12. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Nigeria

Tarfa Bitrus Dawi[1] btarfa@gmail.com, Amapu Ishaku Yoila[1], Daudu Christogonus Kayode[2], Arunah Uthman Lucky[3], Isah Abdulazeez Shero[3], Yakubu Adamu Alhaji[2], Nafiu Abdu[1], Adeogun Tinuke Tawa[1], Bakodo Pwanogoshin Raymond[1], Ugbaje Enemona Marinus[1], Dauda Haratu[3] and Ugbabe Omadachi Ogbodo[4]

[1]Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
[2]National Agricultural Extension Research and Liaison Services, Ahmadu Bello University, Zaria, Nigeria
[3]Department of Agronomy, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
[4]Department of Agric Economic and Rural Sociology, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria

12.1 Introduction

Increasing agricultural productivity in Nigeria requires greater adoption of good agricultural practices (GAP) including efficient use of fertilizers. While all farmers can profit from fertilizer use, only those with adequate finance may strive to maximize net returns per hectare resulting from fertilizer use. In this chapter, these rates are referred to as economically optimal rates (EOR). Others need to maximize return on their limited investment. For example, by increasing the use and correct application of fertilizer, poor farmers surveyed in Nigeria were able to improve their yields by approximately 30–55%. In turn, they benefited by making an additional 30–40% profit through greater commodity sales (PrOpCom 2011).

Most of Nigeria's farmers use traditional low input-low output farming methods that have been in use for generations. Even when knowledgeable of improved GAP, many have not been able to apply their knowledge appropriately due to poor access to agricultural inputs such as improved varieties and fertilizer. Investment in fertilizer use has an opportunity cost vis-à-vis other uses of financial resources for meeting immediate needs. Deliberate efforts must be made in ensuring that fertilizer investments give high returns with little risk. This necessitates employment of ingenious techniques for optimizing fertilizer use. Fertilizer use optimization in this chapter refers to maximizing profit from fertilizer use, including profit per hectare for farmers with adequate finance and profit on the small investment in fertilizer use by the financially constrained farmers.

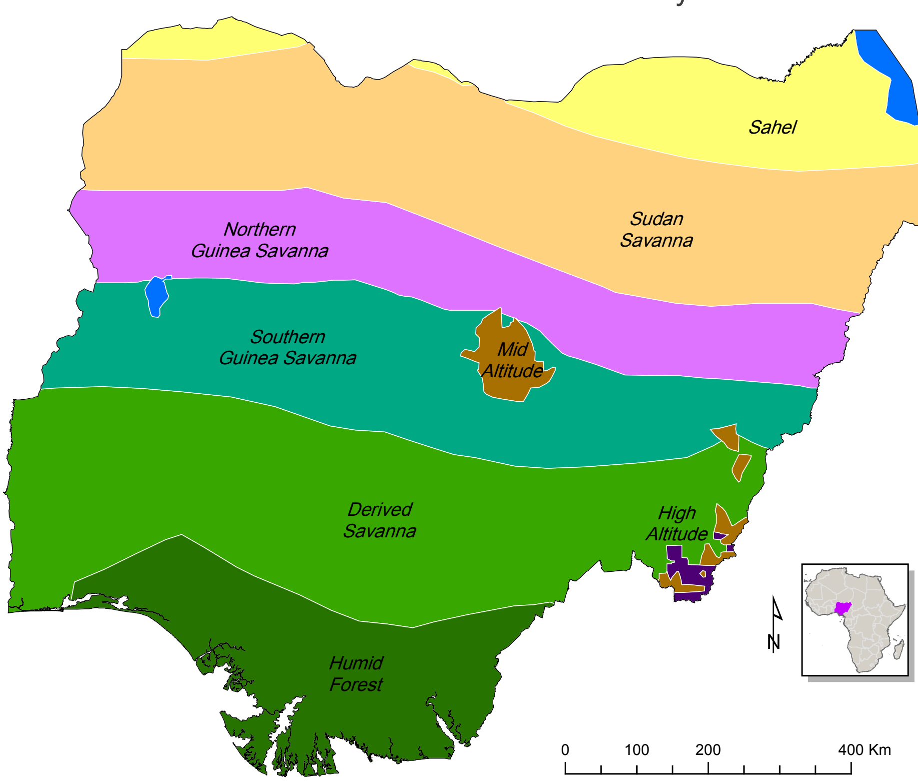

Figure 12.1: Agro-ecological zones of Nigeria.

Fertilizer Use Optimization in Sub-Saharan Africa (2017) Charles S. Wortmann and Keith Sones (eds). Published by CABI.

The combined application of organic materials, especially farmyard manure (FYM), and fertilizer has long been advocated based on research results which established that combined application gave significantly higher yields than either the inorganic or FYM alone. It is recommended that FYM be applied once every two to three years of continuous cropping and then supplemented with fertilizer. However, FYM is inadequate for such application to all cropland and is often of low quality because very little attempt is paid to its storage and handling.

12.2 Agricultural systems of Nigeria

Nigeria's large climatic range is encompassed by the tropical humid forest in the south and the savanna in the north. The derived savanna is a transition zone between the rainforest and savanna biomes caused by forest clearance. The agro-ecological zone (AEZ) delineations in Figure 12.1 are the product of climatic and soil characteristics. The diverse agro-ecological environment of Nigeria makes it feasible to support the growth of several arable and tree crops of tropical and sub-tropical origin.

Rainfall increases northward from 3000 mm close to the equator to 500 mm in northeast Nigeria. The distribution generally is unimodal in areas above 9° N and bimodal between latitudes 4 and 9° N. The rainfall distribution is often erratic. A duration-of-dry-season gradient occurs with a range of three to eight months from the high rainfall areas in the south to the driest areas in the north. The country generally enjoys a high insolation and uniformly high

Table 12.1: Mean monthly rainfall (mm), maximum and minimum temperature (MJ m^2; °C; Tmax; Tmin) for representative locations of AEZ of Nigeria

	J	F	M	A	M	J	J	A	S	O	N	D
Sahel, Gashua (12°52′15″N11°02′53″E, 339 masl)												
Rainfall	1	0	0	8	67	31	101	119	60	6	1	0
Tmax	28	31	35	39	42	42	40	38	39	38	33	29
Tmin	13	15	19	23	27	29	27	26	26	23	18	14
Sudan, Kano (12°00′00″N 08°31′00″E, 484 masl)												
Rainfall	0	1.2	9.6	3	21	57	99	171	60	9	6	0
Tmax	30	33	37	38	37	34	31	31	31	31	31	31
Tmin	13	15	19	24	24	23	22	21	21	19	16	13
Northern Guinea, Samaru (11°06′40″N07°43′21″E, 644 masl)												
Rainfall	0	0	0	0	27	48	123	81	33	21	15	0
Tmax	33	35	36	34	30	28	28	28	28	30	32	32
Tmin	18	22	24	25	24	23	23	22	22	23	22	18
Southern Guinea, Zungeru (09°48′46″N 06°09′20″E, 117 masl)												
Rainfall	6	3	0	0	63	39	60	198	33	6	0	0
Tmax	35	37	37	36	33	31	29	29	30	32	34	35
Tmin	20	23	25	25	24	22	22	22	22	22	19	19
Mid High Altitude, Jos (09°55′00″N 08°54′00″E, 1295 masl)												
Rainfall	0	0	0	6.48	48	66	96	96	72	21	0	1.8
Tmax	28	30	32	31	29	27	25	24	27	29	29	28
Tmin	14	16	18	19	18	18	17	17	17	17	16	14
Derived Savanna, Ilorin (08°30′00″N 04°32′59″E, 310 masl)												
Rainfall	6	6	18	0	63	72	0	21	63	60	3	3
Tmax	34	36	36	34	33	31	29	28	29	31	33	34
Tmin	19	21	23	23	22	22	21	21	21	21	21	18

temperatures throughout the year (Table 12.1). Solar radiation varies from about 1250-1650 megajoule/cm^2/day (MJ/cm^2/d) close to the equator to about 1650- 2100 MJ/cm^2/d above 10° N. A detailed description of the Nigerian agro-ecological zones is contained in Ojanuga (2006).

Most arable crop production is concentrated in the savanna AEZ (the focus of this chapter). The savanna lies between 8 and 19° N, running in approximately east-west bands across the country. The savanna covers about 700,000 of the total area of 923,768 square kilometers (two thirds of the land area) of Nigeria and is subdivided into the Sahel, Sudan, Northern and Southern Guinea, Derived Savannas and Mid-high Altitude AEZ.

In general, soils in Nigeria have formed from the residues of deeply weathered, complex base rocks and alluvial materials derived from these under humid to dry tropical conditions (Table 12.2). Most soils are highly leached resulting in medium to high acidity, moderate to low cation exchange capacity and base saturation, and low organic matter content. The concentration of available levels of nitrogen (N), phosphorus (P) and potassium (K) are correspondingly low. Soil nutrient replenishment from organic and mineral sources is a prerequisite for continuous cultivation of such soils particularly under intensive production.

Many soils are susceptible to erosion due to their relatively low nutrient status and organic matter content, and fragile structure. Soil degradation and attendant depressed yields due to nutrient mining and inadequate soil and water conservation practices has already reached severe proportions in parts of the country. By removing the protective cover of natural vegetation and surface litter, conventional tillage practices lead to soil structure deterioration, loss of nutrients and erosion. Features of the AEZ are summarized in Tables 12.1 and 12.2.

Table 12.2: Description of the major AEZ in Nigeria

AEZ	Annual rainfall (mm)	Annual temperature (°C)	Days of growing period	Pristine vegetation (trees and grasses)	Main crop	Dominant FAO soil group
Humid Forest	2000–3000	25–27	270–360	Forest	Cocoa Oil palm	Ferralsols Acrisols
Derived Guinea Savanna	1500–2000	26–28	211–270	Forest	Oil palm Yam Maize	Ferralsols Luvisols Arenosols Nitosols
Southern Guinea Savanna	1200–1500	26–29	181–210	Savanna (*Dainella olivera* *Andropogon tectorum,* *Imperata cylindrica*)	Yam Maize, Sorghum Soybean Sesame	Luvisol Ferralsols Lithosols
Northern Guinea Savanna	900–1200	27–29	151–180	Savanna (*Dainella olivera* *Andropogon tectorum,* *Imperata cylindrica*)	Maize Sorghum Soybean Cotton	Luvisols Vertisols Lithosols Ferralsols
Sudan Savanna	500–900	25–30	91–150	Savanna (*Combretum, Acacia,* *Terminalia* *Andropogon gayanus*)	Millet Sorghum Groundnut	Lixisols Luvisols Regosols
Sahel Savanna	250–500	21–32	≤90	Grassland (*Acacia,* *Commiphora* *Cenchrus* spp)	Millet Sorghum	Aridisols Regosols
Mid-High Altitude	1100–1500	20–23	160–200	Savanna (*Isoberlinia* spp *Hyparrhenia,* *Andropogon*)	Maize Potato Vegetable	Luvisols Lithosols Ferralsols

Adapted and modified from Akpa et al. (2016)

12.3 Traditional practices affecting soil fertility

As in most parts of tropical Africa, the traditional method of maintaining soil fertility and productivity in Nigeria has been the bush-fallow system whereby arable land is allowed to revert to fallow after 3-4 years of continuous cultivation. The growing human population and other socio-economic pressures on available land have made this practice difficult to sustain. Attempts to improve soil fertility by planting legumes and grass fallows have not been popular and are inadequate for higher-yielding and nutrient-demanding crops and production systems.

The use of manures, particularly where there were large numbers of animals, replaced the fallow system and brought into eminence the agricultural value of FYM, poultry droppings, household refuse and other organic materials. The first recorded indication of the potential values of inorganic fertilizers in Nigeria was in 1937 when it was shown that response of cereal crops to small applications of FYM was matched by the use of single super-phosphate (SSP) containing equivalent quantities of phosphate. The need to apply fertilizer to depleted soils to resuscitate plant productivity heralded fertilizer use experimentation on the response of crops to applied nutrients such as N, P and K.

The recognition of the benefits of FYM by the late 1940s led to government encouragement of penning of cattle on the farm and mixed crop-livestock farming. The supply of FYM was not sufficient to meet farmers' demand as agriculture intensified, coupled with the introduction of higher-yielding and more nutrient-demanding crops. Other issues militating against the effective use of FYM included transportation problems due to bulk and labour costs.

Other practices that affect soil fertility such as crop rotation, green manuring, direct application of phosphate rock and agro-forestry have been promoted by agricultural extension personnel but the uptake and adoption of such practices has been too low to have much impact on production. It is recognized that fertilizer use needs to complement other management practices.

Effective fertilizer use requires good crop management. For example, unimproved local crop varieties of low-yield potential are less responsive to the use of fertilizer compared with improved varieties. Similarly, arrangement of plants and plant population affect yields. The farmer who carelessly plants late using unimproved crop varieties should not expect much benefit from the use of fertilizers, particularly if these are incorrectly applied.

Use of the wrong fertilizers, rates, placement and timing lead to inefficient fertilizer use and problems have developed. For example, the continuous application of sulphate of ammonium result in soil acidification and its use was stopped in 1969. There is the need for more education of farmers on manure management and use, and proper fertilizer use, including the 4Rs of fertilizer use, that is, applying the right fertilizer types at the right rate and time with the right placement.

12.4 Fertilizer use and recommendations

Widespread adoption of fertilizer began in the late 1970s with the proliferation of Agricultural Development Projects, but overall levels of fertilizer use have been too low to compensate for soil nutrient removal. The current national average NPK use hovers at 18 kg/ha of arable land (World Bank 2016).

The current fertilizer recommendations in Nigeria are reported in a manual titled 'Fertilizer Use and Management Practices for Crops in Nigeria', compiled by the National Fertilizer Use Committee and produced by the Federal Fertilizer Department of the Federal Ministry of Agriculture and Rural Development (2011).

Fertilizer recommendations for sole crops emanate almost exclusively from extensive laboratory and/or field trials over time and space. Such trials result in average recommendations for a crop within an area that normally have the approval of extension agencies. Where an approved fertilizer practice is considered inadequate or where no formal recommendation is available, the Fertilizer Use Committee suggests practices on the basis of existing information, including individual or common knowledge and experience. Current recommendations are largely 'blanket' or 'generic' in nature; its perils and the need for site-specific recommendations have been elucidated in a study on nutrient rationalization in Nigerian compound fertilizers by Adeoye (2006).

Fertilizer availability to farmers has been heavily subsidized, to as much as 95% of the real cost, since the late 1970s. The pattern of total fertilizer consumption in Nigeria is largely determined by the flow of federal and state government subsidies and the almost annual changes in procurement and distribution rules. For example, under the Federal Market Stabilization Program (FMSP), Liverpool-Tasie and Takeshima (2013) documented that the Federal Government of Nigeria (FGN) procures fertilizer for sale to states at a subsidy of 25%. State governments typically institute additional subsidies on fertilizer. Under this arrangement, companies make bids to the FGN to import and distribute subsidized fertilizer. Several states also procure fertilizer outside of the FMSP for sale to their farmers. Nevertheless, only an estimated 30 percent of subsidized fertilizer reaches small farmers at the subsidized price.

There is also remarkable variation in the subsidy rates state governments provide on the already federally subsidized fertilizer, ranging from 0 to 50%. In a typical state, there is federally subsidized fertilizer, federally plus state subsidized fertilizer and (in principle) unsubsidized fertilizer procured through private channels. However, the subsidy programmes have been plagued by pervasive problems of late delivery of fertilizer and delivery of inappropriate quantities and types of fertilizer. Political manipulation has also resulted in diversion of subsidized fertilizer from the intended beneficiaries.

Even though the subsidy programmes absorbed large proportions of the national budget, the impact of the programmes on agricultural productivity has been mixed at best. Arbitrage opportunities and incentives to adulterate and mislabel the source of fertilizer also abound.

Farmer access to fertilizer varies widely across states. Vigorous campaigns by the Fertilizer Producers and Suppliers Association of Nigeria (FEPSAN) and some international NGOs aimed at liberalization of fertilizer supply with smart subsidization, such as with the voucher system, are being pursued.

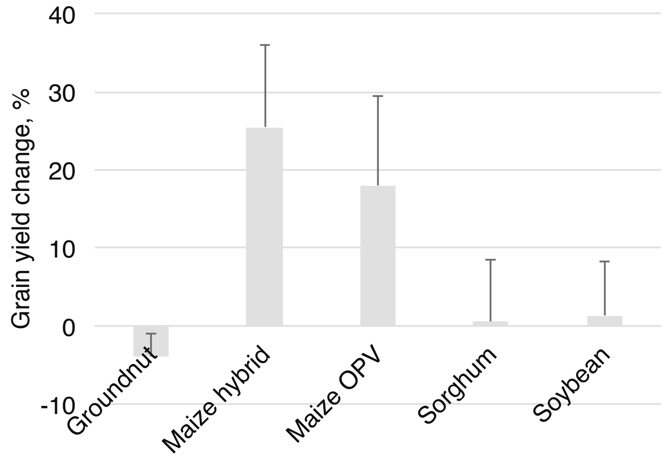

Figure 12.2: Relative yield increase due to application of Zn, S, B and Mg in the Nigerian Guinea Savanna.

12.5 Diagnostic results for the Northern Guinea Savanna AEZ

In 2014-15, 139 on-farm and 39 on-station fertilizer use trials were conducted for several crops in the Northern Guinea Savanna, which included a diagnostic treatment consisting of N+P+K+Mg+S+Zn+B compared with an N+P+K treatment (Figure 12.2).

Hybrid and open pollinated maize yields were increased by an average of 25 and 15%, respectively, by the diagnostic treatment compared with N+P+K. Mean yields of groundnut, sorghum and soybean were not much affected and the diagnostic package had a negative effect on groundnut in some trials. Therefore, one or more of four secondary and micronutrients in the diagnostic package are important to maize. There is ample evidence of maize response to Zn (Table 12.5b,c,e,f). More research is needed to determine if deficiency of Mg, S or B contributed to the maize response to the diagnostic treatment. There was a large

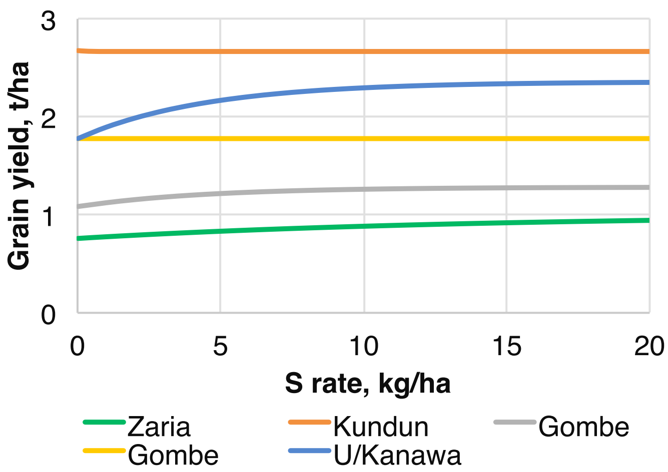

Figure 12.3: Response of soybean to sulphur in Nigerian Northern Guinea Savanna agro-ecological zone.

soybean response to S in the 2014-15 trials at Kaduna but little or no effect at other locations (Figure 12.3).

12.6 Optimizing fertilizer use in the savanna biome of Nigeria

Low commercial fertilizer use by farmers in Nigeria constrains their productivity. Many of the farmers are resource poor and do not have the financial ability to procure the required amount of fertilizers to maximize returns in fertilizer investment over all of their cropland. The unstable commodity prices and the high cost of fertilizers do not guarantee profit. Farmers have to choose between competing needs in deciding on fertilizer procurement. The profit to be made from fertilizer investment should therefore guide fertilizer use decisions.

Profit-oriented farmers without financial constraints (well resourced) invest in fertilizer use to maximize profits per hectare by applying at EOR over all cropland, while farmers with limited finances invest in fertilizer use to obtain high benefit to cost ratio while keeping risk low.

Maximizing net return requires understanding crop response to applied nutrients. The crop yield responses to applied nutrients were captured in curvilinear to plateau yield response functions as shown in Figure 12.4 for maize response (vertical axis or y-axis) to applied N (horizontal axis or x-axis) in the Mid-altitude zone. Maize grain yield response to increasing N rates in the Nigerian Mid-altitude AEZ has a steep response at low N rates and a reduced rate of increase at higher N rates until the yield plateau is reached, after which further increase in N rate has little or no effect to increase yield. There was increasing yield with N rates up to the 100 kg/ha rate beyond which maize grain yield

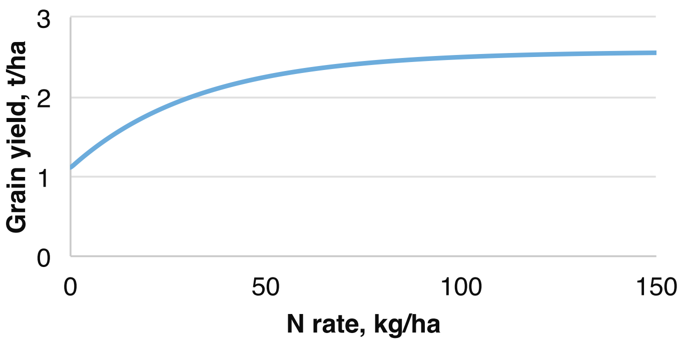

Figure 12.4: Maize response to nitrogen application in the Nigerian Mid-altitude AEZ.

tends to be constant. The maximum expected yield, on average, was 2.57 t/ha.

This type of response to applied nutrients is captured by the equation Yield (kg/ha) = $a - bc^r$, where a is near maximum yield for application of that nutrient, b is the maximum yield increase due to applied nutrient, and c^r determines the shape of the curvilinear response. The c is the curvature coefficient and r is nutrient rate. This function tells us that the benefit relative to cost for N application is expected to be greater with low N levels compared with high N rates.

Profit potential also varies with different nutrients applied to the same or different crops as shown in Figure 12.5 for the Nigerian Mid-altitude AEZ. Each curve represents the profit potential of a nutrient applied to a crop. Where the curve of the graph is steep, the net returns to investments are very high and where the curve flattens, the point of maximum profit per hectare is reached. When the graph slope starts declining, the profit is declining.

The results show that it is more economical to invest in N and K applied to cassava than in fertilizers for other crops. Application of low rates of N to sorghum and K to upland rice also have good profit potential. Other crop-nutrient options that have profit potential include the application of a very low rate of Zn for groundnut.

The resource-poor farmer needs to take advantage of the most profitable options first and gradually build financial capacity in order to take advantage of the less profitable choices. Poor farmers will benefit according to their financial ability by operating within the steep slope of the curves where there are high returns from investment, while well-resourced farmers will attempt to apply at EOR to maximize profit per hectare.

The results suggest the need to consider the various crop nutrient response functions in light of their other agronomic choices, the current economics of fertilizer use and their financial ability. Therefore, easy to use decision tools called fertilizer optimization tools (FOT), which use complex mathematics of linear optimization to consider reiteratively the numerous crop nutrient functions in light of the farmer's agronomic and economic situation, are needed to provide recommendations that maximize

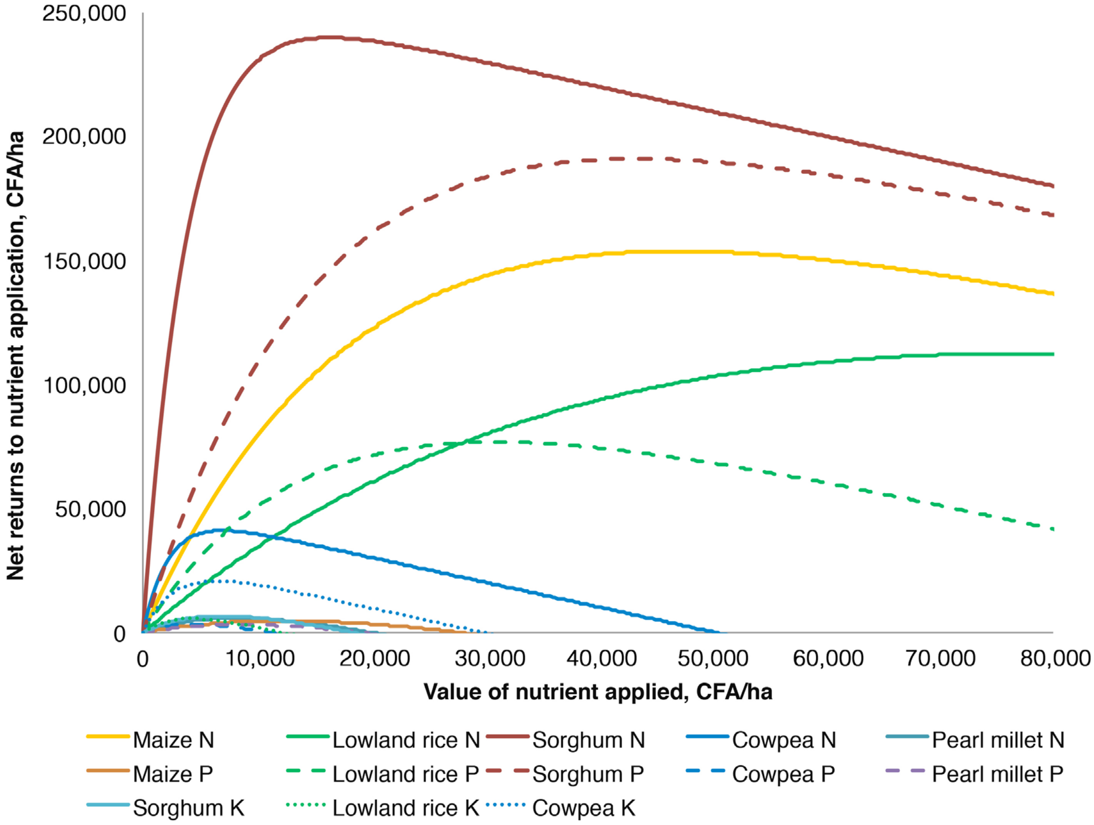

Figure 12.5: Net returns to investment in nutrients in the Mid-altitude AEZ of Nigeria

returns on investment. It also brings to the fore the need for farmers' education on the type of fertilizer they need to procure and use on different crops to maximize profit. Choices of single nutrient and double nutrient compound fertilizers are necessary for optimizing profit.

12.7 Fertilizer optimization tools for Nigerian AEZ

12.7.1 The Excel Fertilizer Optimization Tool

The Excel Fertilizer Optimization Tool (FOT) was first developed by Jansen et al (2013). It has been adapted to 67 country-AEZ of Africa including the six savanna AEZ of Nigeria. The FOTs are public goods that can be accessed by individuals at https://agronomy.unl.edu/OFRA. Educational institutions are encouraged to access the tool for use in their curriculum.

The FOTs are Excel Solver© (Frontline Systems Inc.) tools (Figure 12.6). To use the FOT, the Solver add-in of Excel needs to be engaged and macros need to be enabled; see the 'Help and Instructions' worksheet of the Excel FOT. More detailed instructions are in Extension Materials and the FOT Manual, also available at https://agronomy.unl.edu/OFRA. When Solver is enabled, it is indicated in the upper right of the Quick Access Toolbar under the Data tab.

The FOT is used to optimize investment in fertilizer use for the crops that the farmer chooses to cultivate in that season. It accounts for agronomic efficiency and economic returns from money invested in fertilizer use. The tool provides recommendations based on fertilizer cost, crop grown and resource level of the farmer, as well as the expected values of the various crops to be produced. It provides the best crop-nutrient-rate combinations to maximize returns on fertilizer investment for that farmer's situation.

The FOT has information input and output sections. The input section is a panel to enter: (1) area (ha) to be cultivated and expected value of each crop at harvest, (2) cost of buying and applying 50 kg bags of available fertilizers and (3) amount of money available for the farmer to invest in fertilizer use (Figure 12.6). When steps 1, 2 and 3 are completed, the user clicks on the 'Optimize' (4) button to run the optimization calculations.

The output panel (Figure 12.6) provides results of the optimization calculations. It displays: (5) recommended fertilizer rates for each selected crop, (6) expected average yield increases and

Help

INSTITUTE FOR AGRICULTURAL RESEARCH SAMARU

NIGERIA MID ALTITUDE AGRO-ECOLOGY

Producer Name: xxx
Prepared By: xxx
Date Prepared: March 13, 2016

1 Enter area (ha) to be cultivated for each crop and farm gate grain value (₦) for season

Crop Selection and Prices		
Crop	**Area Planted (Ha)***	**Expected Grain Value/kg †**
Rice, lowland	1	67
Maize	1	50
Sorghum	1	60
Cassava	1	20
Groundnut (UnShelled)	1	120
Soybean	2	120
Rice,upland	1	67
Total	8	

2 Enter the price of 50 kg bag plus transport and application for each type of fertilizer. Another fertilizer 15-15-15 has been added here

Fertilizer Selection and Prices					
Fertilizer Product	**N**	**P2O5**	**K2O**	**zs**	**Costs/50 kg bag ¶***
Urea	46%	0%	0%	0%	5500
Single super phosphate, SSP	0%	18%	0%	0%	4500
Diammonium phosphate, DAP	18%	46%	0%	0%	0
Murate of potash, KCL	0%	0%	60%	0%	7000
zs	0%	0%	0%	12.3%	20000

3 Enter maximum available money farmer can invest in fertilizer (₦1,000 000) in this example

Budget Constraint	
Amount available to invest in fertilizer (N)	1,000,000

Optimize   Reset Form

4 Click on the optimize button

5 Optimized application rate (kg/ha) of fertilizer for each crop is provided in the panel

Fertilizer Optimization					
	Application Rate - kg/Ha				
Crop	**Urea**	**SSP**	**DAP**	**KCL**	**zs**
Rice, lowland	180	0	0	0	0
Maize	162	5	0	0	14
Sorghum	62	0	0	0	0
Cassava	174	94	0	44	0
Groundnut (UnShelled)	0	240	0	22	0
Soybean	0	231	0	0	0
Rice,upland	133	228	0	0	0
Total fertilizer needed	712	798	0	67	14

6 Increased crop yields (kg/ha) and net returns from fertilizer use (₦/ha)

Expected Average Effects per Ha		
Crop	**Yield Increases**	**Net Returns**
Rice, lowland	1,066	51,642
Maize	1,687	60,382
Sorghum	1,357	74,555
Cassava	18,926	344,690
Groundnut (UnShelled)	683	57,279
Soybean	459	34,300
Rice,upland	1,994	98,375

7 Total net returns on fertilizer investment (₦755,524.00 in this example)

Total Expected Net Returns to Fertilizer	
Total net returns to investment in fertilizer (N)	755,524

Print Output

Figure 12.6: Fertilizer optimization tool.

Table 12.3: Paper FOT for the Nigerian Mid-altitude

NIGERIA MID-ALTITUDE AEZ

Fertilizer Use Optimizer

The below assumes:
Calibration measurement is with: a FARO water bottle lid (FARO) that holds about 6.3 g urea, 10 g SSP and KCl, 9 g NPK 15:15:15, 11 g NPK 20:10:10, and 14 g $ZnSO_4$; and with a GINO tomato can (GINO) of 70 ml to hold 49 urea, 77 g SSP and KCl; 165 g ZnSO4, 70 g NPK 15:15:15, and 84 g NPK 20:10:10.
Planting: Maize, sorghum and pulses are planted at 75 cm x 25 cm; pearl millet 1 x 1 m; cassava 1 x 1 m.
Crop values: Naira/kg 50 maize; 60 sorghum; 67 rice; 56 pearl millet; 120 unshelled groundnut; 165 cowpea, 120 soybean and 20 cassava.
Fertilizer use costs for Naira for 50 kg: 5500 Urea; 4500 SSP; 7000 MOP; 6000 for NPK 15-15-15 and 20-10-10; and 2000/kg for $ZnSO_4$.
Broadcast width: 2.5 m: WAP = weeks after planting, WAT = weeks after transplanting. Application rate is in kg/ha.

Level 1 financial ability.	
Cassava	Point apply 100 kg of NPK 15-15-15 (1 FARO for 0.5 plant) at 4 WAP also point apply 100 kg of urea (1 FARO for 0.5 plant) at 8 WAP planting
Maize	Point apply 48 kg urea (1 FARO for 6.5 plants) at 3 WAP
Groundnut	Mix 50kg of NPK 15:15:15 and 25 kg of SSP and point apply (1 FARO for 7 plants) at 2 WAP
Lowland rice	Broadcast 53 kg urea at 1 WAT (1 GINO for 1 m)
Upland rice	Mix 87 kg of SSP with 6 kg urea and broadcast at 3 WAP (1 GINO for 3 m)
Sorghum	Point apply 37 kg urea (1 FARO for 8.5 plants) at 3 WAP
Soybean	Point apply 23 kg SSP (1 FARO for 23 plants) at 2 WAP
Level 2 financial ability.	
Cassava	Mix 150 kg of NPK 15-15-15 and 100 kg of urea and point apply at 8 WAP planting (1 Gino for 2.5 plants)
Maize	Point apply 50 kg urea (1 FARO for 6.5 point) at 2 WAP. Apply 50 kg urea at 6 WAP (1 FARO for 6.5 plants)
Cowpea	Point apply 125 kg SSP at 3 WAP (1 FARO for 4 plants)
Groundnut	Mix 50 kg of NPK 15:15:15, 100 kg of SSP and point apply (1 FARO for 3.5 plants) at 2 WAP
Lowland rice	Broadcast 54 kg urea at 1 WAT (1 GINO for 3.5 m) and broadcast 54 kg urea at 5 WAT (1 Gino for 3.5 m)
Upland rice	Mix 1006 kg of NPK 15:15:15 with 50 kg SSP and broadcast (1 GINO for 2 m) at 2 WAP and broadcast 28 kg urea at 6 WAP (1 GINO for 6.5 m)
Sorghum	Point apply 48 kg of Urea (1 FARO for 6.5 plants) at 3 WAP
Soybean	Point apply 112 kg SSP (1 FARO for 4.5 plants) at 2 WAP
Level 3 financial ability (maximize profit per acre).	
Cassava	Mix 100 kg of NPK 15-15-15 and 87 kg of urea and point apply at 8 WAP (1 Gino for 3 plants)
Maize	Point apply 233 kg NPK 15:15:15 mixed with 7.5 kg $ZnSO_4$ (1 FARO for 2 plants) at 3 WAP. Point apply 75 kg urea at 6 WAP (1 FARO for 4 plants)
Cowpea	Point apply 125 kg SSP at 3 WAP planting (1 FARO for 4 plants)
Groundnut	Mix 100 kg NPK with 155 kg SSP and point apply (1 FARO for 2 plants) at 2 WAP
Lowland rice	Broadcast 90 kg urea at 1 WAT (1 Gino for 2 m) and broadcast 90 kg urea at 5 WAT (1 Gino for 2 m)
Upland rice	Broadcast 228 kg of SSP at land preparation (1 Gino for 1.5 m) and broadcast 50 kg urea at 3 WAP (1 Gino for 3.5 m) and 100 kg urea (1 Gino per 2 m) at 6 WAP
Sorghum	Point apply 62 kg of urea (1 FARO for 5 plants) at 3 WAP
Soybean	Point apply 231 kg SSP (1 FARO for 2.5 plants) at 2 WAP

net returns per hectare resulting from fertilizer use for each crop and (7) expected total net return on fertilizer investment.

The FOT recommendations are intended for the current season because both fertilizer costs and commodity prices vary seasonally. Good prediction of commodity values improves the optimization for a current season.

Once the optimal fertilizer rates are known, the farmer needs to know how to apply the fertilizer at the right rate. Therefore, the Nigerian OFRA project developed a calibration tool to guide application for the correct rates. The calibration tool is a reminder that optimization of fertilizer use does not include haphazard application. The Excel calibration tool offers options of measuring units of different volumes that are common in Nigerian rural communities. The type of fertilizer needs to be selected as fertilizers differ in specific gravity. Method of application and plant spacing are information provided. Depending on the amount and type of fertilizer that will be applied, the tool provides the application solution.

The Nigeria calibration tool used Faro brand water bottle caps (FARO-9ml), Gino brand tomato cans (GINO-70ml), and Peak Milk brand tins (PEAK-180ml). These measuring units were selected because of their availability in rural communities. The calibration units were designed to provide the farmer with visual estimates of fertilizer to be applied for a broadcast area, metres of band, or number of plants in the stand. After the farmer has 'calibrated' her eye and feel for the rate, the farmer proceeds with the actual fertilizer application free-hand.

12.7.2 Paper fertilizer optimization tools

The Excel FOT is useful for scientists, fertilizer retailers, extension staff and others with good computer access. However, paper versions of FOTs were developed for use by farmers and their advisors when a computer is not available (Table 12.3).

Table 12.4: Fertilizer use in an ISFM Framework

FERTILIZER USE WITHIN AN INTEGRATED SOIL FERTILITY MANAGEMENT FRAMEWORK

ISFM practice	Urea	SSP	KCl	NPK 15-15-15
	Fertilizer reduction, % or kg/ha			
Farmyard manure or compost applied	Both yield and response to fertilizer are expected to be increased; therefore fertilizer rates should not be decreased			
Cattle manure 1 t dry material	12kg	59 kg	20 kg	35 kg
Poultry manure 1 t dry material	19kg	106kg	12kg	28
Horse 1 t dry material	12kg	24kg	8.6kg	19kg
Swine 1 t dry material	16kg	80kg	31kg	12kg
Sheep and goats 1 t dry material	12kg	75kg	8kg	24
Residual value of dairy and poultry manure applied for the previous crops per 1 t dry material	6kg	23kg	2kg	12
Compost	16kg	7kg	30kg	121kg
Cereals harvest waste	0% reduction of fertilizers. Use as soil cover for soil water conservation and erosion control.			
Cereal-cowpea or groundnut intercropping	Apply sole crop recommended rates of NPK to cereals only			
Cereal-cowpea or groundnut strip cropping	Apply sole crop recommended rates of NPK to strips of legumes and cereals separately			
Cereal-other legume (effective in N fixation) rotation with return of residues	Reduce urea by 11kg/ha and apply recommended rates sole crop rates of P and K fertilizer			
If Bray-1 >15 ppm	Apply no P			
If soil test K >0.17 cmol/kg (>68 ppm)	Apply no K			

Farmers' financial resource base determines how much fertilizer use they can afford. Farmers without financial constraints to procurement of fertilizers target the potential yield of the crop and can invest large amounts of money to attain optimum yield. Nigerian farmers commonly procure fertilizer blends that do not give maximum return on investment due to lack of knowledge or access to more cost-effective fertilizer choices. The paper FOTs consider three financial ability levels:

- Financial level 1 is the most constrained. This farmer has no more than one-third of the money needed to apply fertilizer at EOR to all cropland.
- Financial level 2, moderately constrained. This farmer has no more than two-thirds of the money needed to apply fertilizer at EOR to all cropland.
- Financial level 3, the least constrained. These rates are the EOR that on average will maximize profit per hectare.

Considering that urea, SSP and NPK 15:15:15 are the most common fertilizers in the Nigerian market, use of the paper FOT in this chapter is based on the use of these fertilizers, either alone or in combination to provide the optimized fertilizer rate for the AEZ. As fertilizer supply becomes more liberalized, more fertilizers will be added.

For a financially constrained farmer in level 1 who wants to produce cassava in the Nigerian Mid-altitude, he/she should procure 200 kg of NPK 15:15:15 and point apply 100 kg/ha (1 FARO per 0.5 plant at 4 weeks after planting (WAP)) and repeat the same at 8 WAP. For his/her maize crop, 48 kg/ha urea (1 FARO for 6.5 plants) should be applied at 3 WAP. For his/her groundnut plot the farmer

Table 12.5a: Sahel savanna, response functions, expected yield increases (t/ha) for crop-nutrients, and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current or recent (REC) recommendations by AEZ in Nigeria. P_2O_5 = P x 2.29; K_2O = K x 1.2. Some functions have zero response because of lack of response or lack of information

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			Yield increase, t/ha				kg/ha	
Pearl millet	N	0.742	0.223	0.930	0.198	0.022	0.003	0.000	18	60
Sorghum	N	1.098	0.273	0.970	0.164	0.066	0.026	0.011	24	64
Maize	N	1.275	0.687	0.951	0.535	0.118	0.026	0.006	39	120
Rice, lowland	N	4.461	0.564	0.942	0.470	0.078	0.013	0.002	38	100
					0-5	**5-10**	**10-15**	**15-20**		
Pearl millet	P	1.717	0.768	0.940	0.204	0.150	0.110	0.081	14	13
Sorghum	P	0.975	0.548	0.908	0.210	0.129	0.080	0.049	11	14
Groundnut	P	0.254	0.032	0.870	0.016	0.008	0.004	0.002	0	24
Cowpea	P	0.605	0.109	0.930	0.033	0.023	0.016	0.011	2	17
Maize	P	1.275	0.687	0.951	0.153	0.119	0.092	0.072	0	26
Rice, lowland	P	5.190	0.189	0.919	0.065	0.043	0.028	0.018	0	22
Groundnut	K	1.093	0.104	0.800	0.070	0.023	0.008	0.002	10	21
Cowpea	K	0.477	0.063	0.650	0.056	0.006	0.001	0.000	6	17
Rice, lowland	K	6.036	0.223	0.750	0.170	0.040	0.010	0.002	9	33

† EOR was determined with the cost of using 50 kg urea and SSP at N 5,500 and 4,500, respectively. Commodity values (N /kg) used were: cassava 20; rice 67; maize 50; sorghum 60; cowpea 165; groundnut 120; soybean 120; and pearl millet 60.

‡Source: OFRA-Nigeria 2015 country recommendation

Table 12.5b: Sudan Savanna

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			**Yield increase, t/ha**				**kg/ha**	
Maize	N	3.000	1.760	0.970	1.054	0.423	0.170	0.068	70	120
Sorghum	N	4.067	1.530	0.860	1.513	0.016	0.000	0.000	27	64
Rice, lowland	N	2.482	0.428	0.970	0.256	0.103	0.041	0.017	43	100
Cowpea	N	1.860	0.168	0.770	0.168	0.000	0.000	0.000	12	20
Pearl millet	N	1.111	0.110	0.930	0.098	0.011	0.001	0.000	9	60
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	0	26
Groundnut	P	1.485	0.399	0.845	0.227	0.098	0.042	0.018	12	17
Sorghum	P	2.770	1.470	0.910	0.553	0.345	0.215	0.134	16	14
Cowpea	P	0.929	0.040	0.700	0.033	0.006	0.001	0.000	2	17
Soybean	P	1.319	0.141	0.855	0.077	0.035	0.016	0.007	5	26
Pearl millet	P	1.520	0.129	0.900	0.053	0.031	0.018	0.011	0	13
Groundnut	K	1.260	0.075	0.800	0.050	0.017	0.005	0.002	9	25
Sorghum	K	2.016	0.114	0.900	0.047	0.028	0.016	0.010	9	25
Rice, lowland	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	0	33
Cowpea	K	0.871	0.100	0.800	0.067	0.022	0.007	0.002	12	20
					0-1	**1-2**	**2-3**	**3-4**		
Maize	Zn	3.590	0.560	0.250	0.420	0.105	0.026	0.007	1.8	0.62
Groundnut	Zn	1.614	0.348	0.397	0.210	0.083	0.033	0.013	0.7	NA
Sorghum	Zn	4.300	0.100	0.500	0.050	0.025	0.013	0.006	0.4	NA
Soybean	Zn	1.614	0.348	0.397	0.210	0.083	0.033	0.013	2.7	NA

should mix 50 kg/ha of NPK 15:15:15 with 100 kg/ha SSP and point apply (1 FARO for 7 plants) at 2 WAP. For lowland rice, the farmer should broadcast 53 kg urea/ha at 1 week after transplanting (WAT) (1 GINO for 1 m length and 2.5m width).

12.7.3 Fertilizer use in an integrated soil fertility management context

Organic residues such as livestock manure, compost, cereal–legume rotation and intercropping with legumes can contribute to soil nutrient availability. Their contributions should be considered and some of the recommended fertilizer can be allocated elsewhere. The fertilizer nutrient substitution values of practices are provided in terms of adjustment to fertilizer rates in Table 12.4. For example, the level 1 farmer in the paper FOT needs to apply 37 kg/ha of urea for his sorghum. If he has already applied 1 t/ha of cattle manure, which has a urea equivalent of 12 kg/ha, he needs to apply only 25 kg/ha of urea and the remaining fertilizer or saved money can be used elsewhere.

12.8 Targeted crops by AEZ

During 2014-15, results of past research were compiled and analysed, and additional field research was conducted to improve the information for fertilizer use decisions in the savanna AEZ of Nigeria (Table 12.5a-f). The food crops addressed were cassava, maize, sorghum, pearl millet, lowland and upland rice, groundnut and soybean.

Current recommendations (REC) guiding fertilizer use in Nigeria were developed over 30 years ago, are outdated and do not reflect current soil, crop and weather situations.

Table 12.5c: North Guinea Savanna

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
			t/ha			**Yield increase, t/ha**			**kg/ha**	
Soybean	N	0.963	0.357	0.762	0.357	0.000	0.000	0.000	0	20
Maize LP <3t	N	2.493	1.601	0.972	0.918	0.392	0.167	0.071	79	120
Maize HP >3t	N	3.513	1.808	0.981	0.791	0.445	0.250	0.141	103	150
Rice, lowland	N	2.729	0.214	0.963	0.145	0.047	0.015	0.005	59	100
Rice, upland	N	3.058	0.738	0.968	0.460	0.173	0.065	0.025	58	80
Sorghum	N	4.154	1.338	0.906	1.269	0.066	0.003	0.000	35	64
					0-5	**5-10**	**10-15**	**15-20**		
Soybean	P	0.961	0.052	0.600	0.048	0.004	0.000	0.000	2	17
Groundnut	P	1.589	0.362	0.760	0.270	0.069	0.017	0.004	9	24
Maize LP <3t	P	2.678	1.653	0.980	0.159	0.144	0.130	0.117	18	26
Maize HP >3t	P	3.541	1.799	0.978	0.189	0.169	0.152	0.136	25	33
Rice, lowland	P	3.058	0.738	0.969	0.108	0.092	0.078	0.067	10	26
Rice, upland	P	3.165	0.770	0.908	0.295	0.182	0.112	0.069	15	17
Sorghum	P	1.721	0.576	0.980	0.055	0.050	0.045	0.041	0	14
Soybean	K	0.821	0.134	0.800	0.090	0.030	0.010	0.003	11	17
Groundnut	K	1.776	0.102	0.630	0.092	0.009	0.001	0.000	6	21
Rice, lowland	K	1.951	0.091	0.810	0.059	0.021	0.007	0.003	7	33
Rice, upland	K	2.500	0.300	0.945	0.074	0.056	0.042	0.032	25	30
					0-1	**1-2**	**2-3**	**3-4**		
Soybean	Zn	1.776	0.195	0.229	0.195	0.000	0.000	0.000	0.7	NA
Maize	Zn	3.729	0.679	0.300	0.677	0.002	0.000	0.000	1.0	0.62

These recommendations were formulated from results of soil samples collected from non-geo-referenced sites and, therefore, do not account for the indigenous potential supply of soils, climatic potential of the various AEZ, economic considerations and fertilizer availability.

In Table 12.5, a synthesis of much research information is presented by crop and nutrient (cols1-2), and the response coefficients are presented in cols 3-5 for the curvilinear to plateau response function represented by the equation $Y = a - bc^r$ where Y = yield, a = yield at the plateau of response to the given nutrient, b = yield increase at plateau in response to the nutrient, c is a curvature coefficient and r is the rate of nutrient application. The yield increases associated with changes in nutrient rates are presented in cols 6-9. The EOR is the nutrient rate required to maximize profit per hectare from fertilizer use and the RECs are given in cols 10-11.

In the Sahel Savanna, response of upland crops was greater to applied P compared with N, while lowland rice was more responsive to N. Cowpea and groundnut were not found to be responsive to N but had modest response to applied P and K.

The field research based EOR were consistently less and generally less than half REC. Therefore, even for cases of no financial constraint on the amount of fertilizer use, the REC are well above the most profitable rates and therefore a profit opportunity is lost in applying according to REC. For farmers with financial constraints to fertilizer use, the most profitable rates will be less than the EOR as determined through use of FOTs. These results suggest that most of the RECs for primary fertilizer elements did not consider economic benefits.

Table 12.5d: South Guinea Savanna

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
		t/ha			**Yield increase, t/ha**				**kg/ha**	
Maize	N	3.130	1.680	0.980	0.955	0.484	0.245	0.124	97	100
Rice, lowland	N	3.100	0.750	0.950	0.588	0.341	0.198	0.115	46	100
Rice, upland	N	2.500	0.300	0.955	1.508	0.002	0.000	0.000	29	80
Sorghum	N	1.720	0.570	0.980	0.864	0.471	0.257	0.140	50	64
Soybean	N	3.160	0.340	0.880	0.333	0.007	0.000	0.000	0	30
					0-5	**5-10**	**10-15**	**15-20**		
Maize	P	3.160	0.340	0.880	0.161	0.085	0.045	0.024	5	26
Rice, lowland	P	3.100	0.000	0.000	0.000	0.000	0.000	0.000	0	17
Rice, upland	P	3.160	0.770	0.970	0.109	0.093	0.080	0.069	10	17
Groundnut, unshelled	P	1.580	0.360	0.760	0.269	0.068	0.017	0.004	9	24
Cowpea	P	1.060	0.185	0.890	0.082	0.046	0.025	0.014	26	17
Sorghum	P	2.190	0.800	0.890	0.353	0.197	0.110	0.062	14	14
Soybean	P	2.010	0.680	0.930	0.207	0.144	0.100	0.070	23	26
Rice, lowland	K	1.950	0.090	0.810	0.059	0.020	0.007	0.002	7	50
Rice, upland	K	4.430	0.840	0.800	0.565	0.185	0.061	0.020	17	33
Groundnut, unshelled	K	1.770	0.100	0.750	0.076	0.018	0.004	0.001	9	21
Cowpea	K	0.820	0.130	0.800	0.087	0.029	0.009	0.003	13	17

In the South Sudan Savanna, maize, sorghum and rice had large responses to applied N and P, and rice responded well to just 1 kg/ha Zn (Table 12.5b). Response of cowpea, groundnut and pearl millet were less but generally economical for all nutrients. The EOR were on average less than half REC although the EOR for sorghum P and the maize Zn EOR was more than recommended. Zinc EORs were determined for groundnut, sorghum and soybean but RECs are not available.

In the Northern Guinea Savanna, all cereals and soybean had a large yield increase with just 30 kg/ha N applied but EOR were generally greater (Table 12.5c). Most crops responded well to 5 kg/ha or more of P applied. Responses to K were small but often economical at low rates. Soybean and maize yield increased with 1 kg/ha Zn applied. The EOR were mostly less than half REC but the differential was less compared with the Sahel. The REC and EOR were similar for upland rice P.

Cereal yield increase with N application in the Southern Guinea Savanna varied from 0.34 t/ha for sorghum to 1.7 t/ha for maize (Table 12.5d). With respect to P, yield increases varied from zero for lowland rice to 0.8 t/ha for sorghum. Yield increases with K application varied from 0.1 t/ha for lowland rice to 0.8 t/ha for upland rice. The EOR for maize N and sorghum P were similar to REC. The EOR for cowpea P was more than REC. All other EOR were less, and mostly less than half, of REC.

Cereal and cassava yield increases with applied N were large in the Mid-altitude AEZ (Table 12.5e). The legumes and upland rice responded well to P and cassava and upland rice responded well to K. Maize had an economic response to 1 kg/ha of Zn. All field research derived EOR were less than REC except for Zn applied to maize.

In the Derived Savanna, cereals responded well to N and P with the exception of lowland rice response to P (Table 12.5f). Rice responded well to K. Maize, sorghum, groundnut and soybean

Table 12.5e: Mid-altitude Zone

	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha				Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	Nutrient	a	b	c	0-30	30-60	60-90	90-120	EOR†	REC‡
		t/ha			Yield increase, t/ha				kg/ha	
Rice, lowland	N	3.792	1.202	0.974	0.657	0.298	0.135	0.061	83	100
Maize	N	2.567	1.456	0.971	0.854	0.353	0.146	0.060	75	120
Sorghum	N	4.354	1.387	0.875	1.362	0.025	0.000	0.000	29	64
Cassava	N	44.800	11.935	0.967	7.574	2.768	1.011	0.370	80	90
Rice, upland	N	3.012	0.680	0.974	0.371	0.168	0.076	0.035	61	80
					0-5	**5-10**	**10-15**	**15-20**		
Rice, lowland	P	3.378	0.000	0.000	0.000	0.000	0.000	0.000	0	22
Maize	P	2.559	0.161	0.860	0.085	0.040	0.019	0.009	0	26
Sorghum	P	1.451	0.149	0.906	0.058	0.036	0.022	0.013	0	14
Cassava	P	28.790	1.527	0.770	1.114	0.301	0.082	0.022	7	9
Groundnut	P	1.875	0.659	0.900	0.270	0.159	0.094	0.056	19	24
Soybean	P	2.107	0.560	0.910	0.211	0.131	0.082	0.051	18	26
Rice, upland	P	3.166	0.770	0.910	0.290	0.181	0.113	0.070	18	17
Sorghum	K	0.869	0.024	0.9	0.010	0.006	0.003	0.002	0	25
Cassava	K	34.000	6.566	0.813	4.234	1.504	0.534	0.190	22	63
Groundnut	K	1.926	0.125	0.8	0.084	0.028	0.009	0.003	11	21
Rice, upland	K	4.439	0.838	0.806	0.553	0.188	0.064	0.022	0	33
					0-1	**1-2**	**2-3**	**3-4**		
Maize	Zn	4.019	0.795	0.310	0.549	0.170	0.053	0.016	1.5	0.62
Sorghum	Zn	4.923	0.252	0.280	0.182	0.051	0.014	0.004	0	na
Groundnut	Zn	1.060	0.080	0.300	0.056	0.017	0.015	0.013	0	na

had economic responses to Zn. The field research derived EORs for upland rice N and P were similar to REC. All other EORs were less than REC except for the Zn EOR of maize which was more than REC.

Overall, RECs were on average 114% greater than the EOR determined from field research results but there were four cases where the REC was low relative to EOR (Table 12.5a-f). Applications at REC generally result in loss of much of the profit potential of fertilizer use. Finance-constrained farmers should apply fertilizer nutrients at less than EOR to take advantage of the greater profit potential associated with relatively large yield increases per kg of nutrient applied at low rates.

12.9 Acknowledgements

The authors appreciate the support of the personnel of Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria, funding support from the Alliance for a Green Revolution in Africa, OFRA management support from CABI, technical support of the University of Nebraska-Lincoln, and data and literature contributions of the Nigerian Soil Health Consortium.

12.10 References

Adeoye GO (2006) Nutrient Rationalization in Nigerian Compound Fertilizers (NPK) with Special Focus on Phosphorus and Potassium Utilization. USAID MARKETS

Akpa IC, Odeh IOA, Bishop TFA, Hartemink AE and Amapu IY (2016) Total soil organic carbon and carbon sequestration potential in Nigeria. Geoderma 271:202–215

Federal Ministry of Agriculture and Rural Development (2011) Fertilizer Use and Management Practices for Crops in Nigeria. Bobma Publishers, Ibadan

Table 12.5f: Derived Savanna Transitional Zone

		Response coefficients, Yield = a – bc^r; r = elemental nutrient rate, kg/ha			Yield increases due to incremental increases in elemental nutrient rate				Recommended nutrient rate	
Crop	**Nutrient**	**a**	**b**	**c**	**0-30**	**30-60**	**60-90**	**90-120**	**EOR†**	**REC‡**
			t/ha			**Yield increase, t/ha**			**kg/ha**	
Maize HP>3t	N	3.787	1.936	0.978	0.955	0.484	0.245	0.124	98	150
Maize LP<3t	N	2.526	1.399	0.982	0.588	0.341	0.198	0.115	92	120
Sorghum	N	4.170	1.510	0.800	1.508	0.002	0.000	0.000	20	32
Rice, upland	N	4.650	1.900	0.980	0.864	0.471	0.257	0.140	80	80
Rice, lowland	N	3.104	0.746	0.953	0.570	0.135	0.032	0.007	48	100
Soybean	N	1.800	0.000	0.000	0.000	0.000	0.000	0.000	0	NA
					0-5	**5-10**	**10-15**	**15-20**		
Maize HP>3t	P	2.820	0.310	0.520	0.424	0.188	0.084	0.037	10	33
Maize LP<3t	P	0.910	0.240	0.780	0.171	0.049	0.014	0.004	0	26
Sorghum	P	1.938	0.547	0.901	0.222	0.132	0.078	0.047	11	7
Rice, upland	P	1.830	0.420	0.910	0.158	0.099	0.061	0.038	0	17
Rice, lowland	P	3.210	0.150	0.700	0.125	0.021	0.004	0.001	0	22
Groundnut	P	4.430	0.830	0.800	0.270	0.069	0.017	0.004	9	23
Soybean	P	1.740	0.110	0.880	0.153	0.098	0.063	0.040	16	26
Maize HP>3t	K	3.759	0.036	0.550	0.035	0.002	0.000	0.000	2	62
Maize LP<3t	K	2.565	0.419	0.855	0.227	0.104	0.047	0.022	16	50
Rice, upland	K	4.430	0.830	0.800	0.558	0.183	0.060	0.020	0	25
Rice, lowland	K	4.43	0.830	0.800	0.558	0.183	0.060	0.020	17	25
Sorghum	K	1.570	0.000	0.001	0.000	0.000	0.000	0.000	4	25
Groundnut	K	1.740	0.110	0.880	0.052	0.027	0.014	0.008	14	21
Soybean	K	1.840	0.000	0.001	0.000	0.000	0.000	0.000	0	NA
					0-1	**1-2**	**2-3**	**3-4**		
Maize	Zn	4.010	0.790	0.310	0.545	0.169	0.052	0.016	2.3	0.62
Sorghum	Zn	4.920	0.250	0.280	0.180	0.050	0.014	0.004	1.4	na
Groundnut	Zn	1.060	0.080	0.300	0.056	0.017	0.005	0.002	1.1	na
Soybean	Zn	1.774	0.194	0.270	0.142	0.038	0.010	0.003	1.7	na

Jansen J, Wortmann CS, Stockton MC and Kaizzi KC (2013) Maximizing net returns to financially constrained fertilizer use. Agron J 105:573-578

Liverpool-Tasie, LSO and Takeshima H (2013) Moving forward with fertilizer in Nigeria: Fertilizer promotion strategies within a complex fertilizer subsector. Agricultural Economics. doi: 10.1111/agec.12075

Ojanuga AG (2006) Agroecological Zones of Nigeria Manual. In: Berding F and Chude VO (eds) National Special Programme for Food Security (NSPFS) and FAO

ProOpCom (2011) Promoting Pro-Poor Opportunities in Commodity and Service Markets. Making Fertilizer Markets Work for the Poor in Nigeria. A PrOpCom case study. Green Ink Ltd (www.greenink.co.uk)

World Bank (2016) World Development Indicators: Fertilizer Consumption. http://data.worldbank.org/indicator/AG.CON.FERT.ZS