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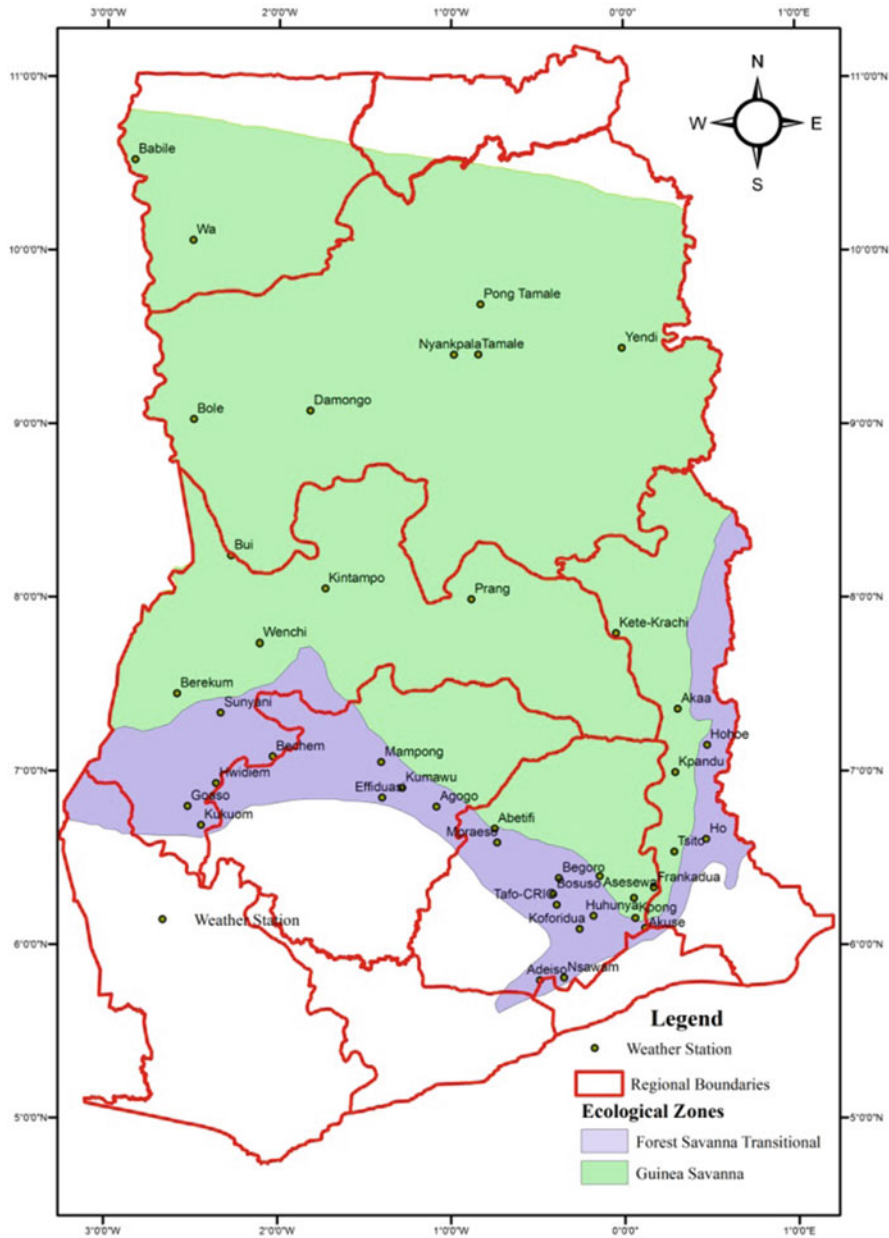
Fig. 10.1 Project sites within Semi-deciduous forest, Forest savanna transition and Guinea savanna zones of Ghana

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

Location		pH	TN	OM	Av. P	Av. K	CEC	Ca	Mg
		%				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 $cmol_c$ kg^{-1}) except in Berekum where the value was moderate. Potassium was low in most cases (<0.20 $cmolc$ kg^{-1}), calcium and magnesium ranged from low to moderate levels (from 5 to 10 $cmolc$ kg^{-1}.). Potassium was deficient in Sekyere West, Ejura Sekyi-dumase 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-P_2O_5-K_2O kg/ha		N-P_2O_5-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

N-P$_2$O$_5$-K$_2$O	Nkoranza	Wenchi	Berekum	Mampong	Kwadaso	A. Plains	Damongo	Nyankpala
	(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
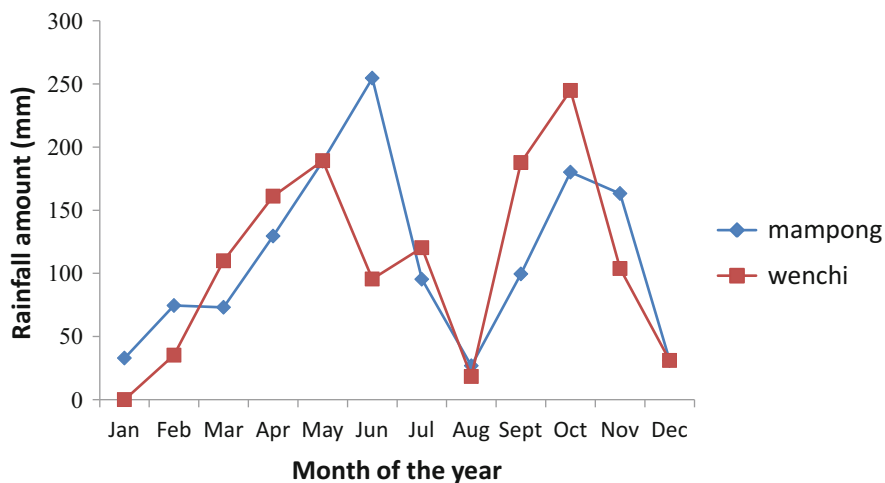

Fig. 10.2 Monthly rainfall distribution in the Guinea savanna zone of Ghana
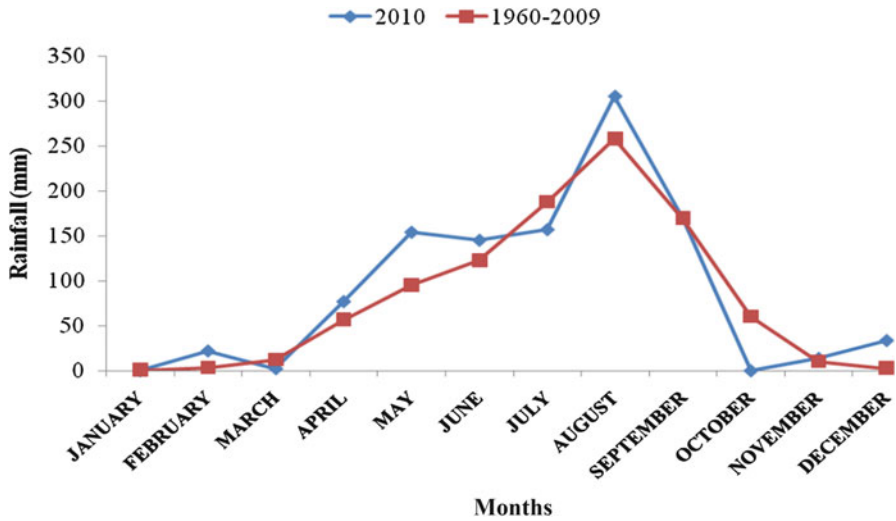
Fig. 10.3 Monthly rainfall distribution in the Guinea savanna zone of Ghana
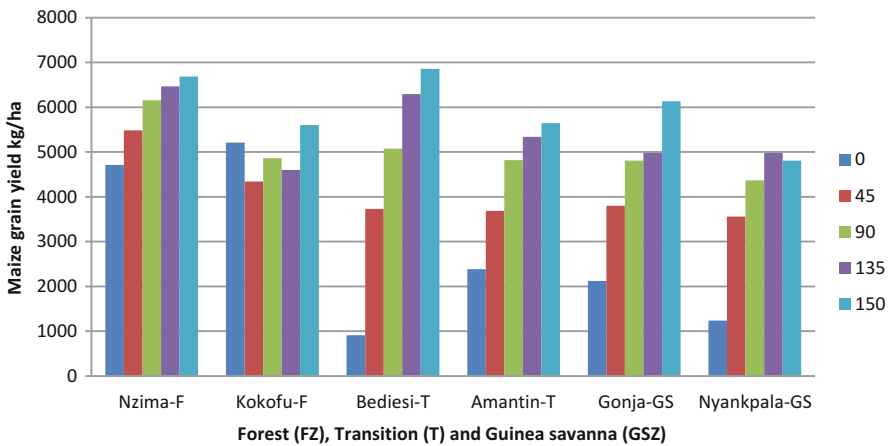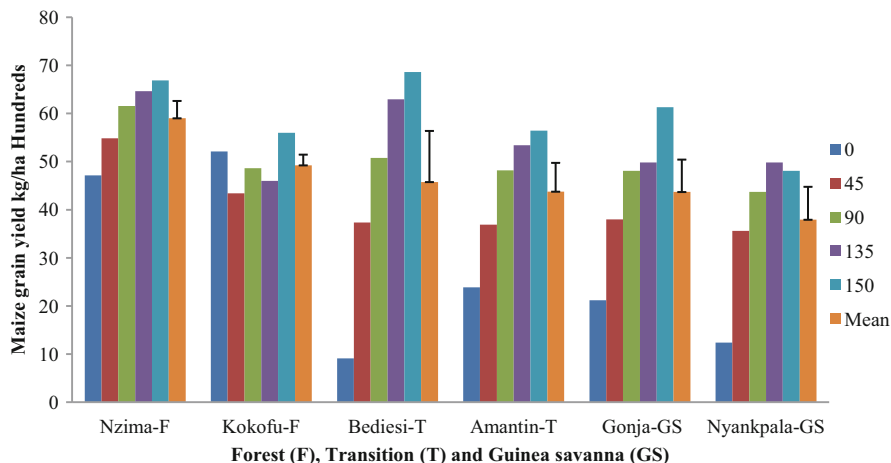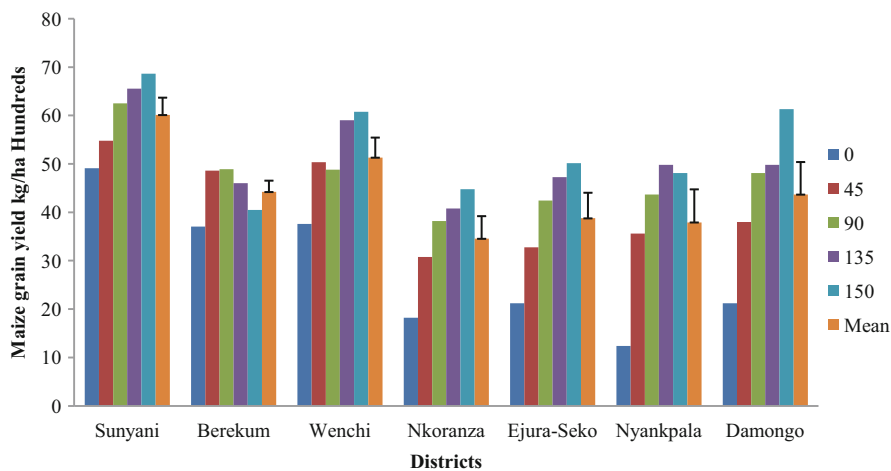

Fig. 10.4 On-farm maize fertilizer trials showing N response in the Forest zone (FZ), Transition zone (T) and Guinea savanna zone (GS)

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$_2$O$_5$-K$_2$O with 90-60-70 and 135-60-70- N-P$_2$O$_5$-K$_2$O.

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 | | |
| | Kwadaso | Manga | Kwadaso | Ejura | Kwadaso |
Treatment	(Mamaba)	(Obatanpa)	(Mamaba)	(Obatanpa)	(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
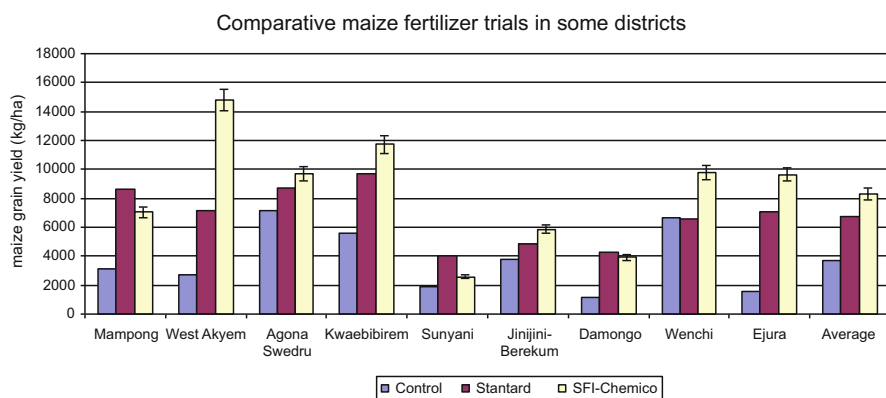
Fig. 10.7 Comparing blanket recommendation (standard) against SFI rates in 10 maize growing areas in Ghana

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.
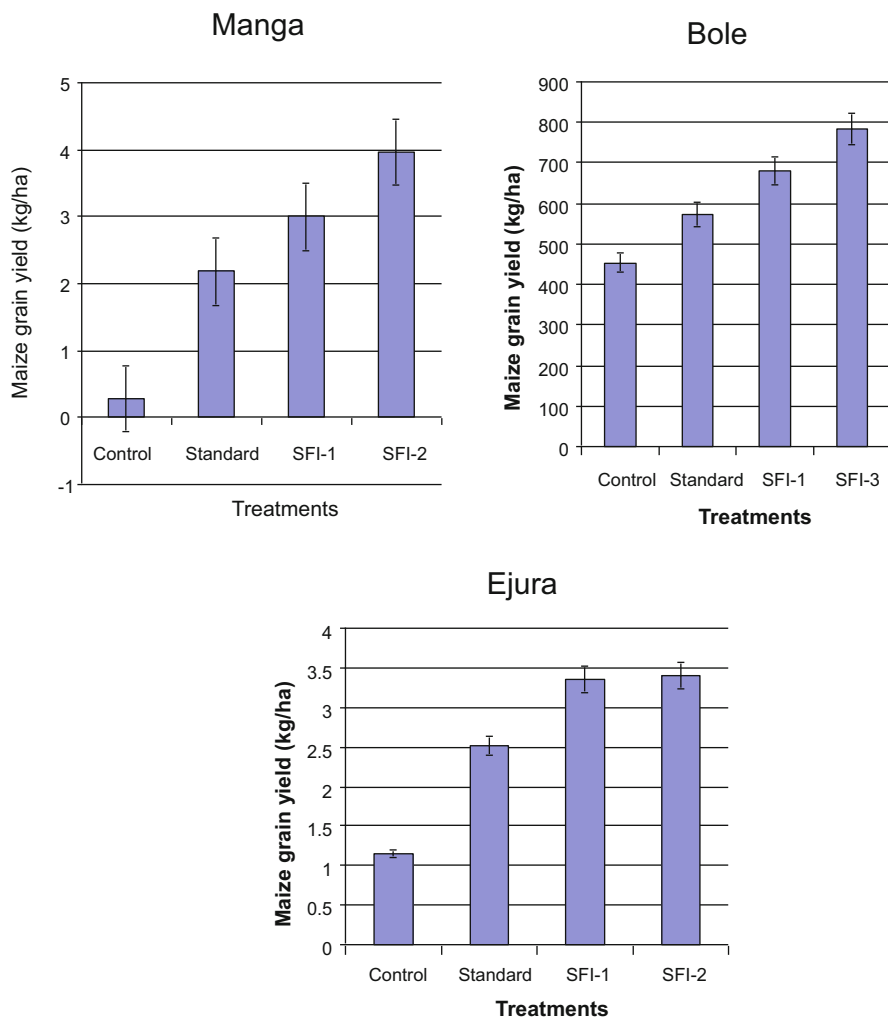
Manga

Bole

Ejura

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)

N	Yield (Y) T/ha	ΔY	Gross Return (¢)	Fert.Cost	Net Return	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
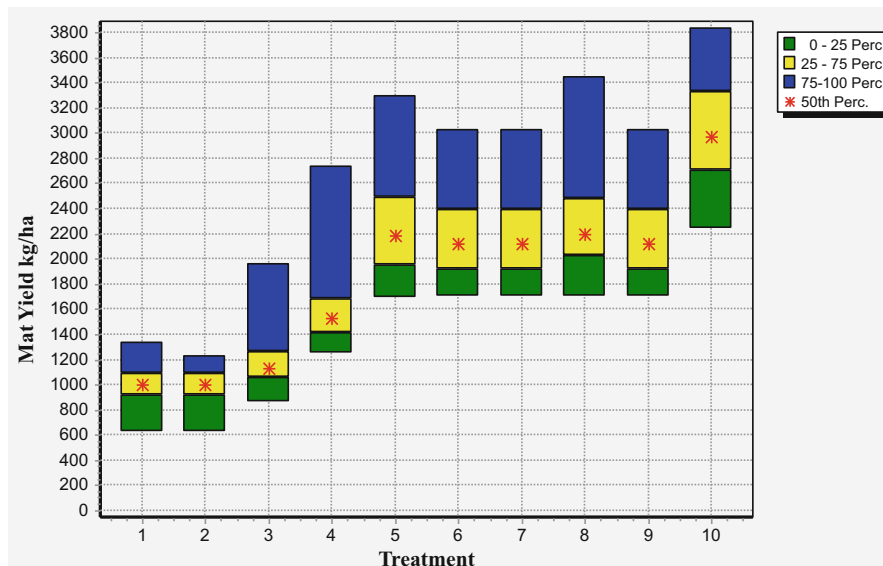
Fig. 10.9 Maize yield as affected by different rates of NPK fertilizer for 50 years (1960–2010) biophysical analysis of seasonal analysis at Tamale. 1 = 0-0-0; 2 = 0-90-90; 3 = 40-90-90; 4 = 80-90-90; 5 = 120-0-90; 6 = 120-45-90; 7 = 120-90-90; 8 = 120-90-0; 9 = 120-90-45; 10 = 160-90-90

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$_2$O$_5$-K$_2$O 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
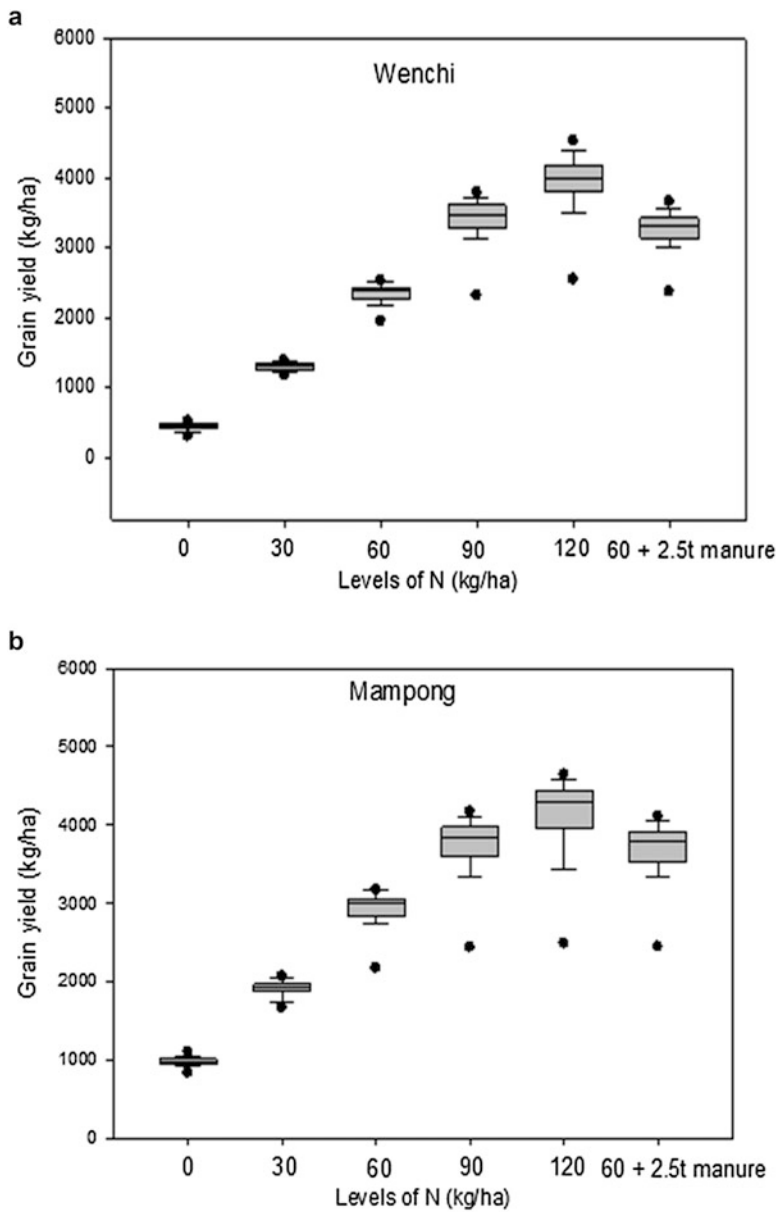
Fig. 10.10 Simulated maize (*Obatanpa*) yield variation in (**a**) Wenchi and (**b**) Mampong over 43 year period in response to N fertilizer application

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

N-P$_2$O$_5$-K$_2$O	Root yield T/ha	Stem fresh Wt T/ha	Leaf fresh wt T/ha	Plant height (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$_2$O$_5$-K$_2$0. 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$_2$O$_5$ – K$_2$O resulted in highest stem growth, leaf growth and highest cassava root yield. Increasing the P component to 60 kg ha^{-1} P$_2$O$_5$ in the 30-60-90 kg ha^{-1} N – P$_2$O$_5$ – K$_2$O 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$_2$O$_5$-K$_2$O and 90-30-90 kg ha^{-1} N-P$_2$O$_5$-K$_2$O at Wenchi and Berekum respectively. Yields ranged

Table 10.17 Cassava Root Yield as influenced by fertilizer application rate

Fertilizer Rates N-P$_2$O$_5$-K$_2$O	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$_2$O$_5$-K$_2$O.
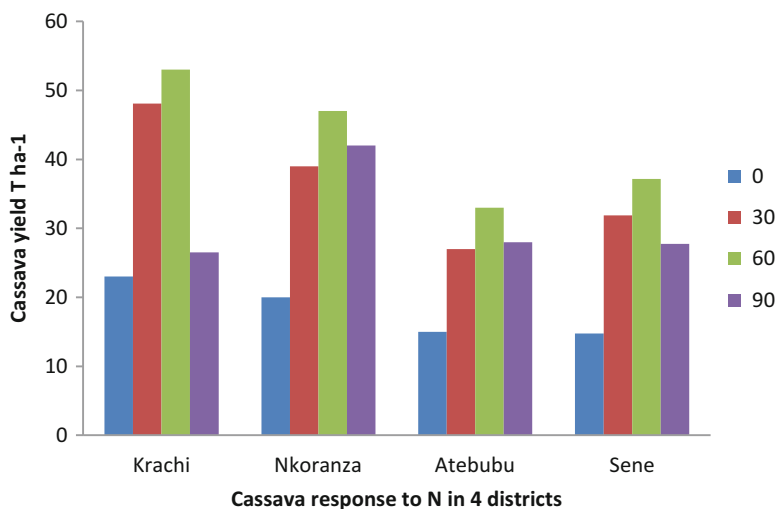
Fig. 10.11 Cassava root yield response to N application 4 districts

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