusion on On-Farm Maize Trials

The relevance of mineral fertilizer in increasing food production cannot be under estimated especially on soils which are deficient in nutrients. The most promising and economic N rate obtained from the various districts was 90 kg N ha^{-1}. Dryer

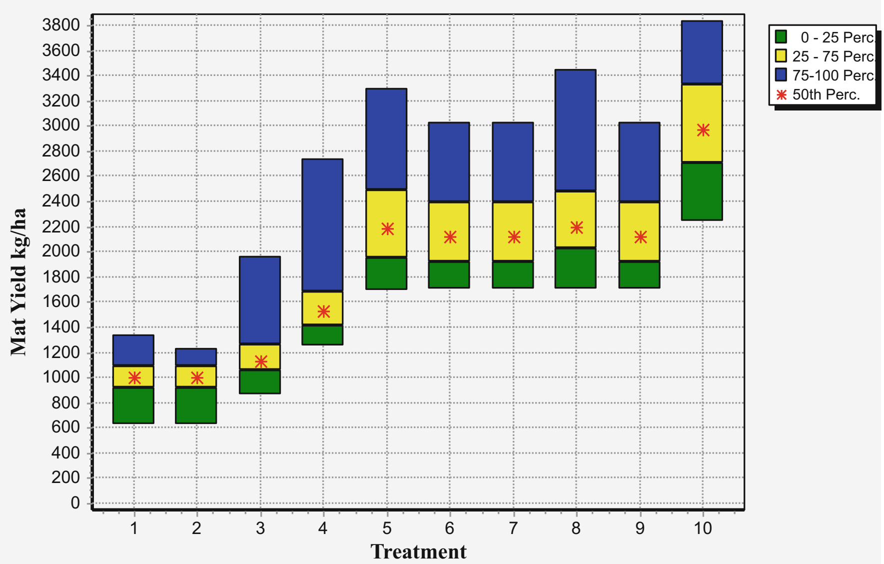

Fig. 10.9 Maize yield as affected by different rates of NPK fertilizer for 50 years (1960–2010) biophysical analysis of seasonal analysis at Tamale. 1 = 0-0-0; 2 = 0-90-90; 3 = 40-90-90; 4 = 80-90-90; 5 = 120-0-90; 6 = 120-45-90; 7 = 120-90-90; 8 = 120-90-0; 9 = 120-90-45; 10 = 160-90-90

areas seemed to have 90 kg N ha^{-1} as their optimum whereas the moist forested areas with higher soil organic matter content (>2.0%) (Table 10.16) had 135 kg N ha^{-1} as the optimum rate.

The most limiting nutrients (Table 10.16) in most of the districts were N and P. Some districts also experienced the most limiting nutrient to be K especially in the second year of cropping. Soil test levels in all the districts have shown that potassium is deficient in some of the districts. Application of potassium fertilizers is therefore very necessary to achieve economic yields.

Yield levels obtain on-station were observed to be lower than the on-farm for a number of reasons. Soils at on-stations have been continuously cropped resulting in reduced fertility and productivity. Secondly, the on-station trials, more often than not, were established after the on-farm trials, resulting in inadequate rainfall at the filling stage or too much rain when seeds have to be dried.

10.10.1 On-Farm Cassava Trials

Five cassava farmers were selected in each district for NPK trials. The treatments were as follows: N-P_2O_5-K_2O 1. 0-0-0. 2. 30-45-90. 3. 60-45-90. 4. 90-45-90. Each farmer represented a replicate. For the researcher managed cassava trials, there

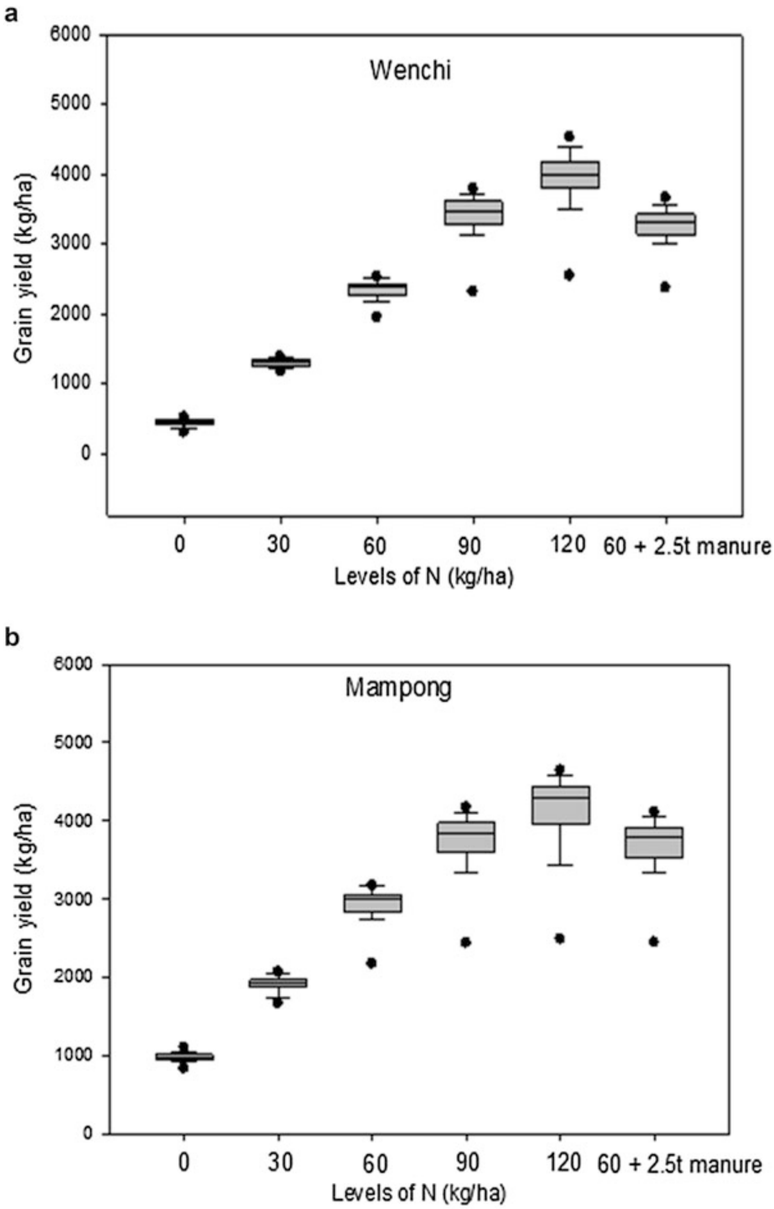

Fig. 10.10 Simulated maize (*Obatanpa*) yield variation in (**a**) Wenchi and (**b**) Mampong over 43 year period in response to N fertilizer application

Table 10.16 Effect of N, P and K fertilizer on cassava root yield and plant growth. On-station at Wenchi

	Root yield	Stem fresh Wt	Leaf fresh wt	Plant height
N-P_2O_5-K_2O	T/ha	T/ha	T/ha	(m)
1. 60-30-90	57.1	40.2	12.1	2.3
2. 90-30-90	53.5	40.9	9.4	2.4
3. 60-60-90	53.5	25.7	11.2	2.3
4. 90-60-30	50.9	32.2	12.0	2.3
5. 0-0-0	47.0	34.2	8.2	2.2
6. 90-60-90	44.8	22.2	9.0	2.3
7. 90-0-90	44.1	23.8	9.5	2.4
8. 30-60-90	36.2	24.6	6.5	2.3
9. 30-30-30	35.9	21.1	7.5	2.2
10. 30-30-60	35.5	19.7	4.9	2.1
11. 0-60-90	32.9	18.4	7.1	2.5
12. 90-60-0	32.1	19.4	4.6	2.2
SED	6.0	6.5	1.7	8.1

were 10 treatments as follows: N-P_2O_5-K_20. 1. 0-0-0. 2. 0-60-90. 3. 90-60-0. 4. 90-0-60. 5. 30-30-30. 6. 30-30-60. 7. 30-60-90. 8. 60-30-90. 9. 60-60-90. 10. 90-60-90. There were 3 replicates arranged in a randomized complete block design. Cassava variety used was Afisiafi.

10.10.2 On-Station Cassava Trials

On- station results showed that each of the major nutrients N, P and K was important in cassava growth and root yield at Wenchi (Table 10.17) when considering the nutrient omission treatments. For example, potassium was the most limiting in Nkoranza and Wenchi whereas nitrogen was liming in Berekum. In order of importance, K was the most limiting, its absence resulting in the most drastic reduction in yield, leaf and stem growth. Phosphorus is the least limiting element for cassava growth and yield at Wenchi. This trend could be seen when comparing yield at 0-60-90 versus 90-0-90, versus 90-0-60. The optimum N rate was seen to be 60 kg N ha^{-1} below and above which cassava root yield declined. It could be concluded that the treatment 60-30-90 kg ha^{-1} $N - P_2O_5 - K_2O$ resulted in highest stem growth, leaf growth and highest cassava root yield. Increasing the P component to 60 kg ha^{-1} P_2O_5 in the 30-60-90 kg ha^{-1} $N - P_2O_5 - K_2O$ resulted in yield depression. Absence of N or K resulted in significant ($p \leq 0.05$) yield reductions compared to when no fertilizer was applied. Generally there was good response of cassava to fertilizer application at all the locations. In 2004/2005 highest root yield was achieved at 60-6090 kg ha^{-1} N-P_2O_5-K_2O and 90-30-90 kg ha^{-1} N-P_2O_5-K_2O at Wenchi and Berekum respectively. Yields ranged

Table 10.17 Cassava Root Yield as influenced by fertilizer application rate

Fertilizer Rates N-P_2O_5-K_2O	Nkoranza	Wenchi	Berekum	Mean
	T ha^{-1}			
1. 0-0-0	7.0	29.8	31.9	22.9
2. 0-30-30	12.4	40.3	27.6	26.8
3. 0-60-90	10.3	40.1	39.8	30.1
4. 30-0-30	14.8	41.0	37.8	31.2
5. 30-30-0	8.7	26.4	33.8	23.0
6. 30-30-30	12.2	41.7	39.5	31.1
7. 30-30-60	11.5	38.8	37.8	29.4
8. 30-30-90	12.4	37.3	28.9	26.2
9. 60-30-90	11.7	34.2	34.2	26.7
10. 60-60-90	12.0	41.8	28.3	27.4
11. 90-0-90	14.7	34.2	31.7	26.9
12. 90-30-90	12.3	35.7	57.3	35.1
13. 90-60-0	13.3	35.9	52.3	33.8
14. 90-60-30	15.6	37.2	55.3	35.5
15. 90-60-90	14.1	37.2	55.3	35.5
$SED_{(0.05)}$	3.0	3.5	8.5	
Mean $Pltsm^{-2}$	0.4	0.7	0.7	

from 7.0 to 15.6 t ha^{-1} at Nkoranza, 26.4 to 41.8 t ha^{-1} at Wench, and 27.6 to 57.3 t ha^{-1} at Berekum. In 2006 cassava root yields at Afram Plains (Forifori) ranged from 32.1 to 56.9 t ha^{-1} with the optimum fertilizer rate being 60-30-90. At Berekum, where N was the most limiting nutrient for root yield, yields were higher at the higher N rate of 90 kg ha^{-1}. Yield increases were 40.3 and 61.8% higher at these rates than yields at zero fertilizer application.

10.11 Conclusions on On-Farm Cassava Results

Cassava root yields followed distinct quadratic trends in Krachi, Nkoranza, Atebubu and Sene districts, with yields increasing with application of N up to 60 kg ha^{-1} and then decreasing with additional N application in these districts (Fig. 10.11). Thus, 60 kg N ha^{-1} was clearly the optimum N rate for cassava root production in the four districts. The full treatment is therefore 60–45-90 kg ha-1 N-P_2O_5-K_2O.

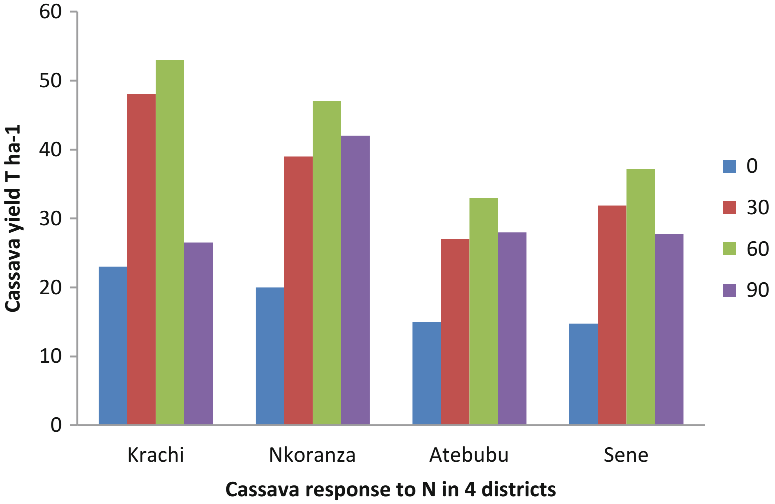

Fig. 10.11 Cassava root yield response to N application 4 districts

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Chapter 11
Combined Effects of Organic and Mineral Fertilizers on Soil Productivity in Tomato Production: Experiments on Soils of the Coast Road of Yantala-Bas

Ibrahim Jamilou Salissou, Saidou Addam Kiari, Sabiou Mahamane, Amadou Abdourhamane Toure, and Bouba Hassane

Abstract Tomato is the most widely grown vegetable in Africa. It goes into the preparation of many dishes, given its nutritional importance due to its content in active substances such as vitamins A and C, iron and phosphorus. Experiments were set up on a vegetable growing site at INRAN's headquarters. This consisted in three trials with different treatments on tomato. Treated rice husk (150 g per plant) was used in the first trial and NPK (0, 2, 4, 6 g per pocket) in the second trial, whereas the third trial included the use of organic manure (1 kg of manure per bed), burned rice husk (1 kg per bed) and rock phosphate (2 g per pocket). Each trial was carried out in complete randomized block with three replicates. The results of these three trials show that the yield of 29 t ha^{-1} achieved with the application of treated rice husk (1.6 t.ha^{-1} rice husk 1.6 t ha^{-1}, 1.6 t ha^{-1} sandy- soil +1.6 t ha^{-1} incubated manure for 14 days) per plant was higher compared to the yield of 25.6 t.ha^{-1} obtained by the application of a microdose of NPK (PP+ 6 g NPK per pocket or 187.5 kg ha^{-1}) per plant. These first two treatments were more efficient than the combination of carbonized rice husk and organic manure (PP + NPK + BRC + PNT incubated for 14 days) per bed, with 22.4 t.ha^{-1}. This clearly shows that the treatment with treated rice husk further improves the soil structure. This favors a good vegetative development and higher yields.

Keywords *Lycopersicum esculentum* · Rice husk · Micro- dose · Organic manure · Phosphate rock

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Contents

11.1 Introduction

In Niger, irrigated crops are growing exponentially as the climate is becoming increasingly unfavorable to rainfed agriculture (Saidou et al. 2013). The production of tomato *Lycopersicum esculentum* is an income generating activity for many farmers (Hanson et al. 2001). It is used in the preparation of most local foods due to its high contents in proteins and vitamins A and C.

The expansion of vegetable production only started in 1984, when the State officially started investing in the operation "Off-Season Crops". The main objective is to alleviate cereal deficit in the country.

Generally, any increases in agricultural production can be achieved through improving soil fertility (Soltner 2000; Batiano et al. 2003). Tomato production, which does not escape the rule, increased from 57,685 t in 1996 to 112,445 t in 2000 and to 141,500 t in 2012 (RECA 2013). These increases were due to the use of organic and mineral fertilizers (RECA 2013).

In line with this, a study was carried out under the title: "Combined Effects of Organic and Mineral Fertilizers on Soil Productivity in Tomato Production: Experiments on soils of the Coast Road of Yantala-bas".

The general objective of this work was to study the effects of different combinations of organic and mineral fertilizers on the growth and productivity of tomato on soils with low organic matter content. The specific objectives were:

- To assess the effects of fertilization on tomato growth, early maturity and productivity;
- To determine the optimal dose of NPK (15-15-15) for good tomato production.

11.2 Materials and Methods

11.2.1 Experimental Site

The experimental site was located on the Coast Road of Yantala-Bas between 13 ° 32′45.2 ′N and 2° 04′30.6′ ′E. The experiments were installed on a vegetable growing site at INRAN's headquarters. Vegetable beds were made of solid materials at the nursery for the conservation and production of forest species of INRAN.

In preparation for this study, the leached sand was replaced by sand taken from the Niger River. The River Niger water was used for watering.

The tomato variety Tropimech (commonly called Chaibo in Hausa and Kangaou in Zarma) was used.

Mineral fertilizers (NPK) and organic fertilizers were used.

11.2.2 Technical Equipment

Wheelbarrow, motor pump, hoe, watering can, caliper, graduated ruler, scales, GPS device, Arc-gis 12, Excel (2010), Statistix10.2.2.

11.2.3 Experimental Design and Treatments

The experimental design for the three trials consisted of randomized complete blocks.

The size of a vegetable bed was: width (75 cm) × length (150 cm), making an area of 1125 m^2 each.

- **Trial 1: Effects of Incubation of the Various Treatments on Tomato Production it consisted of the following treatments:**
    1. Control (T0)
    2. 2.4 t ha^{-1} rice husk +2.4 t ha^{-1} loamy sandy soils (T1)
    3. 2.3 t ha^{-1} rice husk +2.3 t ha^{-1} loamy sandy soils +170 kg ha^{-1} PNT (T2)
    4. 2.4 t ha^{-1} carbonized rice husk +2.4 t ha^{-1} loamy sandy soils (T3)
    5. 1.6 t ha^{-1} rice husk t ha^{-1} loamy sandy soils +1.6 t ha^{-1} manure (T4)
- **Trial 2: Farmer Practice (FP) Combined with Different Rates of NPK on Tomato:**
    - FP (*1 kg of organic fertilizer per bed, or 9 t.*ha^{-1} (T0)
    - FP + 6 g NPK/pocket (T1)
    - FP +4 g NPK/ pocket (T2)
    - FP +2 g NPK/pocket (T3)
- **Trial 3: Farmer Practice (FP) Combined with Tahoua Phosphate Rock (TPR) and Carbonized Rice Husk (CRH) on Tomato:**
    1. Farmer practice (T0)
    2. FP + NPK + CRK+ TPR (T1)
    3. FP + NPK + CRH (T2)
    4. FP + NPK + TPR (T3)

5. ***NB: FP:** 1 kg of organic fertilizer per bed (9 t.ha^{-1}); **TPR**: 2 g per pocket (62.5 kg.ha^{-1}); **NPK:** 2 g per pocket (62.5 kg.ha^{-1}); **CRH:** 1 kg per bed (9 t. ha^{-1})*

11.3 Results and Discussion

11.3.1 Effects of Treatments on Growth and Yield Parameters

11.3.1.1 First Trial: Effects of Incubation of Various Treatments on Tomato Production Evolution of Growth and Yield Parameters

The growth (height and diameter) and yield (leaves, flowers, fruits) parameters evolve according to the treatments with different combinations of fertilizers. The following Table shows the effects of the first trial treatments on growth and yield parameters. The T4 treatment significantly increased the height, diameter, and number of leaves, flowers and fruits (Table 11.1). The sand from the Niger River bed does not contain plant nutrients but with the use of manure and rice husk, after a 2-week incubation period, a favorable effect was observed on tomato growing.

11.3.2 Yield Evolution Trial 1

The overall performance includes foliar and root development as well as tomato fruit production. The Fig. 11.1, 11.2 and 11.3 below shows the evolution of this overall performance.

Table 11.1 Effects of Trial 1 treatments on growth and yield parameters

Treatments	Height (cm)	Diameter (cm)	Leaves (U/P)	Flowers (U/P)	Fruits (U/P)
T4	2.6a	1.57a	403a	40a	42a
T2	2.3ab	1.41ab	313a	31ab	38a
T3	1.93bc	1.2bc	273ab	16bc	17b
T1	1.64cd	1.1c	173bc	9c	10bc
T0	1.18d	0.63d	64.c	1c	2c

NB: *LSD* least significant difference. Values within the same column and followed by the same letter are not statistically different at the 5% threshold (Duncan test)

U/P production unit per plot

T0: control; *T1*: 2.4 t ha–^{1} rice husk + 2.4 t ha–^{1} sandy loamy soil; *T2*: 2.3 t ha–^{1} rice husk + 2.3 t ha–^{1} sandy loamy soil + 170 kg ha–^{1} TPR; *T3*: 2.4 t ha–^{1} of the carbonized rice husk + 2.4 t ha–^{1} sandy loamy soil; *T4*: 1.6 t ha–^{1} rice husk + 1.6 t ha–^{1} sandy loamy soil + 1.6 t ha–^{1} manure

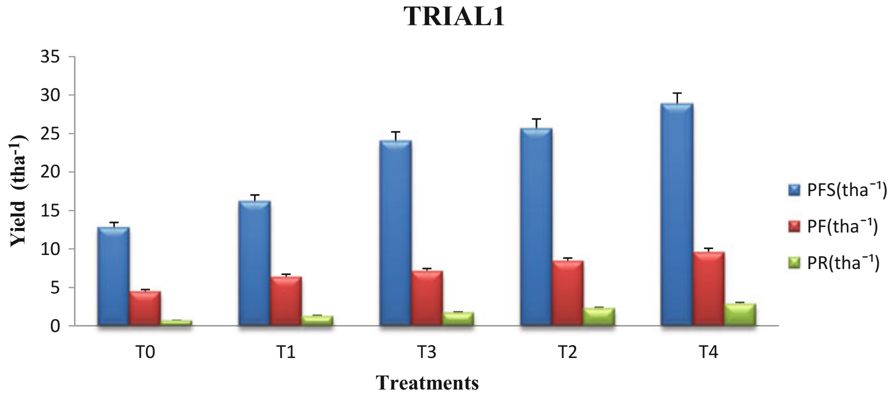

Fig. 11.1 Effects of treatments on yields (Trial 1)
NB: *FW* foliar weight, *RW* root weight, *SFW* Season fruits weight
T0: control; **T1:** 2.4 t ha–^{1} rice husk +2.4 t ha–^{1} sandy loamy soil; **T2:** 2.3 t ha^{-1} rice husk plus 2.3 t ha^{-1} sandy loamy soil plus 170 kg ha^{-1} TPR; **T3:** 2.4 t ha $^{-1}$ carbonized rice husk +2.4 t ha $^{-1}$ sandy loamy soils; **T4:** 1.6 t ha^{-1} rice husk +1.6 t ha^{-1} sandy loamy soil +1.6 t ha^{-1} manure

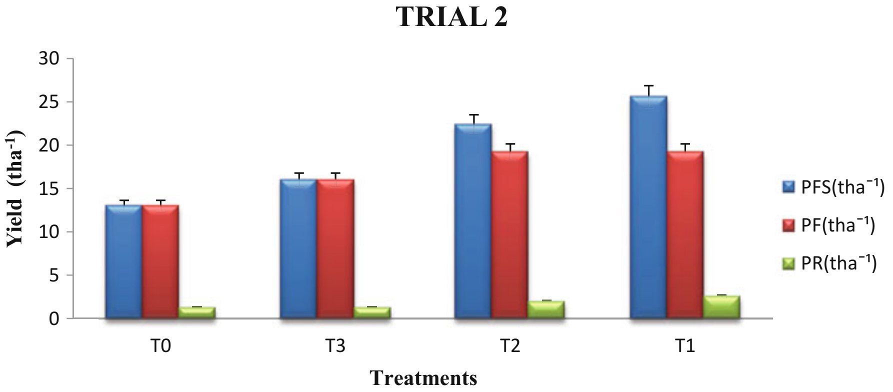

Fig. 11.2 Effects of trial 2 treatments on yields (Trial 2)
T0: control; **T1:** FP + 6 g NPK/pocket or 187.5 kg.ha–^{1}; **T2:** FP + 4gNPK/pocket, or 125 kg.ha–^{1}; **T3:** FP + 2 g NPK/pocket, or 62.5 kg.ha–^{1}

11.3.2.1 Trial 2: Farmer Practice (FP) Combined with Different Rates of NPK on Tomato

The growth parameters (height and diameter) and yield (leaves, flowers, fruits) vary according to the treatments with different combinations of fertilizers. T1 and T2 treatments did not significantly differ in terms of production of tomato fruits (Table 11.2).

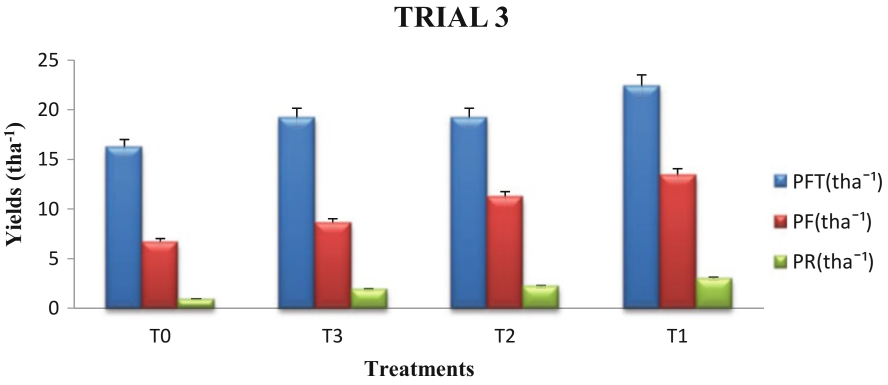

Fig. 11.3 Effect of treatments on yields (Trial 3)
NB: *FW* foliar weight, *RW* root weight, *SFW* Season fruits weight
T0: control; **T1**: FP+ NPK + CRH + TPR; **T2**: FP+ NPK + CRH; **T3:** FP + NPK + TPR

Table 11.2 Effect of trial 2 treatments on growth and yield parameters

Treatments	Height (cm)	Diameter (cm)	Leaves (U/P)	Flowers (U/P)	Fruits (U/P)
T1	2.01a	1.3a	236.75a	19.95a	41.15a
T2	1.57ab	1.1a	188.25ab	8.30b	37.30a
T3	1.29b	1.0a	144.80b	6.4b	14.80b
T0	1.18b	0.63b	67.05c	2.35b	10.90b

NB: *LSD* least significant difference. Values within the same column and followed by the same letter are not statistically different at the 5% threshold (Duncan test)
U/P production unit per plot
T0: control; *T1*: FP + 6 g NPK/pocket or 187.5 kg.ha–^{1}; *T2*: FP + 4gNPK/pocket, or 125 kg.ha–^{1}; *T3*: FP + 2 g NPK/pocket, or 62.5 kg.ha–^{1}

11.3.2.2 Trial 3: Farmer Practice (FP) Combined with Tahoua Phosphate Rock (TPR) and Carbonized Rice Husk (CRH) on Tomato

Effects of Trial 3 Treatments on Growth and Yield Parameters (Table 11.3)

The T3 combination gave the most significant production of tomato fruits and this was consistent with all other growth parameters.

These values were lower than those obtained by Shankara et al. (2005), which showed that the height of indeterminate tomato plants ranged from 80 to 120 cm under natural growing conditions for 2 years. Regarding diameter, the results were in line with those obtained by Kotaix et al. (2013) in Côte d'Ivoire, which showed that diameter values ranged from 1.6 cm to 1.3 cm at the flowering stage.

These results relating to yield parameters (number of leaves, flowers, fruits) were the only ones recorded, since detailed analysis was not carried out in the framework of this study.

Table 11.3 Effect of trial 3 treatments on growth and yield parameters

Treatments	Height (cm)	Diameter (cm)	Leaves (U/P)	Flowers (U/P)	Fruits (U/P)
T2	2.3a	1.41a	273.64a	31.11a	38.29a
T3	1.64b	1.01b	185.92b	8.22b	13.33b
T1	1.42b	0.91b	172.19b	8b	10.40b
T0	0.63c	0.63c	64.93c	1.5b	2.2b

NB: *LSD* least significant difference. Values within the same column and followed by the same letter are not statistically different at the 5% threshold (Duncan test)

U/*P* production unit per plot

T0: control; *T1*: FP + NPK + CRH + TPR; *T2*: FP + NPK + CRH; *T3*: FP + NPK + TPR

Table 11.4 Dates of flowering and first harvest of tomato fruits

	TRIAL 1		TRIAL 2		TRIAL 3	
	Treated	Control	Treated	Control	Treated	Control
Flowering date	15 DAT or 30 DAS	35 DAT or 50 DAS	25 DAT or 40 DAS	35 DAT or 50 DAS	17 DAT or 32 DAS	31 DAT or 46 DAS
Date of first tomato fruits harvest	45 DAT or 60 DAS	75 DAT or 90 DAS	65 DAT or 80 DAS	75 DAT or 90 DAS	55 DAT or 70 DAS	65 DAT or 80 DAS

NB: *DAS* day after sowing, *DAT* day after transplanting

11.3.2.3 Trial 3 Effects of Trial 3 Treatments on Yields (Fig. 11.3)

The statistical analysis carried out on the yields obtained in Trial 1 showed that the performance of T4 treatment (29 t ha$-^1$) was better compared to all other trials.

Results from the three trials were higher than that of the organic fertilizer treatment (Manure: 20 t.ha^{-1} of manure +50 kg of urea +50 kg of super-simple phosphate) which gave a yield of 20 t.ha $^{-1}$ of tomato fruit (MDA 2009).

Some research works have shown that tomato yields can vary from 16 t.ha^{-1} to 30 t.ha^{-1} across the various treatments (Roy-Fortin et al. 2014).

11.3.3 Effects of Treatments on Early Maturity

Results of experiments on the dates of flowering and first harvest of tomato fruits (Table 11.4).

The results of the treatments showed very significant effects on the date of beginning of flowering (date when 50% of plants have flowered) and the date of the first harvest of tomato fruits for the three trials between the positive and negative controls, in the following sequential order: trial1, trial 3 and trial2, regarding early flowering and fruiting.

These were the earlier results compared to the flowering dates of 23 DAT on the sites under the rate of 5 l ha^{-1} and 25 DAT in Bimbresso and 24 DAT in Bouaflé under the rate of 3.75 $l.ha^{-1}$ (Kotaix et al. 2013).

11.4 Conclusion

L'observation de la date de la floraison et de la fructification sur la précocité par les témoins positifs et négatifs montre l'utilité des traitements dans l'ordre de subséquence dont l'essai1 puis essai3 et essai2.

The study results have shown that T4 treatment under trial 1 increased the growth and yield parameters. In trial 2, the combinations T1 and T2 gave the best yields. In trial 3, T2 treatment gave the highest increase in tomato production. These various treatments should be recommended to tomato producers depending on the availability and accessibility of inputs in their production areas.

Observation of the dates of early flowering and fruiting on the positive and negative controls shows the efficiency of the various treatments in the following sequential order: trial1, trial3 and trial2.

In fact, the application of rice husk under micro-dose treatment allows better improvement of soil structure, which leads to a good vegetative development of the crop and a good production of tomato fruits. The 6 g NPK (15-15-15) is the optimal dose for good tomato production. This confirms the assumption of this study and the achievement of its objectives.

Lastly, to ensure integrated soil fertility management and optimal and sustainable use of the nutrient reserves of mineral fertilizers and organic amendments, tomato growers are recommended to:

- Improve farmer practice with the use of rice husk;
- Encourage the treatment of rice husk especially with organic fertilizers; and
- Apply carbonized rice husk in incubation for at least 2 weeks.

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Chapter 12

Maize Response to Fertilizer on Ferralsol and Luvisol in the South Sudan Zone of Burkina Faso

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Abstract A field study was conducted at Farako-Bâ, located in the south Sudan zone of Burkina Faso to update the fertilizer recommendations for maize production according to the soil type and variety of maize. The experiment was a split-plot arranged in a randomized complete block design with three replications on both Luvisol and Ferralsol. The factors were mineral fertilizer options in the sub-plot and maize variety in the main plot. The treatment options were; control, 90 kg N ha^{-1}, 90 kg N ha^{-1}+ 15 kg P ha^{-1}, 90 kg N ha^{-1}+ 7.5 kg P ha^{-1}, 90 kg N ha^{-1} + 22.5 kg P ha^{-1}, 90 kg N ha^{-1}+ 15 kg P ha^{-1} + 10 kg K ha^{-1}, 90 kg N ha^{-1} + 15 kg P ha^{-1} + 20 kg K ha^{-1}, 90 kg N ha^{-1} + 15 kg P ha^{-1} + 30 kg K ha^{-1} and diagnostic (90 kg N ha^{-1} + 15 kg P ha^{-1}+ 20 kg K ha^{-1}+ 15 kg S ha^{-1}+ 2.5 kg Zn ha^{-1}+ 10 kg Mg ha^{-1} + 0.5 kg B ha^{-1}). The maize varieties were Komsaya and SR21. At harvest grain and, stover yield as well as the harvest index were computed. The results showed that, grain and stover yields were significantly affected by both mineral fertilizer and soil type. Between the two maize varieties, Komsaya gave the highest grain yield across fertilizer treatments. Cultivation of Komsaya was the most profitable in terms of returns on investment on both soil types than SR21 which was economically viable when grown on a Luvisol.

Keywords Benchmark soils · Maize · Mineral fertilizer · South Sudan zone

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Contents

12.1 Introduction

Maize (*Zea mays* L.) is a widely cultivated crop throughout the world and a greater quantity is produced each year than any other grain (Riaz et al. 2014). It is currently the world's third most important cereal after wheat and rice (Belfield and Brown 2008). Maize has become a major cereal crop and an important component of human and animal diets as well as raw material for industry (USAID/EAT 2012). It is a widely grown cereal in the tropics (Damsteegt and Igwegbe 2005) and plays a major role as a food security crop in both rural and urban communities in West Africa. In industrialized countries, it is largely used as livestock feed and as a raw material for industrial products, while in developing countries, it is mostly used for human consumption (IITA 2007).

In Burkina Faso, maize is mainly produced under rainfed conditions predominantly in the Hauts-Bassins, Boucle du Mouhoun and Cascades regions with respective yield of 346,500, 199,000 and 123,188 tons over the bulk of production in the country which is about 1,200,000 tons (DGPER 2010).

In spite of the importance of the crop in the country, the average yield of 1.2 ton ha^{-1} is generally low compared to the global average of 4–5 tons ha^{-1} and over 8 tons ha^{-1} in the United States of America (FAOSTAT 2008). This low production according to Shao (1996), may be partly attributed to the use of little or no fertilizers and the predominant use of local varieties.

Research has demonstrated the importance of inorganic fertilizer in crop production (Yamoah et al. 2002; Aflakpui et al. 2005; Conley et al. 2005). Nutrient inputs from chemical fertilizers are needed to replace nutrients, which are exported and lost during cropping, to maintain a positive nutrient balance. Due to various socio-economic constraints encountered by farmers in the country, most farmers apply little or no fertilizer. On the other hand, farmers who can afford to use fertilizer are following the national blanket fertilizer recommendation which was established since 1992. Different soils are endowed with different physical and chemical properties which make them superior or inferior to other soils within a given locality (van Waverson et al. 1993). Therefore, fertilizer recommendation should take into account the effect of soil types in the agro-ecological zone as soil types may result in different responses of crops to a single fertilizer rate (Ndlangamandla 1998). Broad or blanket fertilizer recommendations which assume homogeneity of soil conditions have, thus, partly contributed to the low yield of maize in Burkina Faso. Moreover, there is limited information on major soil nutrient dynamics following mineral fertilizer application. Therefore there is a need to carefully target fertilizer recommendation for specific sites to increase maize growth and improve yield sustainably.

Another factor limiting maize production is the predominant use of local varieties which have low yield potential of about 1 ton ha^{-1}.. It has been demonstrated that modern maize hybrids generally yield more than local open pollinated varieties (Ojiem et al. 1996; Macharia et al. 2010). Therefore, the inclusion of hybrids into the farming system will help in increasing the yield of maize sustainably.

By way of addressing these constraints, this study was conducted to update the blanket fertilizer recommendation rates, taking into account the soil types in the agro-ecological zone. The new fertilizer recommendations will also provide information on fertilizer requirements for both local and hybrid varieties and will reflect farmers' economic situation and ultimately improve maize productivity in Burkina Faso.

Therefore, the main objective of this study was to improve the sustainability of the productivity of maize by determining the appropriate site-specific fertilizer application rates in the sub sudanian zone of Burkina Faso.

The specific objectives of the study were to:

(i) determine the appropriate rate of mineral fertilizer for optimum grain yield on two benchmark soils;
(ii) evaluate the cost effectiveness of fertilizer use for smallholder farmers in Burkina Faso.

The above specific objectives were formulated to test the null hypotheses that:

(i) the application of mineral fertilizer does not lead to increase in grain yield;
(ii) the application of appropriate rates of mineral fertilizers are not profitable to smallholder farmers.

12.2 Materials and Methods

12.2.1 Experimental Site

The experiment was conducted at the sub-station of the *Institut de l'Environnement et de Recherches Agricoles (INERA)* at Farako-Bâ near Bobo-Dioulasso in the southern part of the province of Houet (Fig. 12.1). Farako-Ba is situated on latitude 11° 06′ N and longitude 4° 20′ W and 405 m above sea level in the province of Houet.Farako-Bâ lies within the South Sudan agro ecological zone (Fontes and Guinko 1995). The rainfall pattern of the area is unimodal. The rainy season starts from April–May and ends in October–November, with a peak rainfall in August (Fig. 12.2). The mean daily temperature ranges from 10 to 32 °C.

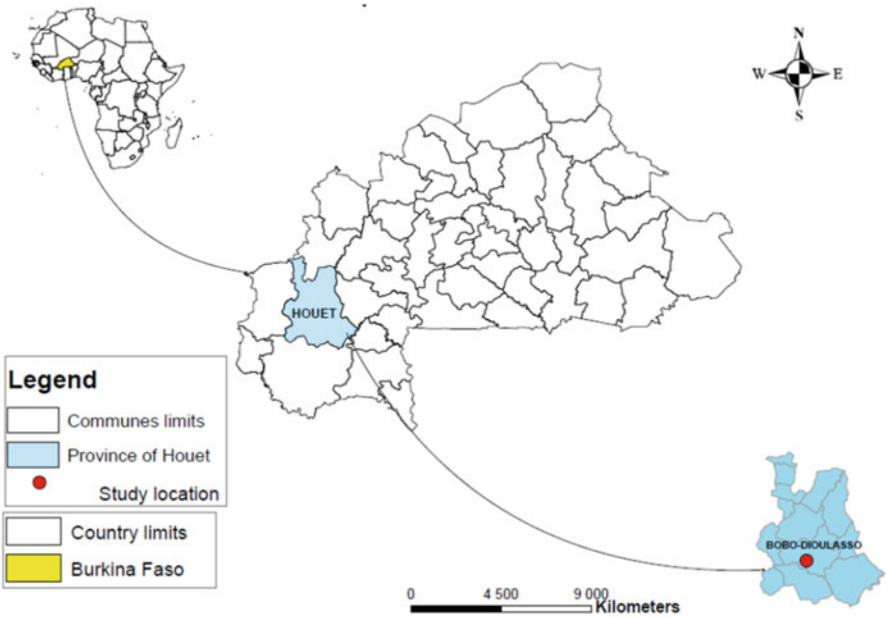

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Fig. 12.1 Location of the study area

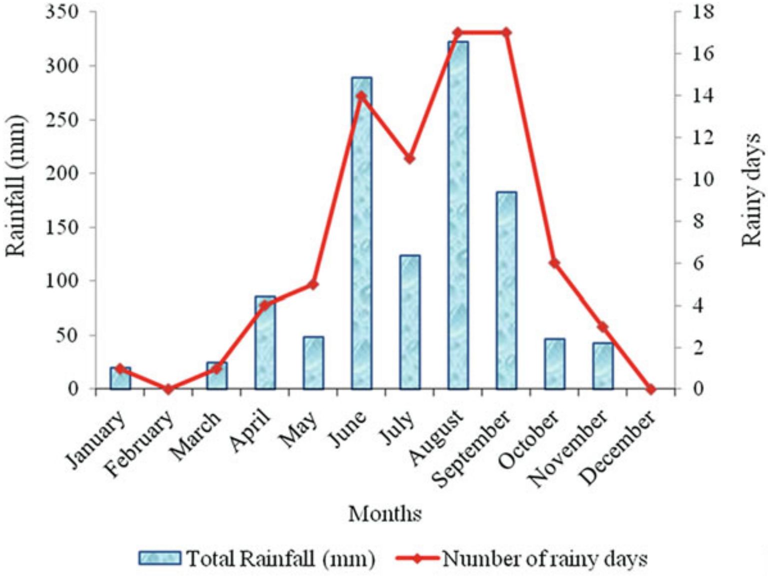

Fig. 12.2 Rainfall during the cropping season of 2014 (INERA/Farako-Bâ)

Table 12.1 Mineral fertilizer treatments

Treatment	N-P-K (kg ha^{-1})	Treatment	N-P-K (kg ha^{-1})
T_1	0-0-0	T_5	90-22,5–0
T_2	90-0-0	T_6	90-15-10
T_3	90-7.5-0	T_7	90-15-20
T_4	90-15-0	T_8	90-15-30
T_9	90-15-20-15S-10 Mg-2.5Zn-0.5B		

12.2.2 Experimental Design and Treatments

The experiment was a randomized complete block design arranged in split – plot with three replications. The main plot factor was the maize variety (Komsaya and SR21). The sub plot factor was application rate of mineral fertilizer. The main plots were 44 m × 20 m in dimensions while the sub plots were 6 m × 4 m. The treatments structure is given in Table 12.1.

Nitrogen, P, K, S, Mg, Zn and B fertilizers used were provided by single fertilizers (see Sect. 3.5). The different treatments were selected based on the assumptions that the optimum rates of N, P and K are 90 kg ha^{-1}, 15 kg ha^{-1} and 20 kg ha^{-1} respectively. Therefore, mineral fertilizer rates below the optimum P and K rates were added to test their performance against the optimum rates.

12.2.3 Soil Sampling

Prior to implementation of the trials, representative soil samples were taken at the four corners and central portions of the field on both soils. The soil samples were collected at a depth of 0–20 cm, mixed thoroughly and a subsample was brought to the laboratory to determine both physical and chemical properties.

12.2.4 Land Preparation and Sowing

Conventional tillage (disc ploughing and harrowing) was used to clear the land. Later, the field was levelled manually where needed. Two (2) varieties of maize; Komsaya and SR21 were used. The first variety Komsaya is a hybrid while the SR21 is an open pollinated variety (OPV). Komsaya (colour orange-yellow) has a growth cycle of 85–90 days and the yield potential is about 8–9.5 tons ha^{-1}. The SR21 has a growth cycle of 97 days with a yield potential of 5.1 tons ha^{-1}.

Three (3) seeds were sown per stand on 15th July, 2014 and later thinned to two seedlings per stand 10 days after sowing. The planting distance used was 80 cm between rows and 40 cm between plants.

12.2.5 Mineral Fertilizer Application

The mineral fertilizers used to supply Nitrogen, Phosphorus, Potassium, Sulphur, Magnesium, Zinc and Boron were respectively: Urea (46% N), Triple Super Phosphate (45% P_2O_5), Potassium Chloride (60.8% K_2O), Kieserite ($MgSO_4$): 15% Mg and 22% S, Zinc sulphate (36.8% $ZnSO_4$) and Borax pentahydrate (48% B_2O_3). The mineral fertilizers were applied 2 weeks after seedling emergence by side placement to their respective treatment plots. Nitrogen was applied in two equal splits doses, the first dose was applied in combination with the other nutrients 2 weeks after planting and the second dose was applied 30 days after the first application.

12.2.6 Data Collection

12.2.6.1 Grain Yield

The grain yield from each plot harvested from the harvestable area was calculated and the yield extrapolated to kg ha^{-1} using the formula below:

$$\text{Grain yield}\left(\text{kg ha}^{-1}\right) = \frac{10000\ \text{m}^2\ \text{x Q grain (kg)}}{\text{Harvest area}\ (\text{m}^2)}$$

where:

Q is the weight of the grain.

12.2.6.2 Stover Yield

The plants harvested from the net plot were weighed and the yield converted into kg ha^{-1}. The formula used in Sect. 3.8.1 was used for the calculation.

12.2.6.3 Harvest Index

In determining the harvest index, five plants were selected randomly from each plot and weighed. The cob was threshed and the grain weighed. The harvest index was taken as the ratio of the grain weight to the above ground dry matter.

$$\text{HI} = \frac{\text{Economic yield}\left(\text{kg ha}^{-1}\right)}{\text{Biological yield}\left(\text{kg ha}^{-1}\right)}$$

where:

Economic yield = grain yield
Biological yield = grain and stover yields

12.2.6.4 Value Cost Ratio

Value cost ratio (VCR) is the ratio between the value of the additional crop yield obtained from fertilizer use and the cost of fertilizer used.

Calculation:

$$\mathrm{VCR} = \frac{x - y}{z}$$

where:

x = value of crop produced from fertilized plots
y = value of crop produced from unfertilized plots
z = cost of fertilizer

12.2.7 Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using GenStat statistical package. The means were compared using Least Significant Difference (LSD) at 5% level of probability. Statistical significance was determined at the probability of 0.05 for the effects of fertilization, cropping varieties, soil type and their interactions on yield. Statistix 10 was use for Maize response function to P application with 90 kg/ha of N applied. The response curve is represented by the equation $Y = a – bc^r$ where Y = yield, a and b are maximum yield (yield at plateau) and maximum yield increase achievable, respectively, with application of this nutrient, c together with exponent r (nutrient rate) determine the shape of the curve.

12.3 Results

12.3.1 Initial Physico-Chemical Properties of the Study Sites

Physico-chemical characteristics of the two soils at the experimental sites are presented in Table 12.2. The soil was moderately (5.59) acidic for Ferralsol and acidic (5.25) for Luvisol with a sandy loam texture.

Bulk density was relatively greater on Luvisol than on Ferralsol. Both the Luvisol and Ferralsol were very low in chemical properties such as organic carbon, nitrogen, available phosphorus and CEC. Nonetheless, the chemical properties of the Luvisol were relatively better than that of the Ferralsol (Table 12.2).

Table 12.2 Characteristics of soils of experimental sites (0–20 cm) at planting

Soil parameter	Ferralsol	Luvisol
pH(1: 2.5 in H_2O)	5.59	5.25
Clay (%)	9.75	10.75
Silt (%)	18.65	28.95
Sand (%)	71.60	60.30
Texture	Sandy-loam	Sandy–loam
Bulk density (0–10 cm) (g cm^{-3})	1.47	1.63
Bulk density (10–20 cm) (g cm^{-3})	1.66	1.62
Organic carbon (g kg^{-1})	2.67	3.60
Total N (g kg^{-1})	0.28	0.35
Available P (mg kg^{-1})	1.57	1.82
Exchangeable cations ($Cmol_c$ kg^{-1})		
Ca^{2+}	0.96	1.12
Mg^{2+}	0.52	0.48
K^+	0.27	0.22
Na^+	0.04	0.05
CEC	2.87	3.87

12.3.2 Maize Response to Phosphorus with 90 kg/ha of N Applied

The response curve is represented by the eq. $Y = a - bc^r$ where Y = yield, a and b = maximum yield (yield at plateau) and maximum yield increase achievable, respectively, with application of this nutrient, c together with exponent r (nutrient rate) determine the shape of the curve.

Maize yield was near the plateau with 15 kg ha^{-1} of P when 90 kg ha^{-1} N applied and remains constant with additional application of P (Fig. 12.3).

12.3.3 Grain and Stover Yield

12.3.3.1 Grain Yield on a Luvisol

The application of mineral fertilizer significantly ($P < 0.05$) increased the yield of maize. The yield ranges from 395 kg ha^{-1} to 5437 kg ha^{-1} (Table 12.3). The plot amended with the mineral fertilizer at the rate of 90 N-15P-30 K gave the highest grain yield corresponding to over 1276% in excess grain yield from the control plots.

The percentage increase in grain yield due to the application of mineral fertilizer ranged from 690 to 1276% representing gains made from the application of 90 N-15P-30 K and 90 N-15P-10 K respectively. The NPK mineral fertilizer

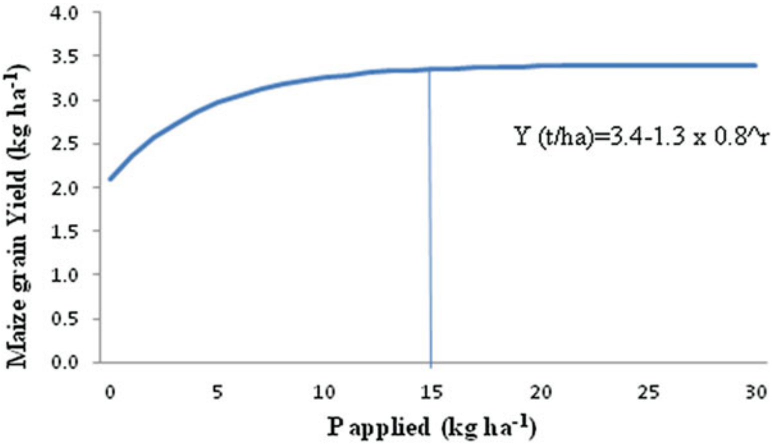

Fig. 12.3 Maize response to Phosphorus with 90 kg ha^{-1} of N applied

Table 12.3 Effect of mineral fertilizer application rate and maize variety on grain and stover yield on a Luvisol

	Luvisol			
Treatment (kg ha^{-1})	Grain yield (kg ha^{-1})	Increase over control (%)	Stover yield (kg ha^{-1})	Increase over control (%)
Fertilizer rate				
Control	395	–	1822	–
90 N-0P-0 K	4391	1011.64	6311	246.38
90 N-7.5P-0 K	4855	1129.11	6609	262.73
90 N-15P-0 K	4591	1062.27	6563	260.20
90 N-22.5P-0 K	4141	948.35	6410	251.81
90 N-15P-10 K	3119	689.62	5477	200.60
90 N-15P-20 K	4696	1088.86	7507	312.02
90 N-15P-30 K	5437	1276.46	8193	349.67
90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	5029	1173.16	7269	298.96
LSD (0.05)	1559.9		2065.1	
Fpr	$< 0.001^{**}$		$< 0.001^{**}$	
Maize variety				
Komsaya	4275		6084	
SR21	3871		6396	
LSD (0.05)	735.3		973.5	
Fpr	NS		NS	
Mineral fertilizer x Maize variety				
LSD (0.05)	2206		2920.5	
Fpr	NS		NS	
CV (%)	32.6		28.2	

NS = not significant at $P < 0.05$; ** = significant at $P < 0.01$

supplemented with sulphur, magnesium, zinc and boron (90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B) increased grain yield by 7% over that of the 90 N-15P-20 K (without the micronutrients) treatment.

There was no significant difference ($P > 0.05$) in grain yield between the two varieties of maize. However grain yield of Komsaya was generally higher than that SR21 (Table 12.3).

12.3.3.2 Stover Yield on a Luvisol

The maize stover yield as affected by the application of mineral fertilizer is presented in Table 12.3. The highest yield (8193 kg ha^{-1}) was obtained from the 90 N-15P-30 K treatment plots and the lowest yield of 1822 kg ha^{-1} was obtained from the control plots. The percentage increase in stover yield due to the application of mineral fertilizer ranged from 201 to 349%.

The highest gain was recorded for 90 N-15P-30 K treatment but this was not significantly different from those of the remaining plots except that of plot treated with 90 N-15P-10 K treatment plots.

In terms of stover yield, the varieties did not show significant difference ($P > 0.05$) even though maize variety SR21 generally gave a higher stover yield than Komsaya.

12.3.3.3 Grain Yield of Maize Grown on a Ferralsol

The yield of maize was significantly ($P < 0.05$) affected by the application of mineral fertilizer. The maize yield ranged from 121 to 3899 kg ha^{-1} (Table 12.4). The plot amended with the mineral fertilizer at the rate of 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B gave the highest grain yield representing 3122% in excess of that of the control plots. This was significantly different from mean values from all the plots amended with mineral fertilizer except that of 90 N-15P-20 K treatment plots.

The percentage increase in grain yield over the control ranged from 606 to 3122% representing percentage increases from 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B and 90 N-0P-0 K treatments respectively.

The NPK mineral fertilizer supplemented with sulphur, magnesium, zinc and boron (90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B) significantly ($P < 0.05$) increased grain yield by 1173%, however the difference between the same formulations (90 N-15P-20 K) without the micronutrients was not significant at $P < 0.05$.

There was no significant ($P > 0.05$) difference in grain yield between the two varieties of maize. Nonetheless the highest grain yield was associated with Komsaya which was 538 kg ha^{-1} higher than that of SR21.

Table 12.4 Effect of mineral fertilizer application rate and maize variety on grain and stover yield on a Ferralsol

Treatment (kg ha^{-1})	Ferralsol Grain yield (kg ha^{-1})	Increase over control (%)	Stover yield (kg ha^{-1})	Increase over control (%)
Fertilizer rate				
Control	121	–	1418	–
90 N-0P-0 K	854	605.78	3498	146.69
90 N-7.5P-0 K	1744	1341.32	4621	225.88
90 N-15P-0 K	1630	1247.11	3939	177.79
90 N-22.5P-0 K	2464	1936.36	5869	313.89
90 N-15P-10 K	2097	1633.06	4415	211.35
90 N-15P-20 K	2839	2246.28	5632	297.18
90 N-15P-30 K	1545	1176.86	5299	273.70
90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	3899	3122.31	5827	310.93
LSD (0.05)	1207		2301.7	
Fpr	$< 0.001^{**}$		0.008^{*}	
Maize variety				
Komsaya	2179		4102	
SR21	1641		4902	
LSD (0.05)	569		1085.0	
Fpr	NS		NS	
Mineral fertilizer x Maize variety				
LSD (0.05)	1707		3255.1	
Fpr	NS		NS	
CV (%)	53.9		46.8	

NS = not significant at $P < 0.05$; * = significant at $P < 0.05$; ** = significant at $P < 0.01$

Maize Stover Yield on a Ferralsol

The stover yield of maize as affected by fertilizer formulation and the maize variety is illustrated in Table 12.4. The highest maize stover yield value was obtained from 90 N-15P-30 K treatment plots and the lowest yield was from the control plots.

The percentage increase in stover yield due to the application of mineral fertilizer ranged from 146 to 349% representing gains from 90 N-0P-30 K and 90 N-0P-0 K respectively. However the highest stover yield was not significantly different from the other rates except that from the plot amended with 90 N-0P-0 K.

In general, the varieties did not show significant ($P > 0.05$) differences in stover yield even though SR21 gave maize stover 312 kg ha^{-1} higher than that of Komsaya.

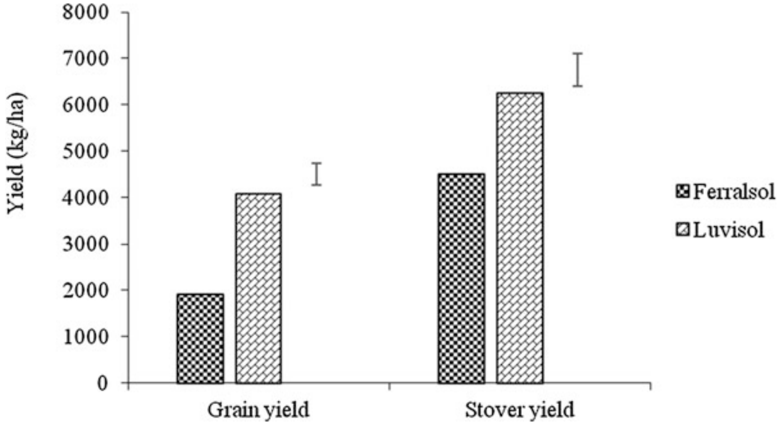

Fig. 12.4 Effect of soil type on maize grain and stover yield (Error bars represent SED (0.05))

12.3.3.4 Effect of Soil Type on Maize Grain and Stover Yield

Maize grain and stover yield as affected by soil type is illustrated in Fig. 12.4. Soil type significantly ($P < 0.05$) influenced grain and stover yield. On the average, grain and stover yield were 113 and 39% respectively higher than the corresponding yield on the Ferralsol.

Effect of Soil Type and Maize Varieties on Grain Yield

Figure 12.5 presents the mean grain yield of maize as influenced by variety and soil type. Maize varieties did vary significantly ($P > 0.05$) in grain yield when grown on the two soils. Nevertheless, Komsaya in general gave the highest grain yield on both soils.

12.3.3.5 Harvest Index

The results of harvest index (HI) on Luvisol and Ferralsol are presented in Table 12.5. The harvest index was significantly ($P < 0.05$) affected by the application of mineral fertilizer. It ranged from 37.84 to 48.85% on Luvisol representing values obtained for the control and 90 N-0P-0 K treatments plots, respectively. The HI of variety was significantly ($P < 0.05$) increased when grown on the Luvisol with Komsaya variety giving higher HI values than that of SR21.

On the Ferralsol, HI was also significantly ($P < 0.05$) affected by mineral fertilizer rates as shown in Table 12.5. The control and the 90 N-0P-0 K treatments gave HI values of 32.37 and 47.61%, respectively. The highest harvest index was obtained from 90 N-0P-0 K treatment but this was not significantly different from that of 90 N-15P-10 K but different from those of all the other treatments. The

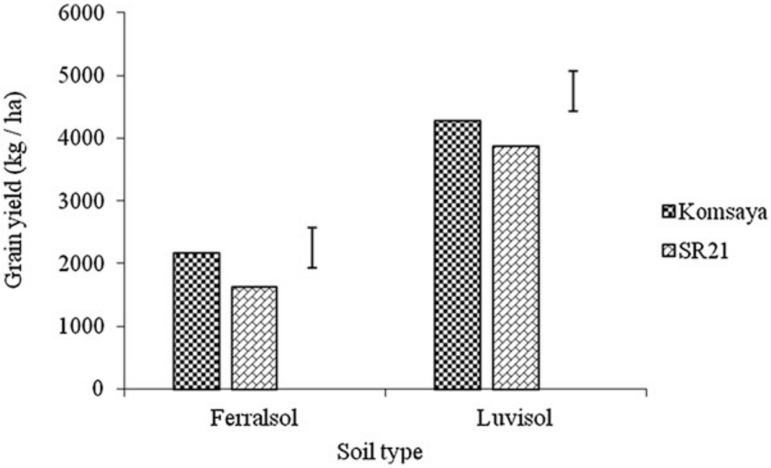

Fig. 12.5 Grain yield of two maize varieties in response to mineral fertilizer application on two soil types (Error bars represent the SED (0.05))

Table 12.5 Effect of mineral fertilizer application rate on harvest index of maize on a Luvisol and a Ferralsol

Treatment (kg ha^{-1})	Harvest index (%)	
	Luvisol	Ferralsol
Fertilizer rate		
Control	37.84	32.37
90 N-0P-0 K	48.85	47.61
90 N-7.5P-0 K	44.85	38.46
90 N-15P-0 K	43.03	39.19
90 N-22.5P-0 K	44.48	35.45
90 N-15P-10 K	43.79	42.59
90 N-15P-20 K	46.10	38.95
90 N-15P-30 K	45.72	40.71
90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	43.48	32.67
LSD (0.05)	5.38	6.73
Fpr	0.029*	0.001**
Variety		
Komsaya	48.59	40.83
SR21	39.99	36.50
LSD (0.05)	2.537	3.172
Fpr	$< 0.001^{**}$	0.009*
Mineral fertilizer x Variety		
LSD (0.05)	7.611	9.517
Fpr	NS	0.019*
CV (%)	10.4	14.8

NS = not significant at $P < 0.05$; * = significant at $P < 0.05$; ** = significant at $P < 0.01$

control treatment gave the lowest HI but this was not significantly different from HI obtained from 90 N-7.5P-0 K, 90 N-22.5P-0 K, 90 N-15P-30 K and 90 N-15P-20 K-10 Mg-2.5Zn-0.5B. The varieties also significantly ($P < 0.05$) varied in HI. The highest HI value was obtained for Komsaya variety and was 4.33% higher than that of SR21 (Table 12.5).

Plots planted with variety Komsaya and amended to the control and the 90 N-0P-0 K gave lower and higher values of HI of 29 and 58.02% respectively (Appendix 10), while those planted with SR21 gave lowest and highest values of HI as 33.21 and 38.97% which were obtained from the diagnostic and the 90 N-15P-0 K treatments plots, respectively. No significant ($P > 0.05$) interactive effect between the mineral fertilizer and maize variety on HI was observed on the Luvisol.

12.3.3.6 Value Cost Ratio

The economic analysis for maize grain yield on Luvisol indicates that all the mineral fertilizer amendments were profitable (VCR > 2) (Table 12.6). While the VCR of Komsaya variety ranged from 2.6 to 8.0, that of SR21 ranged from 2.9 to 4.6. The rates of mineral fertilizer that gave the highest VCR were 90 N-0P-0 K and 90 N-7.5P-0 K treatments for Komsaya while the rates of 90 N-15P-20 K and 90 N-0P-0 K treatments gave the highest VCR for SR21.

On the Ferralsol, the VCR values ranged from 0.5 to 3.5 for Komsaya and from 0.7 to 2.2 for SR21. The rate of mineral fertilizer that gave profitable benefit for planting Komsaya was 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B. For SR21, the best fertilizer treatment was 90 N-15P-20 K while the rest of the treatments were not profitable (Table 12.7).

12.4 Discussion

12.4.1 Effect of Mineral Fertilizer on Grain and Stover Yield of Maize

Judicious application of mineral fertilizer improves yield of crops (Sharma et al. 1996). Consequently, the mineral fertilizer application significantly increased grain and stover yield on Luvisol and Ferralsol. All the mineral fertilizer rates produced grain and stover yield higher than the control. The 90 N-15P-30 K and 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B treatments produced the highest grain and stover yield for Luvisol and Ferralsol respectively. The difference in the optimal rates of mineral fertilizer required to obtain highest yield maybe due to the inherent fertility status of these soils. Luvisol has been reported to be a fertile soil while Ferralsol is known to be deficient in some macronutrients and some micronutrients (WRBSR 2014). The significant response of maize to mineral fertilizer application observed

Table 12.6 Economic viability of maize cultivated under varied fertilizer regimes on a Luvisol

Variety	Mineral fertilizer rate (kg ha^{-1})	Total revenue (F CFA)	Net return (F CFA)	Fertilizer cost (F CFA)	VCR
Komsaya	90 N-0P-0 K	787,950	721,200	90,000	8.0
	90 N-7.5P-0 K	876,900	810,150	107,202	7.6
	90 N-15P-0 K	721,950	655,200	124,404	5.3
	90 N-22.5P-0 K	643,350	576,600	141,605	4.1
	90 N-15P-10 K	410,400	343,650	132,628	2.6
	90 N-15P-20 K	539,850	473,100	140,851	3.4
	90 N-15P-30 K	919,500	852,750	149,075	5.7
	90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	804,000	737,250	190,688	3.9
SR21	90 N-0P-0 K	423,600	382,200	90,000	4.2
	90 N-7.5P-0 K	463,800	422,400	107,202	3.9
	90 N-15P-0 K	524,280	482,880	124,404	3.9
	90 N-22.5P-0 K	479,040	437,640	141,605	3.1
	90 N-15P-10 K	420,240	378,840	132,628	2.9
	90 N-15P-20 K	695,280	653,880	140,851	4.6
	90 N-15P-30 K	569,280	527,880	149,075	3.5
	90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	563,760	522,360	190,688	2.7

Table 12.7 Economic viability of maize cultivated under varied fertilizer regimes on a Ferralsol

Variety	Mineral fertilizer rate (kg ha^{-1})	Total revenue (F CFA)	Net return (F CFA)	Fertilizer cost (F CFA)	VCR
Komsaya	90 N-0P-0 K	65,100	46,500	90,000	0.5
	90 N-7.5P-0 K	312,300	293,700	107,202	2.7
	90 N-15P-0 K	282,000	263,400	124,404	2.1
	90 N-22.5P-0 K	475,650	457,050	141,605	3.2
	90 N-15P-10 K	336,300	317,700	132,628	2.4
	90 N-15P-20 K	441,150	422,550	140,851	3.0
	90 N-15P-30 K	322,200	303,600	149,075	2.0
	90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	688,650	670,050	190,688	3.5
SR21	90 N-0P-0 K	152,880	138,600	90,000	1.5
	90 N-7.5P-0 K	168,600	154,320	107,202	1.4
	90 N-15P-0 K	165,600	151,320	124,404	1.2
	90 N-22.5P-0 K	210,720	196,440	141,605	1.4
	90 N-15P-10 K	234,360	220,080	132,628	1.7
	90 N-15P-20 K	328,320	314,040	140,851	2.2
	90 N-15P-30 K	113,160	98,880	149,075	0.7
	90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B	384,840	370,560	190,688	1.9

in this study in terms of grain and stover yield in both soils may be due to increased availability of essential nutrient in the soil for plant use.

There was no significant difference ($P > 0.05$) in grain and stover yield among the maize varieties on both the Luvisol and Ferralsol. However, Komsaya produced numerically higher grain yield over SR21. Generally, it has been reported that hybrids are better users of both soil and applied nutrients (Mphande 1994) with high yielding attributes (Odendo et al. 2001) than the composite and local maize varieties.

On the other hand, SR21 produced numerically higher stover yield than Komsaya (the hybrid). The numerically higher stover yield but lesser grain yield obtained by SR21 over Komsaya is an indication that most of the dry matter accumulated by SR21 were partitioned into the vegetative sink instead of being translocated to the economic part (grains). Indeed, the harvest index, which reflects the efficiency of dry matter partitioning to the grain, showed that Komsaya partitioned more of its dry matter into the grains than SR21 on both soils. Improvements in maize grain yield have been accompanied by increased total biomass yield (Lorenz et al. 2010), and its efficiency to partition to the grains.

12.4.2 Effect of Soil Type on Maize Grain and Stover Yield

The observation that plants grown on Luvisol produced significantly ($P < 0.05$) higher grain and stover yield than plants grown on the Ferralsol, suggest that the Luvisol was more fertile than the Ferralsol. This result was similar to the findings of Gao et al. (2007), who reported differences in maize yield when grown in two different types of soil but contradicts the report of Li et al. (2012) who indicated that soil type had no significant effects on maize yield. Furthermore, it affirmed the assertion of van Waverson et al. (1993) that different type of soils are endowed with different physical and chemical properties which make them superior or inferior to other soils within a given locality.

12.4.3 Effect of Mineral Fertilizer and Maize Varieties on Harvest Index

Harvest index (HI) is the proportion of grain in the total aboveground biomass of the crop expressed in percentage. The results showed that the harvest index was significantly ($P < 0.05$) increased by the application of mineral fertilizer. This was in line with the findings of Wasonga et al. (2008). The significant increase in HI following mineral fertilizer application might be due to good growth and biomass production thus the tendency for more dry matter to be translocated to the economic part of the plant. The result was in line with the report of Malagi (2005) which showed that there were significant increases in HI following mineral fertilizer application but contradicted the report of Singh et al. (2003).

The Komsaya variety produced significantly higher harvest index than SR21 for both of the soils. The significant difference observed in the harvest index between the varieties might possibly be due to differences in their genetic makeup. This result agrees with that of Singh et al. (2003) who reported that harvest index is a genetic trait and can be influenced by varietal differences.

There was a significant ($P < 0.05$) interaction between mineral fertilizer application and maize varieties on the HI of the Ferralsol. The 90 N-0P-0 K gave the highest HI value of 58% in Komsaya while the 90 N-15P-0 K gave the highest HI (39%) in SR21. This may be due to the ability of the plants to take up the nitrogen supplied by the urea and use it efficiently during grain formation. The control ($HI = 29\%$) and the diagnostic ($HI = 33\%$) treatments gave lower harvest indices in Komsaya and SR21 respectively. These HI values below 40% might be because those plots suffered from either biotic or abiotic stress other than nutrients as explained earlier by Hay (1995).

12.4.4 Value Cost Ratio

The returns on investments in applied mineral fertilizer were appraised by assessing the value cost ratio (VCR). The positive returns earned from the application of mineral fertilizer to maize varieties on both soils highlighted the role of mineral fertilizer as the paramount key entry point for increased crop productivity in Sub-Saharan Africa (Sanginga and Woomer 2009). On the Luvisol, the use of both maize varieties were profitable. In general, VCR declined with increase rate of mineral fertilizer for both varieties. This was in line with the findings of Sime and Aune (2014). Cultivation of Komsaya gave the highest VCR value ($VCR = 8.0$) which was obtained from the lower mineral fertilizer rate of 90 N-0P-0 K; similar observation was made by Roy et al. (2006); Sime and Aune (2014) who attributed high VCR value to low fertilizer application owing to low investment cost and high response. Moreover, $VCR > 4$ was found with the plots planted with Komsaya and amended with the mineral fertilizer rates of 90 N-15P-0 K, 90 N-7.5P-0 K, 90 N-22.5P-0 K, 90 N-15P-10 K, 90 N-15P-20 K and 90 N-15P-30 K (Fig. 12.4.); variety SR21 recorded $VCR > 4$ with the plots treated to 90 N-0P-0 K and 90 N-15P-20 K. $VCR > 4$ implies positive returns on fertilizer investment that was economically viable. Guo et al. (2009) suggested the $VCR > 4$ could accommodate price and climatic risks and still remain profitable to farmers. The relative higher VCR ratio found with the lower mineral fertilizer rate of 90 N-0P-0 K for both varieties also supports the observation that increase crop yield is made through lower fertilizer rate at low cost and with moderate risk to farmers in sub-Saharan region as reported earlier by Aune et al. (2007); Aune and Ousman (2011). The high yielding traits of Komsaya made the use of the variety more profitable than SR21.

On the Ferralsol, VCR values for both maize varieties increased with the increase rate of mineral fertilizer. This contradicted the findings of Sime and Aune (2014) that VCR declines with increasing fertilizer rates. The profitability of mineral fertilizer was found to be very low. This may be due to the poor crop response and unfavourable fertilizer to maize price ratio as reported by Gerner and Harris (1993) and Dembélé and Savadogo (1996). Due to the general lack of higher response of SR21 (recording the lowest grain yield) to mineral fertilizer applied on Ferralsol, none of the applied rates were economically attractive. Similar findings were obtained by Opoku (2011) at Maradi (Niger). Generally, cultivation of Komsaya on a Ferralsol is relatively profitable than cropping SR21.

12.5 Conclusion

The rate of mineral fertilizer which gave higher grain and stover yield on Luvisol was 90 N-15P-30 K while on Ferralsol, the best rate was 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B. There was no significant difference between the two varieties in terms of grain and stover yield across the soil types. However, Komsaya produced the highest grain yield of 2179 and 4275 kg ha^{-1} while SR21 gave the highest stover yield of 4902 and 6396 kg ha^{-1} on Ferralsol and Luvisol respectively. Moreover, grain yield increases over the control on the Ferralsol and Luvisol ranged from 606% (90 N-0P-0 K) to 3122% (90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B) and 690% (90 N-15P-10 K) and 1276% (90 N-15P-30 K), respectively. The significant increases in grain yield following the application of mineral fertilizer refuted the second null hypothesis that the application of appropriate rates of mineral fertilizer does not lead to an increase in grain yield.

The returns on investments were economically viable by growing both maize varieties. Komsaya gave the highest VCR value (VCR = 8) under 90 N-0P-0 K while SR21 gave VCR > 4 on plots which received 90 N-15P-20 K and 90 N-0P-0 K confirming that the use of mineral fertilizer is profitable for farmers. This contradicts the third hypothesis of this study that the application of mineral fertilizer is not profitable for smallholder farmers. Based on the values of the VCR, we recommend for farmers who are working on Luvisol the rate of 90 N-0P-0 K for both maize varieties Komsaya and SR21. For those that are working on Ferralsol, the mineral fertilizer rate of 90 N-15P-20 K is suitable for the production of SR21 and the rate of 90 N-15P-20 K-15S-10 Mg-2.5Zn-0.5B for Komsaya.

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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

		2011		2012	
Sites	Treatments	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 > ǀtǀ	Coefficient	Pr > ǀtǀ
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 > ǀtǀ	Coefficient	Pr > ǀtǀ
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

		2011		2012	
Sites	Treatments	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

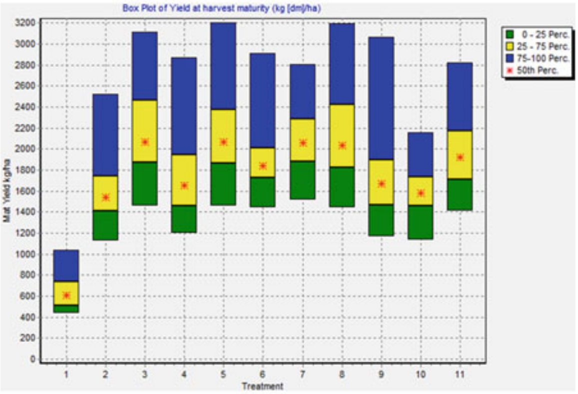
13.4.1 Soil Fertility and Maize Productivity in the South and Centre Benin

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.

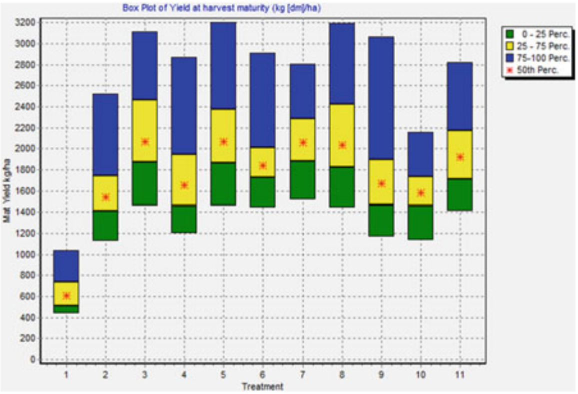
The quadratic regression between maize grain and stover yields and nutrients applied showed an optimum rate of 80.5, 22.5 and 20 kg ha^{-1} respectively for N, P and K to optimize maize yield in both soils. The optimum rate of N is consistent with that generated by DSSAT model for maize production in 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)

Dogbo



Allada



Dassa

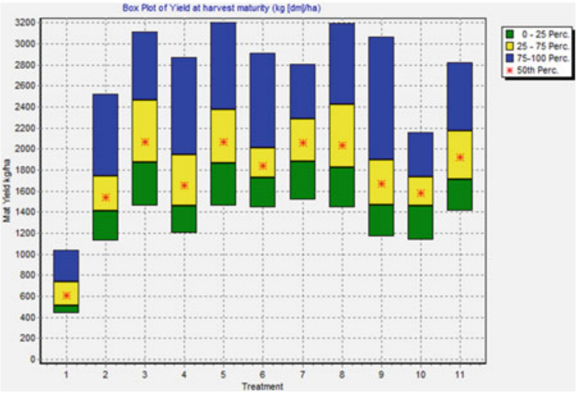


Table 13.7 Mean-Gini dominance of seasonal partial budget analysis for the different rates of N-P-K fertilizer at Dogbo, Allada and Dassa in Benin

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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Chapter 14
Sorghum Grain Yield Under Different Rates of Mineral and Organic Fertilizer Application in the South-Sudan Zone of Burkina Faso

Idriss Serme, Korodjouma Ouattara, Dieudonné Ouattara, Souleymane Ouedraogo, Sansan Youl, and Charles Wortmann

Abstract Soil fertility depletion has been recognized as the most important limitation to food security in Burkina Faso. Crop production eg sorghum is constrained by inadequate supply of fertilizers and there is therefore the need to establish optimum fertilizer rates for increased and sustainable yields. This study is a short-term experiment conducted during the 2014 cropping season on a Luvisol in the sub-sudanian zone of Burkina Faso. The experiment was laid out in a split plot, arranged in a randomized complete block design with three replications. Cattle manure (CM) at two rates (0 t ha^{-1} and 5 t ha^{-1}) constituted the main plot whilst mineral fertilizer (kg ha^{-1}) at eleven rates (0N-0P-0K, 40N-0P-0K, 60N-0P-0K, 40N15P-0K, 60N-15P-0K, 60N-7.5P-0K, 60N-22.5P-0K, 60N-15P-10K, 60N-15P-20K, 60N-15P-30K and 90N-15P-20K-15S-2.5Zn-10Mg-0.5B) constituted the sub-plots. The highest grain yield response was observed under sole application of 60 kg N ha^{-1} and 22.5 kg P ha^{-1}. However, the yield obtained under these treatments was not significantly different from the grain yield observed under the applications of 40 kg N ha^{-1} and 15 kg P ha^{-1}. Since lower N and P rates gave similar grain yield as the reference plot (90N-15P-20K-15S-2.5Zn-10Mg-0.5B), sole application of 60 kg N ha^{-1} and 22.5 kg P ha^{-1} can be considered as appropriate rate for optimum grain yield production. The interaction effect of cattle manure and mineral fertilizer did not significantly ($P > 0.05$) increase sorghum grain yield. The highest grain yield obtained in this case, was with the interaction between 5 t of cattle manure ha^{-1}, 60 kg N ha^{-1} and 7.5 kg P ha^{-1} mineral fertilizer

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rates applied. No significant difference ($P > 0.05$) in sorghum grain yield was obtained above this fertilizer rate which can undoubtedly be suggested as the optimum rate. The Value Cost Ratio (VCR) of 2.01 and 2.23 obtained respectively under 60N-22.5P-0K and the interaction of cattle manure with 60N-7.5P-0K at the beginning of the wet season slightly exceeded the critical value of 2 required to motivate farmers to apply mineral fertilizer. Thus, fertilizer requirement for sustainable sorghum grain production at the study area in Burkina Faso is 5 t ha^{-1} of cattle manure combined with 60 kg N ha^{-1} and 7.5 kg P ha^{-1}.

Keywords Manure · Mineral fertilizer · Sorghum · South Sudan zone

Contents

14.1 Introduction

In the tropics particularly in dry land areas, the decline in soil productivity continues to be a major concern to scientists and policy makers due to its direct implication for food security. According to Smaling (1995), there is a virtual equilibrium for soils under natural vegetation, but as soon as the natural forest or savanna are cleared and so the land altered, this equilibrium is broken and soil fertility declines at a rate depending on the intensity of cropping and replacement of nutrient loss in the systems.

The decline in soil productivity in Burkina Faso is mainly as a result of an increase in human population and a decrease of fallow periods which exacerbate soil nutrient depletion (Bationo et al. 2008). From 2002 to 2004, Burkina Faso recorded nutrient depletion of 43 kg ha^{-1} (Henao and Baanante 2006).

Fertilizer is part of the technological trinity (improved seed, irrigation and fertilizer) responsible for bringing about the green revolution of Latin America and Asia. Its adequate and efficient use should, therefore, be a major ingredient in achieving food security in sub-Saharan Africa (SSA). At present, average fertilizer use rate in SSA is the lowest in the world and the region needs to take affirmative action to improve the situation (Henao and Baanante 2006). The average fertilizer use rate in SSA is around 10 kg ha^{-1} whereas it has reached 222 kg ha^{-1} in Asia, 160 kg ha^{-1} in Oceania and 138 kg ha^{-1} in South America (Hernandez and Torero 2011). The reasons for the dismal fertilizer use intensity in SSA are many and varied, and could be analyzed with respect to response rate (effectiveness), profitability (efficiency) and sustainability of fertilizer use (Dittoh et al. 2012).

Most fertilizer recommendations are based on fertilizer tests conducted during the 1970s. Most soils in SSA are characterized by imbalances in nutrients stocks due to continuous cultivation, changes in cropping systems and soil profiles, creating a decrease in the efficiency of fertilizers applied. This situation, combined with adulterated products, has made farmers sceptical about the fertilizers that are recommended and sold in the market (Bumb et al. 2011).

Additional research on soil testing and fertilizer trials are needed to develop sound crop and area-specific recommendations., The last update of fertilizers recommendation in Burkina Faso was done in 1992 and was based on agroecological zones and plant requirements by Institut de l’Environement et de Recherches Agricoles (INERA) under a project called “Projet Engrais Vivriers” (Hien et al. 1992). In addition, there is a negative nutrient balance indicating that farmers mine their soils and therefore pose a major constraint to sustainable crop production (Bationo et al. 2008).

Dittoh et al. (2012) reported that fertilizer’s full agronomic potential is often unrealized because of poor soil fertility caused by mismanagement of fertilizer at the farm level, failure of extension service to inform farmers about appropriate technology, poor availability of fertilizer and lack of complementary inputs. The use of organic inputs such as crop residues, manure and compost improved the physical, chemical and microbiological properties of the soil as well as nutrient supply and therefore has great potential for improving soil productivity and crop yield (Satyanarayana et al. 2002). Consequently, practices which maintain or increase soil organic matter reserves must be adopted to achieve a sustained productive agriculture (Melenya et al. 2015).

It is in this context that this study was conducted to establish optimum rates for sustainable use of fertilizers by farmers in sorghum production within the framework of integrated soil fertility management (ISFM) practices.

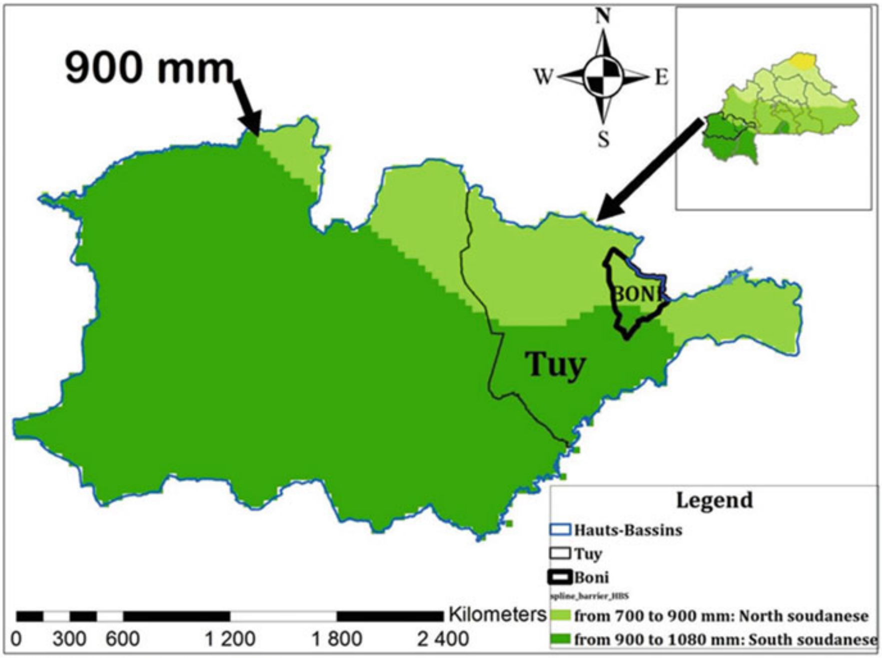
Working on the hypothesis that significant differences will be observed between the effects of cattle manure, mineral fertilizer and their interaction on soil nutrients content and crop uptakes, the objectives of the study were to:

(i) evaluate the impact of varying rates of cattle manure and mineral fertilizer on the yield of sorghum and determine the appropriate rate for sustainable production of sorghum in the south-sudan zone of Burkina Faso;
(ii) assess the cost-benefit of cattle manure and mineral fertilizer use for sorghum production in the sub-sudanian zone of Burkina Faso.

14.2 Materials and Methods

14.2.1 Experimental Site

The study was carried out in 2014 at the Institut de l’Environement et de Recherches Agricoles (INERA) experimental field located in Boni, a village in



Source: Oula Damien, 2014

Fig. 14.1 Map of the study area (Houndé, Boni) (Source: Oula Damien 2014)

the province of Tuy, about 12 km away from Houndé the city centre of Burkina Faso. The area lies between latitudes 11°0.09′ and 11°0.06′ North and longitudes 03°0.25′ and 03°0.28′ West of the Greenwich meridian (Fig. 14.1). The study area is located in the sudanian agro-ecological zone of Burkina Faso and is characterized by one wet season in the year. The rainy season starts from May and ends in October. Rainfall is erratic and the number of rainy days is 54. The rainfall distribution at the area is unimodal with mean annual precipitation between 800 mm and 950 mm (Fig. 14.2).

14.2.2 Experimental Design and Treatments

The experiment was a split-plot arranged in a randomized complete block design (RCBD) with three replications. Cattle manure at two rates (0 t ha^{-1} and 5 t ha^{-1}) constituted the main plot while mineral fertilizer at eleven rates constituted the subplots (Table 14.1). The mineral fertilizers applied were urea (46%), triple super phosphate (45% P_2O_5 water soluble), muriate of potash (60.8% K_2O), kieserite ($MgSO_4$ with 15% MgO and 22% S), borax-pentahydrate (48% B_2O_3) and zinc sulphate ($ZnSO_4$ 36.8%).

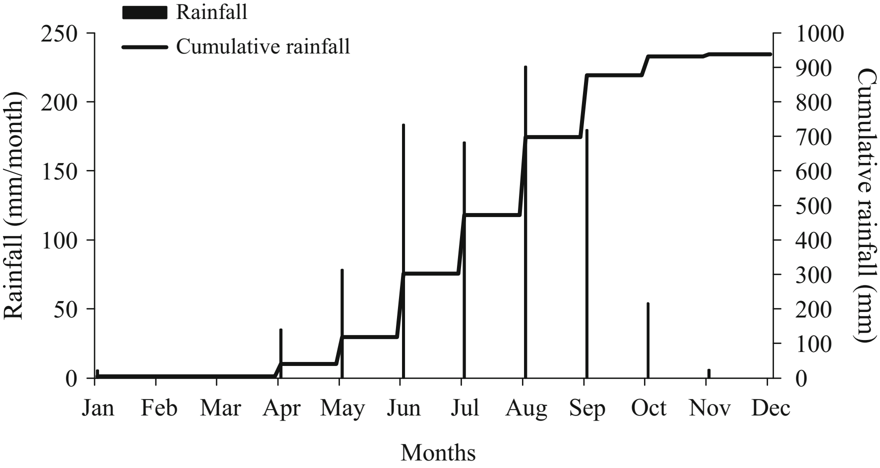


Fig. 14.2 Cumulative rainfall distribution at Boni in 2014

Table 14.1 N-P-K fertilizer rates applied

Treatments	N-P-K (kg ha^{-1})
T_1	0-0-0
T_2	40-0-0
T_3	60-0-0
T_4	40-15-0
T_5	60-15-0
T_6	60-7.5-0
T_7	60-22.5-0
T_8	60-15-10
T_9	60-15-20
T_{10}	60-15-30
T_{11}	90-15-20-15S-2.5Zn-10Mg-0.5B

The total land area measured 52 m × 43 m (2236 m^2) with each sub-plot measuring 6 m × 4 m.

14.2.3 Soil Sampling, Land Preparation and Sowing

Three composite soil samples (each consisting of four sub-samples) were taken randomly from the experimental field at a depth of 0–20 cm for initial characterization. The field was ploughed and harrowed to a fine tilth. An improved sorghum *(Sorghum bicolor L. Moench)* variety called Kapelga was sowed (four seeds per hill) at a spacing of 80 × 40 cm. The seedlings were thinned to two per hill one week after germination giving a total population of 62,500 plants ha^{-1}. The various treatments were then imposed two weeks after planting. During the growing period, the plots were manually weeded twice with hoe.

14.2.4 Grain yield

The grain yield from each plot harvested from the harvestable area was calculated and the yield extrapolated to kg ha^{-1} using the formula below:

$$\text{Grain yield}\left(\text{kg ha}^{-1}\right) = \frac{10{,}000\,\text{m}^2 \times \text{Qgrain}\,(\text{kg})}{\text{Harvestarea}\,(\text{m}^2)}$$

where:

Q is the weight of the grain

14.2.5 Determination of Value Cost Ratio

A survey was done to obtain the price of sorghum grain after harvest at the experimental location. The VCR was calculated by the following formula (Pervez et al. 2004):

14.2.6 Value Cost Ratio

Value cost ratio (VCR) is the ratio between the value of the additional crop yield obtained from fertilizer use and the cost of fertilizer used.

Calculation:

$$\text{VCR} = \frac{x - y}{z}$$

where:

x = value of crop produced from fertilized plots
y = value of crop produced from unfertilized plots
z = cost of fertilizer

VCR > 2 means that the treatment is beneficial financially against investment in fertilizer use contrary to a VCR below 2 (not beneficial in terms of finance against investment in fertilizer use).

14.2.7 Statistical Analysis

All data were subjected to ANOVA using GenStat version 2007 statistical package (Version 9). Standard error of difference was used for means separation. Regression analyses were carried out to establish the relationships between principal parameters measured for predictive purposes.

14.3 Results

14.3.1 Initial Physico-chemical Properties of the Soil

The soil of the study area was characterized before the establishment of the experiment. The results are presented in Table 14.2 and showed that at 0–20 cm depth, the soil had low nitrogen and phosphorus contents, very low organic carbon level and was very acidic with a pH (H_2O) of 4.57. The soil is a Luvisol with a silty loam texture consisting of 39.4% sand, 43.35% silt and 17.25% clay at 0–10 cm depth.

Table 14.2 Initial physico-chemical characteristics of soil at the study site

Soil properties	Mean values
pH (1:2.5 H_2O)	4.57
Organic carbon (%)	0.46
Total nitrogen (%)	0.06
Available P (mg kg^{-1})	4.32
Exchangeable bases (cmol$^{(+)}$ kg^{-1})	
Calcium (Ca^{2+})	1.12
Magnesium (Mg^{2+})	0.32
Potassium (K^+)	0.11
Sodium (Na^+)	0.04
Sum of anions (S)	1.58
Saturation rate (S/CEC) (%)	27.00
Cation Exchange Capacity (CEC) (cmol kg^{-1})	5.80
Particles size distribution (%)	
Sand	39.40
Silt	43.35
Clay	17.25
Texture	Silty loam

14.3.2 Chemical Characteristics of Cattle Manure Used

The chemical composition of the cattle manure (CM) used as main plot treatment in the trial is presented in Table 14.3. The laboratory analysis of the manure showed a slightly high carbon content of 20.59%. The C/N ratio was <20 indicating that it was of high quality.

14.3.3 Effect of Cattle Manure and Mineral Fertilizer Application on Sorghum Grain and Straw Yields

The analysis of variance (Table 14.4) show that manure and mineral fertilizer rates applied to the plots significantly ($P < 0.05$) affected sorghum grain while their interaction did not significantly influence the parameter. Sorghum straw yield was significantly affected by the manure rates. The effect of mineral fertilizer rates and their interaction with manure were not significant ($P > 0.05$) on sorghum straw yield.

The mean value of grain yield ranged from 1082 to 2009 kg ha^{-1} respectively under control and 60N-22.5P-0K fertilizer rate. The differences in grain yield between the control and different mineral fertilizer rates were significant ($P < 0.05$) except with 40N-0P-0K, 60N-0P-0K and 60N-15P-10K. Only plots under control, 40N-0P-0K and 60N-0P-0K mineral fertilizer rates produced grain yield which differed significantly from that of the reference plot. The grain yields obtained from the other plots were not significantly different from that of the reference plot. The effect of mineral fertilizer rates on sorghum grain yield was in a decreasing order of 60N22.5P-0K > 90N-15P-20K-15S-2.5Zn-10Mg-0.5B> 60N-15P-0K > 60N-7.5P-0K > 40N-15P-0K > 60N-15P-30K > 60N-15P-20K > 60N-15P-10K > 60N-0P-0K > 40N0P-0K > Control. The increase in grain yield percentage over control ranged from 18.48% (40N-0P-0K) to 85.67% (60N-22.5P-0K). Cattle manure treated plots produced significantly higher ($P < 0.05$) grain yield than the unamended plots.

The interaction effect of cattle manure and mineral fertilizer rates on grain yield was highest (2220.7 kg ha^{-1}) in the reference plot (90N-15P-20K-15S2.5Zn-10Mg-0.5B). The lowest grain yield recorded on 40N-15P-0K treated plots differed significantly ($P < 0.05$) from that of the reference plot. In terms of sorghum straw yield, the mean values ranged from 5781 to 3823 kg ha^{-1}. There were no significant differences among the control and the mineral fertilizer rates.

Table 14.3 Chemical characteristics of the cattle manure used

Organic material	Carbon (%)	Total N (%)	C/N	Total P (%)	Total K (%)
Cattle manure	20.59	1.21	17.02	0.41	2.15

Table 14.4 Effect of manure and mineral fertilizers on sorghum grain and straw yields

Mineral fertilizer rates (kg ha^{-1})	Grain yield (kg ha^{-1})	% Increase over control	Straw yield (kg ha^{-1})
Control	1082	–	4750
40N-0P-0K	1282	18.48	4235
60N-0P-0K	1391	28.56	3823
40N-15P-0K	1654	52.87	4693
60N-15P-0K	1803	66.64	4636
60N-7.5P-0K	1694	56.56	4579
60N-22.5P-0K	2009	85.67	5781
60N-15P-10K	1528	41.22	5208
60N-15P-20K	1631	50.74	4006
60N-15P-30K	1643	51.85	4407
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	1980	82.99	4235
F pr.	0.022		0.153
LSD (0.05)	514.09		1262.28
Cattle manure rates (t ha^{-1}) 0	1482	–	4192
5	1736	17.14	4964
F pr.	0.024		0.006
LSD (0.05)	219.21		538.24
Manure × mineral fertilizer *F pr.*	0.387		0.215
LSD (0.05)	727.04		2109.40
CV (%)	27.50		23.70

14.3.4 Value-Cost Ratio

The VCR was calculated using the equation presented in 3.13. The increased grain yield values (obtained from the means of the interactive effect of cattle manure and mineral fertilizers) and the fertilizers cost was used to estimate the returns on investments at harvest and at the beginning of the wet season. The prices of sorghum grain were 115 Francs CFA kg^{-1} after harvest and 140 Francs CFA kg^{-1}.

After harvest (Table 14.5), two plots under 40N-15P-0K and 60N-22.5P-0K mineral fertilizer treatments had respectively VCR values of 1.65 and 1.23 whilst the other plots gave VCR less than 1 indicating unsatisfactory risk coverage against investment in fertilizer used. The interaction effect of cattle manure and 60N-7.5P0K, 60N-22.5P-0K, 60N-0P-0K and 60N-15P-0K gave VCR greater than 1 (1.83–1.23) whilst the other plots had VCR less than 1. All the treatments showed unsatisfactory risk ($VCR < 2$) coverage against investment in fertilizer used after harvest.

At the beginning of the wet season (Table 14.6), all the mineral fertilizer treated plots showed no benefit against investment in fertilizer used (VCR less than 2) except 60N-22.5P-0K fertilizer rate which had a VCR of 2.01. However, 40N-15P0K and 60N-15P-0K treated plots gave $VCR > 1$. Cattle manure

Table 14.5 VCR after harvest

Value Cost Ratio (VCR) mineral fertilizer rates (kg ha^{-1})		
	0 t ha^{-1}	5 t ha^{-1}
Control	–	–
40N-0P-0K	0.30	0.85
60N-0P-0K	−0.07	1.25
40N-15P-0K	1.23	0.74
60N-15P-0K	0.98	1.23
60N-7.5P-0K	0.25	1.83
60N-22.5P-0K	1.65	1.36
60N-15P-10K	0.66	0.59
60N-15P-20K	0.73	0.70
60N-15P-30K	0.70	0.65
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	0.51	0.80

*115 FCFA kg^{-1} grain of sorghum (data from survey)

Table 14.6 VCR at the beginning of the wet season

	Value Cost Ratio (VCR)	
Mineral fertilizer rate (kg ha^{-1})	0 t ha^{-1}	5 t ha^{-1}
Control	–	–
40N-0P-0K	0.36	1.04
60N-0P-0K	−0.08	1.52
40N-15P-0K	1.50	0.90
60N-15P-0K	1.20	1.50
60N-7.5P-0K	0.31	2.23
60N-22.5P-0K	2.01	1.65
60N-15P-10K	0.80	0.72
60N-15P-20K	0.89	0.85
60N-15P-30K	0.85	0.79
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	0.62	0.97

*140 FCFA kg^{-1} grain of sorghum (data from survey)

interaction with 60N-7.5P-0K mineral fertilizer rate obtained a VCR of 2.23 showing satisfactory risk coverage against investment in fertilizer used.

14.4 Discussion

14.4.1 Effect of Cattle Manure and Mineral Fertilizer on Sorghum Grain Yield

The relatively higher sorghum grain yield under cattle manure and mineral fertilizer rates could be related to N and P availability to plants and nutrient release from the manure. With only mineral fertilizer application, plant nutrient needs were possibly met under 60N-22.5P-0K, 60N-15P-0K, 60N-7.5P-0K, 40N-15P-0K, 60N-15P-30K, 60N-15P20K and 60N-15P-10K treated plots which gave similar yields as the reference plot. This result could be attributed to the nutrients being readily made available from the mineral fertilizers applied and being taken up by the plants. The lower rate of mineral fertilizer (40N-15P-0K) which produced grain yield similar ($P > 0.05$) to that of the reference plot showed that an increase beyond this rate cannot significantly increase sorghum grain yield. In Burkina Faso, Bado et al. (2013) reported for sorghum mono cropping, an optimum dose of 45 kg ha^{-1} N to produce at least 1600 kg ha^{-1} grain yield. The nutrient requirements for an improved variety of sorghum was 37 kg N ha^{-1}, 23 kg P ha^{-1}, 14 kg K ha^{-1} and 6 kg S ha^{-1} (Hien et al. 1992) in the South Sudan zone of the country. The results obtained in this study with a grain yield of 1654 kg ha^{-1} (52.87% yield increase over the control) under 40N15P-0K mineral fertilizer rate showed a decrease in P rate to 35% of the required rate. The rate of N was less than the 45 kg ha^{-1} which produced grain yield of 1600 kg ha^{-1} in the study of Bado et al. (2013). This is not withstanding, variations in rainfall patterns and other local conditions could account for the yield differences observed in this study and that of Bado et al. (2013).

The interaction of cattle manure and mineral fertilizer did not increase significantly ($P > 0.05$) sorghum grain yield. This might be related to the additive effect between the two sources of nutrients. In a study in Burkina Faso, Bationo et al. (2005) reported that with low-quality manure applied with urea, there were additive effects at all levels of manure with inorganic-N. Ouédraogo et al. (2007) reported that low nutrient utilization efficiency due to moisture stress during grain filling induced antagonistic effect between sheep dung and urea. In this study, the interaction of cattle manure with 60N-7.5P-0K, 60N-22.5P-0K, 60N-15P-0K, 60N-0P-0K, 60N-15P-20K, 60N-15P-30K and 60N-15P-10K gave similar grain yields to that of the reference plot. The variation in K rates did not significantly influence the intended grain yield. The low rate of mineral fertilizer in combination with 5 t ha^{-1} of cattle manure which recorded grain yield of 2197.8 kg ha^{-1} similar to the reference plot was 60 kg N ha^{-1} and 7.5 kg P ha^{-1}. This shows that an increase beyond this rate cannot significantly increase sorghum grain yield. Therefore, a reduction in mineral fertilizer P rate from 15 to 7.5 kg ha^{-1} in combination with cattle manure application can increase grain yield.

14.4.2 Value-Cost Ratio

The typical value-cost ratio (VCR) of fertilizer use for sorghum in West Africa is 1.9 (Bumb et al. 2011). In this study, the VCR from sole manure application was negative ($VCR < 1$) indicating that increased grain yield cannot be correlated positively with cost of investment for cattle manure. Opoku (2011) obtained negative return on investment for using 5 t ha^{-1} sole manure applications at Maradi.

The results of no satisfactory risk coverage against investment for mineral fertilizer in sole application obtained after harvest could be due to high cost of mineral fertilizer and low price of sorghum grain at the study location. Bationo et al. (2012) affirmed that farm-level fertilizer prices in Africa are among the highest in the world. Mineral fertilizer applied alone can cause decline in soil organic carbon as observed on a ferruginous soil in Burkina Faso where 25–50% of indigenous organic matter disappeared with mineral fertilizer application during the first 2 years of cultivation (Bationo et al. 2005). Consequently, research results from long-term field experiments in the West African agro-ecosystems showed that without recycling of organic materials, the use of mineral fertilizers resulted in higher yields, but this increase was not sustainable (Bationo et al. 2004).

The interaction of cattle manure and mineral fertilizer after harvest showed the highest VCR (1.83) less than 2, indicating that the increased grain yield obtained could not cover the nutrients investment made.

The highest VCR of 2.01 and 2.23 obtained respectively under sole application of 60N-22.5P-0K and the interaction of cattle manure with 60N-7.5P-0K at the beginning of the wet season marginally exceeded the critical value of 2 required to motivate farmers to apply mineral fertilizers. Therefore, the rate of application that can motivate farmers is 60 kg N ha^{-1} and 22.5 kg P ha^{-1} whilst the interaction between 5 t of cattle manure ha^{-1} and 60 kg N ha^{-1} and 7.5 kg P ha^{-1} mineral fertilizer is suggested (based on this study) for sustainable sorghum grain production at the study location in Burkina Faso.

14.5 Conclusion

Based on grain yield response from sole application of mineral fertilizer, 60 kg N ha^{1} and 22.5 kg P ha^{-1} can be considered appropriate rates for optimum sorghum grain yield. The combined application of cattle manure (5 t ha^{-1}) and mineral fertilizer (60 kg N ha^{-1} and 7.5 kg P ha^{-1}) gave the highest grain yield and could be appropriate for sorghum production in the study area.

The VCR of 2.01 and 2.23 obtained from the use of 60N-22.5P-0K and cattle manure at 5 t ha^{-1} with mineral fertilizer at 60N-7.5P-0K respectively at the beginning of the wet season were found to be the most cost effective options.

Based on the results of this study, 100 kg ha^{-1} (2 bags) of NPK (14-23-14) and 100 kg ha^{-1} (2 bags) of urea (46%) per hectare is recommended to farmers for sustainable sorghum production at the study area.

Although this study has provided the optimum rate of fertilizer for sorghum production in the sub-Sudanian zone of Burkina Faso, long-term research should be carried out to assess nutrient availability to plants and water use efficiency under varying fertilizer rates in relation to crop yield.

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Chapter 15
Promoting Climate-Smart Agriculture Through Water and Nutrient Interactions Options in Semi-arid West Africa: A Review of Evidence and Empirical Analysis

Robert Zougmoré

Abstract In this paper, we analysed the ability of a range of existing technologies and practices and explored how their outcomes are linked to climate change adaptation and mitigation in West Africa. The rapid population growth alongside poor land use and management resulted in soil and water erosion, desertification, and salinization, creating a spiralling decline in the productivity of the land for food and other ecosystem services. Climate change brings additional threats arising from stresses and shocks caused by higher temperatures and lack of rainfall. Thus, farmers need to utilize agricultural strategies that sustainably increase productivity, resilience, while reducing GHGs emissions where possible. In order to implement such climate-smart agriculture options in semi-arid West Africa, water has to be available for crop nutrient uptake in the right amounts and at the right time, as water stress during plant growth results in major yield reductions for most crops. Also, farmers need to use more inorganic fertiliser, while striking the right balance between managing soil organic matter, fertility and moisture content and the use of fertilisers. The most successful systems are those that provide water, nutrients and a supportive soil structure in a synergistic manner. Indeed, we found that technologies such as *zaï*, half-moons, stone bunds combined with application of organic/inorganic sources of nutrients, are promising climate-smart agriculture practices that could be widely used by smallholder farmers to maintain food production and secure farmers' livelihoods, while possibly protecting the environment. These successful examples can serve as inspiration for future policies and investments that pursue food security goals at all scales.

Keywords Climate change · Resilience · Adapted land use · Food security · Sahel

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Contents

15.1 Introduction

In West Africa, the population has quadrupled over 50 years (from 90 million in 1960 to 342 million in 2011 (Elbehri et al. 2013). This rapid population growth has had a huge impact on the food demand. Many smallholder farmers must deal with low and unpredictable crop yields and incomes, as well as chronic food insecurity. These challenges are particularly acute in the drylands, where land degradation, depleted soil fertility, water stress, and high costs for fertilizers contribute to low crop yields (Winterbottom et al. 2013). Poor land use and management result in soil and water erosion, desertification, and salinization, creating a spiralling decline in the productivity of the land for food and other ecosystem services. Nearly 3.3% of agriculture GDP in Sub Saharan Africa is lost annually because of soil and nutrient losses, estimated to over 30 kg/ha/year.

Climate change brings additional threats arising from stresses and shocks caused by higher temperatures and lack of rainfall. According to Lobell et al. (2011), the potential yield loss due to climate change impact is about 5% for each degree Celsius of global warming. Indeed recent studies report that many crop yields are expected to decline as a result of long-term changes in temperature and rainfall and climate variability (Carter and Barrett 2006; Beddington et al. 2011). The outcome may be higher food prices along with chronic poverty and under nutrition for farming households already battered with climate extreme such as drought and flood.

The Sahel region is highly vulnerable to climate change due its geographic location at the southern edge of the Sahara desert and the strong dependence of its population on rain-fed agriculture and livestock. Rainfall variability, land degradation and desertification are some of the factors that combine to make life extremely difficult in this part of the world (Kandji et al. 2006). As an example, crop–livestock production systems in the Sahel have been adapting their practices and way of life for decades to various risks: climatic variability, economic risks and livestock diseases. To cope with shocks and crisis but also to support changes, various strategies based on the mobility of livestock and/or families, reorganization and diversification of activities, reciprocity and social networks have been developed and used successfully. Nowadays, climate change combined with other major factors (demographic growth, market globalization, decentralization, security issues) puts more pressure on these crop-livestock societies as their strategies might be not sufficient to deal with those global changes on their own and to preserve their food security (Ickowicz et al. 2012).

Thus, eradicating hunger and improving human nutrition, creating sustainable food consumption and production systems, and building more inclusive and effective governance of agricultural and food systems are fundamental in the achievement of the Rio + 20 vision of a world with both healthier people and healthier ecosystems, especially in harsh environment such as the West Africa drylands (FAO 2012). Integrated climate change adaptation and mitigation ensure food security and reduce agriculture ecological footprint. Adaptation is a priority for smallholder farmers, who will pursue mitigation when it brings benefits without increasing costs and risks (Jarvis et al. 2011).

Climate-Smart Agriculture (CSA) is an approach that can greatly help us achieve this target. It embraces multiple objectives, aims to increase agricultural productivity and farmers' income; strengthen the resilience of ecosystems and livelihoods to climate change; and reduce greenhouse gas emissions. As there are huge variations between geographic locations in terms of risks to be faced and capacities to face them, CSA takes into consideration context-specific and locally-adapted actions and interventions, along the whole agricultural value chain.

In semi-arid West Africa, where major constraints that impinge on agricultural development are droughts, soil acidity, and nutrient depleted and degraded soils (Jalloh et al. 2013), most successful CSA options will require a synergistic provision of water, nutrients and a supportive soil structure, the key elements needed to support effective plant growth and to reduce crop failure. Plant nutrient use efficiency in cereal-based farming systems is often very low because of limited soil moisture conditions (Buerkert et al. 2002). The low soil quality combined with the harsh Sahelian climate leads to a low efficiency of fertilizers (Breman et al. 2001). Water and nutrient interactions practices such as *zaï* and half-moons techniques, fertilizer micro-dosing, stone bunds or vegetation strips combined with application of organic/inorganic sources of nutrients, cereal-legume intercropping, appear to be promising CSA options as well as crop-livestock production systems in the Sahel. This paper analysed the ability of the above existing technologies and practices and explore how their outcomes are linked to climate change adaptation and mitigation and to increased agricultural resilience in West Africa.

15.2 Climate-Smart Agriculture: A New Concept to Tackle Climate Change Effects on Agriculture

CSA is a new concept that now dominates current discussions in agricultural development because of its capacity to unite the agendas of the agriculture, development and climate change communities under one brand. Neufeldt et al. (2013) in a recent article provided substantial information on the concept and its implications. According these authors, the CSA concept was presented at the First Global Conference on Agriculture, Food Security and Climate Change at the Hague and defined as agriculture that "sustainably increases productivity, enhances resilience, reduces/removes greenhouse gas emissions, and enhances achievement of national food security and development goals" (FAO 2010). Following the Second Global Conference on Agriculture, Food Security and Climate Change in Hanoi in 2012, the recently published Climate-Smart Agriculture Sourcebook (FAO 2013) further advanced the concept with the intention of benefiting primarily smallholder farmers and vulnerable people in developing countries. CSA is thus promoted through strengthening the knowledge base on sustainable practices, as well as on financial and policy options that would enable countries and communities to meet their food, water and nutritional security and development goals. According to Holmgren (2012), CSA must involve a people-centred approach, keeping farmers and those most vulnerable, including women, at the heart of dialogue, decision-making and action, and empowering them as critical agents of change. Thus, improving farmers' access to and awareness of available knowledge services, finance, agricultural inputs (e.g. seeds and fertilizers), and rights (e.g. land tenure rights) is key to the successful implementation of CSA strategies.

In their analysis, Neufeldt et al. (2013) realized that although in principle only agricultural practices that encompass all components of CSA should be branded as "climate-smart," the term has been used very liberally because it is unclear how the different dimensions interact. Therefore, virtually any agricultural practice that improves productivity or the efficient use of scarce resources can be considered climate-smart because of the potential benefits with regard to food security, even if no direct measures are taken to counter detrimental climate effects. In addition, virtually any agricultural practice that reduces exposure, sensitivity or vulnerability to climate variability or change (for example, water harvesting, terracing, mulching, drought-tolerant crops, index insurances, communal actions) is also climate-smart because it enhances farmers' ability to cope with weather extremes. Likewise, agricultural practices that sequester carbon from the atmosphere (for example, agroforestry, minimum tillage), reduce agricultural emissions (for example, manure management, biogas plants, reduced conversion of forests and rangeland) or improve resource use efficiency (for example, higher productivity crop and livestock breeds, improved crop management and animal husbandry) can all be considered climate-smart because they contribute to slowing the rate of climate change. Almost any agricultural practice or outcome currently qualifies as climate-smart, however, suggesting that CSA is a triplewin for all without regrets, losers and trade-offs. Thus, CSA can easily be appropriated for a wide range of even conflicting agendas. Neufeldt et al. (2013) concluded their analysis through introducing the “safe operating spaces for agricultural and food systems across spatial and temporal scales” as a windows that allows to better meet human needs in the short and long term within foreseeable local and planetary limits, including therefore the concept of climate-smart agriculture. In the present paper, we will confront the selected water and nutrient interaction practices to the triple wins of CSA and explore possibilities for their improvement.

15.3 Climate Change Projections for the Semi-arid West Africa

The influences and interactions that control the region’s climate are complex and models have difficulty in simulating the observed climate. Indeed, the complex nature of West Africa climate, dominated by the monsoon, makes it challenging for reanalysis and GCMs to accurately capture the temporal and spatial variability which is observed in the region (Cook and Vizy 2008). In recent decades, decreased precipitation and drought in the Sahel has become a particular focus for research as it represents one of the largest recent observed climate changes of any region (Dai et al. 2004). According to Washington and Hawcroft (2012), projections for changes in crop cultivation limits are variable over space and time, and so the outlook for agriculture is highly uncertain, particularly in the vulnerable Sahel region. Insufficient observational records constrain the accuracy of reanalysis and gridded data, making the identification of local trends and mechanisms difficult. In addition, there is wide divergence in model projections for the region’s climate by the end of this century. This poses a significant challenge to designing agricultural adaptation strategies.

Two physically consistent scenarios for the Sahel have been put forward; one drying and one wetting (Giannini 2010). Simplistically, the drying interpretation centres on overall warming of the oceans and associated oceanic convection leading to decreased convection at the continental margins and resultant drying of the interior. A positive feedback from the land would lock this system in place (Chou and Neelin 2004). Alternatively, a wetter Sahel could be caused by an enhanced land-sea temperature gradient, either due to greater warming of the land and a stronger monsoon flow (Haarsma et al. 2005) or due to a reversal in the north-south Atlantic SST gradient due to internal oceanic variability (Knight et al. 2006), aerosol forcing (Rotstayn and Lohmann 2002) or a combination of internal oceanic variability and the long term background anthropogenic forcing (Ting et al. 2009). Washington and Hawcroft (2012) therefore concluded that the evidence therefore remains inconclusive as to whether a climatological increase or decrease in precipitation is the more plausible projection of change for the Sahel.

Since approval and publication of the IPCC AR4, new literature has emerged concerning risks for African agriculture and food production that are caused by anthropogenic climate change. These studies use statistical, econometric, or process-based models for different time frames and different basic assumptions, assessing impacts at specific locations, in regions or for the entire continent, for single crops, production systems, or the entire agricultural sector. The IPCC (2007) predicts an approximate 50% decrease in yields from rainfed agriculture by 2020 in some countries, while other studies show an aggregate yield decline of 10% by 2055 for smallholder rainfed maize in sub-Saharan Africa. A study by Ericksen et al. (2011) to identified areas that are food insecure and vulnerable to the impacts of future climate change indicated that West Africa is one of the major climate change vulnerability hotspot region in the world. These authors indicate that length of growing period will declines by 5% or more across a broad area of the global tropics, including heavily cropped areas of West Africa. This suggests that at a minimum, most of the tropics will experience a change in growing conditions that will require adaptation to current agricultural systems. With good consensus from the various GCMs used (i.e., these results are robust), it is expected that reliable crop growing days decrease to critical levels below which cropping might become too risky to pursue as a major livelihood strategy in a large number of places across the global tropics, including West Africa, East Africa, and the Indo-Gangetic Plains.

Therefore, a substantial change in climate could require adjustments for which resource poor farmers lack the essential means (Jalloh et al. 2013). Heavy and persistent rainfall in hitherto dry areas of the Sahel could cause an increase in diseases and pests that livestock in those areas are not adapted to. On the other hand, a marked decrease in rainfall in hitherto wet regions like Liberia could cause significant changes in the growing conditions that may require changes in the farming system with regard to crops and livestock composition and management. The real issue is the inability of resource-poor farmers to react appropriately and fast enough. Unless strong adaptation measures are taken, projected changes in rainfall and temperatures may cause significant declines in crop yields in semi-arid, tropical and sub-tropical regions such as West African Sahel. Recent projections based on African population growth suggest that in order to maintain today's already insufficient food consumption level on the continent, yields of all food crops would have to increase by 230% by 2050 – this in a region where climate change is expected to reduce yields by 10–20% and where a third of the population already suffer from hunger.

15.4 Are Contour Stone Bunds Successful CSA Options in the Sahel?

15.4.1 Background Information

Two major factors characterizing agriculture in the Sahel are: (i) erratic climatic conditions with frequent periods of water shortages (Sivakumar and Wallace 1991), and (ii) the presence of large areas of inherently low fertility and crust prone soils (Breman et al. 2001). What is responsible for water deficiency (i.e. more and/or longer periods of water stress), and low water use efficiency is not primarily water shortage, but loss of water through runoff, soil evaporation and drainage below the root zone (Zougmoré et al. 2000). The loss through runoff is caused by the high intensity of the rainfall, the low organic matter content of the soils and the extent of soils with surface crusts and seals (Roose 1994). These have resulted in severe human-induced land degradation in the Sahel. Indeed, Oldeman et al. (1991) indicated some years ago that in Africa, 40% of agricultural lands were affected by human-induced land degradation. Because of the degradation phenomenon, crops and animal production are at risk. To solve the problem, farmers have developed a range of measures, including runoff control, soil structure improvement, and nutrient management (Mando et al. 2001).

Soil and water conservation extensionists have put emphasis on the implementation of the stone bunds technique to check runoff and to control erosion (Reij et al. 1996). Thus, laying stone bunds in fields is now well known and is widely practiced by farmers in sub-Saharan West Africa (Zougmoré et al. 2000). Indeed, constructing stone bunds is the most widely practiced technique to combat run-off and erosion by farmers. As a result, various government and non-government programmes are promoting the large-scale introduction of the technique and providing technical and logistical backup for collecting and transporting stones (Rochette 1989). Contour stone bunds are erosion control structures built with quarry rock or stones in series of two or three. They are constructed in lines along the natural contour of the land after 10–15 cm of the soil has been removed from the line where they are to be built. They should be built to a height of 20–30 cm from the ground and spaced 20–50 m apart depending on the inclination of the terrain.

On-farm research has shown that stone bunds are efficient in increasing soil water status and in reducing soil erosion and downward particle transport. The technique is particularly efficient in reducing runoff and improving rainwater infiltration (Zougmoré et al. 2000); it also reduces fine sediment transport by runoff. However, the best results are achieved when contour stone bunds are used in combination with biological measures (planting of grass, trees and hedges) and the use of organic fertiliser and mulching (Zougmoré et al. 2010).

Constructing stone bunds is the most widely practiced technique to combat runoff and erosion by farmers (Barry et al. 2008). Indeed, plant nutrient use efficiency in cereal-based farming systems is often very low because of limited soil moisture conditions (Buerkert et al. 2002). The low soil quality combined with the harsh Sahelian climate leads to a low efficiency of fertilizers (Breman et al. 2001). Studies by Zougmoré et al. (2004a, b) reported that the beneficial effect of soil & water conservation (SWC) measures such as stone bunds on soil productivity was limited under continuous non-fertilized cereal cropping. However, interactions of SWC measures with organic or mineral source of nutrients optimize water and nutrient use efficiency, which can boost crop production and induce economic benefits for poor resource farmers.

15.4.2 Beneficial Impacts for Food Production, Adaptation and/or Mitigation

Under water limiting conditions, the stone bunds are efficient measures to improving soil water content through runoff control, which can reach 59% in plots with barriers alone, and even 84% in plots with barriers + organic matter (Zougmoré et al. 2003a). Indeed, the stone bunds form a barrier that slows down runoff and spreads it more evenly over the land. By slowing the flow of water over the land, it can seep into the soil and prevents the loss of rainwater. Rainwater that filters through the bunds infiltrates into the soil. When rainfall is erratic, the stone bunds contribute to conserving more moisture in the soil for longer, which helps to alleviate water stress during dry spells. The effect of stone bunds on soil water moisture depends on the space between the bunds. The larger the spacing, the less their effects. In wet years however, the bunds may cause waterlogging in some parts of the field, which can adversely affect crop production.

Contour stone bunds protect the land against sheet erosion caused by runoff. Some studies reported that the application of compost led to the reduction of total soil loss by 79% in plots with stone bunds as compared to the losses in plots without barriers (Zougmoré et al. 2009). By slowing down the runoff speed, the bunds also induce sedimentation of fine waterborne particles of soil and manure, resulting in a build-up of a layer of sediments rich in nutrients. The seeds of grasses and shrubs are also trapped by the bunds, favouring the establishment of natural vegetation along the structure. This further stabilises the soil and the bunds and contributes to conserving the biodiversity of plants and small wild animals (monitor lizards, birds, snakes and other reptiles).

During dry years, crops in plots with stones bunds could yield two to three times more than crops in control plots (Kaboré and Reij 2004). The increase in sorghum yields varies between 33% and 55% in Burkina Faso's Central Plateau area while grain yields increase by more than 40% for millet up to 15 years after the bunds were established in Niger (Nill 2005). A similar picture also emerged in Niger where farm families with SWC produced an estimated grain surplus of 70% in years of good rainfall (Hassan 1996). Yields increase did not cover annual costs of single SWC measures while application of single compost or urea was cost effective.

Combining stone bunds with application of compost increased sorghum grain yield by about 142% and induced positive interaction effects (mean added effects of 185 kg ha^{-1} for stone bunds combined with compost; which resulted in financial gains of 145,000–180,000 FCFA ha^{-1} $year^{-1}$ under adequate rainfall condition (Zougmoré et al. 2010). A recent report by Cooper et al. (2013) indicates that further support for the need to combine water runoff management with soil nutrient management comes from observations on the impact of the PATECORE project in Burkina Faso. These results indicate that although the harsh Sahelian environment, opportunities do exist for making more efficient use of the limited local sources in order to develop CSA options such as contour stone bunds. This may strengthen the adaptive capacity of farmers while empowering them to invest (climate-smart fertilization of soils) for increased productivity and food security.

Landolt (2011) identified a range of both poverty and hunger reduction benefits (increased yields, introduction of cash crops, greater food security and income) and environmental benefits (raised water tables, increased vegetation cover, increased stock of trees, reduced pressure on nearby savannahs, increased species diversity) when contour stone bunds were constructed and organic fertilizer was used. Higher crop production improves household food security in proportion to the area of a farm improved with bunds. Under the PASP in Niger, an average of 16% of the area of a farm was improved with stone bunds, resulting in an increase of between 8% and 33% in annual output with no other additional measures (Nill 2005). In some areas, a reduction in temporary migration was also observed. From the perspective of climate change adaptation, contour stone bunds are useful for a number of reasons. In years with high rainfall, they protect the land in the event of heavy rain, a phenomenon that tends to increase with climate change. In years with a decline in rainfall, they contribute to more effective rainwater harvesting. They improve water retention and infiltration into the soil, increasing the amount of water available to plants and guaranteeing the harvest. Such an increase in available water in the soil profile will help to mitigate the predicted decrease in the Length of Growing Period (LGP) in the Sahel due to global warming (Thornton et al. 2006). In addition, IPCC (2007) projects that heavy rainfall events in the Sahel are likely to increase in frequency and intensity. And with the development of an important tree cover along the stone bunds, they also lower soil temperature and provide protection against wind erosion. The increased vegetation cover and diversity on the rehabilitated areas, also increase the supply of fuel wood. As a result, more manure is being applied to fields instead of being used as fuel, further increasing soil fertility and crop yields. Groundwater levels are rising, and farmers have started growing vegetables on small plots near wells, thereby increasing both their income and the diversity of their diets. Health benefits from this are likely to be significant, although have yet to be measured. In that respect, durable and effective soil erosion control structures will assume even greater importance and constitute an important adaptation measure.

15.5 *Zaï* and Half-Moons: Two Indigenous Land Rehabilitation Practices to Adapt to the Changing Climate and Land Use in the Sahel

15.5.1 Background Information

In the West Africa Sahel, the combined effects of climatic conditions, inherent poor soil quality and human activities has resulted into soil degradation, due to crusting, sealing, erosion by water and wind. Cultivated lands are particularly characterised by a gradual loss of structure-hardpan formation-reduced permeability-compaction-inadequate aeration-and limited plant root development. On these soils, increasing erosion has ultimately resulted into the development of totally bare, sealed and crusted soils locally called *zipellé* in Burkina Faso, or *harde* soils in Chad (Zougmoré et al. 2003b). No one single measure is sufficient to adapt to climate change and variability. Rather, a mix of measures is needed which targets the various farm variables – water, soil, micro-climate, seeds and crops as well as labour and capital.

This example shows how traditional integrated soil and water management practices called zaï and half-moons can combat land degradation and improve productivity of these sealed and crusted bare soils, previously abandoned as wasteland (shallow depth < 50 cm, pH (H_2O) ~ 5, SOM ~ 1.2%, N < 0.6 g kg^{-1}, total P ~ 0.66 g kg^{-1}, CEC very low ~ 0.11 cmol kg^{-1}). The *zaï* method (also called tassa in Niger or towalen in Mali), is a soil rehabilitation system that concentrates runoff water and organic matter in small pits (20–40 cm in diameter and 10–15 cm deep) dug manually during the dry season. A handful (0.3 kg) of animal manure or compost is supplied per pit, i.e. 9.5 t ha^{-1}. Like *zaï*, the half-moon (originating from Niger), is another method for the rehabilitation of sealed and crusted bare soils consisting of a basin of 2 m in diameter, dug with a hoe or a pick so as to break the crusted layer on the soil surface, and to collect the runoff water. The cultivated area is 6.3 m^2 for each half-moon. A barrowful (35 kg) of animal manure or compost is supplied in each half-moon, i.e. 14.6 t ha^{-1}. Contour stone bunds are usually laid in order to slow down runoff and allow better water retention and infiltration in the *zaï* and half-moons basins.

15.5.2 Beneficial Impacts for Food Production, Adaptation and/or Mitigation

The two soil rehabilitation practices are efficient in improving soil productivity mainly through biophysical and biological processes: Indeed, by breaking the soil crust, pit digging facilitates more water infiltration and runoff water harvesting, thanks to the earthen bund formed downslope of the pits. Also, the applied organic matter attracts termites, which have significant effects on soil structure as they open up large and numerous macropores throughout the entire soil profile as a result of their nesting and foraging activities. Improvement in soil structure following soil fauna activity leads to increased water infiltration and drainage, lower runoff, and reduced soil resistance to root penetration. The application of organic inputs not only enhances soil nutrient availability, but also improves crop nutrient uptake from soil reserves. The improvement of water status in the soil, and the increased decomposition and nutrient release result into a great impact of the *zaï* and half-moon systems on crop performance under semi-arid conditions. Several studies (Zougmoré et al. 2003a, b, 2004a, b; Reij et al. 2009) in the Sahel region reported that applying compost or animal manure allowed substantial gain in sorghum grain yields i.e. about 10–39 times (700–1500 kg ha^{-1}) the yield obtained in the *zaï* or half-moon basin without any amendment ($<$100 kg ha^{-1}). It is a simple solution to reclaim these degraded lands but also to rehabilitate the agroforestry cover in the Sudano-Sahelian semiarid area as it allows, thanks to the plants seeds included in the manure, the regeneration of shrubs and trees in the *zaï* pits. Several studies reported the re-establishment on formerly bare soil of over 20 herbaceous species and 15 woody species following two consecutive years of *zaï* in the central part of Burkina Faso. The *zaï* method at present is still labor-intensive, about 60 working days for 1 ha. INERA scientists in Burkina Faso recommended a so-called 'mechanical *zaï*' that consists of making appropriate holes mechanically with animal-drawn tools (Dent IR12 for sandy soils, or Dent RS8 for other types of soils). This reduces by more than 90% the amount of time required for making the pits as it takes only 11–22 h ha^{-1} to construct these pits with oxen that are well-fed with crop residues. This also resulted into an economic benefit of 165,000 cfa ha^{-1} compared to only 17,000 cfa ha^{-1} with the manually dug *zaï* (Barro et al. 2005).

The above results demonstrate that *zaï* and half-moons practices can be considered as CSA options as they contribute effectively to rehabilitate previously abandoned and degraded bare lands, therefore improve the resilience of smallholder farmers; in addition, these practices increase substantially crop productivity and allow farmers to adapt to climate variability. Also, according to Bayala et al. (2011), *zaï*and half-moons techniques also favour local species regeneration through their seeds contained in the manure applied. However, although their potential contribution to GHG reduction through the subsequent impact of the regenerated trees and their effect on soil carbon and crop production is generally recognized, these aspects still need further investigation, especially in relation to how trees as managed by farmers.

15.6 Conclusion

We've used three integrated soil water and nutrient management practices from the semi-arid West Africa region to analyse their contribution to the 3 pillars of CSA, i.e. sustainable increase of agricultural productivity and incomes (food security), adapting and building resilience to climate change (adaptation) and reducing and/or removing greenhouse gas emissions (mitigation), where possible. We found that stone bunds, *zaï* and half-moon techniques combined with application of organic and/or mineral fertilizers are sustainable land management practices that have increased agricultural productivity, vegetative cover and carbon sequestration, and reduced water erosion. Thus, these techniques can be qualified climate-smart since in one way or in other they contribute to some of the CSA criteria. These successful examples show the many ways CSA can take shape, and should serve as inspiration for future policies and investments. What still remain unclear are the enabling conditions for their widespread uptake to scale. Indeed, a growing phenomenon in most Sahelian countries is the decreasing proportion of the agricultural sector in total gross domestic product. Invariably this has mainly been due to the diversification of the economies of these countries. Nevertheless, this situation reveals the inefficiency of the agricultural sector, because the sector still employs the majority of the workforce in these countries. There is therefore a need to make the necessary changes to improve agricultural productivity with special attention given to climate change, which has been clearly identified as a critical force driving low agricultural productivity in the region. CSA offers such an innovative approach to increase the adaptive capacity of local communities and to achieve national food security goals in the context of climate change. It seems therefore indispensable that CSA also take into consideration the science-policy linkage in a way to inform local, national and sub-regional agricultural and food security investment plans.

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Chapter 16

Decision Support Tools for Site-Specific Fertilizer Recommendations and Agricultural Planning in Selected Countries in Sub-Sahara Africa

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Abstract Recommendations and decisions of crop management in sub-Saharan Africa (SSA) are often based on traditional field experimentation. This usually ignores the variability of production factors in space and time, and hence invalidates such decisions and recommendations outside of the experimental sites. Yet, the use of alternative or complementary decision support approaches such as crop modelling is limited. In this paper, we reviewed the state of the use of crop modelling in informing site specific fertilizer recommendations in some countries in SSA. Even though nitrogen fertilizer recommendations in most countries across Africa are blanket, the limited employment of models show that optimum nitrogen application should be differentiated according to soil types, management and climate. A number of studies reported on increased fertilizer use efficiency and reduced crop production risks with the use of Decision Support Tools (DST). The review also showed that the gross limitation of the use of models as agricultural decision-making tools in SSA could be attributed to factors such as low capacity due to limited training opportunities, and the general lack of support from national governments for model development and application for policy formulation. Proposals identified to overcome these limitations include (1) introduction of the science of DST in the curricula at the tertiary level, (2) encouragement and support for the adoption of model use by governmental and non-governmental

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organizations as additional tools for decision making and (3) simplifying DSTs to facilitate their use by non-scientific audience to scale uptake and use for farm management.

Keywords Risk management · Resource use efficiency · Sub Sahara Africa · Soil productivity

Contents

16.1 Introduction

Agriculture, the mainstay of the economies in sub-Saharan Africa (SSA), is dominated by smallholder farmers, holding often between 0.5–2 ha and relying mainly on rainfall (Adiku et al. 2015). The soils in the region are generally highly weathered (Sanchez 2002), comprising of Low Activity Clays (LAC) with low inherent fertility (cation exchange capacity (*CEC*) between 3 and 15 $\mathrm{cmol_c/kg}$ soil). In some regions such as the West African Sudano-Sahel, the CEC can be as low as 1 $\mathrm{cmol_c/kg}$ soil and hence a great portion of the inherent fertility is derived from the soil organic carbon, which itself is low, often, <10 g/kg (Bationo and Buekert 2001). These, in conjunction with poor management practices such as bush burning, residue removal from fields, very low fertilizer application, mono cropping systems and erratic but intense rainfall lead to accelerated soil degradation and fertility decline. Even then, the use of inorganic fertilizer in SSA is low, being only about 10 kg/ha fertilizer a decade ago (Sanchez et al. 2009) although current evidence suggest that several countries have now increased use. For example, current fertilizer use by farmers in Ghana is about 30 kg N/ha (MacCarthy et al. 2017).

It has long been established that increasing the use of inorganic fertilizer on arable land is critical to improving crop productivity and ending hunger in SSA (van Keulen and Breman 1990). But this must go along with measures that avoid the low fertilizer use recoveries under high application rates and high rainfall conditions (Vanlauwe et al. 2011) associated with large losses through runoff or leaching. In other words, efforts towards increasing food production should also include ways to improve efficiency of fertilizer use. In 2003, the heads of states of African countries re-pledged to allocate 10% of their annual budget and to attain 6% growth in agriculture by 2015 (CAADP 2003), with an enhanced fertilizer use at the core of the strategy. Yet, despite the pockets of increased fertilizer use, the situation has still not changed very much from the observations by Sanchez et al. (2009).

The low application of fertilizers in agriculture in SSA can be attributed to several challenges. First, there is the socio-economic aspects of low incomes of most farmers, and hence their inability to afford fertilizers. This aspect will not be discussed here. From the biophysical point of view, blanket fertilizer recommendations which have been the general approach in many SSA countries have little scientific rigour. For example in Ghana, the fertilizer recommendations for both sorghum and maize are similar and in Zimbabwe recommendations have been done for most crops grown by both commercial and smallholder farmers across the five agro-ecological zones (FAO 2006). The failure to formulate fertilizer recommendations that are soil- and crop-type specific and that also considers the effect of climate variability results in either wastage or deficiencies in fertilizer use. In sum, current fertilizer recommendation practices in the SSA do not properly address the specific local biophysical agricultural production systems, hence making them unprofitable in several instances (Kihara et al. 2015), and a disincentive for smallholder farmers.

Improving the formulation of fertilizer recommendations in the SSA is hampered by the expensive and time-consuming field experimentation and soil analysis approaches that are logistically too expensive to conduct at every location of interest. The results are low adoption rates as the field- and soil analysis-based methods alone do not capture the possible range of yield variabilities that can be associated with a given fertilizer application rate and, in many cases, variable weather. The need for the use of complementary procedures that can more effectively assess the many possible interactive effects of biophysical attributes and management practices including soil and crop types, varieties, fertilizer types, application rates and timing on crop productivity under varying weather, cannot be overemphasized. Typically, these are known as decision support tools (DST) or crop modelling. The purpose of this paper is to provide a historical review of the use of models as DSTs in SSA, and to understand reasons limiting the wide-scale use of these models for agricultural research and development planning and especially for formulating site-specific fertilizer requirements.

16.2 Globally Available Decision Support Tools (DSTs)

Decision support tools range from empirical static models that enable the assessment of soil nutrient concentrations and identify factors limiting productivity, to dynamic software support that combine soils, crop-specific growth parameters and weather. Empirical and static models date back to 1930s (Akponikpe et al. 2014) when a number of nutrient response functions were derived often for single factors (e.g. rainfall, fertilizer, among others) to predict crop response to nutrient application. Indeed, as early as 1913, Mitscherlich derived simple, easy to follow equations to predict crop response to nitrogen application (Mitscherlich 1913), the foundations of which continue to play roles in agronomic research and advice. A suite of such empirical response functions led to development of a set of improved response models that consider multiple soil nutrients such as QUEFTS (Jansen et al. 1990), the effects of soil acidity on crop productivity e.g. NuMAS (La Maran and Leatherman 1992) and the effects of soil organic matter management on soil productivity and crop performance, e.g. NUTMON (Stoorvogel and Smaling 1990). The major limitation of these types of models is the lack of dynamic response to changing management and climate. Their use for future predictions is thus limited. The foundation for the dynamic crop models was laid in the 1950s by de Wit (1958) and van Bavel (1953) (see Jones et al. 2017). These types of models, popularly referred to as "Models of Agricultural Systems" combine physical and biological principles to model agricultural systems. Such models, including APSIM, DSSAT and more recently SEAMLESS, harnessed the strengths of non-system models such as EPIC (Williams 1983), CENTURY (Parton and Rasmussen 1994), NTRM (Shaffer et al. 1983), PARCH model (Hess et al. 1997), STICS (Brisson et al. 1998) and PERFECT (Littleboy et al. 1989) in dealing with soil resources under long-term farming activities, but also recognized their weakness in addressing important systems aspect of cropping such as residue management, crop rotation and dynamic management decisions that are responsive to weather, soil and genotype and hence, affect crop yield (Keating et al. 2003). These model development efforts and applications have occurred in other places such as Australia, America and Europe. Even though model uptake worldwide for agricultural planning beyond the research community has been generally low (Rose et al. 2016), there are indeed efforts and success stories where models have been used in the broader agricultural planning context by farmers, communities and monitors. The FARMSCAPE model (Carberry et al. 2002) provides a proof of one such case in northern Australia. It provides a workable interface between researchers, farmers, communities, among others, enabling model application beyond researchers use. Another DST that is used by farmers and consultants in Australia is the "Yield Prophet" which provides growers with integrated production risk advice and monitoring decision support relevant to farm management. The Monsanto Seed Company employs models to assess the greenhouse gas emission reduction potentials of crops such as maize and soybean under varying soil conditions. Thus, in several respects, some efforts have and continue to be made in modest to popularize the use of models in many ways. In SSA, however, model use is mainly limited to largely donor-funded calibration and validation studies within the research domain. The more crucial aspect of model development to address the peculiar challenges such as soil acidity, phosphorus fixation, soil salinity, among others, on crop production and the adoption of the models by National Governments to assist policy formulation is almost completely under-funded.

Though crop modelling in the world spans more than 60 years or more, it was not until the mid-1980s that both empirical and functional dynamic models were introduced to SSA. Perhaps the earliest model use in the SSA was in South Africa in the early 1970s (Schultze 1975), followed by a rather slow spread to the other regions. Empirical and the semi-empirical models such as AQUACROP (Raes et al. 2009), CROPSYST (Stöckle et al. 2003), STICS, WOFOST (Van Diepen et al. 1989), QUEFT and NUTMON took precedence over the more dynamic ones that simulated the dynamics of the crop growth, development and soil processes. By the mid-1980s, the first application of functional dynamic crop-soil systems model in a developing SSA country was probably in Kenya, within the Australia Dry-land Farming Systems Project (McCown et al. 1992; Keating et al. 1991) that spanned 1985–1992. This formed the foundation of modeling low input systems with the use of the CERES Maize model and then evolved into the use of the Agricultural Production Systems Simulator (APSIM) (McCown et al. 1992). Other DST in use in SSA include WOFOST (Kassie et al. 2015) used to assess the impact of the variability of weather parameter on the yield of maize in Ethiopia and SARA-H, a water balance/stress index based model used mainly in the Sahelian regions of West Africa and that has been used extensively for agrometeorological and food security assessments (Akponikpe et al. 2014).

Despite efforts by Consortium of International Agriculture Research Centres (CGIAR) (e.g. ICRISAT, CIAT and IITA) and IFDC among others to promote DST using software such as Decision Support System for Technology Transfer (DSSAT; Jones et al. 2003) and APSIM, most of the users from SSA are from the research domain and not from the policy makers' domain. In effect, the needs for the types of interface suitable for the non-research community have not been expressed to the model developers. Also, SSA can hardly showcase any model development works except the South African sugar cane model and some limited work to extend some models such as APSIM to include intercropping systems (Adiku 1995; Adiku et al. 1998).

16.3 Challenges to Fertilizer Recommendation Formulation in the SSA

Soil and crop-specific nutrient management recommendations are required to increase farm productivity. The challenge of providing these recommendations to farmers in Africa is huge because soils and climate are highly heterogeneous even over short distances. Local soil variability also results in variability in yields even among replicates of the same treatment (Akponikpe et al. 2014). Crop productivity and profitability of fertilizer use vary widely in space and time even on the same soil, particularly under rain-fed agriculture (MacCarthy et al. 2015; Naab et al. 2015). Some other studies in the Savannah region of West Africa also point to differences in the use efficiencies of applied N fertilizer as a result of differences in the land use history of the fields (MacCarthy et al. 2010).

It was noted earlier that several fertilizer recommendations in SSA do not consider variations in local settings but are rather uniform in space and in time. Furthermore, research sites on which the recommendations are based are sometimes higher in fertility due to better management and residual nutrients from previous trials thus, making them unsuitable as basis for the larger recommendations. Wopereis et al. (2006) observed in the West African Savannah that maize response to fertilizer application was affected by the mineral fertilizer management of maize on farmers' fields as well as inherent soil organic matter. The crop response to fertilizer is also strongly affected by weather variability. With little or no ability to forecast the weather, investment in fertilizer can lead to farmer indebtedness, a phenomenon that serves as a disincentive for the adoption of innovative practices that enhances intensification (Hansen 2005). Several other studies have reported the weather dependence of crop response to fertilizer use and the subsequent inter-seasonal yield variations (MacCarthy et al. 2009; MacCarthy et al. 2015; Naab et al. 2015; Akponikpe et al. 2010).

The response to mineral fertilization is also dependent on the crop and on the variety of crop being used (Haefele et al. 2010). Improved crop varieties which are often used in these fertilizer trials are more responsive than the traditional varieties that most farmers use with the former being less resilient to local weather and disease conditions. Soil physical properties such as texture also influence the response of crops to fertilizer application (Zingore et al. 2007). A large spatial variability in yields can occur on a seemingly uniformly-textured soil over short distances (Voortman and Brouwerd 2004), posing a challenge to interpretation and potentially point to other interacting factors. The variation of soil physical, chemical and other properties in space, particularly in smallholder systems, due to previous variations in soil fertility management imply that the responses to mineral fertilization would also vary largely in space. The practice of precision agriculture to address such challenges is yet to get a foothold in the SSA.

Thus, to adequately consider the above-mentioned factors in determining fertilizer recommendations for farmers will require some form of DST that take these factors into account in determining crop yield. Decision support tools provide the opportunity to assess the impact of fluctuations in weather parameters on the inter-annual variability on fertilizer use efficiency of crops. It also allows for the assessment of the impact of different management practices on soil properties and processes as well yield. If the SSA is to meet its aim of increasing its fertilizer use by 2050 (CAADP), then the reliance of field experimental procedures alone cannot provide the necessary policy foundation.

16.4 Role of Decision Support in SSA

The use of DSTs specifically for fertilizer recommendation formulation in SSA is limited. Several studies, however applied the tools in various ways. Smaling and Fresco (1993) used the NUTMON as a decision support tool to monitor the effects of changing land use, and suggest interventions that improve the nutrient balance in Kisii district of Kenya. They concluded that DST has the potential to inform decision makers in determining the effects of current and alternate land use types on crop productivity and long-term sustainability of cropping systems. De Jager et al. (1998) also used the same model in Kenya and concluded that cash crops such as tea and coffee yielded higher economic benefits to farmers and considerably mined less soil nutrient than food crops such as maize and maize-beans systems. Haefele et al. (2003) applied QUEFTS as a DST to study the internal nutrient efficiencies, fertilizer recovery rates and indigenous nutrient supply of irrigated lowland rice in Sahelian West Africa. Similarly, Wopereis et al. (2003) utilized RIDEV-phenology model in the Sahel to develop a DST for determining appropriate time for cultivating rice to avoid yield lose due to increased temperature. Other studies also calibrated and evaluated DSSAT and APSIM for sorghum, millet and maize-based cropping systems on which fertilizer recommendations could be made (MacCarthy et al. 2010; Akponikpe et al. 2010; Fosu et al. 2012; MacCarthy et al. 2012; Fosu-Mensah et al. 2012).

In the case of functional dynamic crop models, their use has largely remained on the calibration and validation for specific locations in the SSA. For many years in the past, most publications on crop modelling from SSA focused on model calibration (Mabhaudhi et al. 2014; Fatondji et al. 2012; Fosu et al. 2012; MacCarthy et al. 2012; Dzotsi et al. 2010) (Table 16.1). Zinyengere et al. (2015) tested the usefulness of crop models (DSSAT) under data limited dryland conditions of southern Africa using both experimental trial data and district-wide crop yield estimates. Also, Mabhaudhi et al. (2014) calibrated and evaluated AQUACROP for the taro plant in South Africa. Not all calibration attempts were successful; For example, Fosu et al. (2012) explained the failure to predict appropriately yields at high N level (unlike the good predictions at low N) to water stress in the gravelly and shallow soils at the experimental site. Gungula et al. (2003) reported on the inability of the CERES Maize model to predict maize phenology under nitrogen stress condition. Wafula (1995) applied CERES-Maize model to support farmers'

Table 16.1 Selected publication on the use of decision support tools in Sub Sahara Africa (SSA)

Source	Crop	Treatment	Application	Location
MacCarthy et al. (2012)	Maize	N	CSM-CERES (DSSAT v 4.0)	Ghana
Fatondji et al. (2012)	Millet	Manure	CSM-CERES (DSSAT v 4.0)	Niger
Fosu et al. (2012)	Maize	N	CSM-CERES (DSSAT v 4.0)	Ghana
Zinyengere et al. (2015)	Maize	Variable	CSM-CERES (DSSAT v 4.0)	Malawi
Zinyengere et al. (2015)	Groundnut	None	CropGro (DSSAT v 4.0)	Malawi
MacCarthy et al. (2009)	Sorghum	N & P	APSIM v 4.0	Ghana
MacCarthy et al. (2015)	Maize	N	APSIM v 7.4	Ghana
Fosu-Mensah et al. (2012)	Maize	N & P	APSIM v 6.1	Ghana
Tetteh and Nurudeen (2015)	Maize	N & P	CSM-CERES (DSSAT v 4.0)	Ghana

(continued)

Table 16.1 (continued)

Source	Crop	Treatment	Application	Location
Chisanga et al. (2015)	Maize	N and planting dates	CSM-CERES (DSSAT v 4.0)	Zambia
Kisaka et al. (2015)	Maize	N and manure	APSIM	Kenya
Delve et al. (2009)	Maize	P	APSIM	Kenya
Delve et al. (2009)	Maize	P	APSIM	Kenya
Delve et al. (2009)	Bean	P	APSIM	Kenya
Chimonyo et al. (2016)	Sorghum	Water regime	APSIM	South Africa
Chimonyo et al. (2016)	Cowpea	Water regime	APSIM	South Africa
Robertson et al. (2005)	Velvet bean	N and velvet bean as previous crop	APSIM	Malawi
Chikowo et al. (2008)	Maize	Fertilizer and rainfall	APSIM	Kenya
Katambara et al. (2013)	Rice	Water productivity and efficiency	AQUACROPP	Tanzania
Ngwira et al. (2014)	Maize	Climate change, CA, CT	CSM-CERES DSSAT	Malawi
Estes et al. (2013)	Maize, Wheat	Climate impacts, N	CSM-CERES DSSAT v 4.5.0.047	South Africa
Estes et al. (2013)	Wheat	Climate impacts	GAM model	South Africa
Bontkes et al. (2003)	Maize	N, P, K	QUEFTS	Togo
Micheni et al. (2004)	Sorghum, cowpea, pearl millet	Manure	APSIM	Kenya
Tsubo et al. (2005)	Maize	Cereal-legume intercropping	APSIM	South Africa
Tsubo et al. (2005)	Beans	Cereal-legume intercropping	APSIM	South Africa
Smaling and Janssen (1993)	Maize	N, P, K	QUEFTS	Kenya
Okwach and Simiyu (1999)	Maize	Land management practices	APSIM	Kenya
Gaiser et al. (2010)	Maize (West Africa)	Improved varieties, soils	EPIC	West Africa
Folberth et al. (2013)	Maize	N, P, improved seeds	GEMIC	Sub-Sahara Africa
O'Leary (2000)	Sugarcane	N, water, temperature	APSIM	South Africa
O'Leary (2000)	Sugarcane	N, water, temperature	CANEGRO	South Africa

(continued)

Table 16.1 (continued)

Source	Crop	Treatment	Application	Location
O'Leary (2000)	Sugarcane	N, water, temperature	QCANE	South Africa
Ncube et al. 2009	Sorghum	N uptake	APSIM	Zimbabwe
Srivastava et al. (2012)	Yam	Fallow	EPIC	Benin
Jansen et al. (1990)	Maize	SOM, residual P, N	NUE	Kenya
Tittonell et al. (2008b)	Maize	N, P, K manure	QUEFTS	Kenya
Tittonell et al. (2008a)	Maize	Fertilizer, Manure	FIELD	Kenya
Kurwakumire et al. (2014)	Maize	N, P, K, water use efficiency	QUEFTS	Zimbabwe
Mowo et al. (2006)	Maize	N, P, K	QUEFTS	Tanzania
Araya et al. (2010)	Barley	Water regime, planting dates	AQUACROP v 3.0	Ethiopia
Mabhaudhi et al. (2014)	Taro	Water regime, Taro landraces	AQUACROP	South Africa
Mabhaudhi et al. (2014)	Groundnut	Water regime	AQUACROP	South Africa
Karunaratne et al. (2011)	Groundnut	Soil moisture regime	AQUACROP	Swaziland & Botswana
Beletse et al. (2011)	Sweet potato	Irrigation treatment	AQUACROP	South Africa
Kipkorir et al. (2010)	Maize	Water regime	AQUACROP	Kenya
Mugalavai and Kiporir et al. (2015)	Maize		AQUACROP	Kenya
Mhizha et al. (2014)	Maize	Sowing management options	AQUACROP	Zimbabwe
Nyakudya and Stroosnijder, (2014)	Maize	Rooting depth, planting density, planting date	AQUACROP	Zimbabwe
Masanganise et al. (2013)	Maize	Cultivars, planting dates, climate	AQUACROP	Zimbabwe
Singels and Bezuidenhout, (2002)	Sugarcane	Temperature and water stress	CANEGRO	South Africa
Dzotsi et al. (2003)	Maize	Cultivar, sowing date	DSSAT (CERES-Maize)	Togo
Dzotsi et al. (2010)	Maize	N, P	DSSAT	Ghana
Jagtap et al. (1999)	Maize	N, varieties	DSSATv2.1 (CERES-Maize)	Nigeria

(continued)

Table 16.1 (continued)

Source	Crop	Treatment	Application	Location
Hansen et al. (2009)	Maize (Kenya)	Precipitation, fertilizer management	GCM	Kenya
Mupangwa and Jewitt (2011)	Maize (South Africa)	No-till (NT) and CT systems	APSIM	South Africa
Adnan et al. (2017)	Maize	N	DSSAT v 4.6 (CERES-Maize)	Nigeria

decision making with respect to farm management options and the inherent economic implications. The Agricultural Production System sIMulator was applied by Masikati et al. (2014) to show the positive effect of maize mucuna rotation on water productivity in smallholder systems in Zimbabwe. A few studies have recently used crop models for yield gap analysis (van Ittersum et al. 2013; Kassie et al. 2014). A study by Diarisso et al. (2015) in Burkina Faso indicated substantial yield gaps in the smallholder systems which they attributed to low soil fertility, sub-optimal fertilizer input and erratic rainfall condition. Kassie et al. (2014) also applied the DSSAT and the WOFOST DSTs to assess climate-induced yield variability and yield gap of maize in the Central Rift Valley of Ethiopia. Dzotsi et al. (2003) also used the DSSAT model to provide a DST that enabled optimum cultivar-sowing date combination of maize in southern Togo.

16.5 Link Between DST and Site Specific Fertilizer Recommendation

Decision support tools integrate a multiple of parameters known to affect response of crops to inorganic N such as rainfall distribution, type of soil, crop type and crop variety in simulating crop yield. As such, DST is an appropriate tool to enhance farmer decision making especially with regards to site specific fertilizer recommendation. With the use of DST, it can be shown that a wide range of yields can occur even at a given N application rate across soil types, under variable management, or even at same location but under different weather conditions.

In Ghana for example, a farmer investing in 120 kg N/ha application rate can obtain yields varying from 1900 kg/ha to more than 4000 kg/ha (Fig. 16.1). This variation can be attributed to rainfall variability. Without the use of DSTs, such yield/fertilizer response information would require many years of field experimentation to obtain. DSTs can be used together with weather forecast for instance to select appropriate sowing time (MacCarthy et al. 2017) or advise on range of fertilizer to use based on the forecast in order to maximize fertilizer use.

Recently, Nurudeen (2014) used the DSSAT – CSM to refine fertilizer recommendations in Sudan Savannah agro-ecological zone in Ghana. Atakora et al. (2014) also used the DSSAT – CSM to determine fertilizer recommendations for a site in the Guinea Savannah Zone of Ghana. A comparison of these two studies which were both located in the northern part of Ghana show differences in recommended N rates that should be applied to maize to optimize yield. These were all applied on point scale just like most other model applications in SSA. Using the N response data (Fig. 16.1) for Tamale, Ghana, a strategic analysis of the monetary returns of the various N inputs showed 60 kg N ha^{-1} as most appropriate to be recommended to farmers since the returns from that were similar to those obtained from N application levels beyond 60 kg N ha^{-1} (Fig. 16.2). The economic optimum rate was determined using Gini coefficient (Adnan et al. 2017) which determines the best economic strategy. Environmental limitations combined with management and socio-economic conditions also need to be considered when assessing cost benefit for fertilizer recommendations. For example, at optimal

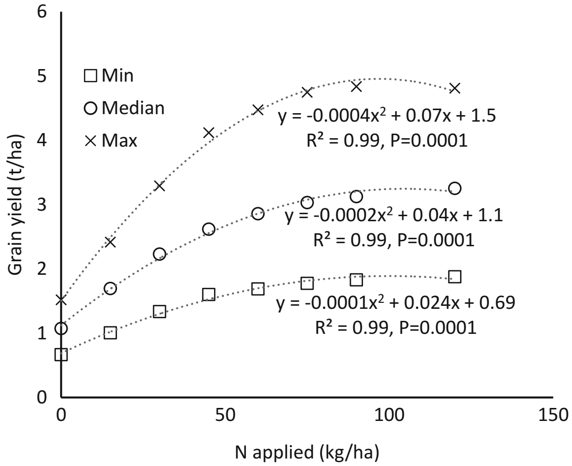

Fig. 16.1 Response curve of maize yield to different levels of nitrogen application over 30 years (1980–2009) simulation period for Tamale, Ghana

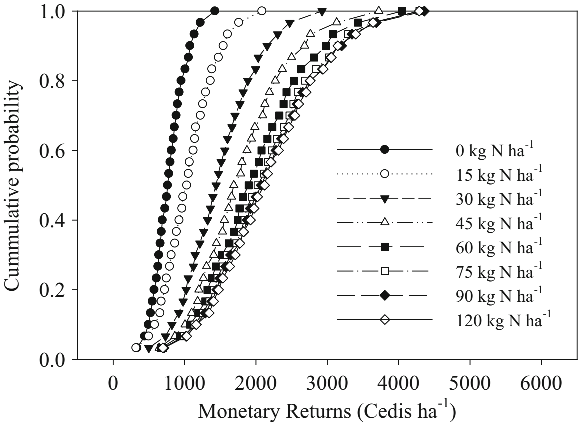

Fig. 16.2 Monetary returns on the use of inorganic fertilizer in maize production at a site in Tamale, Ghana

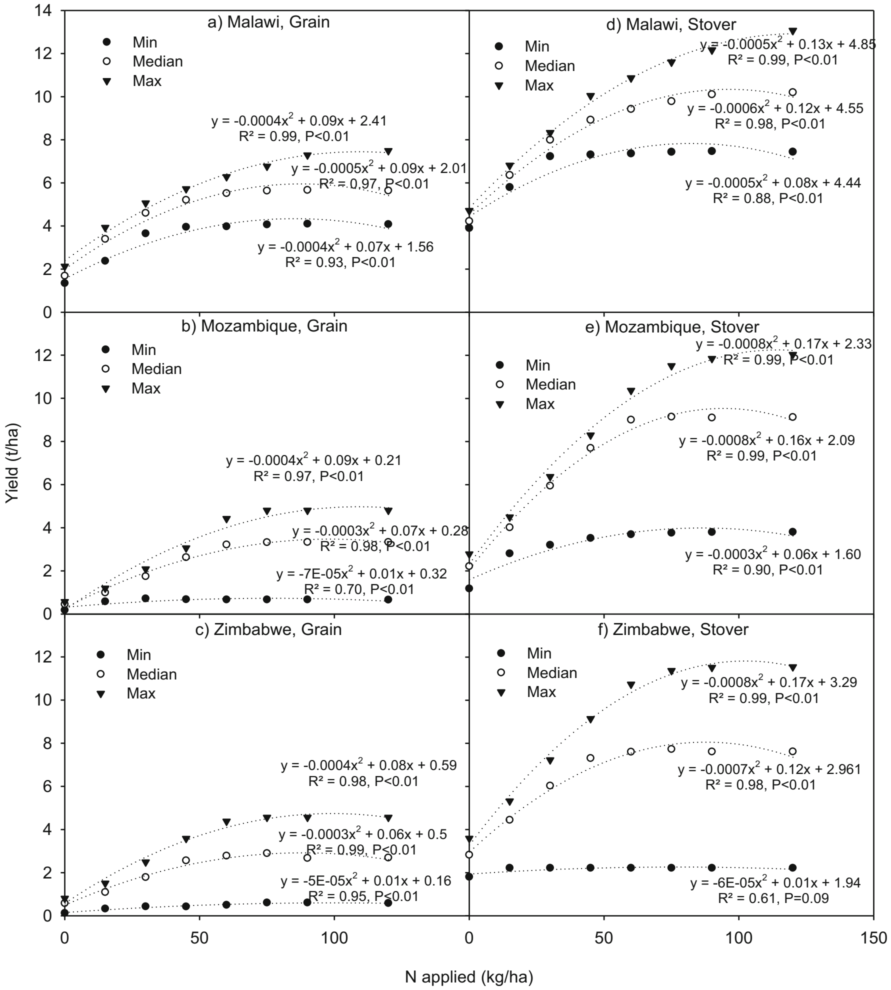

Fig. 16.3 Simulated maize grain and stover yields in response to mineral N fertilization in three countries in southern Africa

simulated fertilizer application of 60 kg/ha in soil with average % SOC 0.6, 0.8 and 0.5 and annual rainfall of 850, 1200 and 650 mm median maize yield was 5200, 3216 and 2780 kg/ha for Malawi, Mozambique and Zimbabwe, respectively (Fig. 16.3a–c). Risk is higher in Zimbabwe at the recommended application rate as shown by high variability of both maize grain and stover yields. While 60 kg N/ha is recommended for Zimbabwe, production at that fertilizer rate gives yields that are 20% less than area potential, i.e., due to soil quality, optimal benefits of applying recommended rates can be compromised. In Senegal for instance, yield increases of between 1000–2300 kg/ha and profitability of USD 216–640 per ha

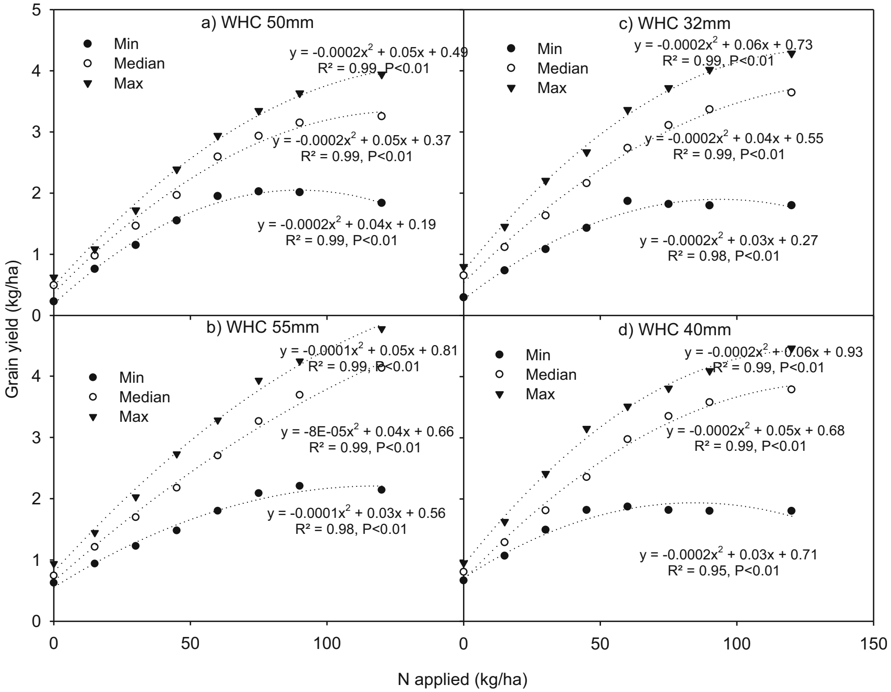

Fig. 16.4 The Simulated effect of soils from Koutiala, Mali with different water holding capacity on the response of maize yield to mineral nitrogen fertilization. WHC is water holding capacity

were reported as benefit from using Nutrient Manager for Rice (NMR) decision support systems for irrigated rice (Saito et al. 2015). A simple Microsoft excel decision support tool has been developed in Uganda to help optimize fertilizer use by farmers and about 400 extension workers and farmers trained on their use. This was part of the Optimizing Fertilizer Recommendation in Africa (OFRA) which is a project being done in seven countries in SSA and is expected to optimize fertilizer use efficiency. The FERRIZ model was also calibrated and evaluated by Segda et al. (2005) and used to improve fertilizer recommendations for irrigated rice in Burkina Faso. These alternative fertilizer recommendations increased the gross returns compared to farmers' practices and existing recommendations.

The shape of simulated response of maize to different levels of N fertilizer vary with soil's water holding capacity as observed in Koutiala, Mali (Fig. 16.4). While grain yield seemed to have peaked at 120 kg N ha^{-1} on soil water holding capacity (WHC) of 50 mm, the response curve for soil with a higher WHC (55 mm) suggested further grain yield increase beyond 120 kg N ha^{-1}. Similarly, the response of crops to N fertilization is also influenced by time of planting (Fig. 16.5). While the use of 120 kg N/ha can result in median yield of about 4000 kg/ha with early planting, using same amount of fertilizer in the late planting

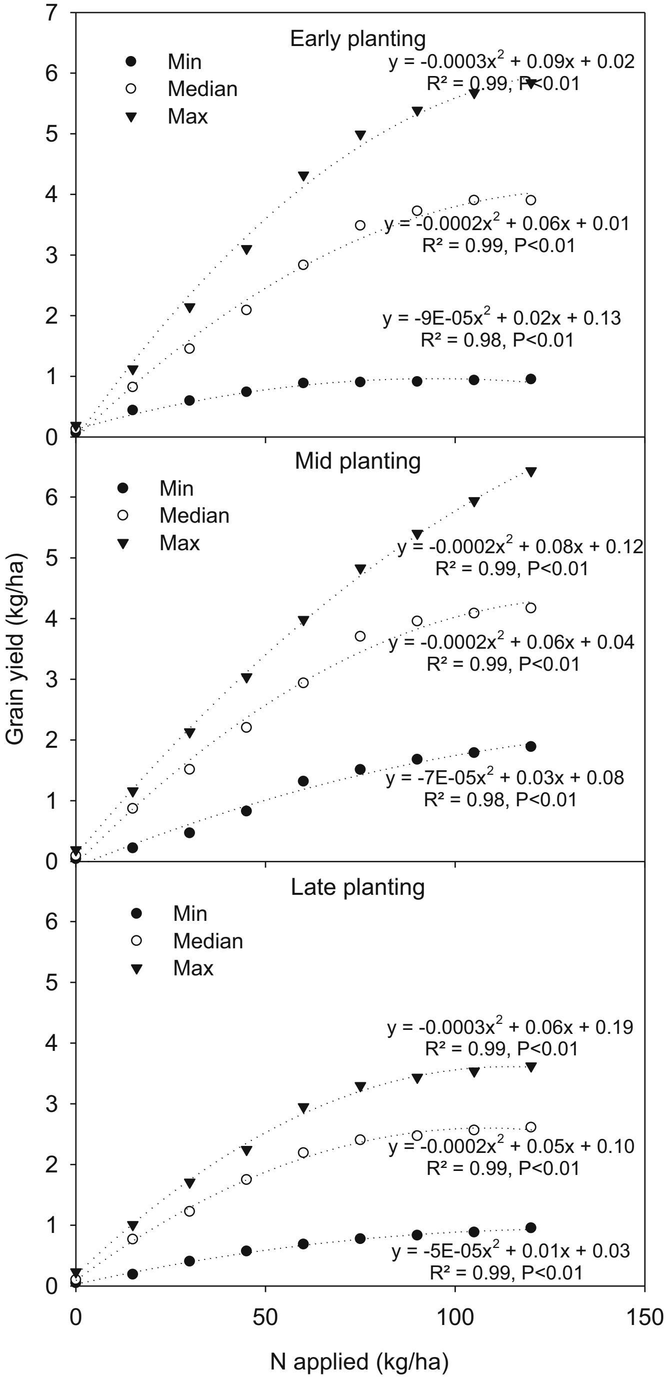

Fig. 16.5 The simulated effect of sowing dates on the response of maize yield to mineral fertilizer application in Nioro. Senegal

window produced a median yield of less than 3000 kg/ha. Decision support tools can also be used to explore what management options to use to minimize yield losses to enhance farmer confidence in fertilizer adoption. Thus, the need to promote site specific fertilizer recommendation to optimize returns on input cannot be over- emphasized.

16.6 Models as DST for Future Climate

Climate change is a major threat to agricultural productivity in the SSA, especially because of (1) high dependence of people and their livelihoods on natural resources, (2) the rapid degradation of these resources and resilience loss, (3) extreme poverty and (4) lack of interventions such as crop insurance. The lingering question is how SSA agriculture will be impacted by future climate. This question cannot be addressed without the use of models. Several projections have been put forward based on different models. IFPRI, for example, simulated changes in crop productivity relative to current yield over several countries in Africa. Others reporting impacts of climate change on agriculture productivity include Jones and Thornton (2003) and Thornton et al. (2009). The work of Thornton et al. (2009) in East Africa highlighted the spatial variability of crop response to climate change and, hence, discouraged the use of spatially contiguous developmental domains in the identification and implementation of adaption options. Areas where yield decline is predicted under current farming practices are also shown to have yield increases when technological changes, such as increased use of fertilizer and varietal improvement, are considered.

Traditionally, DST for future predictions were applied in a variety of ways. In some studies, point based scenarios with single General Circulation Models (GCM) were used, whereas others used point simulation but with multiple GCM (Tachie-Obeng et al. 2013). The trend is now towards the use of multi-locations as well as multi-GCMs (Adiku et al. 2015; Masikati et al. 2015; Rao et al. 2015; Beletse et al. 2015). Within the Agriculture Model Improvement and Inter-comparison Project (AgMIP) framework (Rosenzweig et al. 2013), a combination of biophysical and socio-economic models is being used as DST to assess the impact of climate change on agriculture in various zones of the world. For the West African region, the work is summarized in "Climate Change Impact on West Africa Agriculture: A Regional Assessment" (Adiku et al. 2015). The results showed that net farm income would reduce under climate change. In East Africa, the project focuses on the "Impacts of climate variability and change on Agricultural Systems in East Africa". The results (Rao et al. 2015) indicated that the impact of climate change is not uniform across locations, and that some areas will actually benefit from climate change impacts. Hence the impact on the livelihoods of farmers will also vary based on their location. In other studies, it was projected that the production of maize under climate change scenarios in the Bethlehem District, South Africa would reduce by between 10 and 16% if no adaptation measures are employed (Beletse et al.

2015). In the case of Nkayi, Zimbabwe, the impact of climate change on the productivity of crops under current farmer practice was reported to be marginal (7%). The level of impact is low because the current production systems are low input characterized by depleted soils (Masikati et al. 2015).

16.6.1 Limitations and Challenges to DST Application in SSA

In spite of the evidence provided on the improvement in fertilizer use efficiency and reduction in production risks with the use of DST and modelling to inform agricultural management and planning, the use of DSTs to inform decision making is generally poor. This phenomenon is not peculiar to SSA alone. A recent study by Rose et al. (2016) reported of low uptake of DSTs for agricultural decision making in the United Kingdom. The lag in model use as tool for agricultural decision making in Africa may be attributed to several reasons. First, capacity for modelling use is and continues to be grossly lacking. A survey by Adiku (unpublished) on modelling-related publications from the SSA showed that by the year 2009, about 25, 15, 18 and 14 papers were published using DSSAT, APSIM, NUTMON and RUSLE/USLE, respectively. These papers, which emanated from collaborative works between advanced country researchers and SSA counterparts, appeared in reputable journals over a period of about 40 years. On the average, about two modelling papers or so are published annually from the region, with respect to these four models. Against the backdrop of the low capacity, the African Network for Soil Biology and Fertility (AfNet) and their collaborators organized a series of training that culminated in the publication of a book (Kihara et al. 2012).

Second, except for donor-funded projects, national support for crop modeling research and application for agriculture development is limited. Over the past 20 years of crop modeling activities within Ghana's Universities and Research Institutes, for example, direct government funding is negligible. The funding support may appear to be somewhat better in Kenya and southern Africa, but generally not comparable to Europe, Australia, USA, among others. Therefore, as noted, the effect of many peculiar soil challenges of the SSA including soil acidity, phosphorous deficiency, Mn and Al toxicity, soil erosion and degradation, soil crusts that affect germination and emergence, among others, on crop yields cannot be simulated using the popular DSTs because these processes are not well represented in the models. As a result of the current models lack of sensitivity to these issues, their use in such situations would be limited. Apart, not many institutions in the SSA train expertise in crop modelling and DSTs. Researchers interested in crop modeling must seek training in advanced countries. Interest in modelling among the mainly biology-based students in agricultural sciences in SSA is low, especially because of the need for good mathematical background for modelling. As far back as 1997, the Department of Soil Science at the University of Ghana introduced a curriculum in agricultural systems simulation and modelling. To date, not more than 20 students have participated in the course and not more than 5 crop-modelling related thesis have been produced. There is no effort by SSA governments to financially support training in crop modelling. As indicated earlier, there is low capacity in the use of DST even among scientists. Skills on the use of decision support tools are still rare in Sub-Saharan Africa (Segda et al. 2005).

Third, data unavailability at suitable detail for model validation in particular under broader farm conditions continues to be a major handicap to model use. This requires the need for more research for new versions to include functions that can use routinely collected parameters to estimate those currently required. This will enhance their applicability. The emergence of technologies such as soil-scanners based on IR may be a game-changer for providing extra soil data for areas were data are lacking, particularly with large scale applications. Some efforts have been made to establish minimum data sets and also develop protocols to facilitate the use of DST by other potential users (Hoogenboom et al. 2012; Rosenzweig et al. 2013).

Fourth, the lack of knowledge of the usefulness of DST among agricultural stakeholders for policy formulation is a major handicap. Most DSTs require hardware and computational time and these are often not readily available to potential users in SSA. Organizations that introduce the use of DSTs in SSA often promote specifically those of interest to them whiles smallholder farmers challenges are complex hence require a set of DSTs (DST Toolbox) to adequately address their problems. Critical crops that contribute to food security such as cassava and yam in SSA are usually not adequately captured in most DST. There is also the need to improve use of DST for spatial analysis as most of the existing ones are point based. This will require that they are coupled with geo-spatial tools. Such capabilities already exist in models such as APSIM and DSSAT (Huth et al. 2003) but have not yet been widely applied.

16.7 Conclusions and the Way Forward

Sub-Saharan Africa lags in the use of DST for agricultural decision support even though it is increasingly used in developed countries to support agricultural planning. A great deal of modelling work in SSA has been limited to calibration and validation. Where models were applied to support decision making process, they were hardly used to inform site specific fertilizer recommendation. Inability to capture in models the SSA-peculiar yield limiting factors such as aluminum toxicity, phosphorous deficiency, weeds, and deficiencies of micronutrients limits the application of most of the current models both in representing the real situations and also in making recommendations. The application of models as DST for formulating fertilizer recommendations in the SSA requires much more funding and capacity building support, especially from the national governments and regional bodies in SSA. In sum, for DST to become effective tools for agricultural planning, the following must be achieved:

(i) Capacity building: The introduction of the use of DST in tertiary school curriculum, with a focus on the training especially the next generation not only in model use but more importantly model development. In particular, support from the mathematical disciplines to biological sciences will be required. The setting up of special funds to support students willing to engage in modelling work would be important.

(ii) Demonstration of the utility of DSTs beyond research to policy formulation domain.

(iii) Address peculiar tropical soil and cropping system challenges such as phosphorus deficiency, aluminum toxicity, soil acidity, weed competition, mixed cropping among others to enhance their applicability in SSA.

(iv) Development of DST for other important food crops such as cassava and yam.

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Chapter 17
Fertilizer Deep Placement as One Way of Increasing Nitrogen Use Efficiency and Grain Yield in West African Irrigated Rice Systems

A.A. Bandaogo, B. Fofana, and S. Youl

Abstract Nitrogen (N) is the main nutrient that is limiting rice yields (Oryza sativa L.) in West Africa, and it loss can be very high particularly in the irrigated rice systems with poor water control. Previous studies have reported very low (30%) fertilizer N use efficiency by broadcasting in irrigated cropping systems. And N deficiency can negatively affect phosphorus and potassium plant uptake and reduce rice yields. The effect of fertilizer urea (46% nitrogen – N) broadcast or deep placed (FDP) using urea super granules (USG) on rice yield performance and nutrient uptakes was investigated in West Africa. Fields and pot experiments were carried out in Burkina Faso in the wet and dry season of 2012 and 2013, respectively. The main objective of the experiments was to evaluate how fertilizer N application methods – using prilled urea broadcast (PU) or briquettes (urea supergranules – USGs) affect N use efficiency in irrigated rice systems. PU was broadcast applied, and USGs were point placed deeply into the soil at 5–7 cm to two different Nerica rice varieties (FKR 19 and NERICA 62N), using same fertilizer N rates (52 kg N ha^{-1}). The pot experiments investigated the effect of soil pH on N use efficiency, and phosphorus (P) and potassium (K) uptakes for both PU and USG application methods. Field experiments clearly indicate higher rice fertilizer nutrient N, P and K uptakes with USG than PU, resulting in significantly higher rice yields in USG-plots. Average rice grain yield was 5146 kg ha^{-1} with USG and 4583 kg ha^{-1} with PU in the wet season, and 7000 kg ha^{-1} and 6644 kg ha^{-1}, respectively, in the dry season. NERICA 62N was much more responsive to USG as compared with FKR 19 variety as it produced higher tillers and panicles numbers

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under USG, leading to significantly higher yields as compared with FKR 19. In the wet season, USG significantly increased N agronomic efficiency (NAE) by 39.43% and physiological efficiency by 24.23% over PU. In the dry season, however, differences in N use efficiency (NUE) between USG and PU were not significant. Pot experiments indicate that soil total N was higher in acid than in alkaline soils. And rice N, P and K nutrient uptakes were significantly higher with USG than PU. These confirm the superiority of USG over PU in terms of increasing N, P and K nutrient uptakes and N use efficiency as observed in the field experiments. These studies suggest that in West African irrigated rice systems, fertilizer deep placement could be more effective in improving nutrient N, P and K uptakes, N use efficiency and irrigated rice yields. And smallholder rice farmers in West Africa may derive more benefits from using fertilizer deep placement technology than the conventional urea broadcast application method.

Keywords West Africa · Irrigated rice · Fertilizer deep placement · Nutrient uptakes · N use efficiency

Contents

17.1 Introduction

Nitrogen (N) fertilizers is a major essential plant nutrient and key input for increasing crop yield (Yoseftabar 2013), hence the most yield-limiting nutrient in rice (Oryza sativa L.) cropping systems worldwide (Cassman et al. 1998; Ladha and Reddy 2003). Rice soils in West Africa show marked responses to fertilizer N; however, judicious use of fertilizer N is a must. In order to meet ever-increasing demand for rice by a growing population, farmers will have to apply modest doses of N fertilizers to increase their yields. The most effective management practice to maximize plant uptake and minimize loss is to synchronize nitrogen supply with plant demand for nitrogen (Peoples et al. 1995). In Burkina Faso, the production of paddy rice was 226,448 tons in the period 2008–2010 (Kabore et al. 2011). Currently, the production covers about 60% of the demand and 40% is met from imports. While irrigated lowlands comprise only about 20% of the total rice area, this system contributes about 50% to national rice production. In Burkina, the average use of mineral fertilizer is about 8 kg ha^{-1} (Bassolé 2007), which is very low. Today, farmers' practices for nitrogen fertilizer application generally include basal broadcasting without incorporation before transplanting and/or one or two top dressings in the floodwater immediately after transplanting up to flowering (reproductive stage). The efficiency of fertilizer N use is generally low for lowland rice crop as only 30% of applied N is utilized by crops and the remaining 70% of it is lost through various processes causing serious environmental problems (Craswell and Vlek 1979; Jiang et al. 2005). The predominant loss process and the amounts lost are influenced by the ecosystem, soil characteristics, cropping procedure, fertilizer techniques, and prevailing weather conditions (Peoples et al. 1995).

Rice is mainly cultivated in irrigated paddy fields, where anaerobic conditions prevail under the top layer (a few cm depth or less) and inorganic nitrogen is maintained as NH_4^+ (Freney et al. 1985). The inefficient recoveries of N by plants are caused by nitrate leaching and emissions of N_2O and NOx gaseous from agricultural soil with health and environmental implications (Whitehead 2000). So, proper timing and optimal fertilizer placement can greatly enhance plant uptake of N while reducing environmental contamination. Subsurface placement or incorporated fertilizer is much less subject to surface losses than surface broadcast fertilizer. Thus, the subsurface placement of fertilizer N increases NUE.

In Burkina, mineral fertilizers are directly broadcasted in floodwater. Numerous research reports (e.g. Cassman et al. 1998; Fageria and Baligar 2001) demonstrated that these management practices for application of fertilizer nitrogen in transplanted rice are very inefficient. Crop production systems that optimize yield, reduce N loss and improve N uptake are therefore needed. Nitrogen fertilization positively influences yield (Habtegebrial et al. 2013) as a result of increased tillering capacity, panicle and spikelet number and percentage of filled spikelets (Sathiya and Ramesh 2009).

Soil infertility is a constant threat to sustainability of irrigated rice cultivation. The inerrant low contains of soil N leads to low efficiency of others nutrients that are P and K (Rabat 2003). Nitrogen and phosphorus fertilizers are major essential plant nutrients and key input for increasing crop yield (Dastan et al. 2012; Yoseftabar 2012). Soil pH is a critical indicator of nutrient availability. Soil reaction is not a growth factor as such but it is a good indicator of several key determinants of growth factors, especially nutrient availability. The nutrient absorption amount varies with rice growth stage. Absorption is low at the seedling stage and peaks before the heading stage, and then decreases as root activity declines (Guindo et al. 1994; Liu et al. 2007). The optimum pH for rice growth ranges between 5.5 and 7.0 (FAO 2006). Phosphorus is available at a slightly acidic or neutral pH. High soil pH is also known to affect the efficiency of N fertilizers (Dobermann and Fairhurst 2000). Deep placement of urea supergranules has been shown to effectively reduce N loss (Mohammad et al. 2015) and increase rice yield on near neutral pH soils with alkaline floodwater (Singh 2005; Cai et al. 2002). However, floodwater also increases pH in acid soils and decrease pH in alkaline soils (Dobermann and Fairhurst 2000).To achieve rice production targets, balanced and adequate use of P and K fertilizers as well as N is essential. Information on the response of irrigated rice systems on the technology of urea deep placement with urea supergranules is very limited in Burkina Faso. The yield of rice can be improved by optimising the plant's N uptake through increased N recovery efficiency from urea supergranule (USG; Stangel 1989; Savant et al. 1991). Urea Supergranules or urea briquettes are promising materials for West African smallholder farmers because they are large size particles that can be effectively deep placed by hand—fertilizer deep placement (FDP)—in wetland or irrigated rice fields, and can also be locally produced by rice farmers thus increasing their benefits (Bowen et al. 2004; Pasandaran et al. 1999). Fertilizer deep placement with USG is a technology that is now being promoted in Burkina Faso. This study will provide more understanding of the technology and evaluate genotype and season-specific performance of the FDP technology as compared with the traditional fertilizer application method using broadcast surface application of prilled urea (PU).

17.2 Materials and Methods

17.2.1 Experimental Site

The study was carried out in Sourou Valley in the wet season of 2012 and dry season of 2013. The valley is an intensively cultivated area with a potential irrigated land of about 615,000 ha. The irrigation water is supplied by Sourou River with a capacity of 600,000,000 m^3. The geographic coordinates are 13° 00′ latitude North 03° 20′ longitude west. The region of Sourou is characterized by a north- Soudanian sahelian climate with an average rainfall below 900 mm. Temperature are stable and between a minimum of 17 °C in coolest season and maximum of 41 °C in hottest season. The soils in Sourou Valley are mainly brown, poorly developed, hydromorphic soils and Vertisols with fine texture, high water retention capacity, low permeability, poor ventilation of subsurface horizons and strong compaction (Faggi and Mozzi 2000).

17.2.2 Experimental Design

Field experiment was laid in a split plot design. The first factor, rice variety, was randomized on the main plot and the second factor, fertilizer, was randomized on the sub- plot. The treatments composing of two improved rice varieties commonly used by rice farmers in the Sourou irrigation scheme (FKR 19 and NERICA 62N) and two forms of fertilizer urea (prilled urea and urea supergranule) at the same rate of 52 kg N ha^{-1}. Treatments were replicated four times. Soils used for field experiment were slightly acidic soils with a sandy loam texture (Table 17.1). A recommended rate of 69 Kg P_2O_5 ha^{-1} and 24 kg K_2O ha^{-1} were applied uniformly to all plots except the control at transplanting, as basal in form of triple superphosphate and muriate of potash, respectively. Omission trials conducted at the experimental site indicates that P and K are not limiting rice yield at a certain target yield. Thirty days seedlings were transplanted in 20 cm × 20 cm geometry. Each plot had independent drainage and irrigation ditches, so as to prevent the spread of water and fertilizers between plots. The USG was placed deeply

Table 17.1 Initial soil chemical and physical characteristics in field

Analysis	Wet	Dry
Sand	41.4	33
Loam	21.8	22.3
Clay	36.8	44.7
pH-H_2O	6.1	6.2
pH-KCl	5.5	5.5
Organic carbon	0.66	1.56
Total N (%)	0.06	0.11
Available P (ppm)	4.00	5.6
Na^+ (cmol/kg)	0.23	0.24
K^+ (cmol/kg)	0.25	0.45
Ca^{2+} (cmol/kg)	5.5	4.9
Mg^{2+} (cmol/kg)	0.82	1.18
CEC (cmol/kg)	8.60	8.7

Table 17.2 Initial soil chemical and physical characteristics in pot experiment

Soil property	Acid soil	Alkaline soil
Clay (%)	37.70	19.61
Silt (%)	21.50	45.10
Sand (%)	40.80	35.29
Organic carbon (%)	1.53	1.33
Total N (%)	0.11	0.09
C/N	14.00	15.00
AvailP (mg/kg)	4.56	5.05
pH (1:2.5 H_2O)	6.30	8.02

into the soil at 5–7 cm between four hills. PU was split in two and was applied at 14 days after transplanting and at panicle initiation. The USG granular was applied in soil at 5–7 cm depth only 7 days after transplanting. Both PU and UDP-plots were regularly irrigated depending on the crop's demand throughout the cropping period.

Pot experiment was also carried out using a factorial design with the rice variety FKR62N. The first factor was the type of soil (acidic and alkaline) and the second factor was the type of urea fertilizer (prilled urea – PU and urea supergranules- USG at the same rate of 52 kg N ha^{-1} and the control). Each treatment was replicated 16 times for 4 sampling per treatment at different stages (tillering, panicle initiation, flowering and maturity) of rice growth. Plastic pots of 25 liters were filled with 10 kg of soil from Sourou valley. Two types of soils were used for the pot experiment that were slightly acidic and alkaline with low organic matter content and low total nitrogen (Table 17.2). Soils were wetted during 4 days before transplanting and four plants of rice from thirty (30) days seedlings were transplanted into each pot. A recommended rate of phosphorus (69 kg of P_2O_5 ha^{-1}) and potassium (24 kg of K_2O ha^{-1}) were applied uniformly to all pots except the control at transplanting, as basal in the form of triple superphosphate and muriate of potash respectively. One granule of 1.8 g corresponding to 52 kg N ha^{-1} was placed 7 days after transplanting between four plants in the pot receiving USG. The prilled urea at the same rate was split into two. The first half was applied 14 days after transplanting and the second half during panicle initiation. Irrigation of the pots was done when necessary.

17.2.3 Plant Sampling and Analysis

After harvest, grain and straw samples were collected from each subplot to analyze their total N, P and K contents. The assessment of yield components was made on 1 m^2 in each plot. In pot experiment plant biomass was taken at tillering, panicle initiation, flowering and at maturity. At each stage, four (4) pots of each treatment were destroyed. Rice plants were removed and the roots were washed to remove the remaining soil. Plant biomass and roots were then cut and air dried for two weeks. The samples from each pot were weighed before and after drying. Plant samples were taken during the different stages of rice growth and analyzed for total N, P and K contents were calculated by multiplying N, P and K concentrations by plant biomass weight at each stage in pot experiment.

17.2.4 Soil Sampling and Analysis

Soil samples were collected from five points in field (in each plot at 0–20 cm and 20–40 cm depths). The samples were carefully mixed to provide composite subsample for the analysis of total N, total and available P, exchangeable K, pH in water, CEC, exchangeable bases, organic C. Total N was determined by Kjeldahl digestion, distillation, and titration and available P was determined by the Bray 1 method. Soils used for pot experiment were also analyzed before the experiment. Soils analysis was also done for total N at panicle initiation, flowering, and at maturity in pot experiment.

17.2.5 Assessment of Nitrogen Use Efficiency

The Agronomic Efficiency, which is an indicator of the ability of plant to increase grain yield in response to N application and reflects the overall efficiency of the nitrogen used for dry matter production (Craswell and Godwin 1984) was calculated to assess N use efficiency: Agronomic N use Efficiency (AE) was determined using the equation:

$$AE = (GYN - GYO)/Nr$$

where Nr is the amount of N fertilizer applied (kg N ha^{-1}), GYN is the N dry grain yield with applied N fertilizer and GYO is the N in the dry grain yield without N fertilizer applied.

17.2.6 Analysis

The analysis of variance was conducted in accordance with the split plot design using General Linear Model procedure in the SAS package (SAS 1999) to determine the significance of the effects of N fertilization, cropping varieties, seasons and their interactions on yields, N uptake, and NUE for field experiment. Repeated measurement was conducted with Genstat package edition 9th to determine the significance of the effects of N fertilization with pot experiment. Analysis of variance was conducted to determine significance among yields. Treatment means were compared with the least significant different (Lsd) at the probability of 0.05. Graphical presentations were done using Excel software.

17.3 Results

17.3.1 Crop Yield, Yield Components in Field and NUE

The yield response to the form and application method of urea varied in the dry and wet seasons (Table 17.3). The values of yield and yield components were generally higher in the dry season as compared with the wet season. Urea Supergranule significantly increased grain yield as compared with PU in both cropping seasons. Average grain yield obtained was 5146 kg ha^{-1} in the wet and 7000 kg ha^{-1} dry season. The interaction effect of variety and fertilizer treatments was significant ($P < 0.05$) only in wet season, and USG applied to NERICA 62N gave the highest grain yield (5417 kg ha^{-1}). The straw yield performance recorded in the wet season using USG was 21% higher than using PU, and the highest yield performance (5278 kg ha^{-1}) was obtained with NERICA 62N and USG treatment combination. During the dry season the differences in straw yield among treatments were however not significant. But the differences in yield components including number of tillers m^{-2} and panicles m^{-2} were significant for all treatments. Thus, tillering capacity and the panicle density were higher using USG than PU, and the variety FKR 19 produced the

Table 17.3 Interaction effects of combined application of USG and PU on yield, NUE and yield components of two varieties of rice, Burkina Faso, wet season 2012 and dry season 2013

Treatment	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Total. Dry Matter (kg ha^{-1})	Agronomic efficiency	Number of tillers/m^2	Number of panicles/m^2
Wet season						
Control	3156	3125	6281	–	249	177
PU	4583	4292	8875	27.44	239	204
USG	5146	5139	10,694	38.26	269	224
P (0.05)	<.001	<.001	<.001	<.001	NS	0.003
Lsd	358.9	412.3	640.2	3.8	–	23.36
FKR19 Control	3188	3125	6313	–	246	189
FKR19 PU	5000	4667	9667	34.86	243	212
FKR19 USG	4875	5000	9875	32.45	277	218
FKR62N Control	3125	3125	6250	–	242	165
FKR62N PU	4166	3917	8064	20.03	225	195
FKR62N USG	5417	5278	10,694	44.07	262	230
P (0.05)	*0.005*	*0.048*	*0.005*	<.004	*NS*	*NS*
Lsd	*454.6*	*914.7*	*877.2*	23.16	–	–
Dry season						
Control	4362	5038	9400	–	304	301
PU	6644	5869	12,512	43.87	326	324
USG	7000	6375	13,375	45.31	351	344
P (0.05)	*<.001*	NS	<.001	NS	<.001	<.001
Lsd	*818.8*	–	1425.1	–	12.39	13.34
FKR19 Control	4812	4500	9312	–	318	315.8
FKR19 PU	7038	5362	12,400	42.79	339	340
FKR19 USG	7375	5500	12,875	38.46	355	347
FKR62N Control	3972	5575	9488	–	289	287
FKR62N PU	6250	6375	12,625	44.95	312	309
FKR62N USG	6625	7250	13,875	52.16	346	342
P (0.05)	NS	NS	NS	NS	<.001	<.001
LSD	–	–	–	–	41.66	39.10

highest numbers of tillers 355 m^{-2} and panicles 347 m^{-2} (Table 17.3). In the wet season, Agronomic efficiency (AE) was significantly ($P < 0.05$) affected by the treatments. Applying USG significantly increased AE by 39% over PU. The interaction effects between the rice varieties and the treatments were also significant at $P < 0.05$ where, the best was FKR 62N and USG which significantly increased the AE by 120% over PU with the same variety. In the dry season of 2013 the effect of the type of urea was not significant on NUE.

17.3.2 Plant Nitrogen, Phosphorus and Potassium Uptake in Field

In the wet season, rice grain and straw uptake were significantly ($P < 0.05$) affected by urea fertilizer (Table 17.4). The highest grain N, P and K uptakes obtained using USG was 73.67, 2.71 and 41.01 kg ha^{-1}, respectively. The application of USG increased grain N uptake by 3%, P uptake by 6% and K uptake by 80% over PU. There was no interaction between variety and urea fertilizer type for grain N uptake. However, in the wet season, straw N uptakes varied among treatments, and the interaction between the variety FKR19 and PU showed significantly highest N straw uptake as compared with NERICA 62N. Significant interaction ($P < 0.05$) was observed between urea fertilizer type and rice varieties in straw P and K uptakes. And highest P (3.36 kg ha^{-1}) and K (50.16 kg ha^{-1}) grain uptakes were observed with USG and FKR 19 treatment combination. Urea fertilizer type significantly affected ($P < 0.05$) straw N, P and K uptakes. And highest straw N, P and K uptakes were observed with the control (28.59 kg ha^{-1}), PU (0.84 kg ha^{-1}) and USG (116.75 kg ha^{-1}), respectively (Table 17.4). The combination of rice varieties and urea fertilizer type significantly ($P < 0.05$) affected straw N and P uptakes, and highest N (41.53 kg ha^{-1}) and P (1.21 kg ha^{-1}) uptakes were obtained from the combination of FKR 19 and PU treatment.

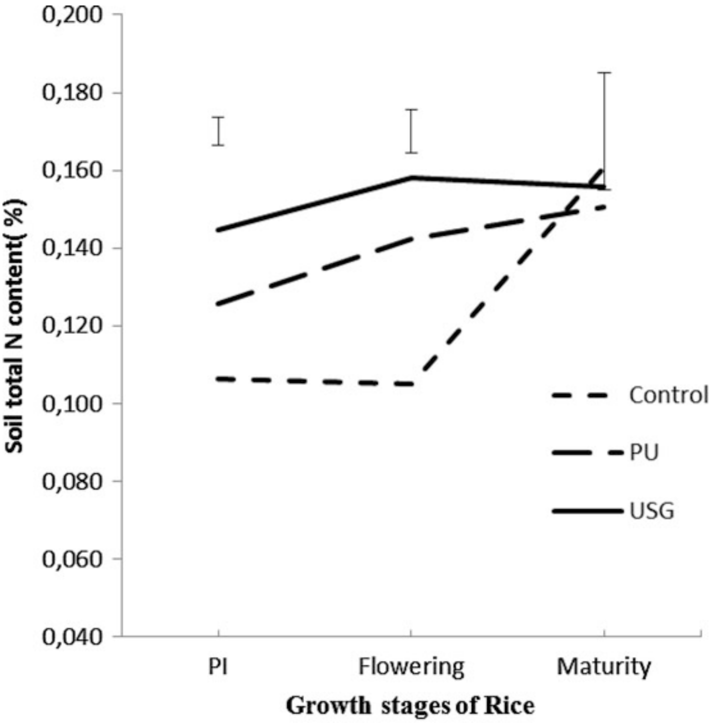
In the dry season, significant differences ($P < 0.05$) were observed in grain N, P and K uptakes, and highest grain N (106.77 kg ha^{-1}) and P 0.98 kg ha^{-1} uptakes were obtained using USG (Table 17.4). Interactive effect between N fertilizers and rice varieties were significant only for grain P uptake. The combination of NERICA 62N and USG gave the highest increase (15%) in straw P uptakes, and increases over the control were 81% for USG and only 27% for PU. Increases in K uptakes as compared with control were 33% and 20% using USG or PU, respectively. Greater P and K uptakes were obtained by NERICA 62N using USG (1.09 kg ha^{-1}) and by FKR 19 using PU (171.49 kg ha^{-1}), respectively.

Table 17.4 Effect of urea of fertilizer type on N, P and K uptake in the wet season of 2012 and the dry season of 2013

	N	P	K	N	P	K
Treatments	Grain (kg ha^{-1})			Straw (kg ha^{-1})		
Wet season						
Control	45.31	1.82	10.46	28.59	0.50	10.46
PU	71.75	2.55	22.83	24.88	0.84	91.61
USG	73.67	2.71	41.01	21.61	0.46	116.75
Lsd (5%)	5.06	0.18	1.83	2.74	0.06	16.62
P (0.05)	0.001	0.001	0.001	0.001	0.001	0.001
FKR19 × Control	47.81	2.20	11.73	30.00	0.66	84.41
FKR19 × PU	76.00	3.35	26.75	41.53	1.21	119.38
FKR19 × USG	73.12	3.36	50.16	29.50	0.55	161.70
FKR62N × Control	42.81	1.44	9.19	27.19	0.34	98.81
FKR62N × PU	67.50	1.75	19.92	8.23	0.47	114.13
FKR62N × USG	74.20	2.06	31.85	13.72	0.37	170.68
Lsd (5%)	6.48	0.22	2.42	6.64	0.15	2.42
P (0.05)	NS	0.001	0.001	0.001	0.001	NS
CV%	7.3	6.9	6.8	10.1	9.5	6.8
Dry season						
Control	72.85	1.52	27.49	49.02	0.48	126.33
PU	99.69	2.77	46.26	54.51	0.61	151.44
USG	106.77	2.98	46.03	55.46	0.87	167.78
Lsd (5%)	14.80	0.31	5.37	9.19	0.15	28.68
P (0.05)	0.001	0.001	0.001	NS	0.001	0.026
FKR19 × Control	80.37	1.64	24.78	40.05	0.45	119.92
FKR19 × PU	95.01	2.67	46.59	46.65	0.59	171.49
FKR19 × USG	102.89	2.66	43.37	47.85	0.66	168.08
FKR62N × Control	65.34	1.41	30.20	57.98	0.50	132.74
FKR62N × PU	104.38	2.88	45.94	56.74	0.64	131.39
FKR62N × USG	110.64	3.31	48.69	63.07	1.09	167.47
Lsd (5%)	24.46	0.51	8.51	13.88	0.19	42.40
P (0.05)	NS	0.029	NS	NS	0.024	NS
CV%	14.8	11.7	12.3	16.6	20.7	17.7

17.3.3 Soil Total N on Pot Experiment

Soil total N increased until maturity with the use of urea fertilizer. Soil total N of the control increased quickly from flowering stage to maturity (Fig. 17.1). The highest N contents were recorded with the USG treatment. Significant difference ($P < 0.05$) was observed between acidic and alkaline soils. Whereas N content in the acid soil tended to increase until flowering, N content in the alkaline soil tended to stabilize at this stage but remained below N curve with acid soil (Fig. 17.2). After the



PI = panicle initiation and bars indicate Lsd (5%)

Fig. 17.1 Soil total N content at different rice growth stages as affected by type of urea fertilizers PI = panicle initiation and bars indicate Lsd (5%)

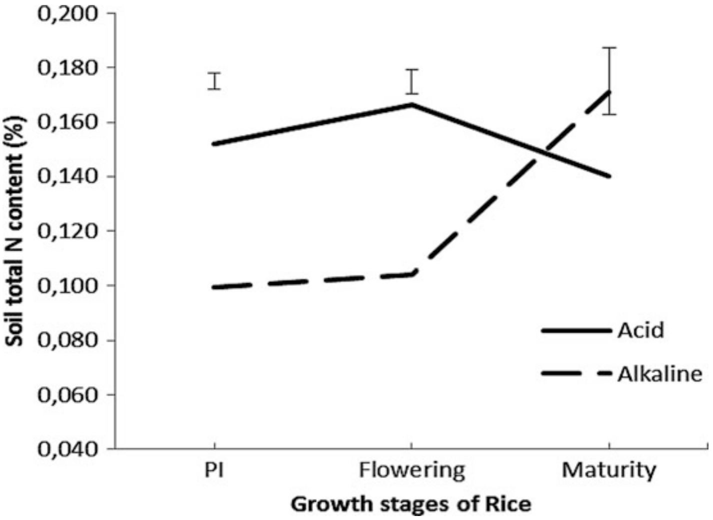


Fig. 17.2 Soil total N content at different rice growth stages as affected by soil pH

flowering stage, N content in acid soil decreased but N content in alkaline soil increased until maturity.

17.3.4 Nitrogen, Phosphorus and Potassium Uptake on Pot Experiment

During rice growth N uptake increased until flowering and then decreased towards maturity with USG and PU treatments. Nitrogen uptake was higher when rice was treated with USG than PU and the control (Fig. 17.3). The peak values at flowering with USG and PU were 1.813 and 0.689 g pot^{-1}, respectively. Nitrogen uptake with the control was stable throughout the growing period. The lowest N uptake was recorded with the control. Nitrogen uptake patterns were similar in acid and alkaline soils. During rice growth stages, plant N uptake increased and a peak was observed at flowering stage in both soils (Fig. 17.4). After this stage, plant N uptake decreased in both soils until rice maturity. Plant N uptake was also significantly greater in the acid soils at rice tillering, panicle initiation and at flowering stages than in the alkaline soils.

The use of USG increased P uptake of rice sharply from tillering to flowering where it attained a peak of 0.418 g pot^{-1} and then declined. A similar pattern was obtained in P uptake with PU treatment which rose up until panicle initiation with a peak value of 0.257 g pot^{-1} and then declined until rice maturity. Lowest P uptake was observed with the control which fluctuated during rice growth stages (Fig. 17.5). The highest (0.303 g pot^{-1}) and the lowest (0.021 g pot^{-1}) P uptake were recorded on the acid and the alkaline soils, respectively. Rapid P uptake was observed after rice tillering until panicle initiation and at flowering in the alkaline soil and the acid soil

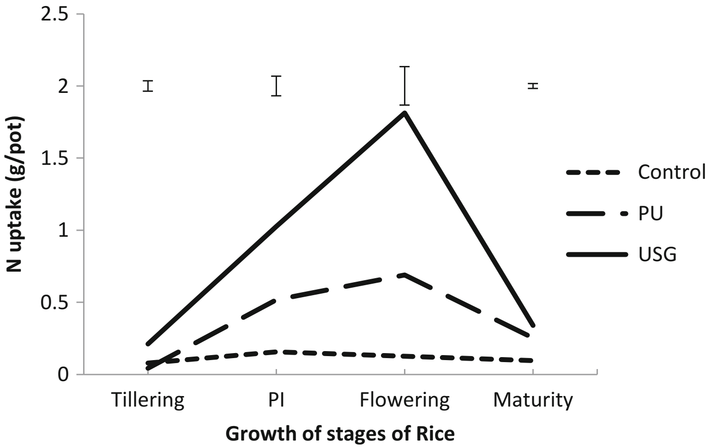


Fig. 17.3 Nitrogen uptake at different rice growth stages as affected by type of urea fertilizers

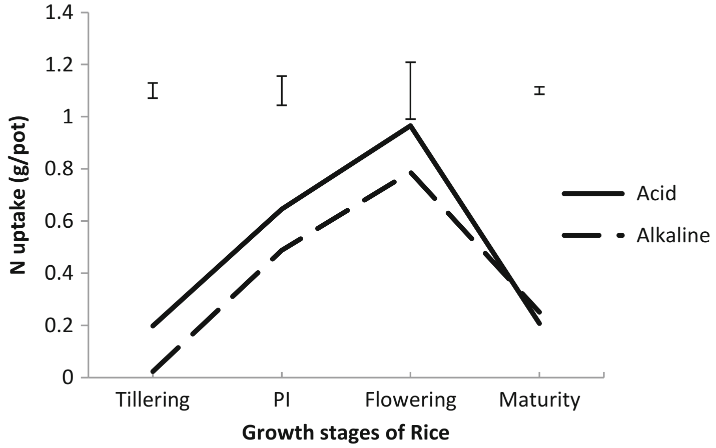


Fig. 17.4 Nitrogen uptake at different rice growth stages as affected by soil pH

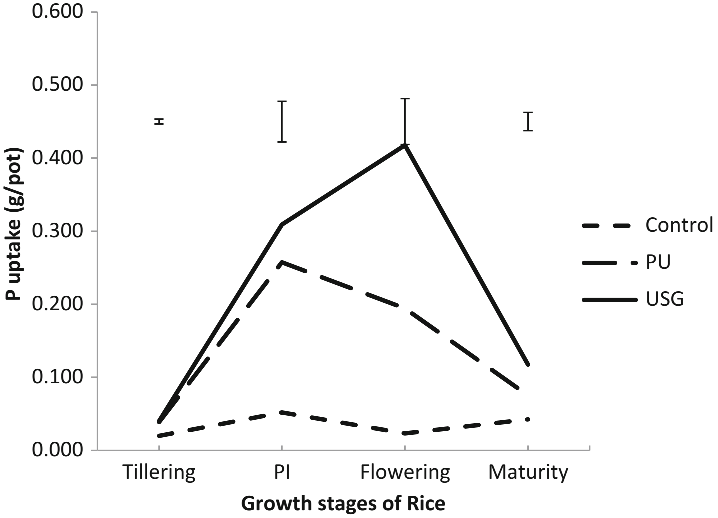


Fig. 17.5 Phosphorus uptake at different rice growth stages as affected by type of urea fertilizers

(Fig. 17.6), respectively. After these growth stages rapid decline was observed in P uptake in both soils until rice maturity. Similar K uptake patterns were observed with the use of PU and USG at the different stages of rice growth except before the PI growth stage (Fig. 17.7). Significant difference ($P < 0.05$) was observed in K uptake with the treatments (Table 17.2). Potassium uptake decreased after tillering until panicle initiation. At this stage K uptake rose up at flowering and declined until rice maturity in both soils. The highest K uptake was observed at flowering (2.123 g pot^{-1}) and at tillering (2.045 g pot^{-1}) with USG and PU, respectively. Potassium uptake with

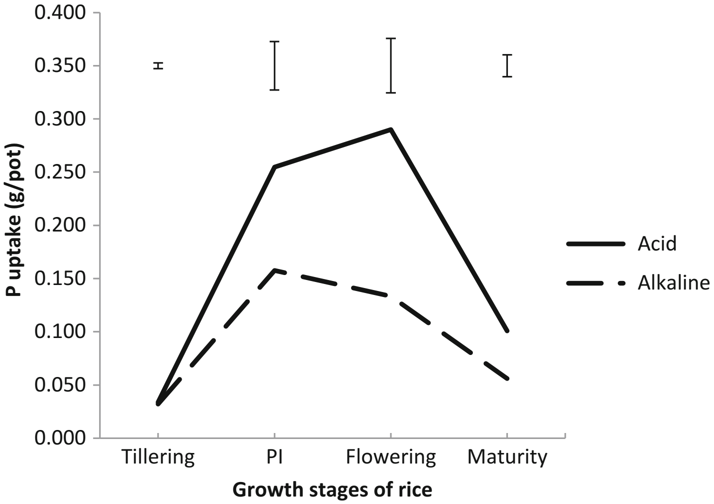


Fig. 17.6 Phosphorus uptake at different rice growth stages as affected by soil pH

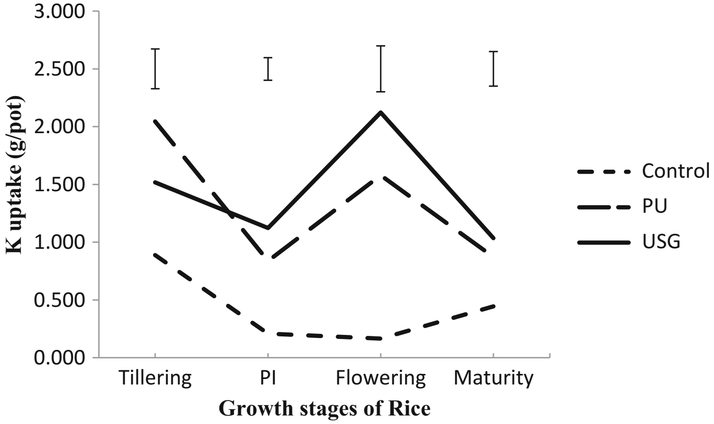


Fig. 17.7 Potassium uptake at different rice growth stages as affected by type of urea fertilizers

the control declined after tillering stage and remained stable at panicle initiation and flowering. An increased was observed at rice maturity in K uptake with the control. Potassium uptake in the two types of soils followed the same patterns as nitrogen uptake (Fig. 17.8). Potassium uptake was significantly ($P < 0.05$) higher during rice growth in acid than alkaline soil.

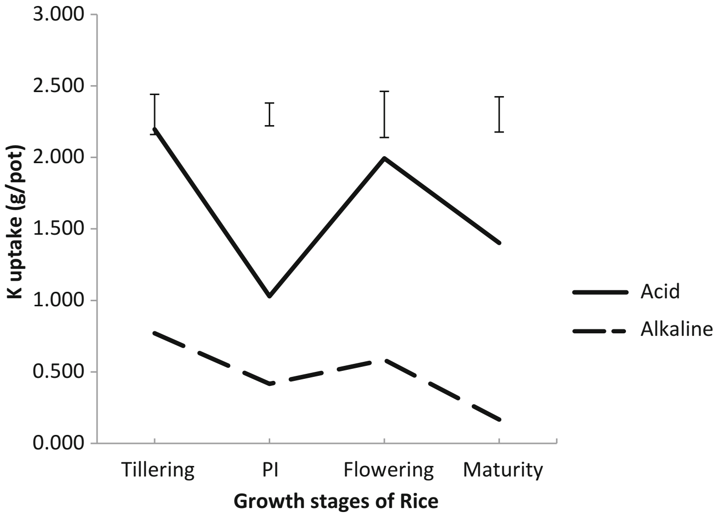


Fig. 17.8 Potassium uptake at different rice growth stages as affected by soil pH

17.4 Discussion

17.4.1 Yield and Yield Components

Fertilizer deep placement significantly increased rice grain yield by 12 and 5% over PU in the wet and dry seasons, respectively. Likewise, straw yield was increased by 20 and 9% in the wet and the dry season, respectively. Bandaogo (2010) and Yaméogo et al. (2013) clearly indicated that FDP increases grain yield and that increases range between 500 and 1000 kg ha^{-1}. Likewise, many authors including Bowen et al. (2004), Savant and Stangel (1990), Dupuy et al. (1990) and Pasandaran et al. (1999) reported significant yield increases with USG as compared with broadcasting PU. Yield components including number of panicle m^{-2} and number of tillers m^{-2} significantly increased ($P < 0.001$) in the dry season as a result of FDP (Table 17.3). These differences can be ascribed to the slow release of N from USG over the period of 65 days in synchrony with the plant demand as observed by Gaudin (1988). Apparently, the increase in N uptake positively influences the number of tillers and panicles produced per m^2, resulting in yield increase (Yoshida et al. 1972). The higher grain and straw yields recorded in the dry season could be ascribed to higher solar radiation and temperature which have led to higher photosynthesis performance, compounded with increased mineralization of soil organic matter "priming effect" and hence availability of soil nutrients without any external nutrient inputs. This can be also explained by the higher N, P and K uptakes in the dry season. These results are in accordance with Sheehy and Mitchell (2011) who also recorded higher irrigated rice grain yields in the dry season under irrigation.

17.4.2 Plant Uptake and Use Efficiency

Average N, P and K uptakes were higher with USG than with broadcasting PU in both, wet and dry seasons. N seems to be the main limiting element for rice yield and its availability may increase the absorption of P and K. Nutrient omissions trials conducted at the experimental site showed that N is the most limiting nutrient as also observed by Dobermann and Fairhurst (2000). Rabat (2003) reported that there is interdependence among plant nutrients. These studies reveal that UDP is effective in increasing fertilizer N use efficiency of irrigated rice as compared to the traditional broadcast application of PU in West Africa. Studies conducted in Asia also invariably showed the superiority of UDP over PU (Hassan et al. 2002; Mohanty et al. 1999). Deep and point placement of urea in anaerobic soil layer limits the concentration of N in floodwater and in the surface oxidized layer, leading to reduced N losses via runoff, ammonia volatilization and denitrification; the final results are increased fertilizer N use efficiency and improved yield gains (Kapoor et al. 2008).

Rice N, P and K uptake and use efficiency varied among the tested rice varieties. The genotypic difference in the rooting system and hence nutrient uptake, and grain filling capacity of FKR 19 and NERICA 62N may vary as nutrient transport to the panicles (translocation) during grain filling is genotype-specific. Many authors reported the influence of genotypic traits such as plant type and growth duration on the nutrient use efficiency (Jiang et al. 2004; Duan et al. 2005; Fageria et al. 2010).

NAE significantly increased with USG application ($P < 0.001$) in the wet season. However the superiority of USG over broadcasting PU was recorded in NERICA 62N plots only. Likewise, nitrogen recovery was genotypic-specific. Sheehy et al. (1998) and Wang et al. (2005) reported that N use efficiency is variable among rice genotypes. NERICA 62N absorbed higher amounts of N, leading to greater yield performance.

17.4.3 Pot Experiment

17.4.3.1 Effect of Urea Fertilizer and Soil Types on Soil Total Nitrogen

Nitrogen availability varied with soil pH during the study. Soil N was higher in the acid soil compared to the alkaline soil during the panicle and flowering stages. This result can be explained by the fact that nitrogen loss may be high in the alkaline soil due to high soil pH. Ammonia losses from floodwater may reduce soil nitrogen availability. In fact, the conversion of $NH4^+$ to NH_3 is governed by soil pH. During urea hydrolysis the pH surrounding the granule initially rises ($pH > 8$) as ammonium bicarbonate is formed. Longo and Melo (2005) measured the rate of urea hydrolysis under laboratory conditions using a range of soil pH from 2.2 to 8.0. According to their finding, as the soil pH increased the rate of urea hydrolysis increased almost exponentially. They also found that the highest rate of urea hydrolysis was at pH 8.0. Similar results were reported by Vlek and Craswell (1981) and Fillery et al. (1986). At rice maturity, soil N increased in the alkaline soil and declined in acid soil. However, soil N remained higher acid soil than alkaline soil. The type of urea fertilizer significantly affected soil total nitrogen. The use of USG increased soil total N more than PU urea. This can be attributed to the fact that USG can be considered slowly available N fertilizer that provides N to meet plant requirements (Savant and Stangel 1990). Higher nitrogen content was recorded by urea deep placement with USG throughout the experiment. This result can also be attributed to the incorporation of nitrogen that reduced N losses via volatilization and denitrification and optimized nitrogen availability in soil (Choudhury et al. 1997; De Datta 1981).

17.4.3.2 Effect of Soil and Urea Fertilizer Types on N, P and K Uptake

The amount of total N, P and K increased in rice plant with the urea deep placement (UDP) during the study. The results are in agreement with findings of Bowen et al. (2004) and Pasandaran et al. (1999) and Bandaogo et al. (2014), who reported that urea deep placement technology was highly effective in improving crop uptake of applied N fertilizers in irrigated rice system in Asia. The results can be attributed to the decrease of soil N loss with USG deep placement observed in pot experiment. According to the study of De Datta and Patrick (1986), the use of urea supergranules could synchronise N release with plant requirements and provide sufficient N in a single application to satisfy plants' requirements while maintaining mineral N in the soil throughout the growing season. The increase in P and K uptake with USG can also be explained by the interdependence between N, P and K as reported by Rabat (2003). It is known that N is a limiting factor in irrigated rice systems (Segda 2006); its availability also increases phosphorus and potassium uptake. As P is relatively immobile in soils and roots can deplete P only from a distance that coincides approximately with the length of the root hair. This finding is in agreement with the findings of Savant and Stangel (1990) who reported that rice roots tend to proliferate near the placement point of urea supergranule and to increase during many weeks after urea placement. Soil type also affected N, P and K uptake. Nutrient uptake was higher in the acid soil and this can be explained by the fact that pH increase inhibits root proliferation as reported by Shaaban et al. (2013). The lower density of roots in the alkaline soil could affect the uptake of nutrients. The rise in pH increased the rate of ammonium conversion to ammonia, which increased its volatilization. Deep placement of urea supergranules has been shown to effectively reduce N loss and increase rice yield on near neutral pH soils with alkaline floodwater (Singh 2005; Maqsood 2016; Cai et al. 2002).

17.5 Conclusion

The results clearly suggest that fertilizer deep placement can increase rice grain yield which could result in increased revenues for farmer and reduction in pollution as compared to the traditional broadcast application of urea. Pot experiment indicated that soil total nitrogen, plant nitrogen uptake were higher in acid soil than alkaline soil. This result confirmed that USG can provide sufficient N in a single application to satisfy the plant's needs and increase plant nitrogen uptake and also confirmed that the performance of USG is greater in acid soil compared to PU. USG technology was more effective with acid soil than alkaline soil. However, FDP's efficiency is seasonal and genotype-specific. The studies suggest that FDP can be used by farmers to improve nitrogen use efficiency in the irrigated rice cropping system. It is a promising technology that can be adopted by African farmers, particularly for those rice farmers growing rice in irrigated schemes.

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